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Impact of conservation tillage and triticale-vetch intercropping on soil physicochemical properties and moisture content

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ABSTRACT

The use of conservation tillage systems and intercropping methods, due to their effects on soil properties, can significantly contribute to the sustainability of agricultural ecosystems. This study aimed to evaluate the effects of different tillage systems and intercropping methods on certain physical and chemical properties of soil. The experiment was carried out as a split-plot based on a randomized complete block design (RCBD) during the 2019–2020 cropping season at the University of Kurdistan research farm. Tillage systems were considered the main factor at three levels: conventional tillage, reduced tillage, and no-tillage. Intercropping patterns were the sub-factor, including monoculture of triticale, monoculture of vetch, and four different replacement ratios of these two species. The results showed that the highest bulk density (1.12 g.cm^{-3}) and soil moisture content (13.26%) were observed under the no-tillage system. Furthermore, intercropping increased the concentration of soil phosphorus and potassium. Soil respiration was higher in mixed cropping systems than in monocultures, with the highest value recorded in the 40% triticale and 60% vetch intercropping treatment. Therefore, combining conservation tillage systems with intercropping can be an effective approach to achieving sustainable agriculture.

Highlights

- Combining conservation tillage with intercropping provides an effective strategy for sustainable agriculture.
- Intercropping of triticale and vetch enhanced soil phosphorus and potassium availability.
- Conservation tillage improved soil properties by increasing moisture and organic matter content.

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1. Introduction

Soil tillage significantly influences key soil properties, including temperature regulation, moisture retention and distribution, as well as soil compaction (Lv et al., 2023). In this context, the proper selection and implementation of a soil tillage system can provide an optimal seedbed environment conducive to plant growth and, ultimately, to achieving desired crop yields (Ahmadi et al., 2024). Conventional tillage systems prepare an optimal growth medium by breaking through impervious soil layers, removing crop residues from the soil surface, and interrupting the life cycles of weeds, insects, and pathogens. However, these systems not only require substantial energy inputs but also tend to degrade the soil's physical properties over time, leading to erosion (Li et al., 2023). Consequently, replacing conventional tillage with conservation agriculture systems has emerged as a crucial strategy for sustainability and has gained international acceptance (Akinola et al., 2023). Multiple studies have demonstrated that zero-tillage and reduced tillage systems, compared to conventional tillage, not only reduce agricultural costs over a year but also decrease surface soil crusting, bulk density, and soil compaction. These systems enhance soil moisture retention primarily through improved water infiltration, reduced evaporation and runoff, and increased nutrient availability (Lv et al., 2023). Research indicates that water infiltration in reduced tillage systems improves due to increased organic matter and earthworm activity compared to conventional tillage practices (Akinola et al., 2023). Additionally, the adoption of reduced or no-tillage systems results in lower energy consumption and mitigates soil erosion and degradation (Li et al., 2023).

One approach to enhancing ecosystem sustainability and maintaining the health of agricultural production systems is the implementation of intercropping (Lal et al., 2019). Intercropping involves cultivating two or more crops simultaneously on the same land area, with at least some overlapping growth periods during which the crops interact and compete (Wang et al., 2024). Recognized as a key method for increasing biodiversity, intercropping has been introduced as an effective strategy within agricultural ecosystems (Begam et al., 2024). The benefits of this method include efficient utilization of growth resources, improved access to light, water, nutrients, and air, better land use efficiency, stable yields, enhanced soil fertility through biological nitrogen fixation by legumes, and increased ground cover that reduces erosion (Cui et al., 2024). Studies have demonstrated that the ecological advantages of intercropping over monoculture systems stem from more efficient use of environmental resources, particularly sunlight, which is stored during photosynthesis and converted into biomass (Wang et al., 2024). Optimal resource utilization depends on selecting appropriate crop species and planting densities that swiftly occupy the ecological niches, thereby maximizing the effective use of light, water, and nutrients compared to separate cultivation (Lal et al., 2019).

Vicia sativa (common vetch) is a plant that naturally grows in pastures and grasslands. It is cultivated as a green manure, forage crop, silage, and green fodder for soil conservation and improvement. Its forage quality is suitable for livestock, with protein content reaching approximately 15-20% at harvest time (Chen et al., 2020). *Triticosecale* Wittmack (triticale), a hybrid of the genera *Secale* (rye) and *Triticum* (wheat), combines the agronomic performance of wheat with the environmental adaptability of rye. Due to its high lysine content, triticale offers a higher protein value than wheat and exhibits favorable genetic diversity and adaptability to a wide range of environmental conditions, making it a suitable fall forage and grain crop (Audenaert et al., 2024).

Conservation tillage, as a sustainable agricultural practice, encompasses a set of techniques designed to preserve and improve soil quality while reducing erosion. This approach involves minimizing soil disturbance and maintaining crop residues on the soil surface. The effects of conservation tillage on the physical, chemical, biological properties, and moisture content of soil depend on the tillage intensity and environmental conditions (Deng et al., 2023). Researchers investigating the impact of conservation tillage on microbial communities have found that it promotes increased activity of soil fungi and bacteria, which in turn enhances soil organic carbon content (Chen et al., 2020). Other studies have shown that soil microbial communities with a higher ratio of fungal biomass are associated with conservation tillage systems and reduced-input farming practices (Akinola et al., 2023). A study examining the effects of minimum tillage on soil properties in Mediterranean regions reported that conservation tillage increased soil fertility but did not significantly affect wheat and soybean yields or their components (Piazza et al., 2020). Further research on the impact of conservation tillage on soil physical and chemical properties revealed that the apparent bulk density of soil was lower under minimum tillage compared to conventional tillage and no-tillage systems (Lv et al., 2023). Additionally, studies have indicated that no-tillage methods improve soil physical characteristics (Ahmadi et al., 2024).

Implementing conservation agriculture systems not only enables farmers to realize acceptable economic returns through increased and quality-oriented yields but also contributes to environmental protection and resource conservation. Preserving favorable soil characteristics through appropriate tillage practices is essential. Given the importance of intercropping and conservation tillage systems for achieving sustainable agricultural goals, this study aimed to evaluate the effects of various tillage and intercropping systems on specific soil properties. The research was conducted using a randomized complete block design with split plots at the University of Kurdistan's research farm in Dehgolan.

