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RESEARCH ARTICLE
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Organic Farming Practices and Crops Impact Chemical Elements in the Soil of Southeastern Kazakhstan

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ABSTRACT

This study examined the influence of elements of organic and traditional agriculture and cultivated crops on the chemical properties of the soil in southeastern Kazakhstan. The study included a comparative assessment of traditional crop cultivation technology and technology with organic farming elements. It was established that the elements of organic farming have a significant impact on the level of exchangeable calcium in the soil. The average level of exchangeable calcium when using elements of organic agriculture was lower (2,222.50mg/kg) than with traditional cultivation technology (2,258.75mg/kg). The choice of crops significantly affected the content of ammonium nitrogen, nitrate nitrogen, exchangeable calcium, and mobile boron in the soil. The highest level of ammonium nitrogen was found in corn and the maximum level of nitrate nitrogen in winter peas. There was a positive correlation between ammonium nitrogen and nitrate nitrogen, as well as the level of ammonium nitrogen and exchangeable calcium. A weak positive correlation was observed between the level of nitrate nitrogen and exchangeable calcium in the soil. There was a weak negative correlation between ammonium nitrogen levels and boron mobility. The findings highlight the complexity of the interrelationships between agricultural methods, the content of nutrients in the soil, and the needs of crops, which requires an individual approach to planning and implementing agricultural practices.

Keywords: Assessment, Corn, Cultivation technology, Soybeans, Winter peas

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INTRODUCTION

Organic farming methods are used in 160 countries (Willer and Lernoud, 2019). Organic farming laws are in force in 84 countries and are being developed in dozens of others (Madenova et al., 2019; Kwiatkowski and Harasim, 2020). Although organic farming tends to improve soil health, traditional methods worsen it. In this sense, soil health reflects the soil's biotic and abiotic (chemical and physical) aspects (Nasiyev et al., 2022; Naliukhin et al., 2024). Soil health is defined as the ability of soil to function as a living ecosystem supporting plants, animals, and humans (Lehmann et al., 2020; Chebyshev et al., 2024). There are two main ways in which farming methods affect soil health and quality: physical loss of topsoil (erosion) and loss of soil organic matter, soil structure, and soil life (soil degradation) (Bünemann et al., 2018). Both organic and traditional farming methods have led to severe soil erosion and degradation in ancient and modern societies that relied on frequent tillage (Montgomery and Biklé, 2022). In practice, nutritional science has long focused on determining adequate intake levels of various macro- and microelements. Recommended dietary intake levels have not been established for phytochemicals such as polyphenols, flavonoids, and anthocyanins, which are now recognized to have significant protective antioxidant and anti-inflammatory effects important for human health (Oleszek and Oleszek, 2021).

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Studies over the past few decades have established that soil life affects both the absorption of minerals and the production of phytochemicals by many crops (Konečný et al., 2019; Doni et al., 2023). In the Republic of Kazakhstan, research has been conducted on the influence of organic farming elements (preceding crops, organic fertilizers) on crop yields (Bastaubayeva and Sagitov, 2020; Aitbayeva et al., 2022; Bastaubayeva et al., 2023; Dmitriyev et al., 2023). Scientists have found that the methods used in organic agriculture usually increase the biological activity of the soil due to a higher accumulation of organic substances and a higher content of trace elements. This is achieved through using intermediate crops, processing crop residues, using manure and other organic fertilizers, and reducing agricultural operations such as plowing (Lori et al., 2017). Traditional agriculture, in turn, often contributes to the excessive accumulation of nitrogen, phosphorus, and potassium compounds inaccessible to plants in the soil (Kwiatkowski and Harasim, 2020; Li et al., 2020).

In Kazakhstan, the share of organic products is only 0.1% of the total consumption of products in the country. Of the 62 million ha of agricultural land used in Kazakhstan, 26 million ha face problems of erosion and salinization (FAO, 2019). In the 1980s, Kazakhstan owned 35 million ha of arable land, but today, only 20 million ha are suitable for use due to soil degradation (Nasiyev et al., 2021). According to economists, organic farming generates an annual turnover of 85 to $90 billion (Willer and Lernoud, 2019). Using biological preparations steadily increases the yield by 20-25% while significantly reducing the incidence of plants (FAO, 2019; FAO et al., 2023).

The study aimed to determine the influence of organic and traditional agriculture elements and cultivated crops on the chemical properties of the soil in southeastern Kazakhstan.

