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Research Article

Impact of Agritechnologies on the Biomass and Nutritional Parameters of Crops: A Study of Corn, Soybean, and Pea in Southeast Kazakhstan

Gulvira Yessenbayeva[1], Aruzhan Ilyas[1], Serik Kenenbayev[1], Yeldos Zhanbyrbayev[1], Kalamkas Kulanbay[1], Yerlan Dutbayev[1] and Bekzatkhan Kultassov[2]

[1]*Department of Agronomy, Breeding and Biotechnology, Kazakh National Agrarian Research University, Almaty, Kazakhstan*
[2]*Department of Water Resources, Land Using and Agrotechnology, Mukhtar Auezov South Kazakhstan University, Shymkent, Kazakhstan*

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Corresponding Author:
Aruzhan Ilyas
Department of Agronomy, Breeding and Biotechnology, Kazakh National Agrarian Research University, Almaty, Kazakhstan
Email: aaruzhan.ilyas@gmail.com

Abstract: The study investigates the impact of various agritechnologies on the biomass and nutritional parameters of corn, soybean, and winter pea cultivated in Southeast Kazakhstan. This research is particularly relevant given the significant challenges facing agriculture in Kazakhstan, including soil degradation, reduced arable land, and the need for sustainable farming practices. Organic and traditional farming methods were evaluated for their effectiveness in enhancing crop productivity and quality. The study was conducted in the Almaty region on grey soils with low humus content (1.3–1.5%). Experimental plots included seven farming practices, incorporating organic and mineral fertilizers, crop residues, and cover crops. Morphological, biomass, and nutritional characteristics, such as protein, fat, fiber, and starch content, were assessed using descriptive statistics, t-tests, and correlation analysis. The results demonstrated significant differences in crop quality and productivity depending on the farming methods. Soybeans grown under organic farming exhibited higher protein (38.51%) and fat (18.42%) content compared to traditional methods (36.15 and 17.11%, respectively). Winter pea stood out with a protein content of 25.68% in grains and a high fiber level of 33.61% in straw. Corn maintained a stable starch content (~53%) across all systems, highlighting its adaptability. Correlation analyses revealed strong relationships between plant biomass components and yield parameters, such as the number of pods and seed weight per plant ($r = 0.89$, $p<0.01$). Additionally, organic practices enhanced soil microbial activity, promoting sustainable agricultural systems. These findings underscore the potential of organic farming to improve crop quality, enhance soil health, and support sustainable agriculture, making it a viable strategy for addressing environmental and agricultural challenges in Kazakhstan.

Keywords: Agritechnologies, Organic Farming, Crop Productivity, Soil Degradation, Sustainable Agriculture, Southeast Kazakhstan

Introduction

Contemporary agriculture faces serious challenges stemming from population growth, climate change, and soil degradation (Hajji-Hedfi *et al.*, 2024; Alexandrovna & Ustinova, 2025; Rosada *et al.*, 2024). A necessary step to ensure food security and sustainable development of the agricultural sector is the introduction of environmentally sustainable technologies. One of the most acute problems in agriculture in Kazakhstan is soil degradation (Abisheva *et al.*, 2024; Tuleyeva *et al.*, 2024; Gumarova *et al.*, 2025). Of the 62 mln ha of Kazakhstan's agricultural land, about 26 mln ha is in poor condition. Consequently, the amount of arable land available for cultivation has fallen from 35 mln ha in the 1980s to 20 mln ha today (Nasiyev *et al.*, 2021; Zhyrgalova *et al.*, 2024). A considerable part of the land is suffering from erosion and salinization, which limits its productivity (Alghamdi, 2024; Konopianov *et al.*, 2024).

In these conditions, organic farming is a promising direction for restoring soil fertility and increasing crop yields (Belopukhov *et al.*, 2023; Silvera-Pablo *et al.*, 2024). Several studies prove that cover crops, organic fertilizers, and minimized soil tillage have a favorable effect on the biological, physical, and chemical characteristics of soil (Lori *et al.*, 2017; Bastaubayeva *et* *al.*, 2023; Chashkov *et al.*, 2024). Organic farming aligns with a key aspect of sustainable development in agriculture, allowing to increase the quality and yield of crops while minimizing negative environmental impacts (Bettiche *et al.*, 2020; Naliukhin *et al.*, 2024; Anwar *et al.*, 2025). Organic farming is practiced in 160 countries, and 84 countries have relevant legislation (Willer & Lernoud, 2019; Kwiatkowski et al., 2020). In several other countries, such laws are already underway, which signals a growing global interest in environmentally sound production technologies (Rednikova, 2023).

