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CURRENT TRENDS AND PROSPECTS FOR THE DEVELOPMENT OF FOOD PRODUCTION IN THE REGIONS OF KAZAKHSTAN

In developed countries, supporting agricultural producers is considered a key goal of government policy. Support for the agricultural industry is focused on subsidies, modernizing production technologies, purchasing fertilizers, increasing the competitiveness of agricultural products, supporting industry research through regulatory and methodological support, and implementing tax, budgetary, and customs tariff measures.

The research purpose was to analyze the significance of potato cultivation by examining key metrics such as cultivation area, total yield, productivity, and fertilizer usage. It utilized methods like descriptive statistics, quartile analysis, and regression analysis to derive insights from the available data.

Originality/value of the research lies in its comprehensive evaluation of how potato production impacts Kazakhstan's food security. By providing detailed statistics, such as Pavlodar region's cultivation area of 24,033.5 hectares and its yield of 6,616,240.6 centners, the study offers a nuanced understanding of the sector's contribution to the national food supply.

Findings reveal that potato production is crucial for Kazakhstan's food security. Regions like Pavlodar and Ulytau, with high yields and productivity levels (e.g., 293.6 centners per hectare in Ulytau region), underscore the efficiency of potato farming. The study also highlights the role of effective fertilizer management in enhancing productivity,vital for maintaining a stable food supply and ensuring nutritional security.

Keywords: potato production efficiency, agriculture of Kazakhstan, food security, economic regions of Kazakhstan.

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Қазақстан өңірлерінде азық-түлік өндірісі дамуының қазіргі тенденциялары мен болашағы

Дамыған елдерде ауыл шаруашылығы тауарын өндірушілерді қолдау мемлекеттік саясаттың негізгі мақсаты болып саналады. Аграрлық саланы қолдау субсидиялауға, өндіріс технологияларын жаңғыртуға, тыңайтқыштар сатып алуға, ауыл шаруашылығы өнімдерінің бәсекеге қабілеттілігін арттыруға, нормативтік және әдістемелік қамтамасыз ету арқылы салалық зерттеулерді қолдауға, салықтық, бюджеттік және кедендік тарифтік шараларды іске асыруға бағытталған.

Зерттеудің мақсаты картоп өсірудің маңыздылығын өсіру алаңы, жалпы өнім, өнімділік және тыңайтқышты пайдалану сияқты негізгі көрсеткіштерді зерделеу арқылы талдау болды. Ол қол жетімді деректерден түсінік алу үшін сипаттамалық статистика, квартильді талдау және регрессиялық талдау сияқты әдістерді пайдаланды.

Зерттеудің түпнұсқалығы/құндылығы оның картоп өндірісінің Қазақстанның азық-түлік қауіпсіздігіне қалай әсер ететінін жан-жақты бағалауында жатыр. Павлодар облысының егістік көлемі 24 033,5 гектар және оның өнімділігі 6 616 240,6 центнер сияқты егжей-тегжейлі статистикалық мәліметтерді бере отырып, зерттеу сектордың ұлттық азық-түлікпен қамтамасыз етудегі үлесі туралы нақты түсінік береді.

Зерттеу нәтижелері картоп өндірісінің Қазақстанның азық-түлік қауіпсіздігі үшін маңызды екенін көрсетеді. Өнімділік деңгейі жоғары Павлодар және Ұлытау сияқты облыстар (мысалы, Ұлытау облысында гектарына 293,6 центнер) картоп өсірудің тиімділігін көрсетеді. Зерттеу

нымен қатар тұрақты азық-түлікпен қамтамасыз ету және тағамдық қауіпсіздікті қамтамасыз ету үшін маңызды өнімділікті арттырудағы тыңайтқыштарды тиімді басқарудың рөлін көрсетеді.

Түйін сөздер: азық-түлік қауіпсіздігі, картоп өндірісі тиімділігі, Қазақстанның ауыл шаруашылығы, Қазақстанның экономикалық аудандары.

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Современные тенденции и перспективы развития производства продовольствия в регионах Казахстана

В развитых странах поддержка сельскохозяйственных товаропроизводителей считается одной из ключевых целей государственной политики. Поддержка аграрной отрасли направлена на субсидирование, модернизацию технологий производства, закупку удобрений, повышение конкурентоспособности сельскохозяйственной продукции, поддержку отраслевых исследований посредством нормативно-правового и методического обеспечения, а также реализацию налоговых, бюджетных и таможенно-тарифных мер.

Целью исследования было проанализировать значимость выращивания картофеля путем изучения ключевых показателей, таких как площадь возделывания, общая урожайность, продуктивность и использование удобрений. Для получения информации на основе имеющихся данных использовались такие методы, как описательная статистика, квартильный анализ и регрессионный анализ.

Оригинальность/ценность исследования заключается в его всесторонней оценке того, как производство картофеля влияет на продовольственную безопасность Казахстана. Предоставляя подробные статистические данные, такие как площадь посевных площадей Павлодарской области в 24 033,5 га и урожайность в 6 616 240,6 центнеров, исследование дает детальное понимание вклада этого сектора в национальное продовольственное снабжение.

Результаты показывают, что производство картофеля имеет решающее значение для продовольственной безопасности Казахстана. Такие области, как Павлодар и Улытау, с высокими уровнями урожайности и продуктивности (например, 293,6 ц/га в Улытауской области), подчеркивают эффективность выращивания картофеля. В исследовании также подчеркивается роль эффективного управления удобрениями в повышении производительности, что жизненно важно для поддержания стабильных поставок продовольствия и обеспечения продовольственной безопасности.

Ключевые слова: эффективность производства картофеля, сельское хозяйство Казахстана, продовольственная безопасность, экономические регионы Казахстана.

Introduction

The production of potatoes is an important strategic element in the agricultural sector and the country's food security system. Potatoes are a staple food that has a considerably high contribution to the diet and the employment of the rural population in Kazakhstan. The fact that there are large areas of agricultural land and varying climate conditions in Kazakhstan gives a positive indication regarding the prospects for growing potatoes. However, the efficiency of production and production levels are quite diverse due to the regional disparities.

Despite the economic and nutritional significance of potatoes in the country, detailed analyses concerning the area wherein potatoes are grown, total production, production per unit area, and the application of fertilizers in the Kazakhstan region appear to be limited in studies conducted in the past. The challenge of this gap in current research will be especially important in view of the challenges the country experiences because of climate variability and the need to improve its self-sufficiency in basic food products. The purpose of the investigation will be to evaluate the present level and regional specifics of potato growing in Kazakhstan based on the four central indicators: cultivation area, total yield, productivity (centners/ha), mineral fertilizer usage.

