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MODELING OF FERTILIZER APPLICATION IN POTATO PRODUCTION UNDER LIGHT CHESTNUT SOILS OF ZHETYSU REGION

Global food security is of particular concern, so agricultural production will need to increase significantly to meet the food needs of growing populations. Increased crop yields can be achieved through the adoption and improvement of nutrient management and fertilizer technology. Results of field research have shown, that unilateral use of increasing doses of nitrogen fertilizers and their combination with phosphorus and potassium provide vegetative activity of potato plants: in accumulation of dry biomass, an increase of leaf area and photosynthetic productivity, that finally was integrated into formation of high yields of tubers – 37,8-45,4 t/ha at 32,4 t/ha in control plots. The obtained regression model reflects adequately enough (R = 0,886) the experimental data. The application of mineral fertilizers decreased the share of a small fraction of tubers down to 6,0 – 8,7 % in potato yield, while increasing the share of large fractions up to 55-69 %. Depending on different doses of fertilizers potato plants accumulated 172,2 to 260,6 kg/ha of nitrogen, 63,3 to 84,1 kg/ha of phosphorus, and 197,0 to 256,3 kg/ha of potassium in biomass. On average, potato plants used 66 % of nitrogen, 26 % of phosphorus, and 59 % of potassium from fertilizers. For 1 ton tuber production, potatoes taken up 4.4 – 5.8 kg of nitrogen, 1.6 – 2.0 kg of phosphorus and 4.6 – 6.1 kg of potassium, depending on the doses and ratios of fertilizers.The effect and interaction of nitrogen, phosphorus, and potassium fertilizers on the normative intake of nutrients by potatoes are described quite adequately (R = 0,727-0,885) by regression models. Economic efficiency of application of fertilizers was high in the treatments where increasing doses of nitrogen were combined with small doses of potassium, and in the treatment with doses of fertilizers applicated for planned yield – 5102,6-5769,9 tenge/ha at relatively low production cost – 50,1-56,5 tenge/kg and high profitability of production – 123,1-149,7 %.

Key words: potato, light chestnut soil, fertilizers, yield, regression, economic efficiency.

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Жетісу облысының ашық қара қоңыр топырақтарында картоп өсіруде тыңайтқыштардың тиімділігін модельдеу

Әлемдік азық-түлік қауіпсіздігі мәселелері ерекше алаңдаушылық тудырып отыр, сондықтан саны өсіп жатқан халықтың азық-түлікке қажеттілігін қанағаттандыру үшін ауыл шаруашылығы өндірісін айтарлықтай арттыру қажет болады. Ауыл шаруашылығы дақылдарының өнімділігін арттыруға қоректік заттарды басқару әдістері мен технологияларын және тыңайтқыштар технологиясын енгізу және жетілдіру арқылы қол жеткізуге болады. Далалық зерттеулердің нәтижелері көрсеткендей, азот тыңайтқыштарының жоғарылатылған дозаларын бір жақты қолдану және оларды фосфор және калиймен бірге қолдану картоп өсімдіктерінің вегетативті өсу белсенділігін арттырды: құрғақ биомассаның жиналуын, жапырақ алаңының өсуін, фотосинтетикалық өнімділіктің жоғарылауын қамтамасыз етіп, нәтижесінде картоптың жоғары өнімділігін қалыптастырды – 37,8-45,4 т/га, ал тыңайтқышсыз бақылауда өнімділік 32,4 ц/га болды. Алынған регрессиялық модель эксперименттік нәтижелерді жеткілікті дәлдікпен қайталады (R = 0,886). Минералды тыңайтқыштарды қолдану картоп дақылындағы түйнектердің ұсақ фракциясының үлесін 6,0-8,7%-ға дейін төмендетті, ал ірі фракцияның үлесін 55-69%-ға дейін арттырды. Тыңайтқыштардың әртүрлі дозаларына байланысты әр гектарға шаққанда картоп дақылы өнімнің биомассасында 172,2-260,6 кг азот, 63,3-84,1 кг фосфор және 197,0-256,3 кг калий элементтерін жинады. Орта есеппен картоп өсімдіктері тыңайтқыштардан 66% азот, 26% фосфор және 59% калий элементтерін пайдаланды. Картоптың қоректік заттардың нормативті тұтынуына азот, фосфор және калий тыңайтқыштарының біржақты әсері және өзара әрекеттесуі регрессиялық модельдермен сипатталды (R = 0,727-0,885). Картопқа арналған тыңайтқыштарды пайдаланудың экономикалық тиімділігін есептеу көрсеткендей, ең жоғары жалпы табыс калийдің аз дозаларымен бірге қолданылған азоттың орташа және жоғары дозалары мен тыңайтқыштардың жоспарлы өнімділікке қолданылған нұсқаларда алынды – 5102,6-5769,9 теңге/га. Кароптың өзіндік құны – 50,1-56,5 теңге/кг, өнімнің жоғары рентабельділігі анықталды – 123,1-149,7%.

Түйін сөздер: картоп, ашық қарақоңыр топырақ, тыңайтқыштар, өнімділік, регрессия, экономикалық тиімділік.

