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Effects of cropping systems on weed infestation, soil properties, yield, and grain quality of winter durum wheat

Abstract. This study examined the effects of a four-field crop rotation and long-term cereal monoculture on the grain yield and quality of winter durum wheat (*Triticum turgidum* L. subsp. *durum* (Desf.) van Slageren), as well as on weed infestation and soil properties. Durum wheat was grown in a crop rotation (CR) system following potato in the sequence: potato – winter durum wheat – spring pea – winter wheat, and in a cereal monoculture (CM) established 36 years ago. All crops were cultivated under conventional tillage. Grain yield was significantly higher under CR than under CM (7.31 vs. 2.51 t ha⁻¹). Similarly, spike density, grain weight per spike, and thousand-grain weight were greater in CR. Grain from CR also exhibited higher test weight, better uniformity, and greater starch content compared with CM. Weed density and biomass were higher in CM than in CR. Soils under crop rotation contained higher levels of organic carbon, total nitrogen, and potassium than soils under monoculture.

Keywords: crop rotation, monoculture, weed biodiversity, soil fertility, soil organic carbon

INTRODUCTION

Soil degradation and climate change are making agricultural production increasingly complex and its outcomes less predictable [Jug et al. 2025]. This necessitates the search for strategies that mitigate the adverse environmental impacts of agriculture and prevent further soil degradation. One such strategy involves implementing ecologically sound crop rotations and soil cultivation practices adapted to the habitat and technical conditions of individual farms [Holland 2004, Woźniak and Haliniarz 2025]. Conservation tillage with mulch cover creates favourable conditions in areas with low precipitation, whereas conventional plough-based tillage proves more effective in moderately humid regions [Peigné et al. 2007, Morris et al. 2010, Gruber et al. 2012, Soane et al. 2012]. Crop rotation and tillage practices affect soil properties and nutrient availability to plants [Maiga et al. 2019, Pranagal and Woźniak 2021], as well as the abundance of soil mesofauna [Woźniak 2024]. Moreover, Seibutis et al. [2025] demonstrated that crop rotation has a stronger effect on earthworm populations than soil cultivation, and

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these geobionts play a crucial role in organic matter cycling and the development of soil fertility [Blouin et al. 2013, Bertrand et al. 2015].

A particularly important role in crop rotation is played by structure-forming plants – annual and perennial legumes, as well as root crops fertilised with manure or other organic amendments. Post-harvest residues stabilise soil structure, increase soil organic carbon, and enhance nutrient availability [Turmel et al. 2015]. Nitrogen contained in leguminous crop residues is readily available to subsequent crops. As reported by Peoples et al. [2009], one tonne of legume residues contains 30–40 kg of nitrogen. This nitrogen is gradually released and, unlike mineral fertilisers, does not migrate beyond the reach of the root system. In addition, the favourable C : N ratio of legume residues promotes nitrogen availability. Crop residues also contribute to replenishing soil organic carbon (SOC) stocks. For instance, Johnson et al. [2014] found that the amount of crop residues required to compensate for SOC loss depends on the interaction between soil management practices and climatic conditions, and estimated that several tonnes of residues per year are needed to maintain SOC at a stable level.

Crop succession and tillage practices also shape weed communities [Andrew et al. 2015, MacLaren et al. 2020, Jaskulska et al. 2022] and the phytosanitary status of crops [Colbach et al. 1997, Kwak and Weller 2013, Feledyn-Szewczyk et al. 2024]. In conventional tillage systems, weed seeds are buried in deeper soil layers, whereas under conservation tillage they remain in the topsoil [Hernández Plaza et al. 2015]. Studies by Mortensen et al. [2012] and Woźniak [2025] have shown that diversified tillage and alternating cereal with non-cereal crops, as well as winter with spring forms, effectively reduce weed competitiveness. Conversely, Chauhan et al. [2012] and Woźniak [2025] demonstrated that cereal monoculture fosters the dominance of several weed species that are difficult to eradicate. In cereals, these are typically tall species that mature and shed seeds before harvest.