Research on organic farming in Kazakhstan continues to develop. A study by Yessenbayeva *et al.* (2024a), conducted in the Baltabai rural district, Enbekshikazakh District, Almaty Region, found that elements of organic farming help reduce the levels of exchangeable calcium (2,222.50 mg/rg) compared to the traditional technology (2,258.75 mg/rg). It was found that the crop of choice has a significant influence on the content of ammonium nitrogen (N-NH4), nitrate nitrogen (N-NO3), exchangeable calcium, and mobile boron. The highest content of ammonia nitrogen was observed in corn, while the maximum levels of nitrate nitrogen were found in winter peas.

In a different study, Yessenbayeva *et al.* (2024b) investigated the influence of organic farming technologies on the development of soil microorganisms. The results indicate that undercrops and cover crops such as winter peas and corn increase the concentration of bacteria compared to traditional cultivation methods. The cultivation of soybeans in the system of organic farming provided the greatest development of bacterial populations, while the use of the green mass of winter pea and soybean as organic fertilizers increased the concentration of actinomycetes. In addition, the Czapek-Dox medium demonstrated a favorable effect on soil fungi, and Hutchison's medium ensured optimal conditions for the growth of actinomycetes.

Methods

Location, Climate, and Geographical Conditions

Samples for the study were collected in 2024 on a farm owned by the Baltabai 2030 LLP located in Balbatai Village, Almaty Region, Kazakhstan (Figure 1). The geographic coordinates of the study site are 43° 30' 23.256" E, 77° 32' 38.76" N. The region has a continental climate and belongs to the zone of foothill desert-steppe landscapes with absolute altitudes from 550 to 700 m above sea level.

Soil Characteristics

The samples were collected from ordinary gray soils with a humus content of 1.3–1.5% and the content of nitrogen in upper soil horizons ranging from 0.10 to 0.13% (Kenenbayev *et al.*, 2023).

Materials of Study

The study used samples of corn, soybean, and winter pea variety "Kosmaj" grown under organic and conventional farming technologies.

Experiment Design

The experimental plots were divided into seven variants differing in cultivation technology and the use of organic and mineral fertilizers:

1. "Kosmaj" for green mass (control)
2. "Kosmaj" for green manure (at the budding to early flowering stage)
3. "Kosmaj" for grain (straw removed from the field)
4. "Kosmaj" for grain (straw used as organic fertilizer)
5. "Kosmaj" as undercrop + corn (organic farming technology)
6. Corn (traditional technology)
7. "Kosmaj" as undercrop + soy (organic farming technology)
8. Soy (traditional technology)

In each of the seven variants, we examined the following parameters:

- Morphological characteristics
  - Plant height at budding and ripening stages
  - Biomass of different parts of the plant (roots, stems, leaves, flowers, and pods)
  - Number of branches and pods per plant, the mass of seeds and straw
- Nutritional composition
  - The content of protein, fat, and carbs (starch and sugar), fiber, ash, Ca, and P in the grain and green mass.
- Yield
  - Number of grains per plant, the mass of seeds and straw, total yield per plot.and data analysis

Methods Assessed Parameters

Descriptive Statistics

The statistics calculated for each variable (e.g., plant height, seed weight) were:

- Mean
- Standard Deviation (SD)
- Minimum and maximum values
- Median

Comparative Analysis

The significance of differences between variables was confirmed using the independent variables t-test with a significance level of $p<0.01$.

Correlation Analysis

Relationships between different parameters (e.g., plant height, biomass, nutritional composition, and yield)

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were detected using correlation analysis (Stybayev *et al.*, 2025). The Pearson correlation coefficient (r) was calculated for each pair of variables with a significance level of $p < 0.05$. This analysis revealed how changes in one parameter (e.g., nutritional composition) affected other indicators (e.g., yield).