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Моделирование эффективности удобрений на картофеле в условиях светло-каштановых почв Жетысуской области

Проблемы глобальной продовольственной безопасности вызывают особую озабоченность, поэтому сельскохозяйственное производство должно будет значительно увеличиться, чтобы удовлетворить растущее население. Повышение урожайности сельскохозяйственных культур может быть достигнуто за счет внедрения и совершенствования методов и технологий управления питательными веществами и технологии удобрений. Результаты полевых исследований показали, что односторонне применение возрастающих доз азотных удобрений и их сочетания с фосфором и калием обеспечивают вегетативную активность растений картофеля: в накоплении сухой биомассы, увеличении площади листьев и фотосинтетической продуктивности, что в конечном итоге отразилось в формировании относительно высоких валовых урожаев клубней – 37,8-45,4 т/га при 32,4 т/га на контроле. Полученная регрессионная модель достаточно адекватно отражает (R=0,886) полученные экспериментальные данные. Применение минеральных удобрений уменьшало в урожае картофеля долю мелкой фракции клубней до 6,0 – 8,7 %, при одновременном увеличении доли крупной фракцией до 55-69 %. В зависимости от различных доз удобрений растения картофеля накапливали в биомассе от 172,2 до 260,6 кг азота, от 63,3 до 84,1 кг фосфора и от 197,0 до 256,3 кг калия. В среднем растения картофеля использовали 66 % азота, 26 % фосфора и 59 % калия из удобрений. Действие и взаимодействие азотных, фосфорных и калийных удобрений на нормативное потребление питательных элементов картофелем достаточно адекватно (R = 0,727-0,885) описываются регрессионными моделями. Расчет экономической эффективности применения удобрений под картофель показал, что наибольший валовой доход обеспечивали варианты, где комбинировали средние и повышенные дозы азота с небольшими дозами калия, и дозы удобрений, внесенные из расчета на планируемый урожай – 5102,6-5769,9 тенге на 1 га при относительно низкой себестоимости – 50,1-56,5 тенге/кг и высокой рентабельности производства – 123,1-149,7 %.

Ключевые слова: картофель, светло каштановая почва, удобрения, урожайность, регрессия, экономическая эффективность.

Introduction

The global population is growing and will reach 9 billion people by 2050, with 60% more food needs than we produce today. We must increase agricultural productivity and farm productivity, in which mineral fertilizers are important because half of the food we consume today is created by using fertilizers. Potatoes are one of the most important agricultural crops worldwide, as the main source of nutrition for the world's population. Potato production ranks third in the world by gross harvest. [1].

In 2018, China was the world's largest potato producer by area and production, with 4.814 million hectares and 90.3 million tons, respectively. India was in second place, 2.151 million hectares and 48.5 million tons, while Ukraine was in third place, 1.320 million hectares and 22.504 million tons, respectively. Kazakhstan with an area of 0.192 million ha produced 3.807 million tons (Table 1).

The Republic of Belarus produced the most potatoes per capita with 619 kg, followed by Ukraine with 532 kg, the Netherlands with 350 kg. Kazakhstan was in eighth place with 208 kg [2].

Table 1 – World potato production in 2018

Country	Production, mln. tons	Production per person, kg	Area, thous. ha	Yield, t/ha
China	90,3	64,8	4813,5	18,8
India	48,5	36,3	2151,0	22,6
Ukraine	22,5	532,5	1319,9	17,0
Russian Federation	22,4	152,5	1313,5	17,0
United States	20,64	62,9	414,1	49,8
Bangladesh	9,74	59,0	477,4	20,4
Germany	8,94	107,8	252,2	35,4
France	7,9	117,0	199,9	39,4
Poland	7,5	194,6	297,5	25,1
Netherlands	6,05	349,5	164,7	36,6
Belarus	5,9	618,8	271,8	21,6
Kazakhstan	3,8	208,3	192,3	19,8

In recent years, the area of potatoes in Kazakhstan has grown significantly – from 183.4 thousand hectares in 2017 to 195.8 thousand hectares in 2021 (Table 2). Almaty region, which is now divided into Zhetysu and Almaty regions, had a leading position in terms of potato planting and in the last 6 years its share did not go below 20% of the republican area, amounting to 39.0-40.6 thousand hectares.

In 2022, the area of potato plantations in Kazakhstan made 198.9 thousand hectares with the gross yield produced 4.1 million tons, at average yield of 20.6 t/ha [3].

Table 2 – Potato production in Kazakhstan

Indicators	2017	2018	2019	2020	2021
Area, thous. ha	183,4	193,000	193	194,4	195,8
Production, thous. ha	3551,1	3 807,0	3912,1	4 006,8	4 031,6
Yield, t/ha	19,4	19,8	20,3	20,7	20,7

Increasing the productivity of agrocenoses and preserving soil fertility are the most important tasks currently facing scientists and practitioners of agricultural production. One of the main factors affecting crop yields, soil properties and economic indicators of production is the use of mineral and organic fertilizers. Their effectiveness depends on the cultivated crop, the technologies used, the doses and the timing of application. The complex economic and environmental conditions of the modern period necessitate the development of new technologies adapted to modern land use requirements [4].