Habitat conditions and agrophages substantially limit crop productivity. According to Oerke [2006], weeds alone account for an average global yield reduction of 34%. Losses caused by pests and diseases are also considerable, although their extent varies. These effects are further exacerbated under long-term cereal monoculture. A long-term experiment conducted by Woźniak and Haliniarz [2025] showed that the productivity of winter wheat cultivated continuously for 35 years was more than two-fold lower than in a four-crop rotation. Monoculture wheat was also characterised by inferior grain quality, including reduced bulk density, protein, gluten, and starch levels, as well as lower sedimentation index values.

Based on the cited literature, we hypothesised that cultivation of durum wheat (*Triticum turgidum* L. subsp. *durum* (Desf.) van Slageren) in a four-crop rotation following potato, compared with a 36-year cereal monoculture, would improve grain yield and technological quality while reducing weed infestation. Furthermore, we expected beneficial effects on soil chemical properties. Accordingly, the present study aimed to evaluate the effects of different cropping systems on grain yield and quality of winter durum wheat, weed infestation, and soil chemical properties.

MATERIALS AND METHODS

Experimental design

The experiment was established in 1988 at the Uhrusk Experimental Farm of the University of Life Sciences in Lublin, Poland. The data presented in this study were collected in 2024. The farm is located in south-eastern Poland, on the Lublin Upland within the Chełm Hills mesoregion.

Winter durum wheat (*Triticum turgidum* L. subsp. *durum* (Desf.) van Slageren) was cultivated following potato in a four-crop rotation: potato (cv. Lord) – winter durum wheat (cv. Sambadur) – spring

pea (cv. Batuta) – winter wheat (cv. RGT Bilnaz), and on plots under a 36-year cereal monoculture. Prior to potato cultivation, manure was applied at a rate of 35 t ha⁻¹.

