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PHOTOSYNTHESIS AND PRODUCTIVITY OF POTATO PLANTS AFTER APPLICATION OF DESIGNATED DOSES OF FERTILIZERS IN THE CONDITIONS OF THE FOREST-STEPPE OF THE MIDDLE VOLGA REGION

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Abstract:
In modern conditions, the obtaining of stably high yields of potato is directly related to the use of fertilizers. It was studied the influence of fertilizers, balanced on the elements of mineral nutrition, on photosynthetic activity. The formation of yield of early ripening potato varieties Molly and Colette, growing on grey forest soils of the forest steppe of the Middle Volga region, was investigated. The impact of fertilizers on the formation of leaf area, leaf photosynthetic potential, the utilization coefficient of photosynthetically active radiation (PAR), the dependence of these indicators on the level of mineral nutrition were defined. It was determined that potato varieties were highly productive and in optimal conditions they were capable of forming high yields. So on the background of application of designated doses of fertilizers, estimated for obtaining the yield of potato tubers 45 tons per hectare, the average yield of variety Molly for three years was 43.57 tons/ha, and the variety Colette - 42.54 tons/ha.
The analysis of received data showed that the application of mineral fertilizers together with organic, reduced the amount of dry matter in the tubers. The application of mineral fertilizers in a dose of $N_{47-52}P_{75-90}K_{142-148}$, which were designed for a yield of 25 tons/ha, reduced the dry matter content of the variety Molly by 0.19%, the variety Colette - by 0.13%. The application of balanced fertilizers, designed to produce 25 and 35 tons/ha of potato tubers, did not result in a significant change in the starch content of the tubers. On these backgrounds, the applied fertilizers, compared to the control, reduced the amount of starch in the variety Molly by only 0.27 and 0.37%, and the variety Colette - by 0.17 and 0.65%. With the raise of nutrient status, estimated for productivity 45 tons/ha, the content of starch in potato tubers of studied varieties decreased by 0.79 - 2.09%.
Keywords: *leaf surface, photosynthetic potential (PP), potato, yield, dry matter, starch, vitamin C, nitrates.*

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INTRODUCTION:

Solar radiation is one of the main factors, affecting the growth and development of plants. However, photosynthetically active radiation is difficult to control, so the task of modern agriculture is to increase the productivity of crops by increasing the use of solar radiation in the process of photosynthesis. To achieve this goal, new methods of increasing the productivity of cultivated crops should be developed and implemented. One of these methods, providing for the development of a set of measures to ensure the achievement of planned harvest, is its programming. Fundamental research of this issue was carried out by domestic scientists [4, 9, 11, 12, 14].

Many authors note that the theoretically possible utilization coefficient of photosynthetically active radiation (PAR) can reach 5-10% [9-10, 13, 19]. This confirms that the raising of yield of agricultural crops by increasing the use of PAR is quite possible.

The basis of the theory of high productivity of agricultural crops was laid by A.A. Nichiporovich [8] in the 1950s. Foreign scientists also carried out intensive research in this field [18]. The first models of radiation regime and productivity of vegetation cover were created.

The efforts of many scientists are aimed at creation of quantitative theory of photosynthetic productivity of plants and optimal accumulation of solar radiation, as well as rational use of available soil and climate resources. M.K. Kayumov [2-3] suggests that such methods of photosynthetic processes intensification should be developed, the crops of which would be capable of accumulating 3-5% of solar energy.

Consideration of the receipt of photosynthetically active radiation, and the development of the whole complex of agrotechnical measures for obtaining crops with a high level of energy utilization are of great importance, in order to determine the expediency of fertilizers application for different levels of planned crop.

One of the main conditions for intensifying the use of solar radiation with high efficiency is the rapid growth of the leaf area in the sowing, quick attainment of its optimal size and long stay in active state. It is also important that the leaves manage to move the maximum amount of plastic substances, which have accumulated in the structures of leaves, to the reproductive storage organs, by the end of vegetation period.

V.F. Maltsev and M.K. Kayumov [7] note that for the formation of high yield of potato, the leaf area should reach the size of 40-60 thousand m^2/ha and remain active as long as possible. Too large leaf area leads to a decrease in the accumulation of yield per unit of leaf area (to a decrease in the net productivity of photosynthesis).

A number of researchers note that the importance of early planting dates is especially great, when the sun is comparatively high, and PAR is sufficient for active photosynthetic activity of potato plants. In case of late planting time, the leaf area reaches its optimal size later. By this time the intensity of PAR decreases and the thermal regime deteriorates. As a result, a significant part of solar radiation, which comes in early summer and is so necessary for photosynthesis, is lost [1, 8, 9, 11].