Global food security is of particular concern, so agricultural production will need to increase significantly to meet food needs of growing populations. Increasing yields and narrowing the gap between actual and attainable yields are to be achieved by introducing and improving nutrient management techniques and fertilizing technology. An evaluation of long-term studies has shown that the average percentage of yield associated with fertilizer application typically ranges from 40 to 60% in temperate climates and is much higher in the tropics. Overall, inorganic fertilizers play a critical role in global food security [5,6]. Global consumption of nutrients in the form of mineral fertilizers is expected to increase to 199 million tons in 2030 [7].

Numerous studies have been devoted to assessing the role of nutrients in the formation of potato yields and the effectiveness of fertilizer application [8,9]. Of great importance are the forms of fertilizers, the range of which is currently diverse. Highly effective and cost-effective use of complex mineral fertilizers for potatoes [10].

It is known that nitrogen, phosphorus, and potassium are the main elements necessary for normal potato development. During the sprouting, formation, and growth of the haulm, which is a powerful photosynthetic apparatus, this crop takes out a lot of nitrogen. Before the haulms close and before flowering, the phosphorus consumption increases, which promotes the development of generative organs. During the period of tubers ripening, the use of potassium, which favors the synthesis of carbohydrates, namely polysaccharide starch, as one of the main indicators of the quality of potato tubers, increases sharply [11].

The positive effect of mineral fertilizers on increasing potato yields, the formation of the assimilative surface and the improvement of photosynthetic productivity, and changes in yield quality, in different soil and climate conditions are widely covered by numerous studies [12-14].

Improving crop yields and quality is impossible without the use of fertilizers. The effectiveness of mineral fertilizers has been proven, but excessively high fertilizer rates can pollute the environment and the resulting products. In this regard, fertilizers of natural origin become of great importance. Potato yields depend not only on soil and climatic conditions of the region, but also on how scientifically justified and qualitative all agro methods of cultivation of this crop are carried out. [15].

Despite the constant increase in the amount of fertilizers applied to potatoes, the issue of crop starvation remains relevant. The first problem is the identification of a relative deficiency of a nutrient, due to which the efficiency of fertilizer use decreases [16].

In the development of fertilizer system for potatoes can not be based only on the removal by plants of nitrogen, phosphorus and potassium, and should take into account the characteristics of soil, their provision of food elements and the need for plant nutrition in different periods of growth [17].

The purpose of our research was to identify the effectiveness of different doses of mineral fertilizers by modeling their relationship with the productive indicators and yields of potatoes in the light chestnut soils of the Zhetysu region.

Materials and methods

Field experiments with potato crop were conducted in 2022 on the production fields of peasant farm "Nam", Yeskeldy district, Zhetysu region at the coordinates 44°53'1.06" N 78°37'26.52" E (Figure 1). Soils of experimental plot are represented by foothill light chestnut soils.

Before laying the experiments, the production site was subjected to agrochemical survey, the results of which are presented in Table 3.

It should be noted that these plots have been in agricultural turnover for a long time and are used mainly for intensively fertilized crops. Soils of the site are characterized by low content of humus in the horizon 0-50 cm – 1,18-1,33%, by granulometric characteristics belongs to average loamy varieties – the content of physical clay 41,1-41,6%, the sum of the absorbed bases – 15,1-17,2 mg-eq/100 g. From mobile forms, we determined the content of hydrolyzable nitrogen, which was 61.6-70.0 mg/kg. The content of mobile phosphorus was relatively high – 66.0-67.0 mg/kg and exchangeable potassium was low – 240 mg/kg. Soils characterized from the surface with a carbonate content of 0.3-0.4%, the soil reaction is neutral, pH – 7.0.

On the experimental plot, planting of potato varieties of Lady Claire was carried out on May 1 by planter in 4 rows 75 cm wide, with an average density of plants 50-52 thousand plants per hectare. The accounting plot area was – 48 m2, replicated 3 times.

Experiment treatments: 1. Control (no fertilizers); 2. N_{50}; 3. N_{100}; 4. N_{150}; 5. N_{200}; 6. $N_{50}P_{50}$; 7. $N_{100}P_{50}$; 8. $N_{100}K_{50}$; 9. $N_{150}K_{50}$; 10. $N_{74}P_{69}K_{112}$ (for planned yield – 50 t/ha).

Ammonium nitrate (N – 34 %), double superphosphate (P_2O_5 – 45 %), and potassium sulfate (K2O – 51 %) were used as fertilizers. Mineral fertilizers were applied manually by spreading under cultivation during ridge formation.

In the main phases of growth and development of potato plants, biometric studies were done and plant samples were taken for the photosynthetic productivity study. On each experimental plot, potato tuber yield with its structure was determined.

