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The effect of manure application timing, mineral fertilisers and planting density on potato growth and development

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Abstract. Increasing potato production should be achieved not only by expanding the cultivated area, but primarily by increasing crop yields. To improve potato productivity, the rational use of local organic fertilisers, alongside mineral fertilisers, is of considerable importance. Therefore, this study aimed to investigate the growth and development of potato plants in relation to the timing of manure application in combination with mineral fertilisers and planting density. Field experiments were conducted using a systematic design, with treatments arranged in tiers and replicated three times. The smallest number of stems was formed under the application of mineral fertilisers at a rate of $N_{60}P_{120}K_{60}$ and a planting scheme of 70×25 cm

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(5.8 stems per plant). The largest number of stems was observed when 40 t/ha of manure was applied during autumn ploughing in combination with mineral fertilisers at a rate of $N_{90}P_{120}K_{60}$ (7.2 stems per plant), as well as when manure was applied after spring reploughing of autumn-ploughed soil, followed by planting according to the 70×35 cm scheme (7.4 stems per plant). The number of stems increased with an expanded feeding area by 0.1-0.3 stems. On average, over three years, spring application of 40 t/ha of manure on the $N_{60}P_{120}K_{60}$ background increased the number of leaves to 50.6, compared with 41.3 leaves under $N_{90}P_{120}K_{60}$. The weight of the haulm of a single plant varied depending on the feeding area, the year of cultivation and the timing of manure application. When the feeding area was expanded to 70×35 cm, the weight of the haulm increased. The highest average haulm yield over three years (61.20 t/ha) was obtained when manure was applied during autumn ploughing, and potatoes were planted according to the 70×25 cm scheme. With the expanded feeding area, haulm yield was 50.20 t/ha, which was 11 t/ha lower. A similar pattern was observed for the other experimental treatments. Based on the results of field experiments conducted under production conditions, recommendations can be developed for producers on the most efficient use of organic and mineral fertilisers to increase potato productivity

Keywords: field research; yield improvement; ploughing; plant haulm weight

INTRODUCTION

The West Kazakhstan region faces complex challenges in increasing potato productivity, making it particularly important to meet the regional demand for potatoes. Potatoes are one of the most important food crops in the region and play a significant role in ensuring food security and a stable supply of agricultural products to the population. At the same time, unstable climatic conditions, insufficient soil fertility and inefficient fertiliser use reduce the efficiency of potato production. Therefore, the development of scientifically grounded approaches to optimising fertilisation systems and planting density under the soil and climatic conditions of West Kazakhstan is highly relevant.

Research by W. Zhong *et al.* (2025) indicated that mineral nutrition is one of the most effective factors influencing plant growth and productivity. According to T. Salikhov *et al.* (2023), regulation of the intensity of nutrient supply through fertiliser application changes the activity and even the direction of biochemical reactions in plants. A.K. Sandhu *et al.* (2024) reported that phosphorus application improved potato yield even when soil-test phosphorus was within the high range. However, A.P.P. Ravensbergen *et al.* (2024) emphasised that improvements in yield and fertiliser-use efficiency must be achieved on a field-by-field basis. Furthermore, it can be concluded that frequent field monitoring combined with crop growth modelling is an effective way to assess yield-gap variability and obtain detailed information on the factors explaining this gap at the field level.

Yield structure and the ratio between the vegetative and productive parts of plants are important indicators for assessing the effect of fertilisers on potato productivity. H. Xue *et al.* (2024) found that using nitrogen alone or in combination with urea can reduce both the total nitrogen application rate and the frequency of application. However, according to Xu *et al.* (2023), increasing fertiliser application rates without considering nutrient balance and the physiological requirements of crops can lead to greater unproductive losses of mineral nutrients from the soil and fertilisers, as well as to environmental pollution. At the same time, the availability and balance of nutrients in agriculture determine crop yields and gross agricultural production. F. Zhao *et al.* (2024) showed that reducing excessive water evaporation during periods of low rainfall, improving drainage during periods of high rainfall, applying fertilisers and planting potatoes at optimal times can contribute to higher potato yields. The results of the study by B. Almunqedhi *et al.* (2025) confirm that poultry manure improves growth, tuber quality and yield because it contains nutrients such as nitrogen, phosphorus and potassium.

Q.G. Liang *et al.* (2026) reported that optimised nitrogen (N) application and planting density can enhance sweet potato yield. However, the agronomic mechanisms underlying their effects on photosynthetic efficiency and carbohydrate metabolism in sweet potato remain unclear. Their results indicate that reduced nitrogen fertilisation combined with dense planting creates a more suitable canopy structure for light distribution at the population level and optimises light and carbon-use efficiency at the individual plant level, thereby improving storage-root yield and the commercial characteristics of sweet potato. Research by D. Ademe *et al.* (2024) found that late planting and higher nitrogen rates increased tuber yield in the near-term climate period. However, in the mid-century climate period, early planting of both medium- and long-maturity varieties with higher nitrogen rates showed potential adaptive benefits, despite their negative impact on yield under the current climate. This result highlights the distinction between optimal management under current conditions and practices that are truly adaptive to climate change. T. Tekalign *et al.* (2023) reported that the adoption of improved potato varieties increases food security by an average of 324.5 kcal per adult per day. The findings showed that the adoption of improved potato varieties had a positive impact on household resilience to food insecurity. According to Y. Xing *et al.* (2022), potato productivity is generally influenced by water and fertiliser use, although the requirements for these factors vary depending on soil type and potato variety. Potato tuber yield was significantly correlated with soil-available potassium, the number of soil actinomycetes, soil catalase activity and soil sucrase activity (SSA). The effect of manure application timing in combination with mineral fertilisers and planting density on weed infestation in potato plantations was established, although this area remains insufficiently studied. Therefore, the purpose of the scientific experiment was to determine how the timing of manure application in combination with mineral fertilisers and planting density affects the growth and development of potatoes in the West Kazakhstan region.

MATERIALS AND METHODS

Phenological observations of the growth and development of Nevsky potato plants were conducted at Tuaytai farm in Chingirlau District of West Kazakhstan region, during the 2017-2019 growing seasons. The study was based on field data collected in 2017-2019. As of 2026, newer observations are not yet available because similar studies are currently being conducted in other soil and climatic regions of Northern Kazakhstan. The research methods included descriptive method, an integrated approach and field experimentation. The experiments were established using a systematic design, with treatments arranged in tiers and replicated three times.

