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Ways of Increasing Solar Energy Use by Potato Plants at Different Level of Mineral Nutrition in the Middle Volga Forest Steppe.

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ABSTRACT

This paper presents the results of studies of the effectiveness of the calculated doses of fertilizers applied to the planned harvest of early-seasoned potatoes Zhukovskii rannii. The studies found that the amount of leaves area, leaf photosynthetic potential, net photosynthesis productivity, utilization coefficient of photosynthetically active radiation (PAR) in gray forest soils of the Middle Volga forest steppe depend on the level of a balanced mineral nutrition. During our research we found that the increase in the estimated doses of fertilizer for obtaining the planned yields of 25-40 t/ha, as compared with the control variant, has expanded leaf area by 4.77-17.57 thousand m^2/ha, and the amount of leaf photosynthetic potential during the growing season by 412-1404 thousand m^2× days/ha. PAR utilization coefficient has been increased by 0.76-1.41 %.Yield of control variant was 17.45 t/ha due to natural fertility, with the application of fertilizers based on the estimated yield of 25 t/ha the yield increased by 2.55 t/ha of tubers, against 30 t/ha - 3.36 t/ha, 35 t/ha - 1.55 t/ha, and 40 t/ha - 0.98 t/ha. Based on the results of laboratory analyzes of the obtained material we have calculated values of potato yield NPK removal by variants of the experiment, and determined removals of nutrient from soil and fertilizers.

Keywords: fertilizer doses, leaf area, photosynthetic potential (FP), potatoes, yield, starch, protein, vitamin C, nitrates, removal of nutrients.

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INTRODUCTION

E.A.Allen, R.K Seott [14] note that the maximum yield of potatoes in Europe is 60-100 t/ha, depending on the group of maturity and climatic conditions. Potato yield in Russia has been remaining at the level of 13.0 t/ha over the last five years.

Among the main factors that influence the growth and development of plants, solar radiation is one of the most difficult factors to control. Therefore, the most important problem of modern agriculture is to improve the productivity of crops by increasing the use of solar radiation in the process of photosynthesis.

Leaves are the main organ of the plant photosynthesis [3, 10]. Leaves account for 80-90% of radiation and 60-90% of the radiation generated in the process of organic matter photosynthesis of total solar radiation absorbed by plants [1]. Many authors believe relying upon their research findings that the optimum leaves area for agricultural crops is 20-70 thousand m^2/ha [15-20].

According to the majority of researchers, the most favorable condition for the formation of high yields is that the leaves area is formed in the range of 40-60 thousand m^2/ha, and remains functional for a long time, and is reduced by the time of harvest giving its macronutrients for the formation of tuber mass. Excessive increase in its value reduces the intensity of the tuber yield per unit of leaf surface [7, 9, 12].

According to M.K. Kaiumov [5] it is necessary to develop methods of improving the processes of the photosynthetic activity of potato plants able to accumulate 3-5% of solar energy. Therefore, the scientists focus their efforts on the creation of a quantitative theory of photosynthetic efficiency of plants, as well as the optimal accumulation of solar radiation and the rational use of the soil and climatic resources.

The process of biological conversion of solar energy - photosynthesis - underlies the biological value of plant products as the protein synthesis consumes more energy than the carbohydrate one. We should also note that the caloric value of essential acids particularly such as lysine, tryptophan, etc. is the highest [4].

Solar energy utilization activity by plants and their final productivity are largely determined by the radiation regime emerging in the crops, as well as supply of plants with mineral elements, water, and other factors [13].

H.G. Tooming [11] in his monograph gives fairly a wise saying of the Indian people that "Sun is the father of harvest, and water - its mother".

Solar radiation indeed is the driving force of all the vital processes of green plants, the source of energy.

The objective of our research was to clarify the features of growth and development of potato plants and the degree of utilization of solar energy, depending on the level of mineral nutrition, subject to a sufficient water supply, i.e. the use of irrigation.