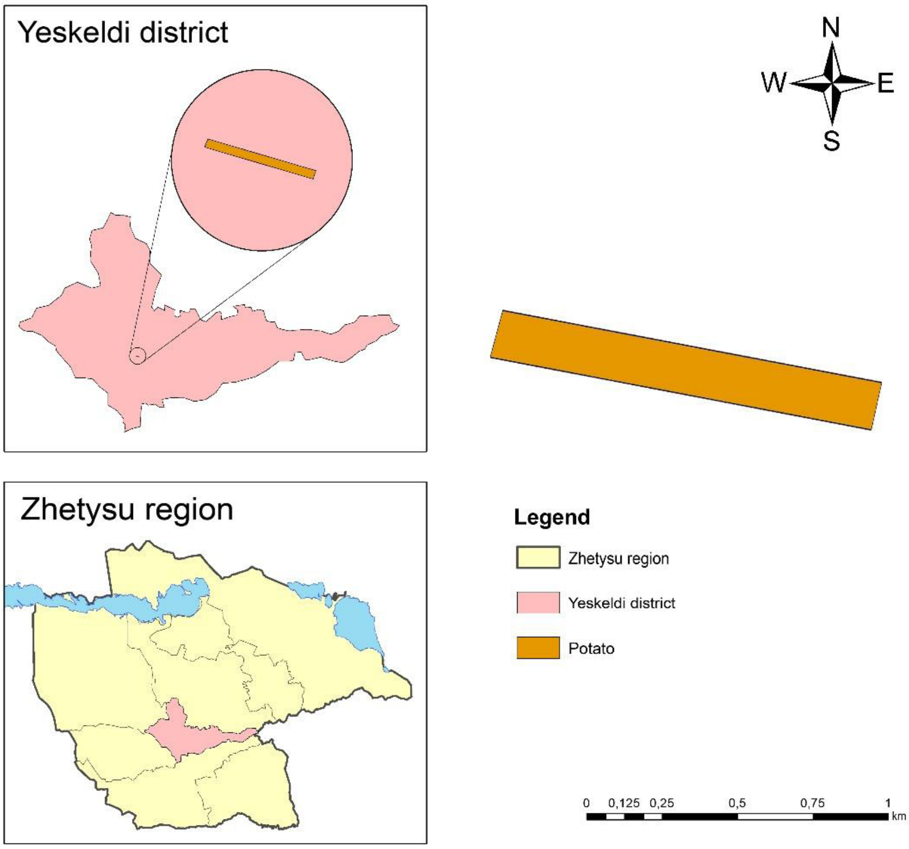

Figure 1 – Area research map

Table 3 – Agrochemical indicators of plots under potatoes, Karabulak, spring, 2022, (n=3)

Sample depth, cm	Humus, %	Physical clay (0,01-0,001 mm), %	Amount of absorbed bases, mg-eq/100g	Mobile forms, mg/kg			Gross forms, %			pH
				Nitro-gen	Phos-phorus	Potas-sium	Nitro-gen	Phos-phorus	Potas-sium	
0-25	1.33±0,11	41.13±3.14	17.16±1.92	70.0±5.6	67.0±5.0	240±26.7	0.11±0.02	0.18±0.02	2.88±0.35	7.0±0.14
25-50	1.18±0.09	41.58±3.41	15.11±1.64	61.6±.6.5	60.0±3.7	240±30.0	0.10±0.01	0.16±0.02	2.88±0.32	7.0±0.12

Soil and plant samples were analyzed in the analytical laboratory of the U.U. Uspanov Kazakh Research Institute of Soil Science and Agrochemistry (KazRISSA) by methods generally accepted in soil science and agrochemistry [18,19]: total humus – by Tyurin, total nitrogen – by Kjeldahl, easily hydrolyzable nitrogen – by Tyurin-Kononova, mobile phosphorus, and potassium – by Machigin; pH – potentiometric, CO_2 – calcimeter, absorbed bases Ca^+, Mg^+ – trilometric, K^+, Na^+ – on a flame photometer.

Leaf surface area and photosynthetic productivity were determined according to the formula of A.A. Nichiporovich [20]. To carry out measurements by this method, an average sample is taken – 10 plants (N), the leaves are quickly cut off and their fresh weight ($M_л$) is determined. Fold the leaves in piles and make cuttings of a certain diameter with a drill, 5 pieces from one sheet. Cut-outs are taken so that both the leaf blades and the central veins are included in the sample. Determine the mass of all raw cuttings ($M_в$). The area of leaves from one plant is determined by the formula:

$$S = \frac{Мл \times a \times \pi Д^2}{Мв \times N \times 4 \times 10000},$$

where S is the leaf area of one plant, m^2; $M_л$ is the mass of leaves in the sample, g; $M_в$ is the mass of cuts, g; a is the number of cuts, pcs; N is the number of plants in the sample, pcs; *Д* – drill diameter, sm, ∏ – mathematical constant ≈ 3.14

Experimental data were subjected to statistical analysis using the Excel analytical package. Analysis of the regression relationship that takes into account the effect and interaction of fertilizers on the productive performance of potatoes was carried out by a non-linear regression model. Regression equations were built by sequential estimation and exclusion of non-significant regression terms at a significance level <0.05. The adequacy of the calculated and actual results was assessed by the multiple correlation coefficient (R). The actions and interactions of the studied factors were presented in the form of a regression equation:

$$Y = a_0+a_1X_1^{0,5}+a_2X_1+a_3X_2^{0,5}+a_4X_2+a_5X_3^{0,5}+$$
$$+a_6X_3+a_7(X_1X_2)^{0,5}+a_8(X_1X_3)^{0,5}+a_9(X_2X_3)^{0,5} \quad (1)$$

where: Y – resulting (dependent) factor;

a_0 – a free term reflecting the value of the resulting factor without applying the studied factors;

a_1, a_2, a_3, … a_n – regression coefficients reflecting the action and interaction of factors;

X_1 X_2 and X_3 – nitrogen, phosphorus and potassium fertilizers, kg a.i./ha.