The total plot area was 84 m^2, the recorded plot area was 56 m^2, and each treatment was replicated three times. The following observations, measurements and analyses were conducted during the experiments. Before planting, total nitrogen was determined by the Kjeldahl method, available phosphorus by the Machigin method, available potassium by the Protasov method and pH in an aqueous extract in the 0-30 cm soil horizon (Research methods for potato crops, 1967). The main nutrients in the manure were determined in samples collected before soil application. The manure was ploughed in immediately after application. The experimental plot was divided into individual plots in the autumn. The required amount of manure was weighed and spread manually across the plots.

The determination of available forms of nitrogen, phosphorus and potassium in the soil was performed at several stages: before planting, during emergence, during flowering and before harvesting. Weed infestation was determined using a quantitative weight-based method. Soil moisture in the 0-50 cm layer was measured 3-4 days after watering, and the amount of productive moisture was expressed in millimetres of water depth. Its reserves were calculated according to the methodology described in Research methods for potato crops (1967).

Phenological observations were conducted daily in all experimental treatments throughout the growing season. The onset of each phase was determined based on the number of plants reaching that phase in each plot. The following phases were recorded: beginning of emergence, full emergence, beginning of budding, full budding, beginning of flowering, full flowering and beginning of senescence. Plant density was calculated after emergence and before harvesting in all plots across all experimental replicates. Plant height was measured every 10 days by assessing 10 consecutive plants in each plot across all replicates.

In addition, the haulm of 10 typical plants from each plot was weighed in all treatments at the beginning of budding, at flowering and during dynamic digging. During this process, the assimilation surface area of the leaves was determined using the punch method, according to Research methods for potato crops (1967). After weighing the haulm, the leaves of each plant were removed, and 100 fresh leaves were taken from each plant. Using a drill of known diameter, 100 leaf discs were punched out and weighed on a technical scale. The leaf area of a single plant was determined by the ratio of total leaf weight to the weight of the leaf discs, and then the leaf area per hectare was converted to m^2. Leaf area per plant was determined using the formula:

$$M = \frac{P}{P_1 \times H \times K}, \quad (1)$$

where M is the leaf area per plant; P is the mass of leaves in the sample; P_1 is the mass of the leaf discs punched from the leaves; K is the area of the punched discs; H is the number of leaves taken for analysis.

The intensity of photosynthesis was determined by changes in the dry weight of leaves, as described in Research Methods for Potato Crops (1967). For the experiment, leaves with the most symmetrical structure were selected. One half of each leaf was removed, while the other half, together with the petiole, was left on the plant. The cut halves were incubated for 15-30 minutes. The leaves were placed in water or wrapped in a damp cloth to achieve complete saturation. They were then dried with filter paper and placed upside down on a smooth cork surface to expose the veins more clearly. At least 100 leaf discs were cut out using a sharp drill. These discs were divided into a series of parallel samples, placed in tared glass containers and dried to a constant weight. The initial weight per unit leaf area was obtained by dividing the weight by the area. At the end of the exposure period (after 4-6 hours), the remaining leaf halves were removed, and the weight per unit area was determined in the same manner. The weight gain observed during the exposure period was calculated per unit area per hour.

To determine photosynthesis, a dark control was introduced. In addition to the experimental samples, parallel leaf samples were taken from the same plant and placed in darkness. Both the control and experimental leaves were cut in half, and one half was covered with an opaque paper cap. Both halves were treated in exactly the same manner as described above, with weight loss per unit area taken into account rather than weight gain. By adding the loss of substance during the experiment, caused by respiration and translocation, to the gain, a substantially more accurate assimilation value was obtained. The photosynthesis rate was calculated using the following formula:

$$I = \frac{(a_1 - a) + (a - a_2)}{r}, \qquad (2)$$

where I is the rate of photosynthesis, mg dry matter/hour; a is the initial leaf weight, mg; a_1 and a_2 are the weights of leaves exposed to light and darkness, respectively, mg; r is the exposure time, hours.

Experimental design:

1. $N_{60}P_{120}K_{60}$
2. $N_{90}P_{120}K_{60}$
3. 40 t/ha manure applied during autumn ploughing + $N_{60}P_{120}K_{60}$
4. 40 t/ha manure applied during autumn ploughing + $N_{90}P_{120}K_{60}$
5. 40 t/ha manure applied on frozen soil + $N_{60}P_{120}K_{60}$
6. 40 t/ha manure applied on frozen soil + $N_{90}P_{120}K_{60}$
7. 40 t/ha manure applied on snow during winter + $N_{60}P_{120}K_{60}$
8. 40 t/ha manure applied on snow during winter + $N_{90}P_{120}K_{60}$
9. 40 t/ha manure applied before spring re-ploughing of autumn-ploughed soil + $N_{60}P_{120}K_{60}$
10. 40 t/ha manure applied before spring re-ploughing of autumn-ploughed soil + $N_{90}P_{120}K_{60}$

Planting scheme: 70×25 cm and 70×35 cm.

Manure was applied in the autumn on 10-15 September before ploughing the fallow land, on 2530 November on frozen fallow land, on 5-7 January on shallow snow and in the spring on 2025 April before ploughing the fallow land. The composition of manure changed little over the years. The following types of mineral fertilisers were used: ammonium nitrate, double superphosphate and potassium chloride. Mineral fertilisers were applied during autumn ploughing. The required amount of manure was weighed and spread manually across the plots. The main nutrients in the manure were determined in samples taken before application to the soil. In the autumn, the manure was ploughed in immediately after application. The development of potato plants in $N_{60}P_{120}K_{60}$ potato plantings was recorded in accordance with Research methods for potato crops (1967). The study was conducted in accordance with the principles of environmental safety set out in the Convention on the Conservation of European Wild Flora and Fauna and Natural Habitats (1979). All agronomic practices and field experiments were carried out in a manner that minimised negative impacts on the surrounding environment and preserved the balance of natural ecosystems.

RESULTS

Field observations showed that mineral fertiliser rates and manure application dates affected the formation of stems and leaves in potato plants (Table 1).