CONDITIONS, MATERIALS AND METHODS OF RESEARCH

Investigations were carried in the field environment, laid in 2012-2014 on the experimental field of Kazan SAU. The soil used was gray forest medium-loamy soil. Thickness of arable layer was 24-26 cm, the pH of salt extract was 5.5-5.6, humus content by Tyurin method was 3.15-3.22%, labile phosphorus - 119-130 mg per 1 kg of soil, and exchangeable potassium - 148-152 mg per 1 kg of soil, hydrolytic acidity was 5.24-5.36 mg-eq/100 g of soil, the amount of absorbed bases was 25.36-25.48 mg-eq/100 g of soil.

The total area of the plot was 72.0 m² and discount area - 60.0 m². Sequential arrangement of variants. The experiment was performed in triplicate. Precursor - winter rye. Planting depth of 8-10 cm. Tubers of middle fraction (60-65 g) were planted. We planted the primary tuber, planting density - 53.2 thousand pc/ha.

Fertilizers were added per 25-40 t/ha tubers gathered. Organic fertilizers were added in autumn for plowing, and mineral fertilizers - during planting. Actual doses of added fertilizers: 1. Without fertilizers

(control). 2. Per 25 t/ha ($N_{43-58}P_{50-60}K_{121-155}$). 3. Per 30 t/ha (manure 20 t/ha + $N_{43-58}P_{30-40}K_{93-127}$). 4. Per 35 t/ha (manure 25 t/ha + $N_{82-96}P_{65-75}K_{128-162}$). 5. Per 40 t/ha (manure 30 t/ha + $N_{118-133}P_{100-110}K_{164-198}$).

ANALYSIS AND DISCUSSION OF RESULTS

Meteorological conditions during the research were quite favorable for the growth and development of potato plants.

Findings of our research showed that adding the fertilizer was an important factor in the formation of leaf area, as well as their vital ability during the growing season.

Analysis of data on the dynamics of leaf area growth showed that potato plants had already formed a large enough leaf area in the phase of buds formation, and control variant showed the area of 23.36 thousand m^2/ha. It was increasing by 7.64-19.57 thousand m^2/ha with increase of nutrient status.

Potato plants had the largest leaf area observed at the flowering stage. Average leaf area formed in the control variant in 2012-2014 was 30.23 thousand m^2/ha. The amount of fertilizers used per 25 t/ha of tubers was increased 1.16 times, per 30 t/ha - 1.27 times, per 40 t/ha - 1.58 times, as compared with the control variant with no fertilizers added. There was a gradual wilting of leaves and significant reduction in their activity observed prior to a harvest season.

Active photosynthetic activity of leaves does not always ensure the formation of a heavy yield, since it depends largely on the photosynthetic potential of potato crops, which is the most important factor of the production process.

Total photosynthetic potential (PP) of potato crops on average for three years of vegetation was 2225 thousand m^2 × days/ha in the control variant, 2637 thousand m^2 × days/ha upon adding fertilizer per 25 t/ha of yield; 2906 thousand m^2 × days/ha - per 30 t/ha; 3275 thousand m^2 × days/ha - per 35 t/ha; 3629 thousand m^2 × days/ha - per 40 t/ha; therefore, increase in doses of fertilizers resulted in the increased PP rate.

Net photosynthetic performance varied depending on the phase of growth and development of potato plants from 9.38 to 12.47 (in the initial period of vegetation) to 0.62-3.01 g/m^2 × day (by the end of the growing season), the weighted average during the growing season, depending on the application of fertilizers doses ranged from 4.78 to 5.99 g/m^2 per day.

Yield of total dry biomass of the fertilizer-free variant was 5.806 t/ha, and 9.120 t/ha from the ground rated per 25 t/ha of tubers. With increase of nutrient status the total yield of dry biomass was also increasing upon adding fertilizers and was 12.181 t/ha per 40t/ha of tubers (Table 1).

Table 1: Average productivity of potatoes Zhukovskii rannii upon adding calculated doses of fertilizers for the period of 2012-2014.