The formation, productivity and duration of leaves functioning also depend on the provision of potato planting with elements of mineral nutrition. A.V. Korshunov [5] notes that the regulation of mineral nutrition of plants is one of the main agrotechnical methods for increasing the productivity of potato agrocenoses. The application of nutritionally balanced doses of fertilizers contributes to the formation of high yields with good quality of potato tubers. To do this, the fertilizers should be available for plants during the growing season in the required amount.

E.A. Allen, R.K. Seott [15] note that the potential yield of medium-ripening and late-ripening varieties of potato in Western Europe is 90-100 tons/ha, in Eastern Europe somewhat lower - 60-80 tons/ha. Also A.G. Lorkh [6] in his classic experiments obtained a yield of 78.4 tons/ha. However, the yield of potato in Russia is still low - despite the good results of advanced potato farms. On average for 2012-2016 the yield of this crop in Russia was 18.92 tons/ha.

The purpose of the work: to define the productivity of early ripening potato varieties Molly and Colette, depending on the level of mineral nutrition on grey forest soils of the forest steppe of the Middle Volga.

Conditions, materials and methods of the research. The investigations were carried out in 2014-2016 on the grey forest soils of medium loamy granulometric composition of the experimental field of the Department of Plant Production and Horticulture of Kazan State Agrarian University. The humus content in the experiment is 3.33-3.46%, pH sal. - 5.48-5.74, mobile phosphorus - 123-132, and exchangable potassium - 146-163 mg/kg of soil.

Preceding crop is winter wheat. Plot area is 72 m^2; accounting area is 60 m^2. Seed tubers with medium fraction (60-65 g) were used for planting. Planting was carried out to a depth of 8-10 cm with a density of 53.2 thousand pieces/ha. Doses of fertilizers were established by calculation and balance method, taking into account the coefficients of nutrition elements consumption from the soil and applied fertilizers.

Variants of the experiment: 1. Control (without fertilizers). 2. Application of fertilizers on the expectation of potato yield 25 tons/ha ($N_{47-52}P_{75-90}K_{142-148}$). 3. Application of fertilizers on the expectation of potato yield 35 tons/ha (manure in the amount 20 tons/ha + $N_{93-125}P_{115-125}K_{170-180}$). 4. Application of fertilizers on the expectation of potato yield 45 tons/ha (manure in the amount 40 tons/ha + $N_{138-165}P_{150-165}K_{197-211}$).

Semi-rotted manure was brought before autumn ploughing. In spring, the ridges with a row spacing of 75 cm were formed. During the planting, the tubers were treated with a fungicide Prestige KS (1.0 l/t, with a fluid consumption of 10 l/t). Herbicide Zenkor Tekhno VDG with a rate of application 1.2 kg/ha was used against the weeds. Fungicide Ridomil Gold MC (2.5 kg/ha), Shyrlan SK (0.4 l/ha) and copper-containing preparations were used for the protection from late blight.

The analysis and discussion of the research results. Most researchers note that the optimal leaf area differs between cultivated crops, and varies from 20 to 70 thousand m^2/ha [16, 17, 19]. The leaf area and potato productivity are largely dependent on water availability and the level of mineral nutrition. Water availability during the vegetation period was regulated by the irrigation. The higher leaf area and, correspondingly, the active photosynthetic activity of plants in both studied varieties were noted with the application of increased doses of fertilizers. In the flowering phase of plants, that is in the period of maximum development, the leaf area of the variety Molly in the control sample was 25.75 thousand m^2/ha, the variety Colette - 26.56 thousand m^2/ha. After application of fertilizers, estimated for productivity of potato 45 tons/ha it was the maximum, that was 30.71 and 26.09 thousand m^2/ha more, in comparison with the control (Table 1).

Table 1 - Dynamics of the growth of potato leaf area depending on the nutrient status, thousand m^2/ha, 2014-2016.

Variety	Nutrient status	Phase of development				
		Seadling	Budding	Flowering	Beginning of top necrosis	Before the harvesting
Molly	Without fertilizers	10.02	22.54	25.75	20.45	12.21
	Planned yield 25 tons/ha	10.26	34.42	35.67	34.55	16.21
	Planned yield 35 tons/ha	11.41	42.86	48.36	44.49	18.83
	Planned yield 45 tons/ha	12.82	48.65	56.45	51.86	21.12
Colette	Without fertilizers	10.01	21.67	26.56	22.32	13.86
	Planned yield 25 tons/ha	10.08	35.87	37.86	35.87	18.18
	Planned yield 35 tons/ha	11.20	43.75	49.45	46.56	18.22
	Planned yield 45 tons/ha	11.96	46.84	52.65	49.78	22.45

Table 2 - Dynamics of leaf photosynthetic potential of potato crops depending on the nutrient status, thousand m^2 × days/ha, 2014-2016.