***Table 1**. Potato development depending on fertiliser application and planting density*

Planting scheme	Manure application dates	Number of stems per plant					
		stems			leaves		
		2017	2018	2019	2017	2018	2019
70×25 cm	$N_{60}P_{120}K_{60}$	5.7	5.7	6.0	148.4	153.6	157.4
	$N_{90}P_{120}K_{60}$	5.9	6.0	6.4	160.1	164.8	169.5
	40 t/ha manure applied during autumn ploughing + $N_{60}P_{120}K_{60}$	6.7	6.9	7.2	192.4	200.7	208.6
	40 t/ha manure applied during autumn ploughing + $N_{90}P_{120}K_{60}$	6.9	7.1	7.6	201.1	202.5	212.4
	40 t/ha manure applied on frozen soil + $N_{60}P_{120}K_{60}$	6.4	6.5	6.7	160.1	166.6	172.4
	40 t/ha manure applied on frozen soil + $N_{90}P_{120}K_{60}$	6.6	6.8	6.9	169.4	172.8	180.6
	40 t/ha manure applied on snow during winter + $N_{60}P_{120}K_{60}$	6.3	6.4	6.6	165.8	173.9	177.8
	40 t/ha manure applied on snow during winter + $N_{90}P_{120}K_{60}$	6.4	6.5	6.7	172.2	175.7	180.4
	40 t/ha manure applied before spring re-ploughing of autumn-ploughed soil + $N_{60}P_{120}K_{60}$	6.9	7.0	7.2	194.9	205.9	210.5
	40 t/ha manure applied before spring re-ploughing of autumn-ploughed soil + $N_{90}P_{120}K_{60}$	7.1	7.2	7.4	197.0	206.7	214.8
70×35 cm	$N_{60}P_{120}K_{60}$	5.8	5.9	6.1	152.2	162.6	166.8
	$N_{90}P_{120}K_{60}$	6.2	6.4	6.6	155.9	172.4	174.8
	40 t/ha manure applied during autumn ploughing + $N_{60}P_{120}K_{60}$	6.9	7.2	7.3	202.6	202.8	216.2
	40 t/ha manure applied during autumn ploughing + $N_{90}P_{120}K_{60}$	7.2	7.4	7.8	205.8	206.6	220.4
	40 t/ha manure applied on frozen soil + $N_{60}P_{120}K_{60}$	6.5	6.6	6.8	174.3	182.6	188.8
	40 t/ha manure applied on frozen soil + $N_{90}P_{120}K_{60}$	6.8	6.9	7.0	176.8	194.8	199.4
	40 t/ha manure applied on snow during winter + $N_{60}P_{120}K_{60}$	6.5	6.6	6.9	168.8	190.6	194.7
	40 t/ha manure applied on snow during winter + $N_{90}P_{120}K_{60}$	6.6	6.6	6.9	174.8	195.2	198.5
	40 t/ha manure applied before spring re-ploughing of autumn-ploughed soil + $N_{60}P_{120}K_{60}$	7.1	7.2	7.2	197.0	206.8	218.6
	40 t/ha manure applied before spring re-ploughing of autumn-ploughed soil + $N_{90}P_{120}K_{60}$	7.4	7.4	7.6	199.9	208.6	222.9

***Source:** compiled by the authors*

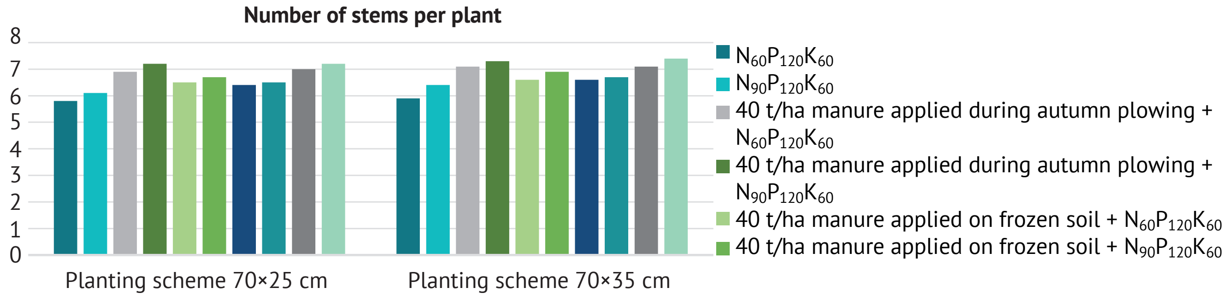

***Figure 1**. Number of stems per plant, averaged over three years*

***Source:** compiled by the authors*

The lowest average number of stems over three years was observed when mineral fertilisers were applied at a rate of $N_{60}P_{120}K_{60}$ (5.8 stems per plant) with a planting scheme of 70×25 cm. The highest number of stems was recorded when 40 t/ha of manure was applied during autumn ploughing in combination with mineral fertilisers at a rate of $N_{90}P_{120}K_{60}$ (7.2 stems per plant), as well as when the same dose was applied before spring re-ploughing of autumn-ploughed soil, with planting according to the 70×35 cm scheme (7.4 stems per plant). A tendency for the number of stems to increase by 0.1-0.3 stems with an expanded feeding area was observed. The largest number of stems in all treatments was recorded in 2019, which was characterised by favourable weather conditions for potato cultivation. These factors also had a significant influence on leaf formation. The largest number of leaves was observed on plants in 2019 because of favourable weather conditions. The difference between the experimental treatments ranged from 9 to 23 leaves per plant. The smallest number of leaves was observed when mineral fertilisers were applied at a rate of $N_{60}P_{120}K_{60}$. When the fertiliser rate was increased to $N_{90}P_{120}K_{60}$, the number of leaves per plant increased by an average of 11.7 over three years. In all treatments with manure application, the number of leaves increased significantly. Thus, in 2017, when 40 t/ha of manure was applied during autumn ploughing in combination with mineral fertilisers at a rate of $N_{60}P_{120}K_{60}$, the number of leaves per plant increased by 44 leaves compared with the control treatment ($N_{60}P_{120}K_{60}$ without manure) and by 52.7 leaves on the $N_{90}P_{120}K_{60}$ background. On average, over three years, spring application of 40 t/ha of manure on the $N_{60}P_{120}K_{60}$ background increased the number of leaves by 50.6, while on the $N_{90}P_{120}K_{60}$ background it increased the number of leaves by 41.3, compared with the same mineral fertiliser rates without manure (Fig. 2).