2. Materials and Methods

2.1 Study area

This research was conducted during the 2019-2020 agricultural year at the research farm of the Faculty of Agriculture, University of Kurdistan, Iran. The farm is located at geographic coordinates 35°08’N, 37°37’E, approximately 35 km east of Sanandaj city. The elevation of the site is 1,866 m above sea level. The region receives an average annual rainfall of approximately 350 mm. Based on the Aridity Index method, the climate of the area is classified as Mediterranean and arid (Amini et al., 2014). Monthly average precipitation and temperature data, obtained from the Kurdistan Meteorological Department, are presented in Table 1.

Table 1 Annual temperature and precipitation for the 2018–2019 crop year

Parameters	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul
Precipitation (mm)	1.7	125.7	31.2	30	39.8	20.1	93.6	22.2	0.1	0.5
Average Minimum Temperature (°C)	11.4	4.0	-3.7	-3.5	-3.7	2.7	3.6	9.64	13.3	18.2
Average Maximum Temperature (°C)	23.9	12.1	4.2	3.9	4.9	12.7	13.4	21.5	26.3	33.5

2.2 Experimental design

The study employed a split-plot design within a randomized complete block framework, with three replications. Main plots consisted of different tillage practices, including conventional tillage (plow with moldboard), disk harrowing, and leveling with a rake, as well as reduced tillage (chisel plow) and no-tillage. Subplots involved six cropping patterns: sole triticale (I1), sole vetch (I2), a mixed cropping system with 80% triticale and 20% vetch (I3), 60% triticale and 40% vetch (I4), 40% triticale and 60% vetch (I5), and 20% triticale and 80% vetch (I6). Conventional tillage was performed in early October by plowing the field to a depth of 30 cm. Subsequently, rock fragments were broken with a disk, and the surface was leveled with a rake. Reduced tillage using a chisel was also carried out simultaneously. Sowing was conducted manually on October 25th. In no-tillage plots, seed planting was performed manually. Each subplot measured 5 m in length and 1.5 m in width, comprising six rows spaced 30 cm apart. Inter-row spacing between subplots was 0.5 m, and the spacing between main plots and replicates was 1.5 m. Fertilizers were applied based on soil analysis results and recommended rates. Weed control was performed manually every week until the end of the growing season.

2.3 Sampling and Variable Measurements

To assess the effects of treatments on soil properties, composite soil samples (each consisting of three sub-samples) were randomly collected from a depth of 0-30 cm across the entire field before the start of the experiment. The soil characteristics before treatment are summarized in Table 2. At the end of the growing season, soil sampling was repeated following the same procedure for each subplot. Samples were immediately transported to the laboratory, where plant residues and stones were removed, and soil aggregates were broken down. Samples were then passed through a 2 mm sieve and stored in clean plastic containers until analysis. Some samples were kept at 4°C for biological analyses.

For physical and chemical analyses, undisturbed soil samples were collected using metal cylinders (5 cm diameter and height). Soil pH and electrical conductivity (EC) were measured in a 1:2 soil-to-water suspension using a pH meter and EC meter, respectively. Bulk density was determined using the standard cylinder method (Walkley and Black, 1934), and gravimetric soil moisture was measured following Gardner (1965). Available phosphorus was extracted with 0.5 M sodium bicarbonate and quantified via colorimetry (Murphy and Riley, 1962). Available potassium, calcium, and magnesium were extracted with 1 M ammonium acetate. Potassium concentrations were determined using atomic emission spectrometry, while calcium and magnesium were quantified via colorimetric complexometric titration (Botha et al., 1952). Ammonium and nitrate contents were measured following the procedures of Bremner and Keeney (1982). Total organic carbon was determined by oxidation using the Walkley-Black. Soil respiration was assessed through induced respiration measurements following Schinner et al. (2012).

Table 2 The soil's physicochemical properties at the experiment's site.

Properties	unit	value
Electrical conductivity	dS/m	0.49
Sand	(%)	14.2
Silt	(%)	38.4
Clay	(%)	47.4
Available iron	mg/kg	2.20
Nitrogen	(%)	0.08
Available Phosphorus	mg/kg	12.4
Available potassium	mg/kg	320
Available Born	mg/kg	0.7

Statistical analyses were performed using SAS software version 9.1. The coefficient of variation (CV) , based on Eq. 1, was calculated to evaluate data dispersion relative to the mean. Differences among treatment means were compared using the Least Significant Difference (LSD) test (Al-Fahham, 2018), which identifies statistically significant pairwise differences, as shown in Eq. 2. An initial analysis of variance (ANOVA) was conducted to detect overall treatment effects. When significant differences were found, the LSD test was applied using Eq. 2.

$$CV = \frac{SD}{MEAN} * 100 \quad (1)$$

$$LSD = T_{\alpha}\sqrt{\frac{2MSE}{N}} \quad (2)$$

Where SD is the standard deviation and MEAN is the average, t_{α} is the t-value at significance level α based on degrees of freedom, MSE is the mean square error obtained from ANOVA, and n is the number of observations per treatment. Data visualization was performed using Microsoft Excel 2020.

3. Results and Discussion

3.1 ANOVA analysis

The results of the analysis of variance for the experimental data indicated that electrical conductivity of soil, nitrate, ammonium, organic matter, and stimulated respiration were significantly influenced by the interaction effect of tillage method and mixed cropping at the 1% significance level. Soil pH and readily available potassium were solely affected by the tillage type, also at the 1% significance level. Available phosphorus, bulk density, and soil moisture were significantly impacted by the effects of mixed cropping and tillage method at the 1% level (Table 3).