Results and Discussion

The results of field experiments have shown that the use of mineral fertilizers significantly increased the vegetative activity of potato plants, which manifested itself in the accumulation of dry biomass, increased leaf area, as well as their photosynthetic productivity (Table 4).

Table 4 – Photosynthetic productivity of potatoes in different phases of the growing season depending on mineral fertilizers, 2022

Treatments	Dry biomass, t/ha		Leaf area, thous. m^2/ha		Net photosynthetic productivity, g/m^2 per day	
	Budding phase	Phase of intensive tuber formation	Budding phase	Phase of intensive tuber formation	Seedling phase – budding	Phase of intensive tuber formation
Control (n/f)	2,00	16,06	11,71	27,35	13,64	16,35
N_{50}	2,31	17,57	14,29	34,80	12,94	14,18
N_{100}	2,68	20,20	16,14	35,50	13,28	15,43
N_{150}	3,43	19,82	18,15	38,29	15,11	13,21
N_{200}	3,52	19,12	17,11	38,65	16,48	12,72
$N_{50}P_{50}$	2,61	16,58	14,51	38,89	14,40	11,90
$N_{100}P_{50}$	2,88	20,85	15,61	41,48	14,74	14,32
$N_{100}K_{50}$	2,84	20,44	15,29	37,73	14,85	15,09
$N_{150}K_{50}$	2,90	18,24	13,78	35,32	16,84	14,20
$N_{74}P_{69}K_{112}$	3,41	20,63	15,24	38,05	17,89	14,68
LSD_{05}	0,23	1,32	1,20	2,67	1,06	1,01
S_X, %	2,45	2,16	2,44	2,29	2,20	2,25

Thus, potatoes had the maximum leaf surface during the period of intensive tuber formation from 27.4 in the control to 41.5 m^2/ha in treatment 7 with the use of $N_{100}P_{50}$. By this period, potatoes in these treatments accumulated, respectively, 16.1 and 20.9 t/ha of dry plant biomass. It should be noted that further unilateral increase in nitrogen doses had no positive effect on the accumulation of dry biomass, although the area of leaf surface continued to grow from 34.8 thousand m2/ha at the dose of N_{50} to 38.6 thousand m^2/ha at N_{200}.

The maximum value of leaf surface was observed in plots where nitrogen was used in combination with phosphorus ($N_{100}P_{50}$) – 41.5 thousand m^2/ha.

The photosynthetic productivity of potatoes changed significantly in the studied interphase periods of plants. Between seedlings and buddings, this indicator was from 12,9 (treatment 2) to 17,9 g/m^2 per day (treatment 10), and between the budding phase and intensive tuber formation – from 12,1 (treatment 6) to 16,3 g/m^2 per day (control).

The effect of mineral fertilizers on the photosynthetic productivity of potatoes in the main active vegetative phases of plant development after the sequential exclusion of insignificant variables (<0.05) has been adequately enough (R=0,826-0,958) described by regression models (2-7):

Total dry biomass in the budding phase, t/ha:

$$Y = 2,0414 + 0,0079X_1 + +0,0184X_3 - 0,0139(X_1X_3)^{05}; R = 0,957 \quad (2)$$

Total dry biomass in the phase of intensive tuber formation, t/ha:

$$Y = 16,203 + 0,2704X_1^{05} - 0,199X_2 + 0,2803X_3 + + 0,1679(X_1X_2)^{05} - 0,177(X_1X_3)^{05} - - 0,131(X_2X_3)^{05}; R = 0,909 \quad (3)$$

Leaf area in the budding phase, thousand m^2/ha:

$$Y = 11,5614 + 0,4393X_1^{05} + + 0,2093X_3 - 0,1574(X_1X_3)^{05} - 0,1048(X_2X_3)^{05}; R = 0,940 \quad (4)$$

Leaf area in the phase of intensive tuber formation, thousand m^2/ha:

$$Y = 28,0881 + 0,7907X_1^{05} + 0,4068X_3 + + 0,0864(X_1X_2)^{05} - 0,2633(X_1X_3)^{05} - - 0,2799 (X_2X_3)^{05}; R = 0,941 \quad (5)$$

Net productivity of photosynthesis in the budding phase, g/m^2 per day:

$$Y = 13,727 + 0,0501X_1 - 0,5237X_1^{05} + 0,0356X_2 + + 0,024(X_1X_3)^{05}; R = 0,958 \quad (6)$$

Net photosynthetic productivity in the phase of intensive tuber formation, g/m^2 per day:

$$Y = 16,129 - 0,0156X_1 - 0,2237X_2 + +0,1547(X_1X_2)^{05} +0,0466(X_2X_3)^{05}; R = 0,826 \quad (7)$$

As equation (2) shows, the total dry biomass of potato in the phase of budding reacts positively to the unilateral application of nitrogen and potassium fertilizers and negatively to their combined application. Model (3) describing the accumulation of dry biomass in the phase of intensive tuber formation shows a positive effect of separate application of nitrogen and potassium fertilizers and joint application of nitrogen and phosphorus fertilizers, while unilateral application of phosphorus had a negative effect.