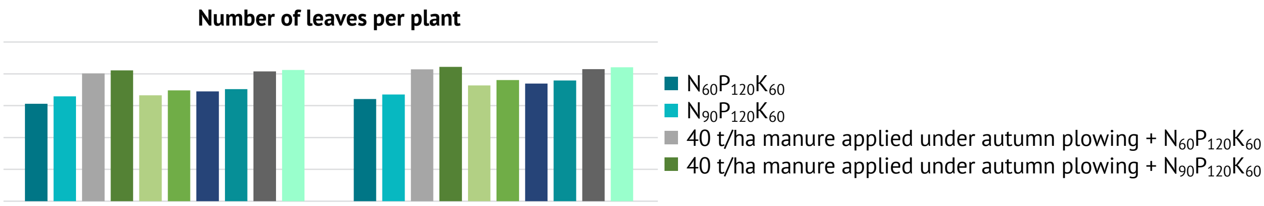

***Figure 2**. Number of leaves per plant, averaged over three years*

***Source:** compiled by the authors*

When manure was applied on frozen soil after autumn ploughing and on snow during winter, fewer leaves were formed. Thus, on average, over three years, when manure was applied on frozen soil on the $N_{60}P_{120}K_{60}$ background, 166.3 leaves per plant were formed, which was 13.2 leaves more than in the control treatment. However, this value was 47.4 leaves lower than when manure was applied during autumn ploughing. On the $N_{90}P_{120}K_{60}$ background, the number of leaves was 9.4 leaves higher than in the control treatment, but 31.1 leaves lower than when manure was applied during autumn ploughing. When manure was applied on snow during winter, the number of leaves increased slightly by 6.2 and 1.9 leaves, but remained significantly lower than when manure was applied during autumn ploughing or in spring before re-ploughing autumn-ploughed soil. The mass of the haulm of a single plant varied depending on the feeding area, the year of cultivation and the timing of manure application (Table 2).

Thus, in 2017, when $N_{60}P_{120}K_{60}$ was applied, the total plant weight was 518.4 g. When $N_{90}P_{120}K_{60}$ was applied, it was 666.5 g, which was 148.1 g higher. When 40 t/ha of manure was applied in combination with the specified fertiliser rates, the total weight was 934.1 g and 993.7 g, respectively, which was 415.7 g and 327.2 g higher, or 80.2% and 49.1% higher, respectively (Fig. 3).

***Table 2**. Haulm weight per plant, depending on fertiliser application and planting density*

Planting scheme	Manure application dates	Total weight of 1 plant, g			Stem weight, g			Leaf mass, g		
		2017	2018	2019	2017	2018	2019	2017	2018	2019
70×25 cm	$N_{60}P_{120}K_{60}$	518.4	528.6	674.8	248.6	255.9	328.2	269.8	272.7	346.6
	$N_{90}P_{120}K_{60}$	666.5	674.2	789.5	300.4	331.4	349.4	363.1	342.8	440.1
	40 t/ha manure applied during autumn ploughing + $N_{60}P_{120}K_{60}$	934.1	984.3	1,184.4	450.0	459.6	583.6	484.1	524.7	600.8
	40 t/ha manure applied during autumn ploughing + $N_{90}P_{120}K_{60}$	993.7	1,003.6	1,218.6	463.2	468.6	594.8	530.5	535.0	623.8
	40 t/ha manure applied on frozen soil + $N_{60}P_{120}K_{60}$	807.5	875.4	907.8	363.4	398.8	431.5	444.1	472.6	476.3
	40 t/ha manure applied on frozen soil + $N_{90}P_{120}K_{60}$	896.4	916.6	964.9	436.1	444.2	452.1	460.3	476.4	512.8
	40 t/ha manure applied on snow during winter + $N_{60}P_{120}K_{60}$	739.7	792.1	814.8	359.4	378.9	388.3	380.3	413.2	426.5
	40 t/ha manure applied on snow during winter + $N_{90}P_{120}K_{60}$	784.5	848.6	902.6	372.2	401.2	448.4	412.3	447.4	454.2
	40 t/ha manure applied before spring re-ploughing of autumn-ploughed soil + $N_{60}P_{120}K_{60}$	894.8	905.4	938.3	432.3	438.1	454.2	462.5	467.3	484.1
	40 t/ha manure applied before spring re-ploughing of autumn-ploughed soil + $N_{90}P_{120}K_{60}$	904.7	941.3	984.6	438.3	462.1	486.4	466.4	479.2	498.2
70×35 cm	$N_{60}P_{120}K_{60}$	598.8	614.2	714.6	275.2	288.4	334.7	323.6	325.8	379.9
	$N_{90}P_{120}K_{60}$	694.2	702.8	796.8	334.0	316.4	375.2	360.2	386.4	421.6
	40 t/ha manure applied during autumn ploughing + $N_{60}P_{120}K_{60}$	964.8	996.4	1,204.5	474.3	461.4	599.4	490.5	535.0	605.1
	40 t/ha manure applied during autumn ploughing + $N_{90}P_{120}K_{60}$	999.6	1,244.3	1,248.4	485.4	714.8	598.6	514.2	529.5	649.8
	40 t/ha manure applied on frozen soil + $N_{60}P_{120}K_{60}$	854.6	898.4	924.4	424.2	442.4	449.5	430.4	456.0	474.9
	40 t/ha manure applied on frozen soil + $N_{90}P_{120}K_{60}$	904.8	966.5	1,001.2	439.9	463.2	475.4	464.9	503.3	525.8
	40 t/ha manure applied on snow during winter + $N_{60}P_{120}K_{60}$	856.7	901.4	983.5	421.6	428.7	481.1	435.1	472.7	502.4
	40 t/ha manure applied on snow during winter + $N_{90}P_{120}K_{60}$	869.5	916.6	998.7	429.5	439.5	488.2	440.0	477.1	510.5
	40 t/ha manure applied before spring re-ploughing of autumn-ploughed soil + $N_{60}P_{120}K_{60}$	944.3	998.3	1,238.6	452.2	464.6	594.3	492.1	533.7	644.3
	40 t/ha manure applied before spring re-ploughing of autumn-ploughed soil + $N_{90}P_{120}K_{60}$	969.5	1,055.4	1,252.4	468.3	501.4	599.9	501.2	554.0	652.5