To accomplish this, the study utilizes the tools of descriptive statistics, quartile comparison, and linear regression analysis, thus enabling the comparison of distributions and the relationship assessment of utilization and production outputs. The combination of the tools gives a systematic and objective approach to understanding production trends and the determi-

nants that cause variability in the results across the respective regions.

The study focuses on the following inquiries:

1. How do the area, production, and productivity of potatoes vary in the respective regions of Kazakhstan?

2. Listing the basic factors associated with higher and lower levels of productivity:

3. To what extent does the application of fertilizers explain the variation in the yields for potatoes?

4. What are the implications of the trends noted above concerning food security and agricultural policies?

The significance of the study is in its contribution to the formulation of the country's food security policy and sustainable agricultural development strategies because the study offers an interdisciplinary assessment of the scale of production and efficiency in order to make informed decisions concerning the improvement of farming practices in the region and the utilization of fertilizers.

The results show a large difference in the levels of development of the potato industry in the regions of Kazakhstan. The top region in terms of the area (24,033.5 ha) and the total production (6.6 million centners) is the Pavlodar region, and the highest production capacity is recorded in the Ulytau. While regression analysis demonstrates that the use of fertilizers has a moderate explanatory value regarding the variation in the productivity levels to the tune of approximately 29.5%, other important determinants include climate and soil quality, amongst other variables. The above results highlight the importance of having a well-balanced and region-specific approach that encompasses the efficiency of fertilizers and agricultural and land practices.

Overall, this report offers a full and fact-based review of potato production in the various regions of Kazakhstan. By highlighting trends, pointing out constraints, and estimating the critical relationships, the study provides a basis for policymakers to make effective interventions to improve efficiency and food security.

Methodology

In order to achieve a better understanding of the Kasakh farming of potatoes, the research uses various research methods to analyze the trends in farming as well as the utilization of lands. The research methods complement each other to present foremost information–such as cultivated lands, overall potato production, farm productivity, as well as the use of fertilizers.

A substantial portion of the analysis dedicates to descriptive statistics. They reduce intricate data to easily interpretable and communicable levels. By employing the help of charts, tables, along with simple figures such as averages, medians, and ranges, the research provides a preliminary look at the data. This way, repeating patterns as well as one-time anomalies that could easily be overlooked can be made prominent.

Another way to get a better picture of how the data is spread around is the quartile analysis. This emphasizes center values and shows how the data points are bunched together by splitting the data into four even parts. This, in research on agriculture, can be used to compare regions since it can be used to display discrepancies in the use of the terrain as well as farm output. This can also detect oddities, where some places are doing significantly better or poorer than the rest, possibly requiring special attention.

The research meanwhile uses regression analysis to analyze the relationship between different farming factors to each other with particular interest given to the relationship between the yield of potatoes as well as the use of mineral fertilizers. Regression analysis is a powerful statistical tool used to model how one main factor is affected by one or more other factors (Postiglione, 2021, pp. 6-7, 64-87, 108-121). It helps in showing how the main variable changes when one of the other factors is adjusted. In this context, the regression model is used to quantify the impact of fertilizer usage on potato productivity, providing insights into the effectiveness and influence of fertilizers on crop yields.

The use of R-squared and adjusted R-squared values in regression analysis offers an understanding of the model's explanatory power (Postiglione, 2021, pp. 6-7, 64-87, 108-121). The R-squared value shows how much of the change in the main variable can be explained by the other factors in the model. The adjusted R-squared value gives a clearer picture by taking into account the number of variables and the size of the data set. This makes it a more accurate measure of how well the model works (Postiglione, 2021, pp. 6-7, 64-87, 108-121).

In Kazakhstan, understanding the pattern of potato cultivation requires more than one analytical prism. By combining various methodological instruments, the research retains significant regional variations, describes current practices, and identi-

fies factors that govern the outcome of crops. This wider overview acts as a basis for decision-taking both in agriculture management as well as policy, with the pragmatic advice given to enhance yields, promote the conservation of ecological material, as well as ensure economic sustainability. Using descriptive measures, quartile division, and regression analysis, the study builds a multi-faceted picture of the variables that dictate the production of potatoes throughout the nation.

Understanding the nuance of the cultivation of potatoes in Kazakhstan requires analysis of the set of principal agronomic measures (Stark et al., 2020, pp. 35-64, 87-100).The factors of potato cultivation area, total potato yield, potato productivity measured in centners per hectare, and usage of mineral fertilizers for potato, each play a pivotal role in painting a comprehensive picture of the state of potato farming. Therefore, these factors were shown below in Table 1.

Table 1 – 2023 potato cultivation and production statistics by regions of Kazakhstan

Regions of Kazakhstan	Potato cultivation area, in hectares	Total potato yield, in centners	Potato productivity, measured in centners per hectare	Usage of mineral fertilizers for potato, calculated as 100% nutrient content, in centners
Abai	8056.9	1766939.0	219.3	5404.0
Akmola	12603.0	2304891.7	182.9	22645.4
Aktobe	5777.0	979862.9	169.6	1234.2
Almaty	23955.0	4583044.6	191.3	400.4
Atyrau	1901.1	291564.0	153.4	88.4
West Kazakhstan	4246.1	688494.1	162.1	6556.4
Zhambyl	11359.3	2852172.4	251.1	815.7
Zhetysu	11867.7	2524198.8	212.7	-
Karaganda	15703.5	3641827.9	231.9	28,385.6
Kostanay	8286.4	1604784.1	193.7	11887.6
Kyzylorda	4156.8	616202.8	148.2	184.6
Pavlodar	24033.5	6616240.6	275.3	43352.6
North Kazakhstan	26456.9	3770637.4	142.5	5419.8
Turkestan	14391.8	2867377.8	199.2	6079.4
Ulytau	515.0	151206.9	293.6	-
East Kazakhstan	10809.1	2589167.8	239.5	388.7
City of Astana	51.3	6621.1	129.1	27.1
City of Almaty	82.5	15211.5	184.3	-
City of Shymkent	53.2	10733.0	201.7	-
Total for Kazakhstan	184306.3	37881178.3	205.5	132869.9

Note – compiled by the author based on Bureau of National Statistics of the Agency for Strategic Planning and Reforms of the Republic of Kazakhstan (2024a; 2024b; 2024c)

The potato cultivation area in hectares is fundamental in understanding the scale of potato production. It indicates the geographical extent to which potato farming is spread across Kazakhstan. This information is key to understanding how important the crop is to Kazakhstani farming industry. A larger cultivation area not only points to the significance of potatoes as a staple food but also influences economic policies, food security considerations, and land use planning. Observing changes in the cultivation area over time can also reveal trends and shifts in agricultural practices and market dynamics (Khatri et al., 2024, pp. 71-82, 243-278; (Postiglione, 2021, pp. 6-7, 64-87, 108-121; Stark et al., 2020, pp. 35-64, 547-572).