Planned yield, t/ha	Yield of dry biomass, t/ha	Leaves productivity, kg tubers per 1 thousand PP un.	Tuber growth rate, g/m^2 per day	PAR utilization coefficient, %
Without fertilizers	5.806	8.18	24.76	1.17
25	9.120	11.01	38.05	1.93
30	10.340	11.96	46.32	2.19
35	11.361	11.58	51.72	2.40
40	12.181	11.67	58.32	2.58

Potato plants in the control variant formed 8.18 tubers per 1 thousand PP units, and 11.01 kg in the second variant calculated for 25 t/ha. Maximum leaf productivity of 11.89 kg was observed in the variant calculated for tuber yield of 30 t/ha. Reduced productivity of 1 thousand photosynthetic potential (PP) against the increased statuses calculated for tuber yield of 35.0 and 40.0 t/ha as compared with the variant for 30 t/ha can be attributed to the development of larger leaf area and shading of lower leaves with the upper ones.

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Utilization coefficient is growing when calculated for tuber yield of 40 t/ha with increase in the added doses of fertilizers, reaching 2.58%, which is 2.21 times more than the same in the control variant is.

Findings of our research have shown that the fertilization amount calculated for the planned yield of potatoes allows increasing yields of potato tubers (Table 2).

Table 2: Yield of potatoes Zhukovskii rannii upon adding calculated doses of fertilizers, t/ha, for the period of 2012-2014.

Planned yield, t/ha	2012	2013	2014	Average	± of program	
					t/ha	%
Without fertilizers	16.83	17.36	18.16	17.45	-	-
25	25.14	28.10	29.42	27.55	+2.55	10.2
30	32.42	33.40	34.25	33.36	+3.36	+11.2
35	34.65	36.24	38.77	36.55	+1.55	+4.42
40	38.45	40.65	43.85	40.98	+0.98	+2.45
$HCP_{0,5}$	0.54	0.65	0.31	0.50		

Due to effective soil fertility, average yield of potato tubers obtained for three years was 17.45 t/ha. After adding fertilizers per 25 t/ha tuber yield the obtained yield was 27.55 t/ha, per 30 t/ha - 33.36 t/ha, per 35 t/ha - 36,55 t/ha, per 40 t/ha - 40.98 t/ha or 102.45% of the planned yield. 35 and 40 t/ha yields were not obtained only in 2012, though they also were close to these values.

Fertilization per 25 and 30 t/ha tuber yields hardly changed starch content in tubers as compared with the control variant. Only enhanced nutrient statuses, where 35 and 40 t/ha tuber yields were planned to obtain, reduced the amount of starch in the tubers by 0.97-1.42% (Table 3).

Table 3: Quality indicators of potato tubers Zhukovskii rannii upon adding calculated doses of fertilizers, for the period of 2012-2014.

Planned yield, t/ha	Starch, %	Vitamin C, mg %	Nitrates, mg/kg	Protein, %
Without fertilizers	12.69	21.08	35.63	2.25
25	12.68	21.59	46.47	2.44
30	12.59	21.94	55.80	2.46
35	11.72	21.71	60.53	2.60
40	11.27	21.05	74.67	2.73
HCP_{05}	0.09	0.11	0.45	0.03

Analysis of the results of laboratory studies has shown that adding moderate doses of mineral fertilizers, especially in combination with organic, had not reduced the amount of vitamin C in the tubers, except for doses of fertilizers applied per 40 t/ha yield, which had reduced its indicators by 0.54 mg % in the control variant.

Many authors believe that the increase in the accumulation of nitrates in tubers depends on the use of organic and mineral fertilizers, especially nitrogen ones. At the same time, A.V. Korshunov [6], B.A. Pisarev [8] consider this statement not true and that the application of nitrogen fertilizer not always leads to a hazardous accumulation of nitrates in tubers.

Our laboratory findings have shown that the tubers from all variants contain nitrates within the maximum permissible concentration. Although the increase in doses of fertilizers increased their content.

Average content of nitrates accumulated for three years was 35.63 mg/kg in the control variant, with mineral fertilizers added per 25 t/ha yield - 46.47 mg/kg, per 30 t/ha - 55.80 mg/kg, per 35 t/ha - 60.53 mg/kg, and per 40 t/ha - 74.67 mg/kg.

Potato protein is more valuable than other vegetable proteins. It contains all the essential amino acids, and is particularly rich in leucine and lysine (Vlasenko, 1987).

Potato protein is highly digestible and has a high nutritional value. Thus, 10 g of potato protein can replace 6-7 g of meat protein [7].

