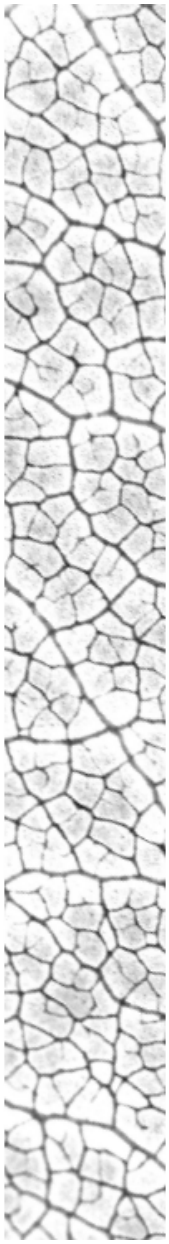

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The efficiency increase of the nutrition element uptake by various potato cultivars grown in one-crop system and in crop rotation

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Abstract
The research conducted in 2012-2015 in the forest-steppe zone of Ukraine proved the feasibility to increase crop capacity and the efficiency of nutrient uptake from fertilizers by various potato cultivars when grown in short-term crop rotation in comparison with one-crop system. Short-term crop rotation with the following crop alternation was suggested: field 1 – barley; field 2 – potato; field 3 – vegetable crops. The introduction of this crop rotation allows to increase potato crop capacity by 43 cwt/ha or by 17.3%. Green manure proved to be an alternative of manure. The use of siderate intermediary crops (oil-bearing radish, white mustard and also oat seed, spring wheat) makes it possible to get 165-273 cwt/ha of biomass due to plant vegetative organs and root system. When siderate biomass is embedded, 63-102 kg of nitrogen, 15-31 kg of phosphorus, 67-108 kg of potassium enter the soil, which is equivalent to 15-25 t/ha of manure, and additional application of mineral fertilizers $N_{45}P_{45}K_{45}$ with them is close in its efficiency to 40 t/ha of manure. The yield increase resulted from green manure application was 16–20% on the average, as compared with the unfertilized plots. When siderates with mineral fertilizers are embedded at a mentioned rate the yield capacity increases by 34–42%. Also the nutrition element uptake from the soil and fertilizers increases (manure, siderates, mineral fertilizers) as well as the coefficient of the use of nutrient substances. The response of the cultivars to the application of organic and mineral fertilizers was determined; the advantage of Shchedryk cultivar over Riviera cultivar was identified.

Keywords: potato, mineral fertilizers, manure, siderates, crop rotation, single-crop

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INTRODUCTION

The issue of the efficient use of fertilizers in potato cultivation has always been relevant, as their application has a serious impact on plant productivity, produce quality and at the same time on tuber cost and their profitability (Polozhenets et al. 2008, Bondarchuk 2007, White 2009).

It is particularly important now, when agriculture is in a critical situation. Very often due to the lack of finance a potato breeder cannot buy enough mineral fertilizers, most of the farmers have no manure, they have to grow potatoes in one-crop system, in particular in the vegetable gardens and homesteads. Taking into account the state of neglect of seed breeding, it becomes clear why potato yields are very low on good chornozem soils (Bondarchuk 2007, Fedoruk et al. 2017, Kononuchenko et al. 2002).

Thus, to determine the conditions for potato production when both tuber yield capacity and the efficiency of fertilizer application increase is important from the theoretical point of view, but mostly for practical potato production.

Analysis of the latest research and publications. Potato differs from most agricultural crops considerably by its biological features: it is very particular to nutrient substances and it responds well to fertilizer application. This crop is superior to grain crops as to the uptake of the main elements of mineral nutrition from the soil. (Gebremedhin et al. 2008, Lorkh 1948, Paul Khurana et al. 2000).

The uptake of nutrients is an integrated indicator which depends not only on the yield amount but also on the biological peculiarities of a cultivar, the amount of applied fertilizers, their form, soil, climatic and meteorological conditions of the zone. If this urgent problem is solved, it becomes possible to determine the

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application rate of organic and mineral fertilizers under planned yield, to slow down agrochemical soil degradation, to maintain ecological balance in a biotic substance cycle (Litinska et al. 2002, Pohorilyi et al. 2007).