Results and Discussion

The results indicate that undercrops, cover crops, and farming technology influence the nutritional composition of the product (Table 1). Soy under an organic system contains more protein (38.51%) and fat (18.42%) than under a traditional system (36.15 and 17.11%, respectively), while corn has high starch levels (around 53%) regardless of the technology. The green mass of winter pea is rich in fiber (26.00%) and fat (4.51%), while pea grain has a high protein content (25.68%). The straw of winter pea demonstrates the highest content of fiber (33.61%), whereas corn is marked by a low content of fiber and sugar. These findings align with previous research indicating the nutritional benefits of organic farming. For example, Souza *et al.* (2023) and Hijrah *et al.* (2024) found that soybean seeds cultivated under organic conditions demonstrated higher protein and fat content compared to conventional systems, which supports the results of the present study. The stability of starch levels in corn across both systems also agrees with data from Belopukhov *et al.* (2023), suggesting that certain carbohydrate-related traits in cereals are less sensitive to changes in farming technology. The high fiber concentration in the green mass and straw of winter pea corresponds with the conclusions of Ansabayeva (2023), who highlighted the dual value of peas for both fodder and grain due to their biomass composition.

Statistically significant differences ($p<0.01$) demonstrate that the employed technology and type of culture do affect nutritional composition.

Some nutritional composition variables (protein, fat, starch, fiber, nitrogen-free extracts (NFE), sugar, ash, Ca, and P) correlate with each other under both organic and traditional farming systems (Table 2). The strongest positive correlations were found between protein and fat ($r = 0.84$, $p<0.001$), starch and NFE ($r = 0.98$, $p<0.001$), and starch and ash ($r = 0.95$, $p<0.001$). The most pronounced negative correlations are those between protein and NFE ($r = -0.81$, $p<0.001$), fat and starch ($r = -0.50$, $p<0.01$), and sugar and Ca ($r = -0.84$, $p<0.001$). These findings showcase the complex relationships of nutritional value components, emphasizing the influence of farming technology on the chemical composition of products. The observed correlations between nutritional parameters support earlier studies demonstrating the interdependence of chemical components in crops under different farming systems. For instance, Volobueva *et al.* (2024) and Naliukhin *et al.* (2024) reported similar positive associations between protein and fat contents in legumes, as well as starch and nitrogen-free extract (NFE) levels in cereals, under varied fertilization conditions. The strong negative correlation between protein and NFE also mirrors findings by Silvera-Pablo *et al.* (2024), who noted that higher protein content often comes at the expense of carbohydrate accumulation in organically grown crops.

Table 1: Effect of Preceding Crop and Farming Technology on Nutritional Composition under Organic and Traditional Systems

Variant	Protein (%)	Fat (%)	Starch (%)	Fiber (%)	NFE (%)	Sugar (%)	Ash (%)	Ca (%)	P (%)
Corn (organic farming technology)	9.05	1.60	52.98	3.02	75.73	2.53	1.25	0.18	0.54
Corn (traditional technology)	8.37	2.44	53.93	2.85	75.36	2.49	1.33	0.17	0.37
Grain of winter pea variety "Kosmaj"	25.68	0.46	16.41	6.62	52.20	1.74	4.92	0.21	0.58
Green mass of winter pea variety "Kosmaj"	21.16	4.51	3.75	26.00	35.72	0.01	4.51	1.88	0.38
Soy (organic farming technology)	38.51	18.42	0.96	7.96	24.42	3.30	5.28	0.29	0.84
Soy (traditional technology)	36.15	17.11	1.25	6.16	31.32	3.51	4.25	0.29	0.86
Straw of winter pea variety "Kosmaj"	15.43	2.64	0.85	33.61	36.17	0.79	4.66	1.45	0.27
P-value	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.015	<0.01

Table 2: Correlation Between Nutritional Composition Variables under Organic and Traditional Systems

Variable	Protein (%)	Fat (%)	Starch (%)	Fiber (%)	NFE (%)	Sugar (%)	Ash (%)	Ca (%)	P (%)
Protein (%)		0.84***	No corr.	No corr.	–0.81***	0.40*	0.77***	No corr.	0.79***
Fat (%)	0.84***		–0.5**	No corr.	–0.68	0.62	0.43*	No corr.	0.8***
Starch (%)	–0.75***	–0.5**		–0.58**	0.98***	No corr.	0.95***	–0.49**	No corr.
Fiber (%)	No corr.	No corr.	–0.57**		–0.49**	–0.79***	0.47**	0.92***	–0.55**
NFE (%)	No corr.	–0.75***	0.97***	–0.49**		No corr.	0.90***	–0.42**	No corr.
Sugar (%)	No corr.	No corr.	No corr.	–0.79***	No corr.		No corr.	–0.84***	0.78***
Ash (%)	No corr.	No corr.	–0.94***	0.47**	–0.90	No corr.		No corr.	No corr.
Ca (%)	No corr.	No corr.	–0.49**	0.92***	No corr.	–0.84***	No corr.		–0.52**
P (%)	No corr.	No corr.	No corr.	–0.55**	No corr.	0.78***	No corr.	–0.53**	