Total potato yield in centners is another critical factor. This number shows how much potatoes are being produced in Kazakhstan. By looking at the to-

tal amount grown, people involved in farming can see how well potato farming is doing each year. It helps them understand if there's enough to meet the country's needs, if there's extra to export, and how it supports the economy. Comparing this data across regions and years also shows which areas have better farming methods or better conditions for growing potatoes.

Potato productivity, expressed as the number of centners per hectare, is a prominent indicator of proper farming. The indicator delivers what the farm ground is capable of doing as well as the farming techniques itself. Where the productiveness is high, the techniques, climate, and measures to control pests are standing strong. Where the productiveness is low, there could be problems such as wrong farming techniques, inferior soil, or harsh climate. The figure is significant to planning within each region to determine the area to inject funds, technologies, as well as training to promote farming.

Finally, considering how much mineral fertilizer is applied to potatoes, measured in terms of full nutritional value, can be used to gain some understanding of what is required to produce the crop. Application of the fertilizer is a crucial function of contemporary agriculture because it significantly influences how much is actually produced as nutrition as well as the quality. Knowing the amount applied can be used to gain some idea of the long-term sustainability of Kazakhstan potato farming. Over-application can cause soil to be lost in quality as it becomes polluted with waters, whereas too meager use could lead to smaller crops as the quality is spoiled. This information is crucial to developing farming practices that stay productive as well as environmentally friendly over the long term.

In summary, the combined components present a balanced account of the farmings of the area. Current conditions are defined, principal challenges are highlighted, and potential avenues of future development are indicated. Such analytical acuity assists decision makers, be they growers, administrators, or industry planners, to improve operation, to save natural resources, and to enhance economic paybacks.

In this detailed analysis of Kazakhstani potato farming, the focus is on two main points: the area used for growing potatoes (in hectares) and the total amount harvested (in centners), along with how these figures are spread across different levels.

The potato cultivation area differsacross Kazakhstan. The smallest area, observed in the City of Astana, only 51.3 hectares, showing that farming is very limited in this city area. On the other hand, the Pavlodar region has the biggest potato-growing area at 24,033.5 hectares, highlighting its key role in national potato production (Bureau of National Statistics of the Agency for Strategic Planning and Reforms of the Republic of Kazakhstan, 2024a). The quartile distribution for the cultivation area reveals that the first quartile (25th percentile) is 3,028.95 hectares, the median (50th percentile) is 8,286.4 hectares, and the third quartile (75th percentile) is 13,497.4 hectares. This data suggests a significant variation in cultivation sizes, with a substantial number of regions engaging in potato farming on a larger scale.

Looking at total potato yield, the highest amount comes from areas with the most land used for farming, especially the Pavlodar region, which produced an impressive 6,616,240.6 centners (Bureau of National Statistics of the Agency for Strategic Planning and Reforms of the Republic of Kazakhstan, 2024b). On the other hand, the City of Astana had the lowest yield at just 6,621.1 centners, which matches its small farming area. The quartile data helps show how potato production is spread out across the country: the first quartile is 453,883.4 centners, the median is 1,766,939.0 centners, and the third quartile is 2,859,775.1 centners. These numbers show clear differences in how much each region produces and also hint at differences in how well resources and farming methods are being used.

Overall, this analysis highlights how potato farming varies across different parts of Kazakhstan. It definesuseful insight on how different farm sizes and crop sizes across Kazakhstani regions are, which allows to make decisions on planning, where resources are recommended to be invested, and how to expand potato farming in the sustainable way. This data is also essential for shaping policies that can help to strengthen farming sector of Kazakhstan through defining how to increase crop production and ensure food supply and safety.

Understanding how mineral fertilizers impact potato yields in Kazakhstan is possible throughapplying the regression analysis. This method looks at how closely these two factors are connected and how strong that connection is, using R-squared and adjusted R-squared values to measure it (Postiglione, 2021, pp. 6-7, 64-87, 108-121).

The data shows a range of productivity levels across different regions of Kazakhstan, from as low as 142.5 centners per hectare in North Kazakhstan region to as high as 293.6 centners per hectare in Ulytau region (Bureau of National Statistics of the Agency for Strategic Planning and Reforms of the

Republic of Kazakhstan, 2024c). Similarly, the usage of mineral fertilizers varies, with the lowest being 27.1 centners in the City of Astana and the highest at 43,352.6 centners in Pavlodar. To understand how these variables interact, we performed a linear regression analysis.

The regression model yielded an R-squared value of 0.295, indicating that approximately 29.5% of the variability in potato productivity is explained by the usage of mineral fertilizers. While this indicates some level of correlation, it also suggests that other factors are at play in determining productivity. The adjusted R-squared value, which takes into account the number of factors in the model and the size of the data set, is a bit lower at 0.240 (Postiglione, 2021, pp. 6-7, 64-87, 108-121). This gives a more reliable picture of the relationship based on the data and variables included.

The R-squared and adjusted R-squared values play an important role in understanding potato farming in Kazakhstan. An R-squared value of 0.295, though not very high, shows a moderate positive link between fertilizer use and potato productivity. This means that regions using more mineral fertilizers often see better yields. However, since the value isn't closer to 1, it also shows that other important factors affect productivity – such as climate, soil quality, farming techniques, and how pests are controlled.

The adjusted R-squared value of 0.240 is a more conservative estimate that adjusts for the number of variables in the model relative to the number of data points (Postiglione, 2021, pp. 6-7, 64-87, 108-121). In practical terms, this means that while fertilizer usage does impact productivity, it is not the only factor, and its effect is not overwhelmingly strong.

For policymakers and agricultural stakeholders in Kazakhstan, these findings emphasize the importance of a balanced approach to improving potato productivity. While the use of mineral fertilizers is indeed a contributing factor, it's clear that other aspects of agricultural practice and environmental conditions also play significant roles (Stark et al., 2020, pp. 87-100, 135-154, 203-257).This shows that increasing potato yields shouldn't depend just on using more fertilizer. A wider approach is needed, e.g. using better farming techniques, taking care of the soil, and managing pests and diseases effectively. It could also be helpful to study and grow potato varieties that are better suited to local conditions.