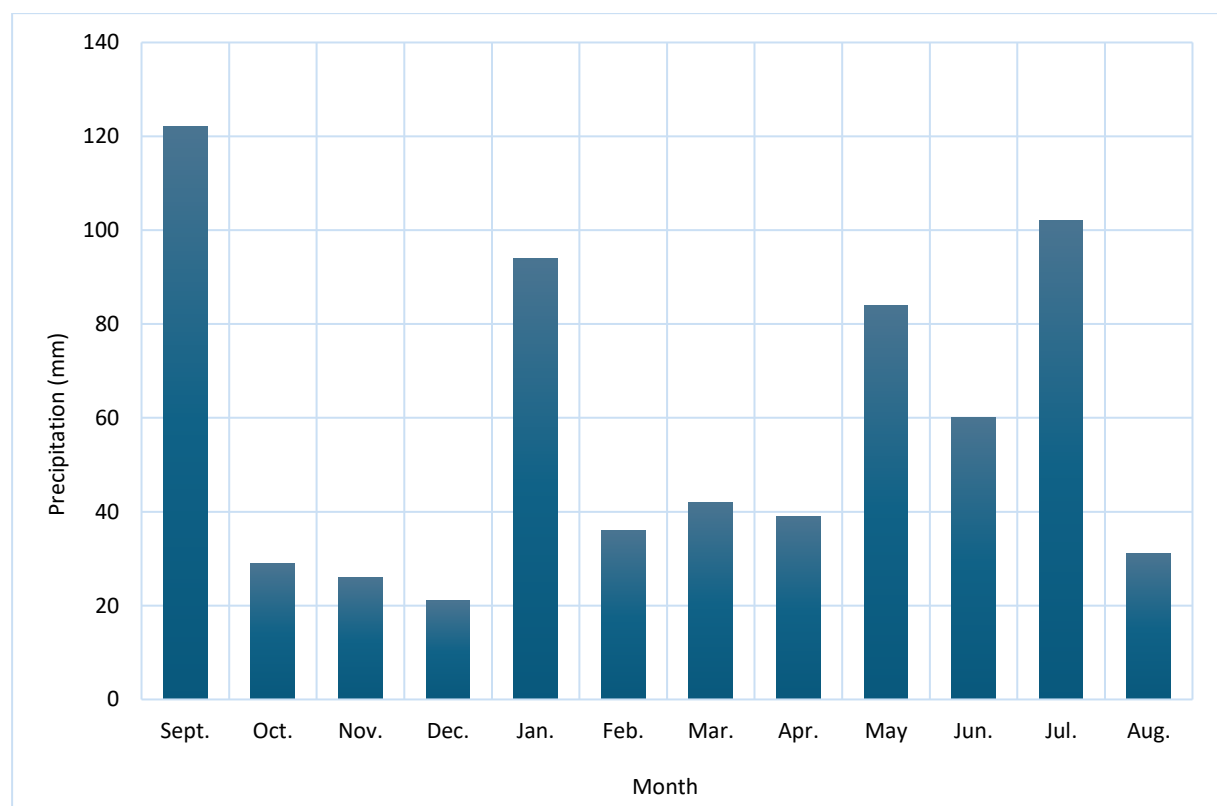
The experiment was conducted in a randomized complete block design with three replicates. Plot size was 25 m × 6 m. Soil preparation for wheat cultivation followed a conventional tillage system. Tillage operations performed after harvest of the preceding crop (potato in rotation or winter wheat in monoculture) included shallow ploughing to 10 cm, followed by pre-sowing ploughing to 18–20 cm in the second week of September. Before pre-sowing ploughing, fertilisers were applied at rates of 20 kg N ha⁻¹ (as ammonium sulphate), 35 kg P ha⁻¹, and 80 kg K ha⁻¹. Winter durum wheat was sown in the last week of September at a density of 380 seeds m⁻². Spring fertilisation comprised 65 kg N ha⁻¹ at tillering, 45 kg N ha⁻¹ at stem elongation, and 20 kg N ha⁻¹ at ear formation.

Weed control at the tillering stage was performed using herbicides containing MCPA + mecoprop + dicamba and fenoxaprop-P-ethyl, while fungicide applications included flusilazole + carbendazim and propiconazole + fenpropidinate.