3.2 Soil electrical conductivity

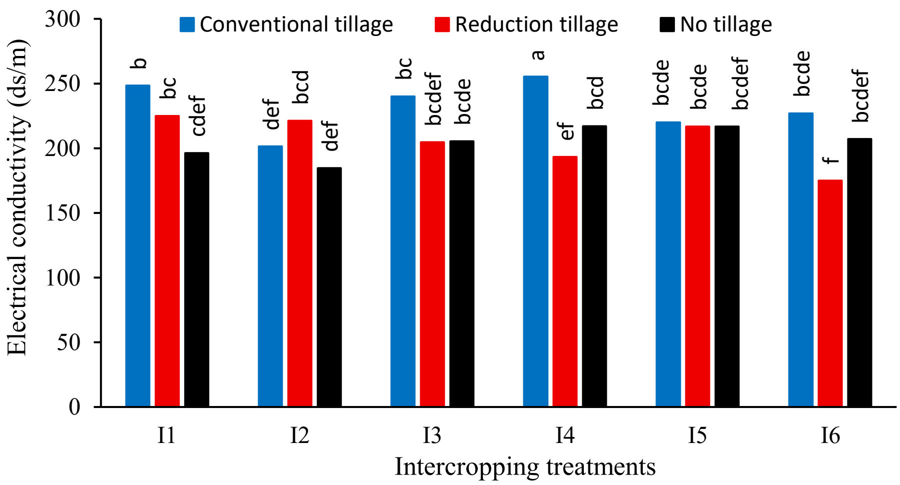
A comparison of the means revealed that the interaction between the tillage method and mixed cropping significantly affected soil electrical conductivity. In all mixed cropping treatments, soil EC under conventional tillage was higher than in no-till systems. Additionally, EC values were greater in mixed cropping compared to monocropping. the highest (0.25 dSm^{-1}) and lowest (0.17 dSm^{-1}) soil electrical conductivity levels were observed, respectively, in the conventional tillage system and the mixed cropping system with a 60% triticale and 40% vetch substitution, as well as in the mixed cropping system with a 20% triticale and 80% vetch substitution in the reduced tillage system (Fig 1). The soil solution's electrical conductivity depends on the concentration of soluble ions; higher ion concentrations lead to increased EC. Consistent with these findings, Komeili et al. (2018) reported the lowest soil EC in the no-till treatment. Similarly, Asgari et al. (2021) found that no-till systems exhibited lower EC than conventional tillage. In another study, Hamzei and Saeyedi (2015) reported that pure wheat cultivation had a more favorable soil solution EC compared to other planting patterns. The lowest and highest EC values were observed in the pure wheat cultivation treatments. Overall, mixed cropping improved the soil solution EC compared to sole cropping.

Table 3 Mean square values for some soil properties affected by tillage types and vetch-triticale intercropping

S.O.V	Replication	Tillage (T)	Error 1	Intercropping (I)	T × I	Error 2	CV (%)
Soil properties df	2	2	4	5	10	30	-
				MSE			
Electrical conductivity (EC)	1281.12**	2888.57**	166.51	1262.91*	1702.19**	417.27	9.69
Potential of hydrogen (pH)	0.37ns	0.34 ns	0.41	0.18 ns	0.22 ns	0.21	5.41
Bulk density (BD)	0.05ns	1.11**	0.01	2.15**	0.02ns	0.02	13.47
Available phosphorus (P)	177.6ns	1470.51**	28.18	315.39**	137.42**	20.71	18.72
Nitrate (NO_3^-)	60.03ns	54.15ns	8.23	25.97ns	114.66**	16.05	35.07
Available potassium (K)	738.01**	642.92**	100.11	38.02ns	45.18ns	68.59	6.18
Ammonium (NH_4^+)	24.93ns	181.25**	17.46	53.34ns	71.09*	30.95	18.08
Substrate induced respiration (SIR)	28803.03ns	857219.94**	33120.82	570832.51**	339028.49**	29639.58	15.34
Soil humidity (SH)	0.82ns	62.71**	5.94	25.52**	0.38ns	5.42	19.72
Organic matter (OM)	0.11ns	0.81**	0.06	0.18ns	0.57**	0.10	34.51

ns: non-significant, *: significant at $P \leq 0.05$, **: significant at $P \leq 0.01$, respectively.

Fig. 1 Mean comparison of the interaction of tillage and vetch-triticale intercropping on soil electrical conductivity (EC)



3.3 Soil pH

The comparison of main effects indicated that soil pH was higher in mixed cropping treatments compared to sole cropping. The highest pH was associated with conventional tillage (Table 4). These results align with Veisi et al. (2022), who reported that soil pH under conventional tillage was higher than in reduced tillage and no-till systems. Another research result related to the findings of this research indicated an increase in soil pH in mixed cropping compared to pure barley and chickpea cultivation (Hamzei and Saeyedi 2015). Researchers reported that legumes play a positive role in increasing soil pH for cultivating various agricultural products. In another experiment involving a mixed crop of maize and beans, the beans, through nitrogen fixation, were able to play an important role in raising soil pH (Li et al., 2023). Legumes share a symbiotic relationship with bacteria of the genus Rhizobium, which are capable of nitrogen fixation. Rhizobia are chemoorganotrophs that obtain their carbon source from soil organic matter and contribute to an increase in soil pH, thereby alkalizing their surrounding environment (Schoebitz et al., 2020).

3.4.Bulk density

Analysis of variance showed that apparent bulk density was highest in the no-till treatment (1.12 g/cm³). However, no significant differences were observed between conventional and reduced tillage systems. The comparison of mixed cropping effects revealed that bulk density was significantly lower in mixed cropping treatments compared to sole cropping (Table 4). bulk density is a common indicator of soil compaction; lower values are generally favorable for crop growth (Asgari et al., 2021). Researchers reported that the use of tillage tools, by displacing and compacting the soil, leads to a reduction in the apparent bulk density of the soil. In other words, an increase in soil displacement is associated with a further decrease in apparent bulk density (Cherubin et al., 2017). In Brazil, Cherubin et al. (2017) reported no significant difference in soil bulk density between conventional tillage and reduced tillage, but significant differences existed compared to no-till systems. Additionally, a reduction in the bulk density of soil has been reported in the intercropping of vetch and barley compared to sole cropping, which is consistent with the findings of the present study (Heydarpour et al., 2018). Conversely, Idaresit et al. (2016) reported that intercropping peanuts, a leguminous crop, with maize resulted in a 35% decrease in soil bulk density; however, this finding is not aligned with the results of the current research.