In summary, the analysis shows a somewhat positive connection between potato productivity and fertilizer use in Kazakhstan. But since the R-squared values aren't very strong, it's clear that boosting yields will take more than just using more fertilizer. Looking into and improving other key factors can help develop better farming practices and guidelines to support potato farming throughout the country.

Building on the analysis of potato farming in Kazakhstan, using specific data gives solid proof to back up the study's results. This in-depth approach looks at several important factors, e.g. the amount of land used, total harvest, productivity, and fertilizer use – each playing a key role in showing how the farming sector works.

For example, the study found that potato farming areas differ a lot across Kazakhstan. Quartile analysis showed that 25% of regions have less than 3,028.95 hectares, the middle value is 8,286.4 hectares, and 75% have less than 13,497.4 hectares. This shows clear differences in how much land is used for growing potatoes. Some areas, like the City of Astana, farm on a very small scale with just 51.3 hectares, while others, like Pavlodar, use much larger areas – up to 24,033.5 hectares.

In the same way, the total potato yield across regions also highlights the differences in how effectively resources are used and how productive farming is in each area. The first quartile for yield is 453,883.4 centners, the median is 1,766,939.0 centners, and the third quartile is 2,859,775.1 centners. Pavlodar region, with its large cultivation area, aligns with the highest yield, producing a staggering 6,616,240.6 centners, contrasting sharply with the City of Astana, which, due to its limited cultivation area, amounts to just 6,621.1 centners.

The regression analysis looked at how potato productivity is related to the use of mineral fertilizers. The R-squared value was 0.295, meaning around 29.5% of the changes in productivity can be linked to fertilizer use. While this shows some connection, it also suggests that many other factors play a role. The adjusted R-squared value, which is slightly lower at 0.240, gives a more accurate view by considering the number of variables and the size of the data set (Postiglione, 2021, pp. 6-7, 64-87, 108-121).

These findings are important for people who make farming decisions in Kazakhstan. Although they are not the only factor involved, mineral fertilizers can lead to increased potato yields. Hence, the well-rounded approach taking into account other key elements is necessary. There are conditions such as climate, soil condition, cultivation techniques, and pest control which also carry considerable weight. This suggests that boosting potato production isn't

simply about increasing fertilizer use. A broader plan is required. This could include better farming practices, maintaining soil quality, and managing pests and diseases effectively. It may also be useful to examine which potato varieties are best suited to local conditions.

In conclusion, this analysis uses the real-world data to examine the state of Kazakhstani potato cultivation. It reveals that cultivating potatoes entails various difficulties and is shaped by multiple conditions. Through examining and refining these aspects, agricultural guidelines and practices may be adjusted to support growers across the nation. The research is a useful tool for creating plans that can boost harvests, protect the environment, and increase profits – helping both the farming sector and the country's food supply.

In the current analysis, the model of regression employs the ordinary least square method in a univariate analysis where potato productivity is dependent on the use of mineral fertilizer at the regional level. The model deployed can thus be considered as exploratory or preliminary. The intention in such calculations is to make an initial quantitative assessment of the link between fertilizer use and productivity, rather than attempting to estimate a complete production function or make claims about causation.

One of the main drawbacks of the univariate model based on OLS analysis is the issue of omitted variable bias. The productivity in potato output is proxied by many variables such as climate factors (rain and temperature) or irrigation facilities. It should be noted that many other factors affect potato productivity collectively; such factors include climate factors like rainfall and temperature. These factors are not included in the model because of data constraints at the regional level. If any of these factors are correlated with fertilizer use, then the estimated coefficient on "fertilizer" will measure not only the impacts of using fertilizer but will also measure the impacts of any of these factors that are not included in the model. It can therefore be said that the regression parameter needs to be considered as a partial association rather than an unbiased estimate of the causal link between fertilizer and productivity.

The model is further restricted by the fact that it is a cross-sectional model and there are few data points per region. Being based on data from a single year, it is not feasible to check for fixed region characteristics or dynamic relationships such as the reaction of yields to fertilizer or weather. In addition, the sample size means that it is not feasible to consider complex models without risking the danger of overfitting. Subsequently, the power of the test has remained low, and the data obtained from the analysis can basically help in pointing out rather than in predicting.

Further, the OLS model has standard assumptions such as linearity, homoskedasticity, and independence of the error terms. In comparison to the linear functional form, where the marginal treatment effect of fertilizer always remains constant regardless of the quantity applied, the actual relationship between yields and fertilizer can result in diminishing returns or thresholds. Possible measurement error in the use of fertilizer and agricultural produce in the region can equally have an influence on the estimates. By taking the aggregate level in the analysis, the result might not apply to farms and households (ecological fallacy).

These factors combined mean that the result from the regression analysis can be considered as exploratory or suggestive analysis in addition to the descriptive analysis and comparison of quartiles. It must be considered that the analysis was done at an aggregate level. Although the model helps in structuring and synthesizing data regarding differences in the use of fertilizer and productivity in different regions, the model fails to generate data regarding complex agricultural factors and socio-economic considerations related to potato farming. In future studies, a multivariate model framework and more detailed data regarding climate, soil, irrigation, varieties, and technology would all be helpful. Also, longitudinal data would strengthen the analysis of causal relationships.

Literature review

In a comprehensive literature review focusing on potato cultivation, particularly in regions like Kazakhstan, scholars typically explore a wide range of topics that are crucial for understanding and improving agricultural productivity. Such reviews delve into the effectiveness of different farming techniques on potato yields, often emphasizing the importance of practices like crop rotation and soil management (Khatri et al, 2024, pp. 123-146, 374-432). The resilience of these methods in maintaining soil health and increasing yield, along with the adaptation of local and indigenous farming practices, forms a significant part of this discourse (Khatri et

al, 2024, pp. 123-146, 374-432; Stark et al., 2020, pp. 417-446).

Climate and environmental impact on potato cultivation is another area that receives considerable attention. Studies in this domain assess how fluctuating weather patterns, including increased temperatures and irregular rainfall, influence potato growth. In this context, research into climate-resilient potato varieties and early-warning systems for climate-related threats is prevalent (Reddy, 2015, pp. 223-272, 280-320; Stark et al., 2020, pp. 135-154, 417-446).