As the model has shown (4) the assimilative surface of potato plants in the phase of budding responded positively to the separate application of nitrogen and potassium fertilizers, but their interaction, as well as the interaction of phosphorus and potassium fertilizers, had a negative effect. The model (5) has described a further increase in leaf index, where plants also responded positively to the separate application of nitrogen and potassium fertilizers and the joint application of nitrogen and phosphorus fertilizers. At the same time, the interaction of nitrogen fertilizer with both phosphorus and potassium fertilizer was negative.

The indicator integrating the size of the accumulated biomass per unit leaf area is the net photosynthesis productivity. In the period between seedlings and budding of potato plants' photosynthetic productivity has been described by equation (6) where the effect of unilateral application of nitrogen fertilizer had a positive, but gradually decreasing character, and the separate application of phosphorus and combined application of nitrogen and potassium fertilizer had a positive effect. In the period between the beginning of budding and intensive tuber formation, as the model (7) has shown, net photosynthetic productivity slightly decreased from the application of nitrogen and phosphorus fertilizers, but from the interaction of nitrogen with phosphorus and phosphorus with potassium fertilizers it increased.

Accounting showed that the gross yield of potatoes responded positively to the application of mineral fertilizers. At the same time, nitrogen fertilizers have the greatest positive effect, then potash fertilizers, and the effect of phosphorus fertilizers was very low, indicating the low efficiency of phosphorus fertilizer on soils with high mobile phosphorus.

Growth and production changes caused by the application of different doses and ratios of fertilizers during the growing season were eventually integrated into the potato yield and influenced its structure (Figure 2).

According to the data obtained, the highest gross productivity indicators in the experiment were the treatments where unilaterally increasing doses of nitrogen (treatments 3-5) – 41.0-43.2 t/ha) and its combinations with phosphorus and potassium were used (treatments 6-9) – 40.1-45.5 t/ha. Doses of mineral fertilizers, calculated on the basis of the coefficients of use of nutrition elements from soil and fertilizers, and taking into account their intake by potato unit yield at the corresponding amount of by-products ensured the planned yield level (50 t/ha) by 97%.

A similar pattern was noted for the marketable yield of potatoes, while the increase in yield over the control amounted to 33.9-38.4% in the treatments with one-sided increasing doses of nitrogen (treatments 2-5), 36.1-40.9% with a combination of -nitrogen with phosphorus or potassium (treatments 6-9), and 44.4% when using calculated doses of fertilizers (treatment 10). Similar data were obtained for the average mass of marketable tubers, which varied from 71.1 g in the control to 86 g in the fertilized treatments.

Structural analysis of potato tuber yield was determined by studying the fractional composition, that is, the division into small, medium, and large, the data of which are presented in Table 5.

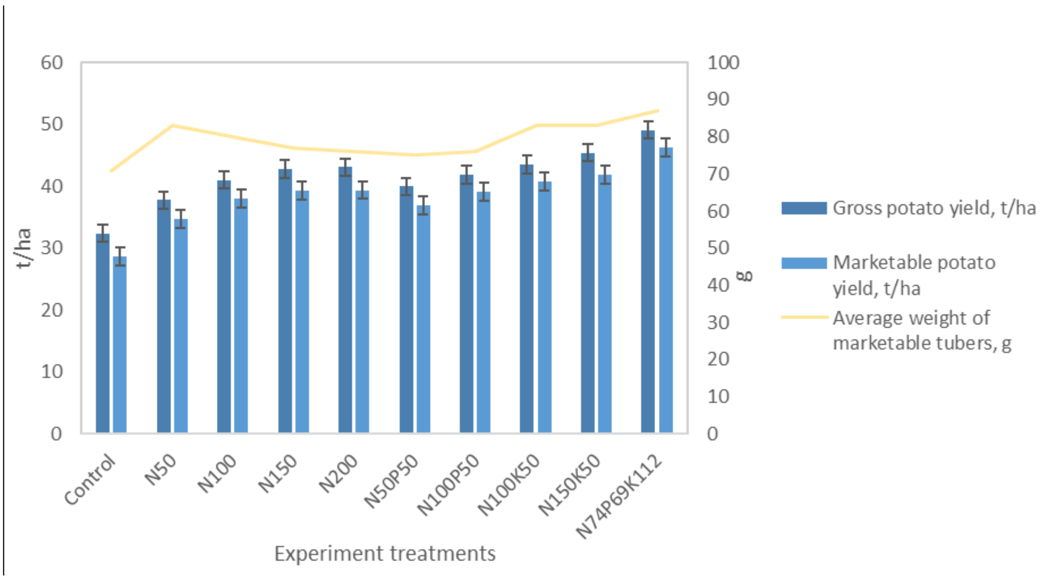

Figure 2 – Potato yield indicators depending on mineral fertilizers, 2022

Table 5 – Structural analysis of potato tuber yield depending on mineral fertilizers, 2022

Treatments	Total weight		Small fraction		Medium fraction		Large fraction	
	%	Average tuber weight, g	%	Average tuber weight, g	%	Average tuber weight, g	%	Average tuber weight, g
Control (n/f)	100	56,5	11,4	21,5	33,6	48,3	55,0	100,2
N_{50}	100	66,7	8,0	20,4	29,8	53,0	62,2	114,4
N_{100}	100	64,6	7,0	17,5	24,2	46,2	68,8	110,7
N_{150}	100	62,3	8,0	19,5	34,8	51,7	57,2	109,6