In our experiments, the complete balanced fertilizer had a positive effect on the protein content of the tubers. The tubers of control variant had 2.25% of protein, which amount was increasing with increase of fertilizer doses and reached 2.73% in the variant with nutrient status optimized for tuber yield of 40 t/ha.

Removal of nitrogen per 1 t of tubers with a relevant amount of foliage in the variant with nutrient status per 40 t/ha of tuber yield was 6.86 kg, phosphorus - 2.47 kg, potassium - 9.90 kg, while the control variant had considerably lower removal of nitrogen - 5.68, phosphorus - 2.13, and potassium - 7.55 kg per 1 t.

Over the period of studies, the average amount of substances used by potato plants from the soil was 27.75% of nitrogen, 10.02% of phosphorus, and 28.48% of potassium. The assimilated by plants amount of mineral fertilizers added per 25 t/ha tuber yield was 64.84% of nitrogen, 26.47% of phosphorus, and 48.91% of potassium.

The assimilated by plants amount of organic fertilizers added per 30 t/ha tuber yield was 21.30% of nitrogen, 28.52% of phosphorus, and 43.14% of potassium.

SUMMARY

1. Leaf area was increasing with increase of nutrient status from 30.23 thousand m^2/ha in the control variant to 47.80 thousand m^2/ha in the variant fertilized per 40 t/ha tuber yield, i.e., it increased 1.58 times.

2. Total photosynthetic potential for vegetation period was 2225 thousand m^2 × days/ha in the control variant, 2637 thousand m^2 × days/ha upon adding fertilizer per 25 t/ha of yield; 2906 thousand m^2 × days/ha - per 30 t/ha; 3275 thousand m^2 × days/ha - per 35 t/ha; 3629 thousand m^2 × days/ha - per 40 t/ha; therefore, increase in nutrient status resulted in the increased PP rate.PAR utilization coefficient was increasing with increase in nutrition level and varied from 1.17 to 2.58% subject to the level of mineral nutrition.

3. Due to the natural fertility, the average yield of tubers formed for three years was 17.45 t/ha. Amount of fertilizers added per 25 t/ha tuber yield ensured increase in the yield by 10.10 t/ha, and per 30 t/ha - by 15.91 t/ha, per 40 t/ha - by 23.53 t/ha. This variety under irrigation gave either the planned yield or yield with minor deviation in almost all years.

4. Fertilization per 25 and 30 t/ha tuber yields hardly changed starch content in tubers as compared with the control variant. Only enhanced nutrient statuses optimized for yield of 35 and 40 t/ha have reduced starch content in the tubers by 0.97-1.42%.

5. Tubers in all variants contained nitrates within the maximum permissible concentration. Increased doses of fertilizers resulted in the increased concentration of nitrates in the tubers.

6. Removal per 1 t of tubers and the relevant amount of foliage in the variant with nutrient status per 40 t/ha of tuber yield was 6.86 kg of nitrogen, phosphorus - 2.47 kg, potassium - 9.90 kg, while removal in the control variant was 2.13 kg of nitrogen, phosphorus - 7.55 kg, and potassium - 7.55 kg.

CONCLUSION

Productivity of potatoes depends on the nutrition level and photosynthetic activity of plants during the growing season. The parameters of photosynthetic activity optimized for the formation of tuber yields of 25-40 t/ha can be: leaf surface of 30.23-4780 thousand m^2/ha, the amount of photosynthetic potential for vegetation period - 2225-3629 thousand m^2 × days/ha, PAR utilization coefficient - 1.17-2.58%.

5.90-6.86 kg of nitrogen, 2.23-2.47 kg of phosphorus and 8.81-9.90 kg of potassium can be taken as removal per 1 t of tubers and the relevant amount of foliage. Removal from soil was 27.75 % of nitrogen, 10.02% of phosphorus, and 28.48% of potassium. The assimilated by plants amount of mineral fertilizers added per 25 t/ha tuber yield was 64.84% of nitrogen, 26.47% of phosphorus, and 48.91% of potassium. The

assimilated by plants amount of organic fertilizers added per 30 t/ha tuber yield was 21.30% of nitrogen, 28.52% of phosphorus, and 43.14% of potassium.

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