Additionally, the role of technological advancements in agriculture, particularly precision agriculture, is a key theme (Khatri et al., 2024, pp. 341-462; Stafford, 2023, pp. 415-421, 443-449). These advancements encompass the use of data analytics, GPS-guided equipment, drones for crop health monitoring, and automated systems for efficient irrigation and pest control. Such technologies are seen as pivotal in optimizing farming practices and enhancing potato productivity (Khatri et al., 2024, pp. 99-240, 341-462; Stafford, 2023, pp. 635-642, 715-721, 909-916).

The relationship between fertilizer usage and potato yield is also a crucial research topic (Stark et al., 2020, pp. 135-154). Optimal fertilization strategies are explored extensively, considering their economic and environmental impacts. The development of sustainable fertilizer alternatives, like organic or slow-release fertilizers, forms a part of this discussion, highlighting the need for balance between enhancing productivity and preserving environmental health (Stark et al., 2020, pp. 135-154; Campos & Ortiz, 2020, pp. 163-217, 451-473; Stafford, 2023, pp. 415-421, 715-721).

Socio-economic factors, including government policies, market dynamics, and the economic aspects of potato farming, are also analyzed (Campos & Ortiz, 2020, pp. 163-217, 451-473; Stafford, 2023, pp. 415-421, 715-721; Stark et al., 2020, pp. 135-154). Research in this area evaluates how agricultural subsidies, trade policies, and infrastructure development boost potato yields and enhance the productivity and viability of potato farming (Stark et al., 2020, pp. 135-154; Campos & Ortiz, 2020, pp. 163-217, 451-473; Stafford, 2023, pp. 415-421, 715-721; Struik & Wiersema, 2012, pp. 315-342).

Land use planning, closely tied to sustainable agriculture and food security, is another significant subject. Research here often involves examining land allocation strategies for potato cultivation and the need to balance agricultural demands with urban development (Campos &Ortiz, 2020, pp. 75-106, 163-217). This aspect of research is intertwined with national and regional objectives for food security.

Moreover, sustainability and environmental practices in farming receive considerable attention (Londhe, 2017, pp. 17-49, 133-151). Sustainable irrigation practices, reduction of the carbon footprint through improved farm management, and the conservation of biodiversity in potato farming ecosystems are critical areas of focus (Londhe, 2017, pp. 50-86, 105-132, 247-269).

In summary, the literature review encapsulates an integrated approach to potato farming, combining traditional and modern techniques, state-of-the-art technologies, and supportive policies. This approach underscores the need for ongoing innovation in potato cultivation to meet global challenges like food security and environmental sustainability (Campos & Ortiz, 2020, pp. 163-217, 451-473; Stafford, 2023, pp. 415-421, 715-721; Khatri et al., 2024, pp. 99-240, 341-462). Particularly in Kazakhstan, where agriculture is a cornerstone of the economy and essential for the populace's well-being, such research is invaluable (Food and Agriculture Organization of the United Nations, 2023, pp. 47-57). It serves not only to guide current practices but also to shape future strategies in agricultural development, ensuring that potato cultivation remains both a sustainable and productive venture (Caliskan et al., 2022, pp. 317-329, 457-470; Food and Agriculture Organization of the United Nations & Organisation for Economic Co-operation and Development, 2021, pp. 21-39, 225-230).

Although prior research provides valuable insights into agronomy, climate impacts, fertilizer management, and technological progress in potato cultivation, much of the existing literature remains descriptive and fragmented when applied to Kazakhstan's regional context. Studies tend to focus on global and country levels in terms of challenges and fail to take into account discrepancies in the areas where the growth and production are taking place in the respective Kazakhstani regions. Consequently, the current results fail to provide an answer to why some Kazakhstani regions, such as Pavlodar and Ulytau, are performing better than others and fail to establish the contribution of specific input indicators, namely mineral fertilizers, to the production discrepancies. Nonetheless, the absence of an assessment based on indicators for the regions creates a significant empirical gap, and this is even more important in the case of a country where the agri-

cultural environment, quality of soil, climate, and availability of fertilizers vary considerably across the territories.

Building on the studies reviewed above, the current study adopts an agricultural production function perspective wherein potato output and productivity may be expressed in terms of a function of the key inputs and relevant management conditions: Potato output/productivity = f(land, fertilizers, climate, technology, management). In this view, land area, soil and climatic conditions, and mineral fertilizer availability are the key inputs into production, while farming practices, pest management, mechanization, and regional policy support are the means by which these inputs are transformed into agricultural output in the form of yield and productivity. These, in turn, feed into the broader outcomes related to food security and rural development that link farm-level decisions to national goals of sustainable agriculture and nutritional security (Food and Agriculture Organization of the United Nations & Organisation for Economic Co-operation and Development, 2021, pp. 21-39, 225-230; Khatri et al., 2024, pp. 3-98).

In accordance with the «inputs–processes–results–sustainability» scheme, this paper places the variables analyzed within a broader framework of sustainability. The area under potato cultivation and the amount of fertilizer used point toward scale and intensity of resource use, whereas yield and productivity describe efficiency in conversion into agricultural produce under given conditions of climate and soil. These production results directly affect the capability of Kazakhstan to offer a stable supply of potatoes and reduce inequalities in the food supply at a regional level. At the same time, policies about land use planning, support to modern technologies and precision agriculture, and promoting balanced fertilizer management shape the long-term sustainability of the potato production systems by encouraging efficient resource use, protection of environmental quality, and resilient regional development (Campos & Ortiz, 2020, pp. 163-217, 451-473; Stafford, 2023, pp. 415-421, 715-721).

Despite the shortcoming, this current study incorporates the use of descriptive statistics, comparative quartiles, and regression analysis to consistently analyze the production of potatoes in the regions of Kazakhstan. For instance, unlike the current study and its focus on the production of potatoes in the various regions in Kazakhstan based on the data collected in 2023, previous studies tend to focus broadly on the issues of sustainability and precision farming. Through the quantification of the link between the utilization of fertilizers and the levels of productivity ($R^2 = 0.295$), the study offers a better insight into the structural levels that regulate the production of potatoes. The combination of the insights derived from literature and the current empirical realities enhances the theoretical basis for conducting an investigation into the indicators and their significance.