Soil and weather conditions

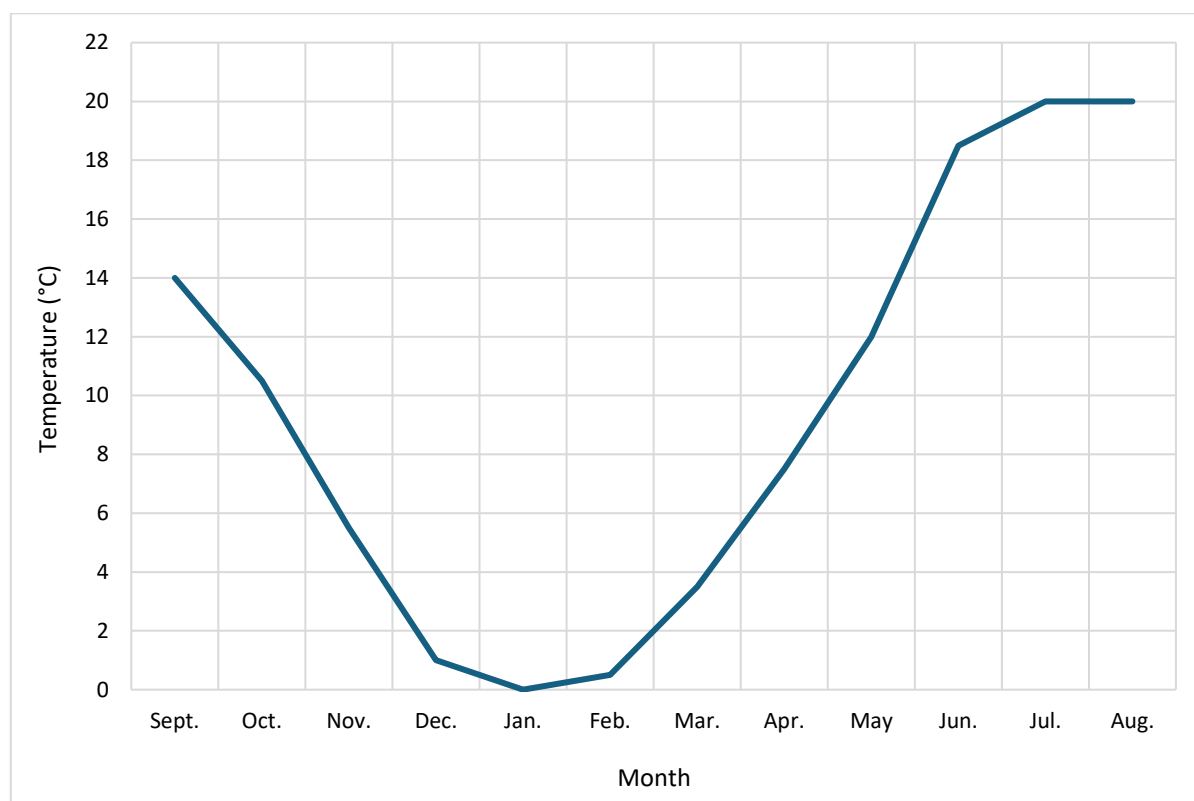
According to the IUSS WRB Working Group [2022], the soil was classified as Rendzic Phaeozem. Texture analysis indicated that it consisted of 53% sand (2.0–0.05 mm), 24% silt (0.05–0.002 mm), and 23% clay (<0.002 mm). The soil was rich in phosphorus and potassium, had a medium magnesium content, and was slightly alkaline.

Figure 1. Monthly precipitation sums during the 2023/2024 growing season at the Uhrusk Experimental Farm



The regional growing season typically lasts 210–215 days, beginning in mid-March. During the 2023/2024 winter durum wheat season (sown in September 2023 and harvested in August 2024), total precipitation was 571 mm, of which 312 mm fell between April and September (Figure 1). The warmest months were June to August, whereas December to February were the coldest (Figure 2).

Figure 2. Mean monthly air temperatures during the 2023/2024 growing season at the Uhrusk Experimental Farm



Production traits and statistical analysis

The experiment aimed to assess: (1) wheat grain yield and its components, (2) technological quality of the grain, (3) weed infestation in crop stands, and (4) soil chemical properties. Grain was harvested at full maturity using a plot harvester. Spike number was recorded per 1 m² of each plot, 1000-grain weight was determined from two subsamples of 500 grains each, and mean grain weight per spike was calculated from 30 randomly selected spikes per plot.

Technological quality of the grain, including total protein content, wet gluten content, sedimentation index, and starch content, was measured using an OmegaAnalyzer Grain apparatus. Grain volume by weight (test weight) was determined using a 1 L densimeter, and grain uniformity was assessed using 2.5 mm × 25 mm sieves.

Weed infestation was evaluated at the milk maturity stage of wheat using the botanical–gravimetric method. This involved determining weed species composition and density within two 1.0 m × 0.5 m per plot, followed by measurement of their air-dry biomass. Collected weeds were dried on ventilated shelves in a well-ventilated room until constant air-dry weight was achieved. Vertical distribution of weeds within the wheat canopy was classified as: (1) upper layer – species taller than the crop; (2) middle layer – species reaching 50–100% of crop height; (3) lower layer – species up to 50% of crop height; and (4) ground layer – prostrate species ≤10 cm in height.