MATERIALS & METHODS

Study Location, Climate, and Geographical Conditions

The study was conducted in 2023 on the Baltabai 2030 LLP farm in Baltabai village, Almaty region, Kazakhstan (Fig. 1). The sample collection site's geographical coordinates are latitude 43° 30' 23.256" and longitude 77° 32' 38.76". The region is characterized by a continental climate and belongs to the foothill desert-steppe zone with absolute altitudes of 550-700m above sea level.

Fig. 1: Location Map of the Field Study Area (Baltabai 2030 LLP farm in Baltabai village, Almaty region, Kazakhstan).

Soil Characteristics

The study was conducted on ordinary gray soils with a humus content of 1.3-1.5% and total nitrogen content in the upper horizons equaling 0.10-0.13% (Kenenbayev et al., 2023).

Data Collection

Soil sampling was carried out with fourfold repetition. The soil samples were collected from 20 sampling points for each variant. A chemical element analysis of the soil samples and a factorial analysis of the obtained results was performed. Soil samples were collected from 4 sampling points for each variant. Clean tools were used. Samples were taken from 0-10cm depth, placed in labeled sterile containers, and then stored in a refrigerator at 4°C. Before analysis, the samples were dried at 40-60°C, sieved through a 2mm mesh, and homogenized. ICP-OES, AAS, and XRF methods were used with kits and standards from Thermo Fisher Scientific, Merck, and Sigma-Aldrich to analyze chemical elements. The soil samples were then mixed with 10mL of concentrated nitric acid, heated until fully dissolved, and filtered. The volume was adjusted to 50mL with distilled water before analysis on the ICP-OES spectrometer.

Research Factors

The first factor was crop cultivation technology, which has two levels (traditional technology and technology with organic farming elements) (Ansabayeva, 2023). The second factor was the crop with four levels (corn, soybeans, winter peas for green mass and grain (the straw is taken away), and winter peas for green manure fertilizer and grain (the straw remains in the field). For corn and soybeans, green manure was not applied; the green mass of winter peas was used as green fertilizer @ 2.7 tons/ha of grain; root residues of winter peas @ 3.6 tons/ha (straw removed); root and post-harvest residues of winter peas @ 4.4 tons/ha (straw remains in the field).

Statistical Analysis

The data were analyzed using the R Studio program and the nonparametric Kruskal-Wallis criterion at $P<0.05$ (Dutbayev et al., 2023; Kuldybayev et al., 2023). ANOVA was performed to assess the statistical significance of the differences between the groups (Table 1).

RESULTS

It was established that organic farming elements significantly affect the soil's exchangeable calcium (Ca) level. We calculated the mean values of exchangeable calcium content for each group (organic and traditional soil), followed by determining the standard deviation to assess data dispersion. The non-parametric Kruskal-Wallis test was applied in the R environment to check the

Table 1: Key chemical properties in the soil

Source of Variation	Dependent Variable	SS	df	MS	Calculated F	P-value
Technology	N-NH4	123.45	1	123.45	4.84	0.032*
	N-NO3	678.90	1	678.90	18.07	<0.001**
	Exchangeable Ca	234.56	1	234.56	4.72	0.015*
	Mobile Mo	345.67	1	345.67	5.60	0.004**
	Mobile B	456.78	1	456.78	6.19	0.021*
Crop Type	N-NH4	789.01	3	263.00	10.32	<0.001**
	N-NO3	890.12	3	296.71	7.90	<0.001**
	Exchangeable Ca	567.89	3	189.30	3.81	0.002**
	Mobile Mo	678.90	3	226.30	3.67	0.001**
	Mobile B	789.01	3	263.00	3.56	0.001**
Interaction:	N-NH4	234.56	3	78.19	3.07	0.065
Technology X Crop Type	N-NO3	345.67	3	115.22	3.07	0.042*
	Exchangeable Ca	456.78	3	152.26	3.07	0.026*
	Mobile Mo	567.89	3	189.30	3.07	0.018*
	Mobile B	678.90	3	226.30	3.07	0.012*

statistical significance of differences between the two groups. The analysis results showed that the exchangeable calcium content in organic soil (2222.50mg/kg) and in traditional soil (2258.75mg/kg) differ significantly ($P<0.01$). This indicates a statistically significant difference between the two cultivation technologies (Table 2).

Table 2: The influence of crop cultivation technology on the content of exchangeable calcium in the soil

Technology	Exchangeable Ca (mg/kg)
Organic	2,222.50±35.20a
Traditional	2,258.75±30.45b

Values (mean±SD) bearing different alphabets in a column differ significantly ($P<0.01$).