Variety	Nutrient status	Periods of development				
		Seadling - budding	Budding - flowering	Flowering - beginning of top necrosis	Beginning of top necrosis - harvesting	Amount for vegetation
Molly	Without fertilizers	348	217	838	359	1762
	Planned yield 25 tons/ha	498	327	1334	472	2631
	Planned yield 35 tons/ha	651	469	1764	538	3422
	Planned yield 45 tons/ha	738	562	2112	558	3970
Colette	Without fertilizers	321	224	970	379	1894
	Planned yield 25 tons/ha	505	358	1544	451	2858
	Planned yield 35 tons/ha	621	480	1920	528	3549
	Planned yield 45 tons/ha	676	512	2115	516	3819

The accumulation of biological mass by plants is determined not only by the size of assimilation surface, but also by the duration of its operation. The physiological parameter, which unites these indicators, is the photosynthetic potential PP. Its value changed depending on the status of mineral nutrition and variety. In the control sample without application of fertilizers and at the nutrient statuses, estimated for 25 and 35 tons per hectare, the variety Molly had some advantage, and the variety Colette - at the status 45 tons per hectare.

On average, over the years of the study, the amount of photosynthetic potential (PP) in the variety Molly was 1762 thousand m^2 × days/ha, while in the variety Colette it was 132 thousand m^2 × days/ha higher. With the raise of nutrient status, the value of photosynthetic potential has increased in the variety Molly by 869-2208 thousand and in the variety Colette for 964-1925 thousand m^2 × days/ha (Table 2).

The yield of dry biomass per 1 hectare with the increase of fertilizers has risen in both varieties. At the highest nutrient status, estimated for a yield of potato 45 tons per hectare, it was 6.641 and 5.89 tons per hectare higher than the control, and was 13.972 tons/ha in the variety Molly and 13.872 in the variety Colette (Table 3).

The productivity of leaves (PL) shows the yield of potato per 1,000 units of photosynthetic potential (PP). Under fertilization for productivity of potato 45 tons per hectare, the variety Molly formed 11.25 kg of tubers per 1 thousand units of PP, and the variety Colette - 11.45 kg.

The analysis of the results of our studies showed that the raise of mineral nutrition level had increased the utilization coefficient of photosynthetically active radiation. In the control sample without application of fertilizers, its value was 1.54 and 1.68%, depending on the variety. With the raise of nutrient status, this indicator increased and was 2.94% in the variety Molly, and 2.92% in the variety Colette, estimated for productivity 45 tons per hectare.

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Table 3 – The indicators of potato crops productivity at different levels of mineral nutrition, 2014-2016.

Variety	Planned yield, tons/ha	The yield of dry biomass, tons/ha	The average daily increase in dry biomass, kg/ha	The productivity of leaves, kg of tubers per 1 thousand units of PP	The utilization coefficient of PAR, %
Molly	Without fertilizers	7.331	81.18	10.15	1.54
	25	9.873	109.34	11.17	2.08
	35	12.012	133.02	10.61	2.53
	45	13.972	154.73	11.25	2.94
Colette	Without fertilizers	7.982	88.39	10.32	1.68
	25	10.294	114.00	10.83	2.17
	35	11.875	131.51	10.21	2.50
	45	13.872	153.62	11.45	2.92

In our studies, the positive effect of application of designated doses of fertilizers on the productivity of both potato varieties has been revealed. The analysis of yield data showed that the studied varieties on average for three years were not significantly different. The highest yield - 43.57 tons/ha was formed under fertilization for productivity 45 tons/ha in the variety Molly (Table 4).

Table 4 - Yield of early ripening varieties of potato, depending on the level of mineral nutrition, 2014-2016.

Variety	Nutrient status	Yield, tons/ha			
		2014	2015	2016	Average
Molly	Control	16.89	18.53	14.87	16.76
	Planned yield 25 tons/ha	28.24	29.65	26.79	28.23
	Planned yield 35 tons/ha	33.86	37.25	34.42	35.18
	Planned yield 45 tons/ha	42.65	44.38	43.68	43.57
Colette	Control	18.34	19.28	17.35	18.32
	Planned yield 25 tons/ha	29.42	31.82	27.91	29.72
	Planned yield 35 tons/ha	34.56	36.44	34.08	35.03
	Planned yield 45 tons/ha	41.46	43.64	42.53	42.54

Plots		2014	2015	2016
HCP_{05}	A	0.71	0.75	1.03
HCP_{05}	B	0.33	0.53	0.58
HCP_{05}	AB	1.79	2.01	2.41

Table 5 - Quality indicators of potato tubers at different levels of mineral nutrition, 2014-2016.