Soil chemical properties were determined as follows: organic carbon (SOC) by the Tiurin method, total nitrogen (N) by the Kjeldahl method, available phosphorus (P) and potassium (K) by the Egner–Riehm method, and magnesium (Mg) by the Schachtschabel method. All determinations were conducted in triplicate on soil samples collected from the 0–25 cm layer after wheat harvest.

Statistical analysis was performed using analysis of variance (ANOVA) in STATISTICA software (StatSoft, Poland). Differences between the crop rotation and monoculture treatments were evaluated using Tukey's HSD test at $p < 0.05$.

RESULTS

Grain yield and quality

Winter durum wheat grown in the crop rotation (CR) system achieved a significantly higher grain yield than in monoculture (CM), with the difference exceeding 191% (Table 1). Yield components, including spike number per m², grain weight per spike, and thousand-grain weight, were also greater in CR than in CM, by 31.7%, 118.3%, and 13.3%, respectively.

Grain from CR plots exhibited higher test weight, improved uniformity, and greater starch content compared with grain from CM, by 12.4%, 11.6%, and 10.2%, respectively (Table 2). In contrast, protein content, gluten content, and sedimentation index were not significantly affected by the cropping system.

Table 1. Grain yield and yield components of winter durum wheat

Specification	Cropping systems		Statistics	
	^a CR	CM	F-value	p
Grain yield (t ha ⁻¹)	7.31	2.51	195.70	**
Spike number (pcs m ⁻²)	470.1	356.9	31.59	**
Grain weight per spike (g)	1.55	0.71	27.18	**
1000 grain weight (g)	45.2	39.9	43.34	**

^a CR – crop rotation, CM – cereal monoculture, ** $p < 0.01$.

Table 2. Grain quality traits of winter durum wheat

Specification	Cropping systems		Statistics	
	^a CR	CM	F-value	p
Protein content (g kg ⁻¹)	137.0	139.0	50.7	ns
Wet gluten content (g kg ⁻¹)	282.0	288.0	22.5	ns
Zeleny's sedimentation index (mL)	41.0	41.7	0.63	ns
Test weight (kg hL ⁻¹)	74.3	66.1	14.59	**
Grain uniformity (%)	89.6	78.0	17.76	**
Starch content (g kg ⁻¹)	616.0	514.0	416.3	**

^a CR – crop rotation, CM – cereal monoculture, ns – not significant, * $p < 0.05$, ** $p < 0.01$.

Weed infestation

Weed infestation in winter durum wheat varied markedly between the cropping systems (Tables 3 and 4, Figure 3). Both weed density and biomass were significantly higher in CM than in CR. In CM, the mean weed density reached 64.9 plants m⁻², with an air-dry biomass of 40.7 g m⁻², compared with 44.0 plants m⁻² and 15.8 g m⁻² in CR. Species richness was also reduced under CM, with six species compared with 13 in CR.

The dominant weeds in CR were *Apera spica-venti*, *Avena fatua*, and *Fallopia convolvulus*, whereas in CM the prevailing species were *A. spica-venti*, *A. fatua*, *Tripleurospermum inodorum*, and *Papaver rhoeas* (Figure 3). These species were mainly concentrated in the upper and middle canopy layers, representing 90% of the weed population in CR and 100% in CM (Table 4). Weeds occurring in the lower and ground canopy layers were observed only in CR plots, including *Myosotis arvensis*, *Veronica persica*, and *Lamium purpureum*, which together accounted for 10% of the weed community.