Results and discussion

A Directed Acyclic Graph (DAG) is a conceptual tool used in various fields, including epidemiology, genetics, and social sciences, to visually depict assumptions about relationships and causal pathways between variables (Bang-Jensen&Gutin, 2009, pp. 1-20, 643-694; Digitale, 2022). In the context of potato cultivation in Kazakhstan, constructing a comprehensive DAG involves identifying and connecting various factors that influence potato productivity. This graphical representation aids in understanding the complexity of agricultural systems and the interplay of multiple factors.

The DAG for potato productivity in Kazakhstan would start with the primary node: potato productivity measured in centners per hectare. This variable is the outcome of interest, influenced by multiple factors, each represented as nodes in the graph. For instance, Figure 1 demonstrates the Directed Acyclic Graph (DAG) that visually represents the factors influencing potato productivity in Kazakhstan, as described earlier.

In our research, the Directed Acyclic Graph or DAG can be viewed as a conceptual framework which encapsulates our conjectures regarding the relationships between important inputs like land, fertilizers, climate and soil characteristics, and farming methods, and the intermediate data related to farming, and, ultimately, the output of interest, which in our case is potato productivity in the regions of Kazakhstan. The analysis of the DAG framework relies on agricultural production theory and sustainability-minded conceptualizations because in these, productivity arises based on the interactions of biophysical factors, management actions, and policy considerations.

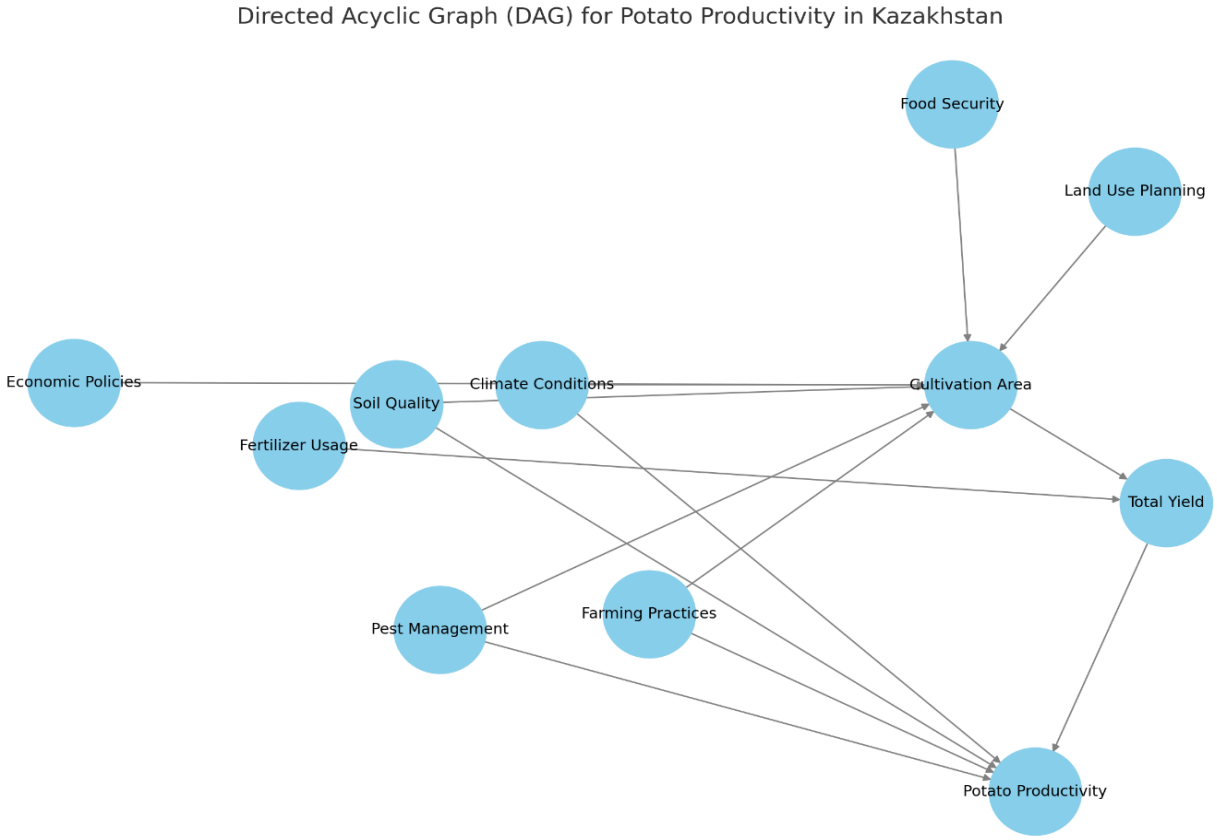

Figure 1 – Directed Acyclic Graph (DAG) for potato productivity in Kazakhstan.
Note: The figure illustrates hypothesized causal relationships among factors influencing potato productivity in Kazakhstan. Arrows indicate the assumed direction of influence between variables. Source: compiled by the authors.

The DAG shows the directional influences among various factors:

- "cultivation area" is a starting point, influencing "total yield";
- "potato productivity" and cultivation area" are affected by "pest management", "soil quality," "farming practices" and "climate conditions";
- "fertilizer usage" also influences "total yield";
- "potato productivity" is strongly influenced by "total yield";
- "economic policies," "food security," and "land use planning" are linked to "cultivation area."

Each arrow indicates the direction of influence, demonstrating the complex network of factors contributing to the overall productivity of potato farming in Kazakhstan. This DAG provides a clear visual framework for understanding the intricate relationships and dependencies within the agricultural sector (Bang-Jensen&Gutin, 2009, pp. 1-20, 643-694; Digitale, 2022).

The DAG for potato productivity in Kazakhstan would start with the primary node: potato productivity measured in centners per hectare. This variable is the outcome of interest, influenced by multiple factors, each represented as nodes in the graph.

One major influencing factor is the cultivation area in hectares. As shown in the research, the size of the cultivation area varies significantly across regions, ranging from as small as 51.3 hectares in the City of Astana to as extensive as 24,033.5 hectares in Pavlodar. This variability directly impacts the total potato yield, which is another crucial node in the DAG. Yield data reveals disparities in agricultural efficiency and resource utilization, with first and third quartiles being 453,883.4 centners and 2,859,775.1 centners, respectively.

Another critical factor is the usage of mineral fertilizers, quantified as 100% nutrient content in centners. The regression analysis conducted in the study indicated that approximately 29.5% of the variability in potato productivity is explained by fertilizer usage, as reflected by an R-squared value of 0.295. This relationship suggests a moderate positive correlation, positioning fertilizer usage as

an important node in the DAG, influencing potato productivity.