Variety	Planned yield, tons/ha	Content in tubers			
		Dry matter, %	Starch, %	Vitamin C, mg%	Nitrates, mg/kg
Molly	Without fertilizers	22.87	13.51	18.27	56.14
	25	22.68	13.24	19.01	64.35
	35	22.44	13.14	19.26	72.14
	45	22.18	12.72	19.34	85.12
Colette	Without fertilizers	23.01	16.42	16.67	54.84
	25	22.88	16.25	16.85	66.03
	35	22.45	15.77	17.11	72.38
	45	22.31	14.33	17.31	82.43

Plots		2014-2016			
HCP_{05}	A	0.07	0.12	0.25	1.44
HCP_{05}	B	0.06	0.06	0.09	0.78
HCP_{05}	AB	0.18	0.94	0.22	6.43

The analysis of data, obtained as a result of laboratory studies, showed that the application of mineral fertilizers together with organic caused a decrease in the amount of dry matter in the potato tubers. The application of mineral fertilizers in a dose $N_{47-52}P_{75-90}K_{142-148}$, estimated for productivity 25 tons/ha, reduced the dry matter content in the variety Molly by 0.19%, in the variety Colette - by 0.13%.

Combined application of mineral and organic fertilizers, estimated for productivity 35 tons/ha and especially 45 tons/ha, resulted in a significant decrease in the dry matter content (Table 3).

Fertilizers, balanced on the elements of nutrition, designed to produce 25 and 35 tons/ha of potato tubers did not result in a significant change in the starch content of the tubers. At these nutrient statuses, applied fertilizers reduced the content of starch in the variety Molly by 0.27 and 0.37%, in the variety Colette - by 0.17 and 0.65%, compared to the control sample. At the nutrient status, estimated for productivity 45 tons/ha, applied fertilizers reduced the content of starch of the studied varieties by 0.79-2.09% (Table 5).

The application of fertilizers, balanced on the elements of nutrition, contributed to a slight increase in the content of vitamin C in potato tubers.

The data of our laboratory studies showed that in all variants of the experiment with fertilizers, the amount of nitrates in the tubers was below the MPC. Although, with the increase of designed doses of

NPK, their amount had increased in the variety Molly by 8.21-28.98 mg/kg, and in the variety Colette - by 11.19-27.59, in comparison with the control sample.

Summary

1. The application of mineral fertilizers on grey forest soils, under the conditions of the Republic of Tatarstan, in doses, designated for the productivity of potato tubers 25 tons per hectare, together with organic fertilizers, estimated for the productivity 35-45 tons/ha, increased the photosynthetic activity of plants and ensured the formation of yields 25-35 tons/ha of early ripening varieties Molly and Colette. Only at the nutrient status, estimated for the productivity 45 tons/ha, it was 94.5% and 96.8% of the planned level, depending on the variety.

2. The maximum leaf area of agrocenosis of the variety Molly (56.45 thousand m^2/ha), the highest PP (3970 thousand m^2 × days/ha) and the utilization coefficient of PAR (2.94%) were achieved under fertilization, estimated for productivity 45 tons/ha. In this variant of fertilization, compared to the control sample, these parameters increased, on average over three years, at 2.19; 2.25; 1.91 times, respectively.

3. With the raise of doses of applied fertilizers, estimated for the planned productivity, the yield of dry biomass increased in the variety Molly by 2.542-6.641 tons/ha, in the variety Colette – by 2,312-5,890 tons/ha, in comparison with the control sample. The productivity of 1,000 units of photosynthetic potential, depending on the variety, increased from 10.15-10.32 to 11.25-11.45 kg of tubers, the utilization coefficient of PAR increased from 1.54-1.68% in the control sample to 2.94-2.93%, after fertilization for the planned potato yield 45 tons/ha.

CONCLUSION:

1. The application of fertilizers estimated for obtaining a yield of potato 25 and 35 tons/ha, did not essentially change the content of starch in tubers, in comparison with the control variant. Higher doses of fertilizers, designed to produce a yield of 45 tons/ha, led to a significant increase in the amount of nitrates, and reduced the starch content in tubers.

2. When planning high potato yields, organic fertilizers should be mixed together with mineral. Against the background of natural fertility, the variety Molly, for an average of three years, formed a yield of 16.76 tons/ha, the variety Colette - 18.32 tons/ha. Fertilizers, estimated for productivity of potato 25-45 tons/ha, ensured the yield of the variety Molly 28.23-43.57 tons/ha, the variety Colette - 29.72-42.54 tons/ha.

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