Table 3. Weed infestation indicators of winter durum wheat

Specification	Cropping systems		Statistics	
	^a CR	CM	F-value	p
Number of weeds (pcs m ⁻²)	44.0	64.9	40.95	**
Air-dry weight of weeds (g m ⁻²)	15.8	40.7	64.30	**
Number of weed species (m ⁻²)	13	6	73.50	**

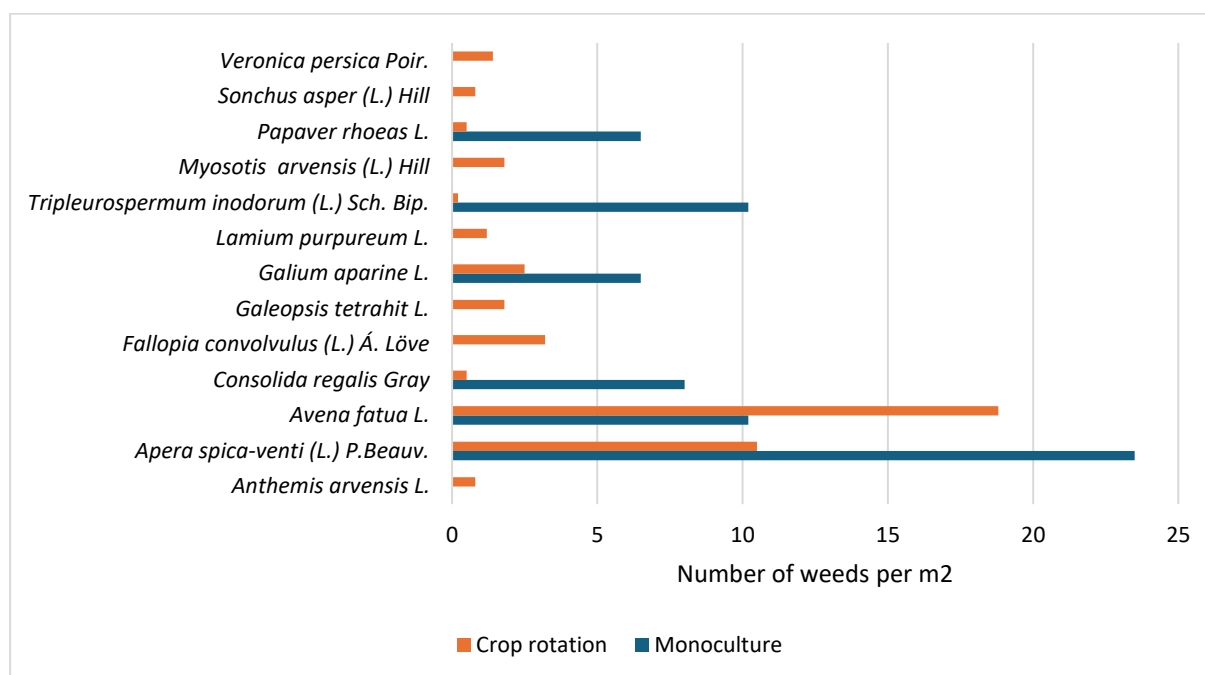
^a CR – crop rotation, CM – cereal monoculture, ***p* < 0.01.

Table 4. Distribution of weeds at different canopy levels in winter durum wheat

Crop level	Cropping systems	
	^a CR (%)	CM (%)
Upper level	67.7	61.9
Middle level	22.3	38.1
Lower level	4.1	–
Ground level	5.9	–

^a CR – crop rotation, CM – cereal monoculture, – no occurrence observed.

Figure 3. Species composition of weeds under crop rotation and cereal monoculture



Soil chemical properties

The cropping system significantly influenced soil chemical properties (Table 5). Compared with CM, soils from CR plots contained higher levels of organic carbon (by 66%), total nitrogen (by 38.3%), and potassium (by 36%).

Table 5. Soil chemical properties (0–0.25 m layer)

Trait	Cropping systems		Statistics	
	^a CR	CM	F-value	p
Organic C (g kg ⁻¹)	13.25	7.98	69.23	**
Total N (g kg ⁻¹)	0.83	0.60	8.44	*
P (mg kg ⁻¹)	214.0	211.0	0.10	ns
K (mg kg ⁻¹)	156.5	115.1	6.44	*
Mg (mg kg ⁻¹)	76.8	67.2	1.39	ns
pH _{KCL}	7.2	7.1	0.91	ns

^a CR – crop rotation, CM – cereal monoculture, ns – not significant, **p* < 0.05, ***p* < 0.01.