Table 4 Mean comparison of tillage and intercropping effect on soil pH, bulk density, phosphor and soil moisture

Treatments	Levels	pH	BD (g/m^3)	P (mg/kg)	Sh (%)
Tillage	Conventional tillage	8.73^{a}	0.72^{b}	6.41^{c}	10.22^{b}
	Reduction tillage	7.36^{b}	0.76^{b}	10.29^{b}	12.89^{ab}
	No tillage	6.81^{b}	1.12^{a}	12.23^{a}	13.26^{a}
Intercropping	I1	7.09^{ab}	0.38^{b}	10.19^{ab}	1.05^{b}
	I2	7.73^{ab}	0.52^{b}	10.87^{a}	11.69^{b}
	I3	8.87^{a}	1.33^{a}	8.81^{d}	12.46^{ab}
	I4	8.89^{a}	1.22^{a}	8.62^{d}	12.4^{ab}
	I5	8.45^{a}	1.28^{a}	9.05^{cd}	14.35^{a}
	I6	7.82^{ab}	1.25^{a}	8.66^{d}	14.39^{a}

Means in each column followed by similar letter(s) are not significantly different at 5% probability level based on the LSD test

3.5 Soil available phosphorus

The mean comparisons indicated that available phosphorus was higher in sole cropping and no-till treatments, with the maximum value (12.23 mg/kg) observed in the no-till system (Table 4). Consistent with these findings, previous research has shown that conservation tillage increases soil available phosphorus, likely due to the role of crop residues in preventing phosphorus fixation and leaching (Nafi et al., 2020). It appears that the application of optimal plant densities for the two species in mixed cropping systems, along with improved root distribution throughout the soil profile, leads to more effective occupation of vacant ecological niches and enhanced nutrient uptake per unit area. This phenomenon may consequently result in a reduction of the available phosphorus content in the soil under the aforementioned treatments (Rahimizadeh et al., 2021). On the other hand, in calcareous soils of dry and semi-dry regions with alkaline pH, available phosphorus reacts with calcium and magnesium, forming insoluble phosphate compounds of calcium and magnesium. This reaction reduces the amount of available soil phosphorus. It appears that one of the reasons for the low available phosphorus in conventional tillage and mixed cropping treatments is the higher pH in these treatments compared to other examined treatments (Schoebitz et al., 2020).

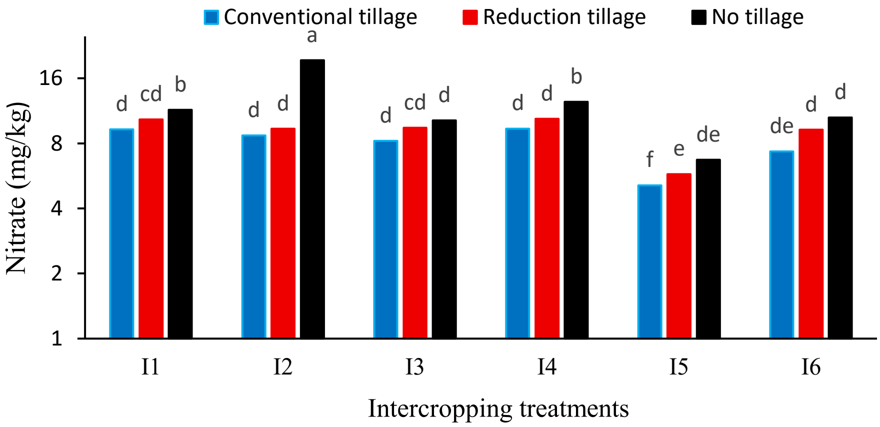


Fig. 2 Mean comparison of the interaction of tillage and vetch-triticale intercropping on soil nitrate

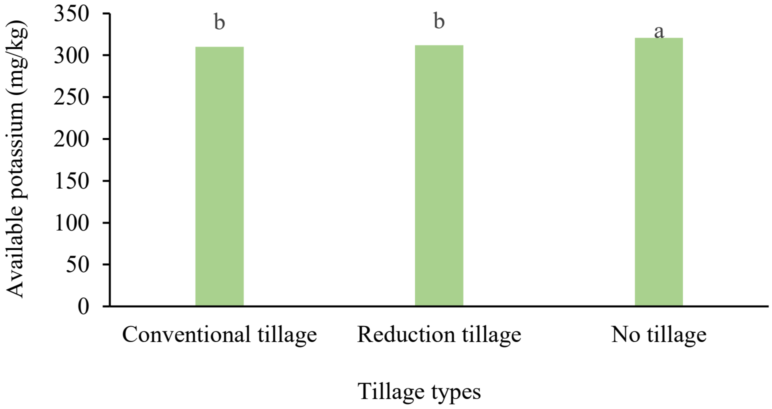
3.6 Soil nitrate

Analysis of the mean data revealed that soil nitrate levels were higher in all mixed cropping treatments under no-till compared to conventional tillage and reduced systems The highest value was observed at 38.19 mg/kg and the lowest at 11.5 mg/kg in the pure vetch cultivation treatment and the no-tillage system, as well as in the mixed cropping treatment with 40% triticale replacing 60% vetch in the no-tillage system (Fig. 2). Factors such as the plant's nitrate absorption and transfer potential, root morphology, and different biochemical and physiological mechanisms contribute to variations in soil nitrogen concentration due to nitrate assimilation in plants (Obour et al., 2021). Researchers reported that the no-till system can play an effective role in increasing the levels of organic matter and nitrate in the soil. Furthermore, the mobility of nitrogen in no-till systems has decreased compared to tilled systems. Conventional tillage practices prevent nitrate leaching, resulting in elevated nitrate concentrations in no-till treatments (Roozbeh and Ghanbary, 2018). Several studies have reported increased soil nitrate concentrations in legume-based cropping systems (Li et al., 2023). Similarly, in line with the findings of this study, an increase in soil nitrate concentration has been reported to decrease in tillage systems (Akhavan and Shabanpour, 2016). It has also been reported that soil nitrate concentration is higher in pure legume cultivation compared to mixed cropping (Mirzavand and Asadi, 2020), which is consistent with the results of this experiment.

3.7 Readily available potassium

The mean comparisons showed that available potassium was higher in the no-till system (321 mg/kg) than in conventional (310 mg/kg) and reduced tillage treatments (85.31 mg/kg), as shown in Fig. 3. Prior studies have shown that conservation tillage can increase soil potassium levels (Nafi et al., 2020). In another study aimed at examining the effect of tillage on the distribution of soil nutrients, the results showed that conservation tillage (no-till) significantly increased the available potassium concentration in the soil (Lv et al., 2023). In a study, an increase in available soil potassium was also reported in no-tillage treatments. These researchers reported that in conventional tillage systems, annual soil tillage causes potassium to circulate and become available to plants, which consequently reduces its amount in the soil (Obour et al., 2021). Additionally, consistent with the findings of the present study, an increase in the concentration of available soil potassium under no-tillage systems has also been reported (Veisi et al., 2022).