The coefficient of the use of soil and fertilizer nutrients is also an important factor which shows the share of nutrition elements used by the plants to form the yield increase in the year of their application. This indicator depends on the form of fertilizer first of all. The coefficient of NPK use from organic fertilizers is much lower than from mineral fertilizers (Bondarchuk 2010).

Thus, proper combination and application of organic and mineral fertilizers are of a great significance for the maintenance of a deficit-free cycle of nutrition elements. Besides, equivalent rates of these fertilizers prove to have an impact on the yield in a similar way, but the nutrient uptake level by the plants increases under their combination.

The purpose of our research was to study the uptake efficiency of different forms of fertilizers by various potato cultivars grown in crop rotation and in one-crop system.

MATERIALS AND METHODS

The experimental work was carried out in 2012-2015 in the conditions of bio-facility of Bila Tserkva NAU, the lands of which are situated in the central area of the Forest-steppe zone of Ukraine.

According to the research examination, the soil of the experimental plot is typical chornozem, low-humus, average sandy loam grain composition, it has weak acidic, almost neutral reaction to soil solution (pH 6.0), average humus content (3.11%), low supply of plants with available nitrogen (98 mg/kg), higher content of exchange potassium (112 mg/kg) and high level of labile phosphorus (172 mg/kg).

One of the most promising ways of supplying potatoes with nutrition elements is to use mineral and organic fertilizers. Nitro-ammophos ($N_{17}P_{17}K_{17}$) was used in the trial, and manure was used as organic fertilizer. The conducted analyses showed that on the average it contained N – 0.33-0.37%, P_2O_5 – 0.25, K_2O – 0.55-0.60%.

However, because of manure deficit, science and potato breeders challenged the task to find alternative means to maintain soil fertility using own reserves. Two groups of siderates were formed by us: grain ones (oat seed, spring wheat) and cabbage ones (white mustard, oil-bearing radish). Manure, nitroammphos, siderates were applied and embedded into the soil in the fall.

To avoid one-crop system in potato cultivation, we studied the feasibility of using short-term crop rotations in homesteads (spring wheat – potato – vegetable crop).

Record plot area is 25 m^2 in a fourfold replication. Field trials were conducted by standard methods (Dospekhov 1985).

In the course of the research, records, observation and soil and plant analyses were made according to methodological recommendations (Kononuchenko 2012).

The coefficient of the nutrient use was calculated with help of a differential method.

The technology of crop cultivation is standard for the area of central Forest-steppe zone.

RESULTS AND DISCUSSION

The research conducted by us convincingly confirms the advantage of crop rotation in the formation of potato yield capacity over one-crop system (**Table 1**).

When potatoes were grown in one-crop system tuber yield in the trial was 249 cwt/ha, whereas in crop rotation the yield was 292 cwt/ha, the increase being 17.3%.

When potato was grown after potato for several years, the yield decrease was recorded, as compared with the cultivation of the crop in crop rotation, in the experiments of foreign researchers which was quite regular (Wright et al. 2017).

According to the statistics of the Institute of Potato Research of Ukraine's NAAS, it is possible to compensate a negative effect of one-crop system by using manure and mineral fertilizers. But in view of manure deficit, soil fertility can be maintained with help of other reserves. In the conditions of the Forest-steppe zone the cheapest biological factor can be this reserve – the use of green manure (Litinska et al. 2002, Molotskyi et al. 2004).

It was found out that siderate crops developed better and accumulated more nutrition elements when they were grown in crop rotation, as compared with those grown after potato continuously for 5 years.

Cabbage siderates predominated by biomass yield capacity in continuous cropping and in crop rotation, and on the average in the years of the research it was 213 and 262 cwt/ha, which was more than that of grain crops by 35 and 44 cwt/ha. However, grain crops predominated by the accumulation of nutrition elements in siderate biomass. If in short-term crop rotation when biomass of cabbage crops is embedded, 66-89 kg/ha of nitrogen, 15-26 kg of phosphorus, 76-78 kg of potassium enter the soil, then when grain crops are used, the soil receives 83-102 kg of nitrogen; 19-31 kg of phosphorus and 81-108 kg of potassium, respectively.