Table 3 reflects the morphological and biomass characteristics of the winter pea variety "Kosmaj", including stem length (120–260 cm), the number of branches (1–4), and the weight of the plant (11.3–74.3 g)

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and its roots (0.3–2.5 g), stem (3.5–25.5 g), leaves (6.9–43.8 g), and flowers and pods (0.3–11.1 g). The mean values show high biomass potential (stem length — 194.8 cm, plant weight — 35.3 g) with variation in parameters indicating the influence of growing conditions and technology.

Table 4 presents the coefficients of correlation between different morphological characteristics and the green biomass of the winter pea variety "Kosmaj". Significant positive correlations were observed between stem weight and total plant weight (r = 0.91) and between leaf weight and total plant weight (r = 0.97), indicating a significant contribution of these components to the total biomass. Stem length correlates positively with stem mass (r = 0.46, $p<0.01$) but negatively with flower and bean mass (r = –0.37, $p<0.01$), indicating a possible trade-off between these characteristics. Root mass moderately correlates with total plant mass (r = 0.71) and the number of branches (r = 0.65), which reflects its importance in supporting the plant's overall development. These data highlight the interconnectedness of the morphological traits of plants and their influence on biomass distribution.

Table 5 shows the variability of key parameters of the yield of the winter pea variety "Kosmaj". The number of beans per plant varies from 3 to 38 with an average of 11.7. The number of seeds per plant ranges from 13 to 132, averaging 52.78. The weight of seeds per plant varies from 1.0 to 15.7 g with an average of 4.8 g, and straw weight falls between 2.4 and 18.3 g with a mean of 6.0 g. These indicators emphasize significant yield potential that depends on growing conditions and agritechnologies.

Table 3: Morphological and Biomass Characteristics of Green Mass of Winter Pea Variety "Kosmaj"

Statistical features	Stem length (cm)	Number of branches	Total plant weight (g)	Root weight (g)	Stem weight (g)	Leaf weight (g)	Flower and pod weight (g)
Minimum	120.0	1.0	11.3	0.30	3.5	6.9	0.30
1st Quatile	171.5	1.0	23.4	0.40	8.4	11.2	0.80
Median	190.0	1.0	30.5	0.60	12.3	15.9	2.15
Mean	194.8	1.6	35.3	0.60	13.4	18.7	2.67
3rd Quantile	220.0	2.0	48.1	0.80	16.5	23.7	4.30
Maximum	260.0	4.0	74.3	2.50	25.5	43.8	11.10

Table 4: The correlation between variables on Green Mass of Winter Pea Variety "Kosmaj"

Statistical features	Stem length (cm)	Number of branches	Total plant weight (g)	Root weight (g)	Stem weight (g)	Leaf weight (g)	Flower and pod weight (g)
Stem length (cm)		0.16	0.21	–0.11	0.46**	0.16	–0.37**
Number of branches	0.16		0.56	0.65	0.53	0.53	0.10
Total plant weight (g)	0.21	0.56		0.71	0.91	0.97	0.43
Root weight (g)	–0.11	0.66	0.71		0.59	0.68	0.39
Stem weight (g)	0.47	0.53	0.91	0.91		0.84	0.22
Leaf weight (g)	0.16	0.53	0.97	0.68	0.84		0.35
Flower and pod weight (g)	–0.37**	0.10	0.43	0.39	0.22	0.35	

Table 5: Yield Characteristics of Grain of Winter Pea Variety "Kosmaj"

Statistical features	Number of pods per plant	Number of seeds per plant	Seed weight per plant (g)	Straw weight per plant (g)
Minimum	3.0	13.00	1.0	2.4
1st Quartile	8.0	36.00	3.1	3.85
Median	11.0	46.00	4.1	5.7
Mean	11.7	52.78	4.8	6.0
3rd Quantile	14.0	65.00	5.8	7.1
Maximum	38.0	132.00	15.7	18.3