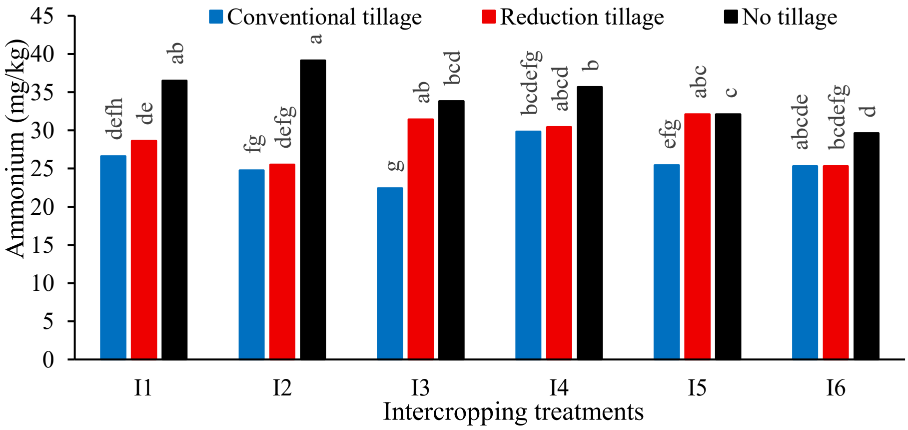
Fig. 3 Mean comparison of the effects of tillage types on soil available potassium content



3.8 Soil ammonium

The results of the analysis of variance for the current experimental data showed that soil ammonium levels were significantly affected by the interaction between tillage and mixed cropping. Specifically, soil ammonium concentrations in the no-tillage treatments were higher across all mixed cropping combinations compared to the conventional tillage system. Additionally, in the pure vetch cultivation treatments, this trait's value was higher than in the mixed cropping treatments (Fig. 4). Obour et al. (2021), in coordination with the findings of this study, reported that nitrogen mineralization in compacted soils (conventional tillage) showed a significant decrease compared to non-compacted samples (reduced tillage and no-till). This indicates that in conventional tillage treatments, less organic nitrogen is converted into ammonium, resulting in a decrease in ammonium mineralization and formation.

Fig. 4 Mean comparison of the interaction of tillage and vetch-triticale intercropping on soil ammonium

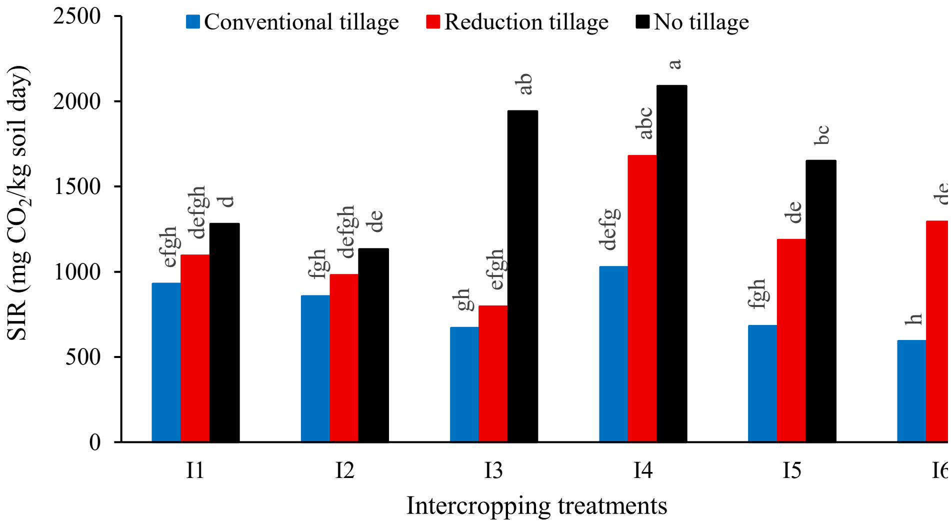


On the other hand, the reduction of soil enzyme activities, especially urease, in conventional tillage systems has been reported due to increased mechanical resistance, reduced large pores, poor soil aeration, and limited activity of organisms involved in the nitrogen cycle (Akhavan and Shabanpur, 2016). In addition, the activity of the urease enzyme in highly compacted soils, where the mineralization of nitrogen into ammonium decreases due to the reduction in organic nitrogen content, is lower (Bach et al., 2018). The increase in nitrogen fixation resulting from the symbiosis between bacteria and leguminous plants (vetch) leads to an increase in ammonium concentration in pure vetch cultivation treatments, a result similar to that reported by Hauggaard-Nielsen and Jensen (2021). The reduction of soil ammonium concentration in common tillage systems has also been reported by Akhavan and Shabanpur (2016) and Mirzavand and Asadi (2020).

3.9 Soil respiration

The highest soil respiration rates were recorded in the no-till treatment and mixed cropping systems involving 40% triticale and 60% vetch. Soil respiration was greater under conservation tillage than under conventional tillage. Additionally, mixed cropping enhanced soil respiration compared to sole cropping (Fig. 5). Activated respiration, respiration caused by the added substrate to the soil, is measured based on the maximum initial CO_2 emission. In other words, activated respiration indicates the maximum rate of initial microbial respiration after soil enrichment with an additional carbon and energy source and is significantly related to the total microbial biomass in the soil (Dawson et al., 2007). Researchers, in their study of microbial activity in soil within mixed cropping systems, concluded that increasing crop diversity in mixed cropping leads to an increase in soil microbial biomass and, consequently, enhanced soil respiration compared to monoculture systems. Additionally, these researchers explained that the higher soil respiration in mixed cropping is due to greater diversity of soil microorganisms and the complexity of predator-prey and bacterial predation relationships among the microorganisms present in the soil (Bagheri et al., 2020). Research results showed that the rate of soil respiration in no-till systems was higher than in conventional tillage. Overall, tillage reduces microbial activity in the soil (Aziz et al., 2013). An increase in soil respiration has been reported in mixed cropping systems of bean and safflower (Bagheri et al., 2020) and reduced tillage systems (Aziz et al., 2013), which is consistent with the results of the present experiment.