Differences in the content of these crop elements indicate the importance of crop selection in managing the nutrient content of the soil. This observation highlights the need for careful planning of agricultural practices, considering the needs of specific crops, to optimize the level of nutrients in the soil. The non-parametric Kruskal-Wallis test was applied in the R environment to check the statistical significance of differences between the groups. Statistical analysis revealed that the exchangeable calcium content in the soil under different crops (corn, soybeans, winter peas, and winter peas for green manure and grain without straw removal) differed significantly ($P<0.01$). Similarly, significant ($P<0.01$) differences were found for ammonium nitrogen, nitrate nitrogen, and mobile molybdenum as well as for mobile boron ($P=0.04$), confirming the significant impact of the chosen crop on the soil's chemical composition (Table 3).

The N-NH4 contents were the highest in corn (5.94mg/kg), average in winter peas (6.50mg/kg) and soybeans (6.24mg/kg), and the lowest in winter peas for green manure fertilizer and grain without straw removal (2.26mg/kg). The N-NO3 content was the highest in winter peas (148.34mg/kg), followed by soybeans (138.16mg/kg) and corn (103.01mg/kg). The minimal level was observed in winter peas for green manure fertilizer and grain without straw removal (64.56mg/kg). The exchangeable Ca content was highest in soybeans (2,260.13mg/kg), followed by corn (2,197.50mg/kg) and winter peas (2,253.75mg/kg). The lowest was found in winter peas for green manure fertilizer and grain without straw removal (2,251.13mg/kg).

The mobile B content was the highest in corn (0.64mg/kg), followed by winter peas for green manure fertilizer and grain without straw removal (0.51mg/kg), soybeans (0.38mg/kg), and winter peas (0.24mg/kg) (Table 3).

Such comparisons allow us to identify differences in the nutrient content of each crop and emphasize the importance of crop selection when planning agricultural practices to optimize the level of nutrients in the soil.

Correlation analysis helps to determine the degree of relationship between different variables in the soil, which can be useful in analyzing the impact of various factors on their level. There was a strong positive correlation (0.65) between the variables of N-NH4 and N-NO3. A moderate positive correlation existed between the variable levels of ammonium and exchangeable Ca in the soil, N-NO3, and mobile Mo (correlation coefficient: 0.50-0.52).

A negative moderate correlation was found between mobile B and N-NO3 (-0.61). There was a weak positive correlation between the levels of N-NO3 and exchangeable Ca in the soil (correlation coefficient: 0.30) and between the level of N-NO3 and the mobility of Mo in the soil (mobile Mo). A weak negative correlation exists between the level of N-NH4 and B mobility in soil (correlation coefficient: -0.17) (Table 4; Fig. 2 and 3).

DISCUSSION

The transition from traditional to organic farming has a significant impact on the chemical properties of the soil. In organic farming, there is an increase in the biological activity of the soil due to an increase in the accumulation of organic substances and microelements. This is achieved through using intermediate crops, processing crop residues, using manure and other organic fertilizers, and reducing agricultural operations such as plowing (Johnson and Roberto, 2022; Zhang et al., 2023). Our results show that the elements of organic farming have a significant impact on the level of exchangeable Ca in the soil.

The soil's chemical composition affects crop yield in crop rotation under both cultivation systems (Atabayeva et al., 2018). Research by Kwiatkowski and Harasim (2020) shows that organic farming contributes to a favorable chemical composition of the soil, including higher pH, increased overall sorption capacity, and humus, organic carbon, total nitrogen, magnesium, B, copper, manganese and zinc content. However, the soil's

Table 3: The effect of the crop factor on the content in the soil on the level of N-NH4, N-NO3, exchangeable Ca, molybdenum (mo) and mobile boron in the soil**

Crop	N-NH4 (mg/kg)	N-NO3 (mg/kg)	Exchangeable Ca (mg/kg)	Mobile Mo (mg/kg)	Mobile Boron (mg/kg)
Description	This form of nitrogen is available to plants and is present in the soil as ammonium ions. It is important for plant nitrogen nutrition	A form of nitrogen available to plants, present in the soil as nitrate ions. It is easily absorbed by plants and is a key component for growth	The amount of calcium available for exchange in the soil. It is important for soil structure and plant health and influences the availability of other nutrients	The amount of molybdenum available in the soil for plants. It is important for nitrogen fixation and other biochemical processes	The amount of boron available in the soil for plants. It is important for plant growth and development, especially flowering and fruiting.
Corn	5.94±0.24b	103.01±5.12c	2,197.50±45.20c	0.10±0.01b	0.64±0.03a
Soy	6.24±0.30b	138.16±6.80b	2,260.13±40.45a	0.21±0.02a	0.38±0.02c
Winter peas	6.50±0.28a	148.34±7.24a	2,253.75±35.75a	0.07±0.01c	0.24±0.01d
Winter peas*	2.26±0.12c	64.56±3.20d	2,251.13±33.13b	0.02±0.01d	0.51±0.02b

*Winter peas are for green manure fertilizer and grain without straw removal; **Values (mean±SD) bearing different alphabets within the same column differ significantly at P<0.05.