***Source:** compiled by the authors*

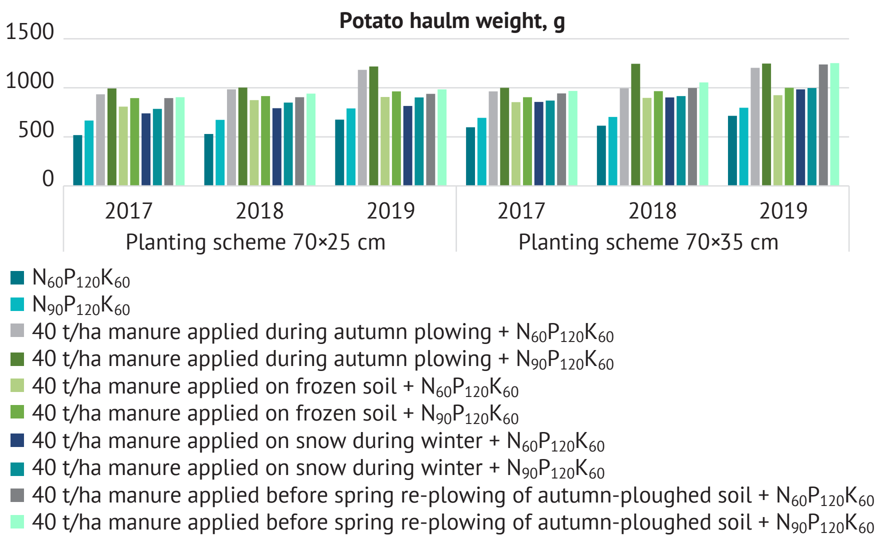

***Figure 3**. Potato haulm weight depending on fertiliser application and planting density, g*
***Source:** compiled by the authors*

When manure was applied on frozen soil after autumn ploughing, plant biomass decreased compared with manure application during autumn ploughing: by 126.6 g on the $N_{60}P_{120}K_{60}$ background and by 97.3 g on the $N_{90}P_{120}K_{60}$ background. When manure was applied on snow during winter, an even greater decrease in plant biomass was observed, at 194.4 g and 209.2 g, respectively. When manure was applied before spring re-ploughing of autumn-ploughed soil, the haulm weight per plant increased compared with application on frozen soil and on snow in winter, but remained lower than with manure application during autumn ploughing: by 39.3 g on the $N_{60}P_{120}K_{60}$ background and by 89.0 g on the $N_{90}P_{120}K_{60}$ background.

Thus, in 2017, when $N_{60}P_{120}K_{60}$ was applied, and potatoes were planted according to the 70×35 cm scheme, haulm weight per plant was 80.4 g higher than with the 70×25 cm scheme. When $N_{90}P_{120}K_{60}$ was applied, it was 27.7 g higher. Application of manure during autumn ploughing led to an increase in haulm weight with the expansion of the feeding area, by 30.7 g and 5.9 g, respectively. This difference in plant biomass formation is probably explained by differences in soil microbiological activity associated with the timing of manure application and planting density. This issue requires further, more detailed study.

A similar pattern of above-ground biomass formation was observed in 2018; however, favourable weather conditions in May and June contributed to the development of greater foliage mass than in 2017. Thus, when $N_{60}P_{120}K_{60}$ was applied, and potatoes were planted according to the 70×25 cm scheme, haulm weight per plant reached 528.6 g, which was 10.2 g higher than in 2017. On the $N_{90}P_{120}K_{60}$ background, the increase was 7.7 g. When 40 t/ha of manure was applied during autumn ploughing, haulm weight increased by 50.2 g and 9.9 g, respectively. When manure was applied on frozen soil after autumn tillage, the increase was 67.9 g and 20.2 g, and when it was applied on snow during winter, the increase was 52.4 g and 64.1 g. When manure was applied before spring re-ploughing of autumn-ploughed soil, the increase was 10.6 g and 36.6 g. However, when potatoes were planted according to the 70×35 cm scheme, haulm weight per plant increased significantly. Thus, when $N_{60}P_{120}K_{60}$ was applied, haulm weight per plant was 85.6 g greater than under denser planting, and when $N_{90}P_{120}K_{60}$ was applied, the increase was 28.6 g. When manure was applied during autumn ploughing, the increase reached 121.1 g and 240.7 g, respectively.

The warm spring and cool summer of 2019 contributed to a substantial increase in above-ground biomass. Thus, when $N_{60}P_{120}K_{60}$ was applied and potatoes were planted according to the 70×25 cm scheme, haulm weight per plant in 2019 exceeded that of 2017 by 156.4 g and that of 2018 by 146.2 g. When $N_{90}P_{120}K_{60}$ was applied, the increase was 123.0 g and 115.3 g, respectively. A pronounced increase in growth was observed when manure was applied. When manure was applied during autumn ploughing on the $N_{60}P_{120}K_{60}$ background, haulm weight in 2019 exceeded that of 2017 by 250.3 g and that of 2018 by 200.1 g. On the $N_{90}P_{120}K_{60}$ background, the increase was 224.9 g and 215.0 g, respectively.

When the feeding area was expanded to 70×35 cm, haulm weight per plant increased. Thus, when manure was applied during autumn ploughing, haulm weight reached 1,204.5 g on the $N_{60}P_{120}K_{60}$ background and 1,248.4 g on the $N_{90}P_{120}K_{60}$ background, which was 20.1 g and 29.8 g higher than under denser planting (70×25 cm). When manure was applied before spring re-ploughing of autumnploughed soil, the increase was 300.3 g and 267.8 g, respectively. The highest haulm weight per plant in 2019 was recorded when 40 t/ha of manure was applied before spring re-ploughing of autumn-ploughed soil (1,252.4 g). A similar pattern was observed for stem mass (Fig. 4). The lowest stem mass was recorded when $N_{60}P_{120}K_{60}$ was applied. In 2017, it was 248.6 g, in 2018 it was 255.9xg, and in 2019 it was 328.2 g. When $N_{90}P_{120}K_{60}$ was applied, the values were 300.4 g, 331.4 g and 349.4 g, which were 51.8 g, 75.5 g and 21.2 g higher, respectively.