Fig. 5 Mean comparison of the interaction of tillage and vetch-triticale intercropping on soil substrate-induced respiration



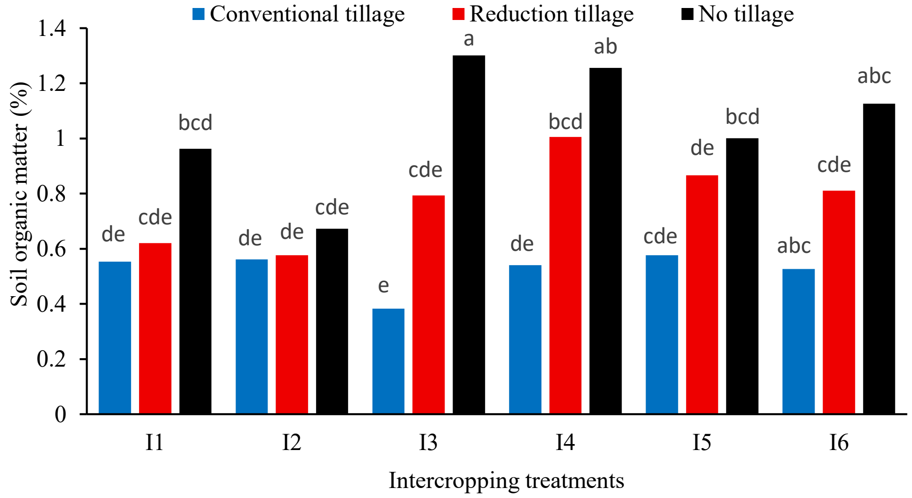
3.10 Soil moisture

The results of comparing the average soil moisture content data showed that the highest (13.26%) and lowest (10.22%) soil moisture levels were respectively in no-tillage systems and conventional plowing systems. Additionally, soil moisture percentage in monoculture treatments was lower than in mixed cropping. The highest soil moisture (14.39%) was observed in the mixed cropping treatment where 20% Triticale was substituted for 80% vetch, which was statistically similar to the treatment with 40% Triticale replaced by 60% vetch (Table 4). Although the variation trend of soil gravimetric moisture percentage can depend on time and rainfall at the sampling time, the greater retention of moisture in these treatments is likely due to reduced soil compaction, increased organic matter, plant residue preservation, prevention of evaporation, and the shielding of snow and rain on the field surface (Hauggaard-Nielsen and Jensen, 2021). In pure crops, due to lower compaction and direct sunlight exposure, surface evaporation increases, leading to higher water loss from the soil. In arid regions, intercropping is a solution for water conservation because transpiration plays a more significant role in reducing soil dryness than evaporation (Sharifi Nejad et al., 2018). In these cropping systems, one of the plants covers the soil surface, and the taller plant provides physical protection against wind, thereby reducing the wind energy reaching the field surface. This results in decreased evaporation. The reduction of evaporation and transpiration from the soil surface and lower leaves due to shading by taller plants increases relative humidity and helps maintain soil moisture in intercropping systems. The microclimate created in intercropping enhances soil microbial activity and facilitates biological nitrogen fixation by legume species in mixed cropping (Sharifi Nejad et al., 2018). The increase in soil moisture percentage in reduced-tillage systems compared to conventional tillage has also been reported by other researchers, aligning with the results of this study (Heidarpour and Mohtashami, 2024).

3.11 Organic matter

Analysis of the mean data indicated that reduced tillage and no-till systems increased soil organic matter content compared to conventional tillage. Furthermore, mixed cropping of vetch and triticale resulted in higher organic matter percentages than sole cropping (Fig. 6). In the conventional tillage method, disturbing the soil causes faster and greater decomposition of plant residues, leading to the quicker mineralization of carbon and nitrogen present in organic materials. As a result, the organic matter in the soil decreases (Nadeem et al., 2019). Several studies have confirmed that conservation tillage practices tend to increase soil organic matter levels, consistent with the present results (Heidarpour and Mohtashami, 2024; Mirzavand and Asadi, 2020). Some researchers have also stated that one of the reasons for the superiority of mixed cropping over pure cropping is the increase in soil organic matter in legume and non-legume mixed cropping. The increase in soil organic matter in the mixed cropping of chickpeas and barley, compared to sole cropping, has been reported by Hamzei and Saeyedi (2015), which is consistent with the findings of the present study.

Fig. 6 Mean comparison of Tillage and Vetch-Triticale interaction effect on soil organic matter



4. Conclusion

This study evaluated the effects of conservation tillage and mixed cropping of triticale and vetch on soil physical and chemical properties and moisture content. The results demonstrated that:

1. Mixed cropping patterns significantly enhanced soil properties, with the highest soil organic matter contents recorded in the 80% triticale–20% vetch and 60% triticale–40% vetch mixtures under no-tillage conditions.

2. Soil pH reached its maximum value (7.3) under conventional tillage, while mixed cropping systems generally improved soil moisture content and bulk density relative to monocropping systems.

3. Reduced tillage practices combined with mixed cropping notably increased rhizosphere-stimulated respiration in both triticale and vetch.

Based on the findings of the present study, it can be concluded that the application of conservation tillage methods within mixed cropping systems leads to improvements in the physical and chemical properties of the soil, and integrating conservation tillage techniques with mixed cropping can serve as an effective strategy for achieving sustainable agriculture and soil resource conservation in arid and semi-arid regions.

Statements and Declarations

Data availability

The data obtained from the experiments conducted in this study are presented in the text of the paper

Conflicts of interest

The author of this paper declared no conflict of interest regarding the authorship or publication of this paper.

Author contribution

A. Jamali: Conducting the research, data collection, and writing the paper; G. Heidari: Designing and leading the research, supervising data analysis, and editing the scientific and editorial aspects of the article; Y. Sohrabi and Z. Sharifi: Providing consultation during various stages of conducting the research and writing the article.

AI Use Declaration

AI assistance was employed exclusively for final editing and adjustment of certain specialized terminology.

References

Ahmadi, H., Mirseyed Hosseini, H., Moshiri, F., Alikhani, H. A., & Etesami, H. (2024). Impact of varied tillage practices and phosphorus fertilization regimes on wheat yield and grain quality parameters in a five-year corn-wheat rotation system. *Scientific Reports., 14(1),* 14717. https://doi.org/10.1038/s41598-024-65784-w

Akhavan, S., & Shabanpour, M. (2016). The Effect of soil compaction on ammonium and nitrate concentrations and wheat nitrogen uptake in two different soils. *Water and Soil Science, 27(1),* 199-212. [In Persian]

Akinola, F. F., Fasinmirin, J. T., Olanrewaju, O. O., Ewulo, B. S., & Olorunfemi, I. E. (2023). Changes in soil physical and mechanical properties under different tillage and cropping systems in Alfisol soil of southwestern Nigeria. *Farming System, 1(3),* 100050. https://doi.org/10.1016/j.farsys.2023.100050.