Climate conditions, soil quality, farming practices, and pest management strategies are additional nodes that significantly impact potato productivity. These factors are not as directly quantifiable as the others but are essential components of the overall agricultural environment. They interact with both the cultivation area and the use of fertilizers. This affects how much is harvested and how efficient the farming is.

The DAG would also take into account economic strategies, concerns about stable food supply, and how land is managed as underlying influences. These wider background elements shape choices about how much land is used for farming and which methods are applied, which can then have an indirect effect on crop output.

In the DAG, arrows would show how different elements affect each other. For instance, lines would go from land size and fertilizer use toward total harvest, and then continue toward potato output. Individual indicators would extend from weather patterns, land fertility, and agricultural methods toward both the planted area and crop output, illustrating their multifaceted influence.

Creating this DAG provides a visual framework to understand the interdependencies and causal pathways in potato cultivation. It highlights that while some factors have a more direct impact on productivity, others exert their influence through a web of interrelated agricultural practices and environmental conditions. This graphical representation is invaluable for policymakers and stakeholders in Kazakhstan's agricultural sector, providing a clear overview of the factors that need to be addressed to enhance productivity, sustainability, and profitability in potato farming. It serves as a roadmap for developing targeted interventions and policies that address the specific needs and challenges of the potato cultivation sector in Kazakhstan.

Using the Directed Acyclic Graph (DAG) for potato productivity in Kazakhstan, along with the research findings, here are three simple and clear suggestions to help increase potato yields in the country:

1. Optimize fertilizer use: while the regression analysis shows that fertilizer usage does influence potato productivity, the R-squared value of 0.295 indicates that there are additional factors at play (Postiglione, 2021, pp. 6-7, 64-87, 108-121; Mueller et al., 2021, pp. 349-372, 513-525). It is recommended that Kazakhstan develop a precision agriculture strategy. This strategy should focus on optimizing fertilizer use to ensure that each region applies the right type and amount of fertilizers based on specific soil quality and climate conditions (Campos & Ortiz, 2020, pp. 163-217, 451-473; Mueller et al., 2021, pp. 513-525, 661-677;). This could involve soil testing programs to tailor fertilizer types and quantities to the needs of different areas, potentially enhancing productivity more efficiently.

2. Improve farming methods: since agricultural techniques play an important role in shaping both the amount of land used and the level of crop output, it's important to focus on raising the quality of these methods. A nationwide effort should be made to upgrade how farming is done. This could involve applying modern agricultural methods like rotating crops, managing pests in a combined way, and planting potato types that produce larger harvests (Khatri et al., 2024, pp. 37-98, 182-188).Moreover, funding farmer education initiatives can provide them with the skills needed to apply up-to-date and effective cultivation techniques, which could help raise the average yield of 205.5 centners per hectare, as observed in the analysis.

3. Introduce well-managed land allocation practices: the notable variation in potato growing areas, from the lower quartile at 3,028.95 hectares to the upper quartile at 13,497.4 hectares, demonstrates that there is the need for better coordination in land use. To guide this, the government authorities should create policies that encourage responsible expansion of cultivated zones suited to potato farming (Caliskan et al., 2022, pp. 317-329, 457-470; Londhe, 2017, pp. 152-168, 189-204). These measures may include land-use zoning laws that safeguard farming areas, along with support for restoring degraded or underutilized lands (Caliskan et al., 2022, pp. 317-329, 457-470; Londhe, 2017, pp. 1-16, 247-270). Careful planning of both location and cultivation methods can help Kazakhstan to use its land resources more effectively in order to align food supply and safety with broader economic strategies (Food and Agriculture Organization of the United Nations, 2023, pp. 47-57; Londhe, 2017, pp. 1-16, 246-271).

Hence, the Kazakhstani government can adopt the holistic approach to increasing potato yield productivity by addressing the above mentioned three areas. This involves not only direct interventions in agricultural practice but also broader policy and infrastructural changes that create a supportive environment for efficient and sustainable potato farming (Caliskan et al., 2022, pp. 317-329, 457-470).

Drawing from the study findings on potato farming in Kazakhstan, the following region-specific suggestions are provided. They consider weather patterns, soil health, and available farmland to help boost potato yields:

1. The Southern economic region of Kazakhstan:

- Almaty region has one of the largest cultivation areas at 23,955 hectares. The region should focus on advanced pest management and disease control strategies to maintain its high yield of 4,583,044.6 centners. The introduction of climate-resilient potato varieties would be beneficial due to variable weather patterns;

- Kyzylorda region: with a smaller area of 4,156.8 hectares and yield of 616,202.8 centners, the priority should be on diversifying farming practices. Introducing high-yield potato varieties could help increase its relatively low productivity (148.2 centners per hectare);

- Turkestan region can benefit from enhanced water management and irrigation practices, considering its cultivation area of 14,391.8 hectares and yield of 2,867,377.8 centners. The region's moderate fertilizer usage (6,079.4 centners) suggests an opportunity to optimize fertilizer application methods for better yield;

- Zhambyl region: with a notable productivity of 251.1 centners per hectare, should focus on expanding its cultivation area from the current 11,359.3 hectares to boost overall yield. The usage of fertilizers (815.7 centners) should be optimized with precision agriculture techniques to enhance efficiency;

- in Zhetysu region land rehabilitation programs can help expand the current cultivation area of 11,867.7 hectares. Developing more efficient water management systems would also be beneficial for this region.

2. The Western economic region of Kazakhstan:

- Aktobe region: with a smaller area of 5,777 hectares and yield of 979,862.9 centners, Aktobe can benefit from improved irrigation techniques, considering the region's semi-arid climate. Fertilizer usage is relatively low (1,234.2 centners); thus, tailored fertilizer programs based on soil testing can enhance productivity;

- Atyrau region: with a modest area of 1,901.1 hectares and a yield of 291,564 centners, Atyrau can improve yields by adopting modern farming techniques and equipment. Training programs for farmers on efficient farming practices would be valuable given the region's lower productivity (153.4 centners per hectare);

- West Kazakhstan region's cultivation area of 4,246.1 hectares and yield of 688,494.1 centners suggest room for improvement in farming efficiency. Initiatives to enhance soil quality and farming practices can be implemented, supported by a moderate level of fertilizer usage (6,556.4 centners).