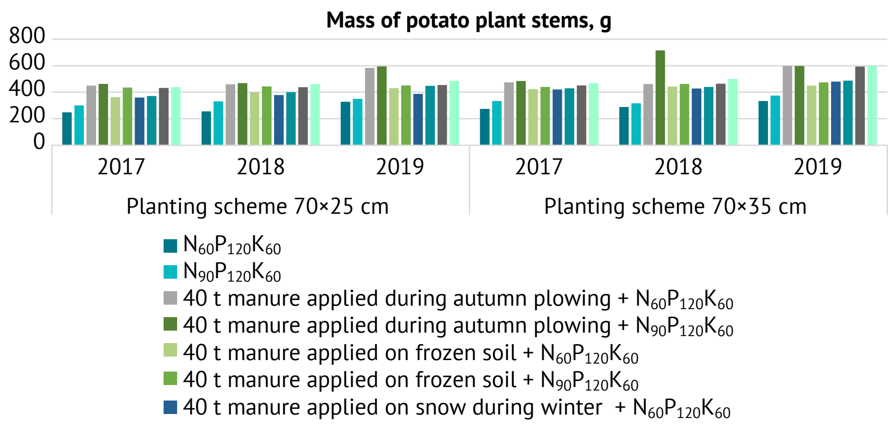

***Figure 4**. Mass of potato plant stems depending on fertiliser application and planting density, g*

***Source:** compiled by the authors*

When manure was applied, stem mass increased significantly in all treatments; however, the highest stem mass was observed when manure was applied during autumn ploughing and before spring re-ploughing of autumn-ploughed soil. Thus, when manure was applied during autumn ploughing, stem mass in 2019 exceeded that obtained with mineral fertilisers without manure by 255.4 g on the $N_{60}P_{120}K_{60}$ background and by 245.4 g on the $N_{90}P_{120}K_{60}$ background. The most vigorous and leafy plants were formed in 2019 (Fig. 5). However, in all years of this study, leaf mass exceeded stem mass. Thus, when $N_{60}P_{120}K_{60}$ was applied, leaf mass exceeded stem mass by 21.2 g in 2017, by 16.8 g in 2018 and by 18.4 g in 2019. When $N_{90}P_{120}K_{60}$ was applied, the corresponding differences were 62.7 g, 11.4 g and 90.7 g, respectively.

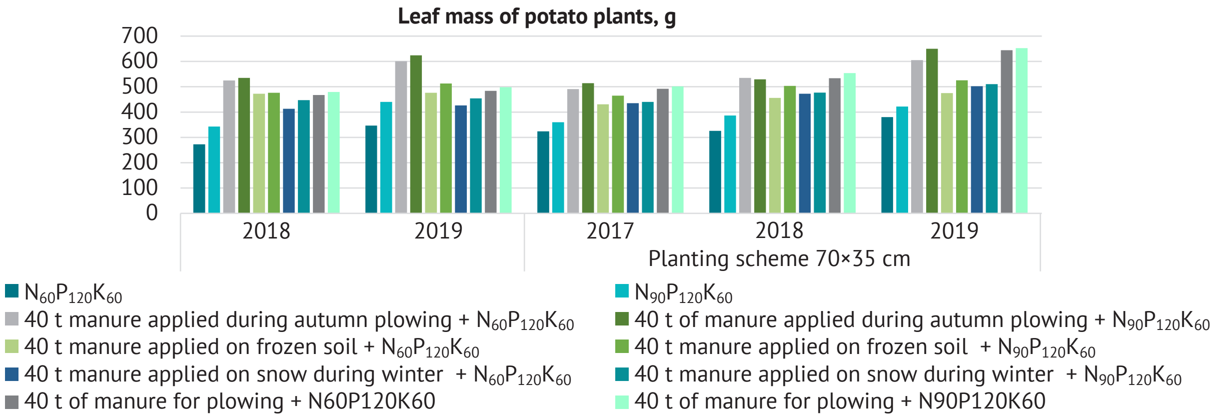

***Figure 5**. Leaf mass of potato plants depending on fertiliser application and planting density, g*
***Source:** compiled by the authors*

The same pattern was observed when manure was applied. Thus, when 40 t/ha of manure was applied during autumn ploughing on the $N_{60}P_{120}K_{60}$ background, leaf mass exceeded stem mass by 34.1 g in 2017, by 65.1 g in 2018 and by 17.2 g in 2019. On the $N_{90}P_{120}K_{60}$ background, the differences were 67.3 g, 66.4 g, and 29.0 g, respectively. The highest leaf mass per plant in 2019 was observed when manure was applied in spring before re-ploughing autumn-ploughed soil, with planting according to the 70×35 cm scheme. Thus, when 40 t/ha of manure was applied before spring re-ploughing on the $N_{60}P_{120}K_{60}$ background, leaf mass per plant reached 644.3 g, which was 264.4 g higher than without manure. On the $N_{90}P_{120}K_{60}$ background, the value was 652.5 g, which was 230.9 g higher. In the other manure treatments, leaf mass was also higher than in the treatment with $N_{60}P_{120}K_{60}$ without manure under the 70×25 cm planting scheme by 79.9-254.2 g, and on the $N_{90}P_{120}K_{60}$ background by 14.1-183.7 g.

The pattern of above-ground biomass formation depending on manure application timing and mineral fertiliser background is particularly clear when the three-year average data are analysed (Table 3).

***Table 3**. Effect of fertilisation and planting density on haulm formation per unit area, averaged over three years*

Planting scheme	Manure application dates	Weight of plant, g			Above-ground mass, t/ha		
		stems	leaves	total	stems	leaves	total
70×25 cm	$N_{60}P_{120}K_{60}$	277.5	296.3	573.8	15.84	16.91	32.75
	$N_{90}P_{120}K_{60}$	327.0	382.0	709.0	18.67	21.81	40.48
	40 t/ha manure applied during autumn ploughing + $N_{60}P_{120}K_{60}$	497.7	536.5	1,034.2	28.41	30.63	59.04
	40 t/ha manure applied during autumn ploughing + $N_{90}P_{120}K_{60}$	508.8	563.1	1,071.9	29.05	32.15	61.20
	40 t/ha manure applied on frozen soil + $N_{60}P_{120}K_{60}$	397.9	464.3	862.2	22.72	26.51	49.23
	40 t/ha manure applied on frozen soil + $N_{90}P_{120}K_{60}$	444.1	503.1	947.2	25.35	28.72	54.07
	40 t/ha manure applied on snow during winter + $N_{60}P_{120}K_{60}$	375.5	406.6	782.1	21.44	23.21	44.65
	40 t/ha manure applied on snow during winter + $N_{90}P_{120}K_{60}$	407.2	437.9	845.1	23.25	25.00	48.25
	40 t/ha manure applied before spring re-ploughing of autumn-ploughed soil + $N_{60}P_{120}K_{60}$	441.5	531.3	972.8	25.20	26.91	52.11
	40 t/ha manure applied before spring re-ploughing of autumn-ploughed soil + $N_{90}P_{120}K_{60}$	462.2	481.2	943.4	26.39	27.47	53.86