Al-Fahham, A. A. (2018). Development of new LSD formula when numbers of observations are unequal. *Open Journal of Statistics, 8(1),* 258-263. https://doi.org/10.4236/ojs.2018.82016

Asadi, S., Rezaei-chiyaneh, E., & Amirnia. R. (2020). Evaluation of ecophysiological characteristics of row intercropped linseed (*Linum usitatissimum* L.) with chickpea (*Cicer arietinum* L.) affected as fertilizer sources under dryland conditions. *Journal of Agroecology, 12(2),* 241-264. https://doi.org/10.22067/jag.v12i2.75309 [In Persian]

Asgari, H., Varnaseri, S., Ajami, M., & Boali, A (2021). Comparison of the Effect of Tillage Operations in Different Time Sequences on Physical and Chemical Properties of Surface Soil (Case Study: Agricultural lands of Qarabolagh village, east of Aq-Qala City). *Degradation and Rehabilitation of Natural Land, 1(2)*, 35-45. https://doi.org/20.1001.1.27174425.1399.1.2.3.4 [In Persian]

Amini, A., Ghazvinei, P. T., Javan, M., & Saghafian, B. (2014). Evaluating the impacts of watershed management on runoff storage and peak flow in Gav-Darreh watershed, Kurdistan, Iran. *Arabian Journal of Geosciences, 7*(8), 3271-3279. https://doi.org/10.1007/s12517-013-0950-1

Audenaert, K., Troch, V., Landschoot, S., & Haesaert, G. (2014). Biotic stresses in the anthropogenic hybrid triticale (× Triticosecale Wittmack): current knowledge and breeding challenges. *European Journal of Plant Pathology, 140,* 615-630. https://doi.org/10.1007/s10658-014-0498-2

Aziz, I., Mahmood, T., & Islam, K. R. (2013). Effect of long term no-till and conventional tillage practices on soil quality. *Soil and Tillage Research, 131*, 28 -35. https://doi.org/10.1016/j.still.2013.03.002

Bach, E. M., Williams, R. J., Hargreaves, S. K., Yang, F., & Hofmockel, K.S. (2018). Greatest soil microbial diversity found in micro-habitats. *Soil Biology and Biochemistry, 118*, 217-226. https://doi.org/10.1016/j.soilbio.2017.12.018

Bagheri, M., Rasouli-Sadaghiani, M. H., Barin, M., & Rezaei, E. (2020). Evaluation of some soil quality indices as influenced by the intercropping patterns of bean and Moldavian balms, and microbial inoculation. *Journal of Soil and Plant Interaction, 11(3),* 57-68. [In Persian]. https://doi.org/10.47176/jspi.11.3.6396

Begam, A., Pramanick, M., Dutta, S., Paramanik, B., Dutta, G., Patra, P. S., & Biswas, A. (2024). Inter-cropping patterns and nutrient management effects on maize growth, yield and quality. *Field Crops Research, 310*, 109363. https://doi.org/10.1016/j.fcr.2024.109363

Botha, C. R., & Webb, M. M. (1952). The versenate method for the determination of calcium and magnesium in mineralized waters containing large concentrations of interfering ions. *Institute of Water Engineers Journal, 6(1),* 459-462.

Bremner, J. M., & Mulvaney, C.S. (1982): Nitrogen – Total. In: Methods of Soil Analysis, Part II, 2nd edition, Page, A. L., Miller, R. H, Keeney, D. R. (Eds.), Madison, Wisconsin, USA 1159. https://doi.org/10.4236/oalib.1100971

Chen, H., Daic, Z., Allison, M., Zheng, J., Xuc, J., & Schadt, W. (2020). Global meta-analyses show that conservation tillage practices promote soil fungal and bacterial biomass. *Agriculture, Ecosystem & Environment, 293(1),* 167-178. https://doi.org/10.1016/j.agee.2020.106841

Cherubin, M. R., Tormena, C. A., & Karlen, D. L. (2017). Soil quality evaluation using the Soil Management Assessment Framework (SMAF) in Brazilian Oxisols with contrasting texture. *Revista Brasileira de Ciência do Solo, 41*, e0160148. https://doi.org/10.1590/18069657rbcs20160148

Cui, J., Li, S., Baoyin, B., Feng, Y., Guo, D., Zhang, L., & Gu, Y. (2024). Maize/Soybean intercropping with straw return increases crop yield by influencing the biological characteristics of soil. *Microorganisms., 12(6), 1108*. https://doi.org/10.3390/microorganisms12061108

Dawson, J. J. C., Godsiffe, E. J., Thompson, I. P., Ralebitso-Senior, T. K., Killham, K. S., & Paton, G. I. (2007). Application of biological indicators to assess recovery of hydrocarbon impacted soils. *Soil Biology and Biochemistry, 39(1),* 164-177. https://doi.org/10.1016/j.soilbio.2006.06.020

Deng, Z., Huang, M., Zhang, W., Wang, G., Huang, X., & Liang, G. (2023) Effects of five years conservation tillage for hedging against drought, stabilizing maize yield, and improving soil environment in the drylands of northern China. *PLoS ONE 18(3):* e0282359. https://doi.org/10.1371/journal.pone.0282359

Gardner, W. G. (1965). Water content. In Methods of Soil Analysis, *American Society of Agronomy, Madison*, 23(1), 82–127. https://doi.org/10.1002/gea.3340050110

Hamzei, J. and Saeyedi, M. (2015). Soil physicochemical characteristics and land use efficiency in cereal-legume intercropping systems. *Water and Soil Sciences, 24(4),* 261-271. [In Persian]

Hauggaard-Nielsen, H., & Jensen, E. S. (2021). Evaluating pea and barley cultivars for complementarity in intercropping at different levels of soil N availability. *Field Crops Research, 72(3),* 185-196. https://doi.org/10.1016/S0378-4290(01)00176-9

Heidarpour, N., & Mohtashami, R. (2024). The effects of different rotations under the conservation and conventional tillage conditions on soil physicochemical properties and crop yield of wheat and barley. *Iranian Journal of Field Crop Science, 55(2)*, 169-183. https://doi.org/10.22059/ijfcs.2024.365534.655029. [In Persian]

Heydarpour, N., Namdari, A., & Baghbani-Arani, A. (2018). Evaluation of quantitative yield and some physical properties of soil in three years mixed barley (Khorram)-vetch forage (*Vicia sativa*) cropping system under rain-fed conditions. *Agricultural Science and Sustainable Production, 28 (4)*, 1-13 [In Persian]

Idaresit, A., Ernest, E., & Etebom, W. (2016). Assessment of groundnut/maize intercropping system on soil bulk density and volumetric moisture content grown in typic paleudult soils of Southeastern Nigeria. *Direct Research Journal of Agriculture and Food Science, 4,* 228-232.