DISCUSSION

Crop rotation integrates diverse cultivation and agrotechnical practices in plant production. A key feature is the inclusion of crops from different botanical families and growth forms, including both winter and spring species. Such systems enhance crop health and competitiveness against weeds, resulting in yields that are consistently higher than those achieved under monoculture. In the present experiment, the grain yield of winter durum wheat under crop rotation was almost three times greater than in long-term monoculture (7.31 t ha⁻¹ vs. 2.51 t ha⁻¹). Similarly, Woźniak and Haliniarz [2025] reported that the yield of winter wheat sown in rotation after peas was more than twice as high as in monoculture.

Cereal species differ in their responses to monoculture and the duration of continuous cultivation. Wheat, in particular, is highly sensitive, with substantial yield reductions primarily due to take-all disease caused by *Gaeumannomyces graminis* var. *tritici* [Freeman and Ward 2004, Andrade et al. 2011, Woźniak 2023]. Beyond yield, monoculture also diminishes grain quality. In this study, wheat grain from monoculture exhibited lower bulk density, poorer uniformity, and reduced starch content compared with grain from crop rotation. Woźniak [2023] likewise observed that long-term wheat monoculture decreased bulk density and uniformity while increasing grain ash content. This supports the view that monoculture-grown wheat produces poorly filled kernels with reduced starch, which translates into lower density, poorer uniformity, and higher ash levels.

Another adverse effect of monoculture is increased weed infestation, both in terms of abundance and biomass, along with changes in weed community structure [Woźniak 2025]. Crop rotation, in contrast, involves varied tillage practices and agronomic measures that, while supporting greater weed species richness, limit their competitive impact on crops [Hernández Plaza et al. 2015, MacLaren et al. 2020]. In the present study, weed density and biomass were higher in monoculture, whereas species richness was greater under rotation (13 vs. 6 species). In rotation plots, weeds were mainly confined to the upper and middle canopy layers (90% of the total), whereas in monoculture only strongly competitive species dominated. High-biomass weeds from these canopy layers exert the strongest competition against crops [Mahajan and Timsina 2011]. In the present experiment, the dominant species in rotation were *Avena fatua*, *Apera spica-venti*, and *Fallopia convolvulus*, whereas in monoculture they were *A. spica-venti*, *Tripleurospermum inodorum*, and *Papaver rhoeas*.

Crop rotation also positively influences soil properties by alternating crops with contrasting nutrient demands and tillage requirements. In this study, soils from rotation plots contained higher levels of soil organic carbon (SOC), total nitrogen, and potassium compared with soils under monoculture. This is largely attributable to wheat being grown after potato fertilised with manure, which enhanced soil fertility. As Rasool et al. [2008] highlighted, organic fertilisers supply substantial amounts of carbon

and essential nutrients, thereby improving soil fertility and crop productivity. In contrast, cereal monoculture generates less diverse crop residues, negatively affecting soil microbial activity and biodiversity [Olsson and Alström 2000, Balota et al. 2004], which in turn reduces plant productivity.

CONCLUSIONS

Crop rotation markedly improved the productivity and technological quality of winter durum wheat, with yields over 190% higher than in monoculture. Grain from rotation also showed higher bulk density, better uniformity, and increased starch content. Monoculture resulted in greater weed density and biomass, whereas rotation enhanced species richness and limited the dominance of highly competitive weeds. Soils under crop rotation contained higher levels of organic carbon, total nitrogen, and potassium.

These results highlight that diversified cropping, supported by organic fertilisation, enhances soil fertility and contributes to the long-term sustainability of agricultural systems.

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