Table continuation

Treatments	Total weight		Small fraction		Medium fraction		Large fraction	
	%	Average tuber weight, g	%	Average tuber weight, g	%	Average tuber weight, g	%	Average tuber weight, g
N_{200}	100	61,3	8,7	20,0	26,8	48,8	64,6	100,7
$N_{50}P_{50}$	100	63,7	7,7	21,6	33,2	50,5	59,1	104,1
$N_{100}P_{50}$	100	61,4	6,7	16,7	28,0	46,5	65,3	103,8
$N_{100}K_{50}$	100	67,7	6,2	17,8	25,9	48,6	67,9	115,3
$N_{150}K_{50}$	100	67,7	7,8	21,1	30,7	52,6	61,5	116,5
$N_{74}P_{69}K_{112}$	100	68,3	6,0	16,1	34,1	55,8	59,9	125,7
LSD_{05}		7,48		4,86		7,92		12,91
S_X, %		3,94		8,58		5,32		3,95

The results of the structural analysis of potato tubers have shown that with the use of fertilizers, the share of a small fraction decreased. Thus, if in the control the share of small tubers was 11,4 %, in the fertilized treatments it was reduced to 6,0 – 8,7 %, thus the least amount of small fraction of tubers was found in the treatment where calculated doses of fertilizers (treatment 10) were applied – 6,0%. Since tubers weighing less than 20-25 g were referred to as the small fraction and considered to be not marketable yield. The marketable part of the potato crop (55-69% of the total weight) was mainly provided by the presence in the batch of large fraction (above 55-60 g). Thus, fertilizers played the leading role in the formation of a large fraction of tubers.

The effect of mineral fertilizers on the gross productivity of potatoes after sequential treatment and the exclusion of insignificant factors has been described by the equation:

$$Y = 32,475 + 0,7915X_1^{0,5} + 0,0355X_2 + + 0,0652X_3;\ R = 0,886 \qquad (8)$$

where: Y – gross potato yield, t/ha

X_1 X_2 and X_3 – doses of nitrogen, phosphorus and potassium, respectively, kg a.i./ha

It was found that the gross yield of potatoes responds positively to the application of mineral fertilizers. At the same time, nitrogen fertilizers have the greatest positive effect, then potash fertilizers, and the effect of phosphorus fertilizers was very low, indicating the low efficiency of phosphorus fertilizer on soils with high mobile phosphorus.

In the conditions of precision farming, the differentiated application of fertilizers for the planned yield is a necessary requirement. For this purpose, normative expenditure of soil nutrients and fertilizers are developed, which are set by the absolute consumption of nitrogen, phosphorus, and potassium by the potato crop at the corresponding amount of by-products. Our calculations showed (Table 6), that depending on different doses of fertilizers potato plants accumulated in biomass from 172,2 to 260,6 kg of nitrogen, 63,3 to 84,1 kg of phosphorus, and 197,0 to 256,3 kg of potassium. On average, potato plants used 66% of nitrogen, 26% of phosphorus, and 59% of potassium from fertilizers.

For 1 ton of tubers with the appropriate amount of by-products potatoes at gross yield 32,4-49,1 t/ha potato plant taken up 4,4 to 5,8 kg of nitrogen, 1,6 to 2,0 kg of phosphorus and 4,6 to 6,1 kg of potassium depending on doses and fertilizer ratios. The average uptake made 4.9 kg of nitrogen, 1.8 kg of phosphorus, and 5.4 kg of potassium. From the arable soil layer the potato crop absorbed on average 63% of mineralizable nitrogen, 34% of mobile phosphorus, and 28% of exchangeable potassium.

It is interesting to note that there was a strong correlation between total and normative intake of nitrogen (R=0.76) and potassium (R=0.53), while the correlation of total and normative phosphorus intake was weak ((R=0.30).

Table 6 – Nutrients uptake by potato plants depending on mineral fertilizers, 2022

Treatment	Total nutrient uptake, kg/ha			Nutrient uptake per 1 ton of potato tubers, kg			Fertilizer utilization rate, %			Soil utilization rate, %		
	N	P	K	N	P	K	N	P	K	N	P	K
Control (n/f)	142,3	64,7	192,8	4,40	2,00	5,98		-	-	62,6	29,7	24,7
N_{50}	172,2	63,3	219,8	4,56	1,67	5,82	59,7	-	-	-	29,1	28,2
N_{100}	197,7	71,5	231,1	4,83	1,75	5,64	55,4	-	-	-	32,8	29,6
N_{150}	229,9	72,3	207,6	5,38	1,69	4,84	58,4	-	-	-	33,2	26,6
N_{200}	225	78,1	197	5,23	1,81	4,59	41,4	-	-	-	35,8	25,3
$N_{50}P_{50}$	184,5	73,8	228,9	4,62	1,84	5,71	84,3	18,2	-	-	-	29,3
$N_{100}P_{50}$	201,6	83,3	252,9	4,86	2,01	6,10	59,3	37,2	-	-	-	32,4
$N_{100}K_{50}$	234,8	82,6	227,9	5,42	1,90	5,25	92,4	-	70,1	-	37,9	-
$N_{150}K_{50}$	260,6	84,1	217,5	5,77	1,86	4,82	78,8	-	49,4	-	38,6	-
$N_{74}P_{69}K_{112}$	189,3	79,5	256,3	3,86	1,62	5,24	63,5	21,4	56,6	-	-	-
LSD_{05}	17,8	9,9	26,6	0,57	0,17	0,97	-	-	-	-	-	-
S_X, %	2,93	4,43	4,01	3,89	3,31	6,11	-	-	-	-	-	-