Table 3. Continued

Planting scheme	Manure application dates	Weight of plant, g			Above-ground mass, t/ha		
		stems	leaves	total	stems	leaves	total
70×35 cm70×35 cm	$N_{60}P_{120}K_{60}$	299.4	343.1	642.5	12.21	13.99	26.20
	$N_{90}P_{120}K_{60}$	341.6	389.4	731.0	13.93	15.88	29.81
	40 t/ha manure applied during autumn ploughing + $N_{60}P_{120}K_{60}$	511.7	543.5	1,055.2	20.87	22.17	43.04
	40 t/ha manure applied during autumn ploughing + $N_{90}P_{120}K_{60}$	599.6	631.1	1,230.7	24.46	25.74	50.20
	40 t/ha manure applied on frozen soil + $N_{60}P_{120}K_{60}$	438.7	453.7	892.4	17.89	18.51	36.40
	40 t/ha manure applied on frozen soil + $N_{90}P_{120}K_{60}$	459.5	498.0	957.5	18.74	20.31	39.05
	40 t/ha manure applied on snow during winter + $N_{60}P_{120}K_{60}$	443.8	470.0	913.08	18.10	19.17	37.27
	40 t/ha manure applied on snow during winter + $N_{90}P_{120}K_{60}$	452.4	475.8	928.2	18.45	19.41	37.86
	40 t/ha manure applied before spring re-ploughing of autumn-ploughed soil + $N_{60}P_{120}K_{60}$	503.7	556.7	1,060.4	20.55	22.71	43.26
	40 t/ha manure applied before spring re-ploughing of autumn-ploughed soil + $N_{90}P_{120}K_{60}$	523.2	569.2	1,092.4	21.34	23.22	44.56

Source: *compiled by the authors*

The table shows that, with a planting scheme of 70×25 cm, the lowest haulm weight per plant was observed when $N_{60}P_{120}K_{60}$ was applied; this was 135.2 g lower than when $N_{90}P_{120}K_{60}$ was applied. When 40 t/ha of manure was applied during autumn ploughing, haulm weight per plant increased by 460.4 g on the $N_{60}P_{120}K_{60}$ background and by 362.9 g on the $N_{90}P_{120}K_{60}$ background. When potatoes were planted according to the 70×35 cm scheme, haulm weight per plant increased under all fertiliser treatments. However, the highest haulm weight per plant was observed when 40 t/ha of manure was applied during autumn ploughing and in spring before re-ploughing autumn-ploughed soil. Thus, when manure was applied during autumn ploughing on the $N_{60}P_{120}K_{60}$ background, haulm weight exceeded that under denser planting by 21 g, and on the $N_{90}P_{120}K_{60}$ background by 158.8 g.

With spring application of manure before re-ploughing autumn-ploughed soil, haulm weight per plant increased compared with autumn application during autumn ploughing by 5.2 g on the $N_{60}P_{120}K_{60}$ background and by 138.3 g on the $N_{90}P_{120}K_{60}$ background. It should be noted that, although haulm weight per plant increased with wider spacing, total biomass per unit area decreased (Table 3). Thus, when $N_{90}P_{120}K_{60}$ was applied, the average total haulm weight over three years was 32.75 t/ha under the 70×25 cm planting scheme and 26.20 t/ha under the 70×35 cm scheme, which was 6.55 t/ha lower. When $N_{90}P_{120}K_{60}$ was applied, the corresponding values were 40.48 t/ha and 29.81 t/ha, respectively, with the wider planting scheme producing 10.67 t/ha less. The highest average haulm yield over three years (61.20 t/ha) was obtained when manure was applied during autumn ploughing with planting according to the 70×25 cm scheme. When the feeding area was expanded, haulm yield was 50.20 t/ha, or 11 t/ha lower. The same pattern was observed in the other experimental treatments.

DISCUSSION

Field studies by M.N. Suraganov *et al.* (2024) demonstrated that the number and weight of potato stems, with the number of stems per plant varying from 3-5 to 10-12, were correlated with tuber size. The larger the tuber, the larger the stems. The highest stem weight was 81.6-91.7 g in the treatments with the growth regulators Humika, Enrivel and Zerebra Agro, compared with 64.1 g in the control treatment. The lowest stem weight was observed following treatment with the growth regulator Gufos. In the research of D. Stewart *et al.* (1998), soil physical properties had a significant effect on potato yield, regardless of fertiliser application. The effect of changes in soil physical properties on plant growth was most evident when fertiliser was not applied. The results of D. Peddle *et al.* (2024) made it possible to determine the optimal leaf density and timing of measurements and also demonstrated the ability to detect vegetation stress and nitrogen deficiency in three potato varieties. These results will form the basis for further research using UAVs/drones/satellite systems and will be used to develop other methods for assessing plant physiology. In research by S. Nepal *et al.* (2016), the number of stems per plant was identified as an early predictor of potato yield and tuber size. For each treatment and location, the number of stems per plant, the number of tubers and average tuber size were compared. The physiological age of seed potatoes can influence the number of stems per plant, as well as the number and size of tubers available for harvest. Changes in harvested tuber size have economic consequences that depend on the market and pricing. Economic returns were analysed using the ordinary least squares method. The economic impact of physiological ageing of seed potatoes, expressed in dollars per hectare for the fresh and processing markets, was mixed.

N. Marks & P.S. Szecówka (2010) emphasised the beneficial effect of magnetic induction and radiation dose on stem length and number, leaf and stem weight, and the potato germination index. These treatments increased these parameters compared with the control treatment, demonstrating that magnetic stimulation of potato tubers has a beneficial effect on the vegetation of the above-ground parts of potato plants. The available data support the conclusions of the present study: increasing the nitrogen dose in the mineral fertiliser background from 60 to 90 kg/ha led to an increase in the number of stems by 0.1-0.4 stems per plant. The largest number of stems was recorded when manure was applied after spring re-ploughing of autumn-ploughed soil and potatoes were planted according to the 70×35 cm scheme (7.4 stems per plant), whereas the lowest number was recorded with mineral fertilisers alone 5.8 stems per plant).

The most important part of a potato plant is its leaves. A larger leaf area supports more active photosynthesis, which contributes to higher yield formation. M. Hossain *et al.* (1989) reported that, as the percentage of seed tubers infected with PLRV increased, growth parameters, including plant height and the number of stems per hill, as well as yield components, including the number and weight of tubers per hill and yield (t/ha), gradually declined. Similarly, N. Budanov *et al.* (2023) analysed biometric data and found that the largest number of leaves was observed in the 70×30 cm control treatment, whereas the smallest number was observed in the 70×20 cm treatment. These findings are consistent with the present study, in which the largest number of leaves was observed when manure was applied during ploughing and potatoes were planted according to the 70×35 cm scheme (210.4 leaves per plant). The lowest number was recorded when mineral fertilisers were applied at a rate of $N_{60}P_{120}K_{60}$ under the 70×35 cm planting scheme (153.1 leaves per plant). In addition, when the feeding area was expanded from 70×25 cm to 70×35 cm, the number of leaves increased by 9-12 leaves per plant. Therefore, the number of leaves and stems ultimately characterises the potential size of the harvest.