3. The Northern economic region of Kazakhstan:

- Akmola region: with a larger cultivation area of 12,603 hectares and a yield of 2,304,891.7 centners, should invest in precision farming technologies. This would help optimize the use of its considerable fertilizer application (22,645.4 centners). Water conservation strategies are also critical here, considering the region's climate conditions;

- Kostanay region: with an area of 8,286.4 hectares and a yield of 1,604,784.1 centners, can benefit from advanced soil health management strategies. The region should also focus on enhancing crop rotation techniques to maintain soil fertility;

- North Kazakhstan region: with a vast cultivation area of 26,456.9 hectares but lower productivity (142.5 centners per hectare), North Kazakhstan needs to address soil quality and introduce advanced farming methods. The emphasis on training programs for farmers and the adoption of innovative agricultural practices could significantly boost productivity;

- Pavlodar region: with the largest cultivation area of 24,033.5 hectares, should leverage its high yield (6,616,240.6 centners) by adopting state-of-the-art agricultural technologies. The region's significant fertilizer usage (43,352.6 centners) calls for a focus on precision agriculture to enhance yield efficiency and environmental sustainability.

4. The Eastern economic region of Kazakhstan:

- Abai region: with a cultivation area of 8,056.9 hectares and a yield of 1,766,939 centners, the focus in Abai should be on enhancing soil fertility. Implementing crop rotation practices and organic farming could boost productivity, currently at 219.3 centners per hectare. Given the moderate usage of fertilizers (5,404 centners), a shift towards more organic and sustainable fertilizers could benefit both yield and environmental health;

- in East Kazakhstan region, improving crop varieties and implementing integrated pest management can enhance the current yield from its 10,809.1 hectares of cultivated land. Given its low fertilizer usage (388.7 centners), there's an opportunity to explore more efficient and sustainable fertilizer options.

5. KazakhstaniCentral economic region:

- the region of Karaganda: with high area of sowing of 15,703.5 ha and high yield, the region should introduce technological solutions such as auto-maidan machinery to preserve the existing levels of productivity as high as possible (231.9 centners per ha). As the high utilization of fertilizers reaches 28,385.6 centners, one should encourage the use of balanced and highly efficient fertilizers;

- the region of Ulytau: though the region demonstrates the best productivity of 293.6 centners per ha, the limited area of sowing of 515 ha implies potential growth. The introduction of the use of the lands on the sustainable basis can expand the region's agrarian produce to the maximum.

These area-specific recommendations seek to promote the high-cascade irrigation farming of potatoes in Kazakhstan through the alignment of each region's climate, soil, and land use with enhanced technologies, climate-resilient farming practices, and favorable policies to achieve long-term success and profit sustainability.

Conclusion

The objective of this research was to analyze the condition of potato cultivation in Kazakhstan. The study concerned the role played by potato cultivation in ensuring that there is sufficient food supply through examining the extent of area coverage, the quantity of potatoes produced, the intensity of farming, and the use of fertilizer. The research ran various techniques – e.g. simple data summaries, quartile analysis, and regression – to grasp the variation in farming as well as farming productivity across regions. The research also utilized a Directed Acyclic Graph (DAG) to present the relationship between these various factors as they are interrelated as influencing overall potato production.

The data revealed significant variations in the cultivation of potatoes between regions. Pavlador, for example, had the highest area of territory devoted to cultivating potatoes – 24,033.5 ha – as well as the highest yield, with 6,616,240.6 centners, to demonstrate the significance of this region as a source of the republic's general potato yield.

In terms of productivity per hectare, Ulytau region stood out with the highest value at 293.6 centners per hectare, signaling efficient farming practices and optimal resource use. Other regions, while showing lower productivity, indicate potential for targeted improvements through enhanced agricultural practices and resource management.

Quartile analysis provided a deeper look into the distribution of cultivation sizes and yields. The first quartile for cultivation area was 3,028.95 hectares, while the third quartile reached 13,497.4 hectares. This spread highlighted the differences between smaller-scale operations and larger, more intensive cultivation efforts. Likewise, the data showed that regions with lower harvests could do better by improving soil health, using modern farming equipment, and finding better ways to deal with pests and plant diseases.

A regression analysis was done to see how fertilizer use affects potato productivity, showing an R-squared value of 0.295. This means about 29.5% of the changes in productivity can be linked to how much mineral fertilizer is used. The adjusted R-squared value was 0.240, which gives a more accurate picture by considering the number of variables and the size of the data. Although fertilizers contributed positively, the findings also revealed that additional factors such as climate, soil condition, and cultivation practices hold substantial influence. This modest connection points to the importance of a balanced strategy that considers more than just fertilizer application.

The additional layer of depth to the study was added by the DAG, which showed that different factors work together by affecting the potato productivity in Kazakhstan. For instance, weather, farming methods, and government policies. Among the key diagram components of diagram were the area planted, and the amount of fertilizer used, where both were directly associated with harvest volume and farming efficiency. There are other factors, e.g. climate and soil quality, which had an indirect impact by shaping how farmers work and how well crops grow. Hence, the DAG helped to illustrate how everything connects, making it easier for farmers and decision-makers to find ways to improve results and increase efficiency.

These results not only confirm that fertilizer usage impacts potato yields in Kazakhstan, but also show that land use, applied technology, and the ability to manage weather changes are important factors in potato production. For example, average to high productivity yield areas, e. g. Karaganda and East Kazakhstan, could work on wiser fertilizer usage. For instance, switching to precision-based or organic agricultural methods that are better for the environmental sustainability. On the other hand, lower yield regions, e. g. North Kazakhstan, could move forward by paying more attention on the soil care. For instance, more efficient water usage or growing

only those potato types that match the local climate.

The research findings also demonstrated that improving farming practices in Kazakhstan requires a well-rounded approach that includes promoting sustainable methods, introducing new technology, and offering training programs to help farmers learn better techniques, rather than focusing solely on increased fertilizer use. This approach is necessary to secure Kazakhstani food security and supply through strengthening its farming economy by allowing better resource handling and increasing crop yields.

Further studies might explore how emerging farm technologies, including precision equipment and intelligent irrigation systems, impact long-term potato yields, as well as how climate change impacts plant health and how farmers might adapt their strategies accordingly. Additionally, what new policies and tools actually achieve across seasons might be uncovered with long-term studies to help better address what fosters long-term sustainability in farming. In summary, this research provides valuable information about the different factors that relate to Kazakhstan potato farming, including what motivates productivity and how those factors relate to each other to help guide decision-making and planning narrowed to desired long-term environmental and economic wellness globally. Hence, Kazakhstan by following these suggestions can make potato farming more efficient and stable in the long term, strengthening its agricultural sector and boosting the national food supply.

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