Table 6: The correlation between variables on Grain of Winter Pea Variety "Kosmaj"

Statistical features	Number of pods per plant	Number of seeds per plant	Seed weight per plant (g)	Straw weight per plant (g)
Number of pods per plant		0.82	0.80	0.52
Number of seeds per plant	0.82		0.89	0.42
Seed weight per plant (g)	0.80	0.89		0.42
Straw weight per plant (g)	0.52	0.89	0.42	

Table 6 displays the coefficients of correlation between different characteristics of the grain of the winter pea variety "Kosmaj". The most significant positive correlations are observed between the number of beans and the number of seeds per plant (r = 0.82), as well as between the number of seeds and seed weight per plant (r = 0.89), which stresses the close connection of these characteristics in the formation of yield. In addition, seed weight per plant correlates positively with bean number (r = 0.80) and straw weight (r = 0.42), indicating a dependence of grain weight on total plant biomass. These results demonstrate the interdependence of indicators affecting the productivity of pea plants. The strong correlations between pod number, seed number, and seed weight observed in the winter pea variety "Kosmaj" are consistent with previous research emphasizing the interconnectedness of morphological yield components in legumes. For example, Ansabayeva (2023) found similarly high correlations between the number of pods and seed biomass in organic pea systems, suggesting that pod productivity is a key determinant of final grain yield. Likewise, Volobueva *et al.* (2024) reported that seed mass was closely linked to both reproductive and vegetative biomass traits, including straw weight, under organic treatment.

The conducted data analysis indicates a significant influence of farming technologies and growing conditions on the nutrient composition and yield of crops. Soybean under organic farming shows better results in terms of protein (38.51%) and fat content (18.42%), which makes this technology promising for improving product quality (Souza *et al.*, 2023; Hijrah *et al.*, 2024). Corn has a stable starch content (about 53%) irrespective of the technology, indicating its resistance to changes in agritechnologies. Winter pea variety "Kosmaj" is distinguished by a high grain protein content (25.68%) and straw fiber content (33.61%), which highlights its nutritional value and versatility. The analysis confirms that farming practices and growing conditions significantly affect crop nutrition and yield quality. In line with our findings, major reviews have shown organic soybean to consistently yield higher protein and fat levels than conventional counterparts, providing compelling evidence for its nutritional advantage (Thaise de Oliveira Faoro *et al.*, 2024). Similarly, meta-analyses of broader crop varieties including peas and cereals report enhanced nutrient density under organic or regenerative systems. The demonstrated stability of corn starch content aligns with the understanding that major carbohydrate traits in cereals are relatively resilient to changes in farming technology. Finally, the dual nutritional assets of the winter pea variety “Kosmaj” – high grain protein and straw fiber — echo findings in legume-focused reviews that highlight peas as a multifunctional crop valued for both food and forage applications (Jevtić *et al.*, 2023). Together, these data support a strategic shift toward organic methods in legumes to boost quality while maintaining yield consistency in cereals.

Correlation analysis shows significant associations between the morphological and yield characteristics of the crops. In winter peas, stem length correlates positively with stem weight (r = 0.46, p<0.01), but negatively with flower and bean weight (r = −0.37, p<0.01), which emphasizes the balance between vegetative and reproductive development. Seed number per plant strongly correlates with seed weight (r = 0.89) and bean number (r = 0.82), confirming their role as key yield factors. The strong correlation between plant biomass (stem, leaf, and root weight) and total plant weight (r>0.8) indicates the importance of optimizing agricultural techniques to increase productivity (Ansabayeva, 2023; Volobueva *et al.*, 2024).

The mean values of the morphological characteristics of the pea also confirm its great potential: stem length reaches 260 cm, plant weight stands at 35.3 g, and the number of beans per plant averages 11.7 with a seed weight of 4.8 g. The variability of these parameters emphasizes the influence of cultivation technology and conditions on productivity. The high biomass of peas makes it suitable for green fodder and grain production.

Conclusion

Our results support the importance of choosing the optimal farming technology to improve the quality and yield of crops. Organic farming is particularly effective for crops with high protein and fat content, such as soybean, while winter pea, due to its nutritional value, adaptability, and high biomass, is a versatile crop suitable for various agricultural purposes.

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Author’s Contributions

All authors took equal part in writing the article, editing and processing the data. All authors approved the final version of the article.

Ethics

This article is composed of original content and doesn’t include any material previously published elsewhere.

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