The effect and interaction of nitrogen (X1), phosphorus (X2), and potassium (X3) fertilizers on nitrogen (Y1), phosphorus (Y2), and potassium (Y3) intake by 1 ton of potatoes, with the appropriate amount of by-products, is adequately described (R = 0,727-0,885) by the following regression models (9-11):

$$Y_1 = 4,3695 + 0,0051X_1 + 0,0119X_3 - 0,025(X_2X_3)^{0,5}; R = 0,885; \quad (9)$$

$$Y_2 = 1,9928 - 0,0705X_1^{0,5} + 0,004X_1 + 0,0033X_3 + 0,004(X_1X_2)^{0,5} - 0,0082(X_2X_3)^{0,5}; R = 0,805; \quad (10)$$

$$Y_3 = 6,1362 - 0,008X_1 - 0,0497X_2 - 0,0456(X_1X_2)^{0,5}; R = 0,727 \quad (11)$$

It should be noted, the normative nitrogen intake responded positively to an increase in unilateral nitrogen and potassium fertilizer, but negatively to the interaction of phosphorus and potassium fertilizer.

The phosphorus intake by 1 ton of potatoes, with the corresponding amount of by-products, looks a little different – it had an increasing character from the separate action of nitrogen and potassium fertilizers and the interaction of nitrogen and phosphorus fertilizers. From the interaction of phosphorus and potassium fertilizers normative phosphorus consumption rate tended to decrease.

The normative potassium intake coefficient responded significantly negatively to the application of nitrogen and phosphorus fertilizers in separate actions and interactions, with the effect of potassium fertilizer being excluded from the equation during treatment as insignificant (<0.05).

Calculation of the economic efficiency of the application of fertilizers on potatoes (table 7) has shown the high gross income in treatments, where middle and increased doses of nitrogen were combined with small doses of potassium (treatments 8 and 9) showing 5102,6; 5231,8, respectively.

The highest income was gained with the doses of fertilizers for the planned yield (treatment 10) – 5769,4 tenge/ha. These treatments also were effective by a relatively low production cost, showing respectively, 56.5; 56.0, and 50.1 tenge/kg. Profitability of potato production with the application of the same doses of fertilizers made up 121,3; 123,1 and 149,7%.

Table 7 – Economic indicators of potato production depending on mineral fertilizers, 2022

Treatments	Total costs, thousand tenge/ha	Gross income from marketable yield, thousand tenge/ha	Conditionally net income, thousand tenge/ha.	Cost tg/kg	Profitability, %	Economic efficiency, thousand tenge/ha
Control (n/f)	2236,2	3583,8	1347,7	78,0	60,3	-
N_{50}	2209,0	4350,2	2141,2	63,5	96,9	793,6
N_{100}	2247,8	4764,7	2516,9	59,0	112,0	1169,2
N_{150}	2286,6	4917,8	2631,1	58,1	115,1	1283,4
N_{200}	2325,5	4919,0	2593,5	59,1	111,5	1245,8
$N_{50}+P_{50}$	2246,0	4624,1	2378,0	60,7	105,9	1030,4
$N_{100}+P_{50}$	2284,8	4894,9	2610,0	58,3	114,2	1262,3
$N_{100}+K_{50}$	2306,1	5102,6	2796,5	56,5	121,3	1448,9
$N_{150}+K_{50}$	2344,9	5231,8	2886,9	56,0	123,1	1539,2
$N_{74}P_{69}K_{112}$	2310,2	5769,4	3459,2	50,1	149,7	2111,5

The highest net income in the experiment was gained in the treatment with calculated doses of fertilizers, making 2111.5 thousand tenge/ha against 793.6-1539.2 thousand tenge/ha in other treatments.

Conclusion

The results of experimental research showed that in general on the experiment the maximum value of the leaf surface of potato crop variety "Lady Claire" in conditions of light chestnut soils of Zhetysu region occurred in the period of intensive tuberization. The highest index of leaf area of 41.5 thousand m^2/ha was noted in treatment 7 with the joint application of nitrogen and phosphorus ($N_{100}P_{50}$).

Between the phase of seedlings and the phase of budding photosynthetic productivity varied from 12.9 (treatment 2) to 17.9 g/m^2 per day (treatment 10), and between the phase of budding and intensive tuber formation – from 12.1 (treatment 6) to 16.3 g/m^2 per day (control), which showed no adequate relationship between this indicator and the applied doses of fertilizers.

According to the results of structural analysis of tubers, the share of small fraction decreased to 6,0-8,7% with the use of fertilizers, and the marketable part of the potato crop was mainly provided by the presence of a large fraction (above 55-60 g).

The obtained experimental results made it possible to build mathematical models that adequately describe the effects of mineral fertilizers on the biometric and yielding indicators of potatoes and the uptake of nutrients by plants. The resulting models are useful for predicting the changes in biometric and yielding indicators and allow determining the needs of potatoes in fertilizers to achieve a targeted yield.

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Conflicts of Interest

The authors declare no conflict of interest.

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