A. Zanon *et al.* (2013) determined the number of accumulated leaves on the main stem and the final leaf count. Variations in phyllochron, final leaf count and leaf area index were observed depending on the genotype in each growing season. It was found that the duration of the phases from seedling emergence to the onset of tuber formation and from the beginning of tuber formation to the onset of senescence determines tuber productivity. A. Jama-Rodzenska *et al.* (2021) reported that variety had a significant effect on potato tuber weight. Irrigation level had a significant effect only on total potato biomass, while the potato harvest date had a significant effect on both examined traits. The growth dynamics of the above-ground part and potato tubers were highest under constant irrigation level 1. Regardless of the variety studied, irrigation level 3 reduced potato biomass production. The highest water consumption was observed from the tuber growth period to flowering. These findings are also confirmed by the present study, in which manure application resulted in the formation of strong, well-developed stems. Expanding the feeding area from 70×25 cm to 70×35 cm contributed to an increase in haulm weight per plant. When manure was applied on frozen soil on the $N_{60}P_{120}K_{60}$ background, the increase was 47.1 g, and on the $N_{90}P_{120}K_{60}$ background, it was 8.4 g. When manure was applied on snow during winter, the increase was 117.0 g and 85.0 g, respectively. When manure was applied in spring before re-ploughing autumn-ploughed soil, the increase reached 49.5 g and 64.8 g, respectively. The largest increase in haulm weight per plant was observed when manure was applied before spring re-ploughing autumn-ploughed soil on the $N_{90}P_{120}K_{60}$ background, amounting to 114.1 g. The sharp increase in haulm weight when manure was applied during autumn ploughing and before spring re-ploughing can be explained by the higher nitrogen content in the soil, which stimulated rapid vegetative growth.

The results obtained are also consistent with the findings of X. Liu *et al.* (2025) and T.L. Gobena *et al.* (2022), who reported that balanced phosphorus nutrition improves potato growth, nutrient uptake and overall plant productivity. In the present study, the combined application of manure and mineral fertilisers contributed to more intensive vegetative development, confirming the importance of a balanced nutrient supply for the formation of a productive assimilation apparatus. Similar conclusions were reported by L. Adam *et al.* (2026), who demonstrated that planting density and nutrient management significantly influence tuber yield and plant development depending on environmental conditions. Furthermore, R. Setyobudi *et al.* (2024) emphasised that nutrient imbalance may negatively affect root development and delay phenological stages, whereas the balanced fertiliser systems used in the present experiment promoted more vigorous plant growth and biomass accumulation. Thus, the analysis shows that the results for the West Kazakhstan region are consistent with international and national studies on potato growth and development in terms of manure and mineral fertiliser application timing and planting density. At the same time, they reveal specific features associated with local climatic and soil conditions. The data confirm that the application of fertilisers at optimal rates and with an appropriate nutrient ratio makes it possible to regulate potato plant growth and development, thereby contributing to higher yield formation in the region.

CONCLUSIONS

The analysis of potato plant growth and development showed that these processes are influenced by mineral fertiliser rates, manure application timing, planting density and weather conditions. The mineral fertiliser rates and manure application timings studied in the experiment did not affect the timing of seedling emergence; however, they significantly influenced the onset and duration of interphase periods by up to 16 days. The growth and development of potato plants also depended on the meteorological conditions of the growing season. Manure application contributed to vigorous growth of the above-ground biomass of potato plants. As the feeding area expanded from 70×25 cm to 70×35 cm, haulm weight per plant also increased. The application of mineral fertilisers together with manure improved the soil supply of nitrogen, phosphorus and potassium and had a significant effect on plant growth and development. When manure was applied during autumn ploughing in combination with mineral fertilisers, the plants were 9.1-11.8 cm taller than in the treatments without manure.

Thus, manure application in all treatments increased the weight of above-ground biomass. The highest haulm weight was observed in the treatments where manure was applied during autumn ploughing and before spring re-ploughing of autumn-ploughed soil on the $N_{90}P_{120}K_{60}$ background. Prospects for further research include studying the long-term effects of combined organic and mineral fertilisation on potato yield and tuber quality, changes in soil microbiological activity and nutrient availability, and the adaptation of fertiliser application systems to different soil and climatic conditions. Further investigations should also focus on optimising planting density and irrigation regimes to improve resource-use efficiency and ensure sustainable potato production under changing climatic conditions.

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CONFLICT OF INTEREST

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Вплив внесення гною з мінеральними добривами та густоти посадки на зростання та розвиток картоплі

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Анотація. Збільшення виробництва картоплі має здійснюватися не тільки за рахунок розширення площ під культурою, а головним чином – за рахунок підвищення врожайності. Для підвищення врожайності картоплі, поряд із застосуванням мінеральних добрив, велике значення має раціональне використання місцевих органічних добрив. Отже, метою даного дослідження було вивчення росту та розвитку рослин картоплі у залежності від термінів внесення гною у поєднанні з мінеральними добривами та густотою посадки. Польові дослідження здійснювалися систематичним методом з ярусним розташуванням варіантів у досвіді з 3-кратною повторністю. Найменша кількість стебел формувалася при внесенні $N_{60}P_{120}K_{60}$ (5,8 шт.) при посадці за схемою 70×25 см, а найбільше – при внесенні 40 т/га гною під зяб у поєднанні з мінеральними добривами в дозі $N_{90}P_{120}K_{60}$ (7 переорювання зябку та посадки за схемою 70x35 см (7,4 стебла) а також збільшується числа стебел у міру розширення площі живлення на 0,1-0,3 стебла. У середньому за 3 роки при весняному внесенні 40 гною на фоні $N_{60}P_{120}K_{60}$ кількість листя зросла на 50,6 шт., а на фоні $N_{90}P_{120}K_{60}$ – на 41,3 шт. Маса бадилля однієї рослини змінювалася при розширенні площі живлення, по роках і в залежності від термінів внесення гною, при розширенні площі харчування (70×35 см) маса бадилля одного куща зростає, де найбільша маса бадилля в середньому за 3 роки (61,20 т/га) була отримана при внесенні гною5 вона становила 50,20 т/га, чи 11 т менше. Така сама закономірність спостерігається і за іншими варіантами досвіду. За отриманими результатами польових дослідів у виробничих умовах будуть надані рекомендації виробництву, що дозволяють раціональніше використовувати органічні та мінеральні добрива та підвищувати продуктивність картоплі

Ключові слова: польові дослідження; підвищення врожайності; оранка; вага куща