Komeili, H. R., Ghodsi, M., Rezvani Moghaddam, P., Nassiri Mahallati, M., & Kamali, M. (2018). Study of soil characteristics, yield and yield components of barley (*Hordeum vulgare L.*) under different tillage methods and the rate of crop residues. *Iranian Journal of Field Crops Research, 16(3),* 541-556. https://doi.org/10.22067/gsc.v16i3.55501 [In Persian]

Lal, B., Rana, K. S., Rana, D. S., Shivay, Y. S., Sharma, Y. S., Meena. B. P., & Gautam, P. (2019). Biomass, yield, quality and moisture use of Brassica carinata as influenced by intercropping with chickpea under semiarid tropics. Journal of the Saudi Society of *Agricultural. Science, 18(1),* 61-71. https://doi.org/10.1016/j.jssas.2017.01.001

Li, L., Zhang, F., Li, X., Christie, P., Sun, J., Yang, S., & Tang, C. (2023). Interspecific facilitation of nutrient uptake by intercropped maize and faba bean. *Nutrient Cycling in Agroecosystems, 65*: 61-71. https://doi.org/10.1023/A:1021885032241

Li, Z., Liu, H., Yang, H., & Wang, T. (2023). Effects of deep vertical rotary tillage management methods on soil quality in saline cotton fields in southern Xinjiang. *Agriculture, 13(10),* 1864. https://doi.org/10.3390/agriculture13101864

Lv, L., Gao, Z., Liao, K., Zhu, Q., & Zhu, J. (2023). Impact of conservation tillage on the distribution of soil nutrients with depth. *Soil Tillage Research, 225*, 105527. https://doi.org/10.1016/j.still.2022.105527

Mirzavand, J., & Asadi Rahmani, H. (2020). Effect of different tillage practices on phosphatase and urease activities in a calcareous soil. *Journal of Soil Biology, 8(1),* 16-25. [In Persian]. https://doi.org/10.22092/sbj.2020.121869

Murphy, J., & Riley, J. P.A. (1962). Modified single solution method for determination of phosphate in natural waters. *Analytica Chimica Acta, 27(1),* 31-36. https://doi.org/10.1016/S0003-2670(00)88444-5

Nadeem, F., Farooq, M., Nawaz, A., & Ahmad, R. (2019). Boron improves productivity and profitability of bread wheat under zero and plough tillage on alkaline calcareous soil. *Field Crops Research, 239*, 1-9. https://doi.org/10.1016/j.fcr.2019.05.010

Nafi, E., Webber, H., Dansoc, I., Jesse, B., Freia, M., & Gaisera, T. (2020). Interactive effects of conservation tillage, residue management, and nitrogen fertilizer application on soil properties under maize-cotton rotation system on highly weathered soils of West Africa. *Soil & Tillage Research, 196(1),* 121-132. https://doi.org/10.1016/j.still.2019.104473

Obour, A. K., Holman, J. D., Simon, L. M., & Schlegel, A. J. (2021). Strategic tillage effects on crop yields, soil properties, and weeds in dryland no-tillage systems. *Agronomy, 11(4),* 662. https://doi.org/10.3390/agronomy11040662

Piazza, G., Pellegrinoa, E., Cristina, M., & Ercolia, L. (2020). Long-term conservation tillage and nitrogen fertilization effects on soil aggregate distribution, nutrient stocks and enzymatic activities in bulk soil and occluded microaggregates. *Soil Tillage Research, 196(1),* 160-173. https://doi.org/10.1016/j.still.2019.104482

Rahimizadeh, M., Zare Feizabadi, A., & Kashani, V. (2011). Investigation of nitrogen use efficiency in wheat- based double cropping systems under different rate of nitrogen and return of crop residue. *Iranian Journal of Field Crops Research, 9 (2),* 211-221. [In Persian]. https://doi.org/10.22067/gsc.v9i2.10996

Roozbeh, M., & Ghanbary, A. H. (2018). Impacts of residue management methods and fertilizer levels of nitrogen on soil residual nitrate and nitrogen uptake under no-tillage system of corn. *Agricultural Mechanization and Systems Research, 18(69),* 85-96. [In Persian]. https://doi.org/10.22092/erams.2017.108069.1144

Schinner, F., Öhlinger, R., Kandeler, E., & Margesin, R. (2012). Methods in Soil Biology. Springer Science & Business Media. 426 pages. https://doi.org/10.1007/978-3-642-60966-4

Schoebitz, M., Castillo, D., Jorquera, M., & Roldan, A. (2020). Responses of microbiological soil properties to intercropping at different planting densities in an acidic Andisol. *Agronomy, 10(6),* 781- 796. https://doi.org/10.3390/agronomy10060781

Sharifi Nejad, M., Ghanbari, A., & Sirousmehr, A.R. (2018). Evaluation of the ecophysiological aspects and forage quality indices in the intercropping of maize (*Zea mays* L.) and cowpea (*Vigna unguiculata* L.). *Journal of Agroecology, 10(1):* 267-280. [In Persian]. https://doi.org/10.22067/jag.v10i1.60479

Veisi, A., Veisi, H., Khoshbakht, K., Mirzaei Talarposhti, R., & Haghparast, R. (2022). Efficacy of conservation tillage systems on soil quality in wheat-based cropping systems in dryland agroecosystems. *Environmental Sciences, 20(3),* 173-190. [In Persian]. https://doi.org/10.52547/envs.2022.37244

Walkley, A., & Black, I. A. (1934). An examination of the Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. *Soil Science, 34*, 29-38. https://doi.org/10.1097/00010694-193401000-00003

Wang, Y., Han, X., Zhao, X., Zhang, Y., Qi, B., & Li, L. (2024). Grain yield and interspecific competition in an oat-common vetch intercropping system at varying sowing density. *Frontiers in Plant Science*, 15, 1344110. https://doi.org/10.3389/fpls.2024.1344110