Table 4: Significant correlation between dependent variables

Chemicals	N-NH4	N-NO3	Exchangeable Ca (mg/rg)	Mobile Mo (mg/kg)	Mobile B (mg/kg)
N-NH4		0.65***	0.0	0.52**	-0.18
N-NO3	0.65***		0.31*	0.30*	-0.61**
Exchangeable Ca (mg/rg)	0.0	0.31*		-0.21*	-0.37**
Mobile Mo (mg/kg)	0.52**	0.30*	-0.21*		0.06
Mobile B (mg/kg)	-0.17*	-0.61**	-0.37**	0.05	

Asterisks denote weak correlation (*), moderate correlation (**), and strong correlation (***).

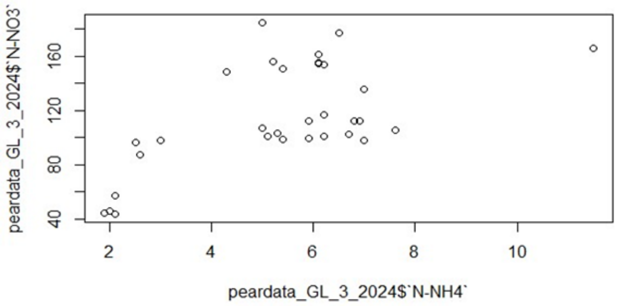

Fig. 2: Significant correlation between dependent variables.

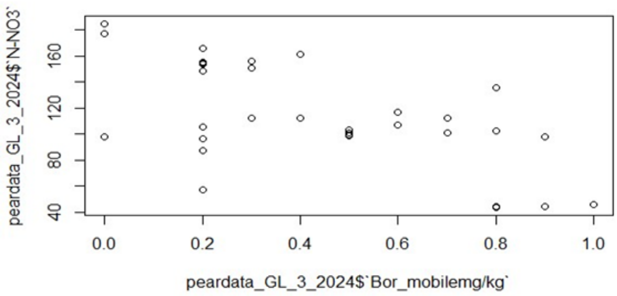

Fig. 3: Significant correlation between dependent variables.

phosphorus and potassium content may be lower than the conventional system.

According to Kwiatkowski and Harasim (2020), legumes can negatively affect the accumulation of phosphorus, potassium, and magnesium in the soil and increase the overall sorption capacity and the content of both forms of nitrogen in the soil, complementing the understanding of the effects of crops on soil chemical properties. Kenenbayev et al. (2023) found that 2021-2022 weather conditions in southeastern Kazakhstan and biofertilizers may not have affected the content of microelements in soybean seeds. There is evidence in the scientific literature that the genus and species of agricultural plants also have a significant effect on the chemical properties of the soil. Some previous studies have shown that root crops (Kwiatkowski et al., 2020) and legumes (Harasim et al., 2020; Woźniak, 2019) contribute to a more favorable chemical composition of soils and their enzymatic properties than cereals. This is due to the more beneficial chemical composition of the residues of root crops and legumes entering the soil (Kwiatkowski et al., 2020). According to our data, the choice of crops significantly affects the content of N-NH4, N-NO3, exchangeable Ca, and mobile B in the soil. Overall, our results highlight the importance of crop selection in organic farming and its impact on the chemical properties of the soil.

Conclusion

The findings highlight the complexity of the interrelationships between agricultural methods, the content of nutrients in the soil, and the needs of crops, which requires an individual approach to planning and implementing agricultural practices:

1. The elements of organic farming significantly (P<0.01) impact the level of exchangeable Ca in the soil. The average level of exchangeable Ca when using elements of organic agriculture was lower (2,222.50mg/kg) than with traditional cultivation technology (2,258.75mg/kg).
2. The choice of crops significantly affected the content of N-NH4, N-NO3, exchangeable Ca, and mobile B in the soil.
3. Corn had the highest level of N-NH4, and winter peas had the maximum level of N-NO3. This highlights the diversity of different crops' requirements for nitrogen content in the soil.
4. There was a positive correlation between N-NH4 and N-NO3, as well as the level of N-NH4 and exchangeable Ca. There was a negative correlation between B mobility and N-NO3 content.
5. A weak positive correlation was observed between the level of N-NO3 and exchangeable Ca in the soil. There was a weak negative correlation between N-NH4 levels and B mobility. This may indicate the influence of nitrogen compounds on the B mobility in the soil.

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