In continuous potato cropping, the accumulation of nutrients in siderate biomass decreased, in particular that of nitrogen and potassium. The content of phosphorus remained almost the same.

Table 1. Effect of potato growing conditions on tuber crop capacity and use of nutrients from fertilizers, average in 2012–2015

Trial variants	Crop capacity, cwt/ha	Increase, cwt/ha	Nutrient uptake with the yield, kg/ha			Nutrients with fertilizers applied, kg/ha			Coefficient of nutrient use, %		
			nitrogen	Phosphorus	potassium	nitrogen	phosphorus	potassium	nitrogen	phosphorus	potassium
One-crop system											
Without fertilizers (control)	199	-	107	34	163	-	-	-	-	-	-
40 t of manure	271	72	146	46	222	140	94	230	28	13	26
40 t of manure + $N_{45}P_{45}K_{45}$	315	116	170	54	258	185	139	275	34	14	35
$N_{45}P_{45}K_{45}$	234	35	126	40	192	45	45	45	43	13	64
Oil-bearing radish	225	26	122	38	185	63	15	69	23	29	31
Oil-bearing radish + $N_{45}P_{45}K_{45}$	258	59	139	44	212	111	63	125	29	16	39
White mustard	229	30	124	39	188	78	23	70	21	21	35
White mustard + $N_{45}P_{45}K_{45}$	262	63	141	45	215	129	73	126	27	14	41
Oat seed	232	33	125	39	190	97	26	67	19	21	40
Oat seed + $N_{45}P_{45}K_{45}$	271	72	146	46	222	152	76	124	26	16	48
Spring wheat	229	30	124	39	188	73	19	88	23	26	28
Spring wheat + $N_{45}P_{45}K_{45}$	268	69	145	46	220	124	67	145	30	17	39
In crop rotation											
Without fertilizers (control)	228	-	123	39	187	-	-	-	-	-	-
40 t of manure	315	87	170	54	258	140	94	230	34	15	31
40 t of manure + $N_{45}P_{45}K_{45}$	361	133	195	61	296	185	139	275	39	16	40
$N_{45}P_{45}K_{45}$	273	45	147	46	224	45	45	45	54	16	82
Oil-bearing radish	266	38	144	45	218	66	15	76	31	41	40
Oil-bearing radish + $N_{45}P_{45}K_{45}$	303	75	164	52	248	111	60	122	37	21	50
White mustard	271	43	146	46	222	89	26	78	26	27	47
White mustard + $N_{45}P_{45}K_{45}$	307	79	166	52	252	134	71	121	32	18	54
Oat seed	273	45	147	46	224	102	31	81	24	24	46
Oat seed + $N_{45}P_{45}K_{45}$	317	89	171	54	260	147	76	126	33	20	58
Spring wheat	271	43	146	46	222	83	19	108	28	37	33
Spring wheat + $N_{45}P_{45}K_{45}$	315	87	170	54	258	128	64	153	37	23	47
Factor (BC): SSD_{05}	12,2										

The application of organic and mineral fertilizers had a great effect on the potato yield capacity.

In the control variant (without fertilizer application) in one-crop system tuber crop capacity was 199 cwt/ha, and in crop rotation – 228 cwt/ha, i.e. it was higher by 29 cwt/ha, or by 14.6%.

Tuber crop capacity in crop rotation, when 40 t/ha of manure were applied, was increased up to 315 cwt/ha, which was higher by 38%, and when $N_{45}P_{45}K_{45}$ were applied separately and with manure its increase was 20 and 58%, respectively, as compared with the control.

When cabbage siderates were used, the yield increase was 18%, and together with mineral fertilizers – 34%, comparing with the control. Being plowed down, grain siderate crops increased yield capacity by 19% and additional $N_{45}P_{45}K_{45}$ application on their background – by 39%, as compared with the variant, in which fertilizers were not applied.

The research material confirmed that the increase of crop capacity resulted from embedded siderates was close to the effect, received from $N_{45}P_{45}K_{45}$ application, and when siderates and mineral fertilizers were applied together – to the effect of 40 t/ha of manure.

The studies of short-term crop rotation and its impact on the efficiency increase of nutrition element use have been conducted by national and foreign scientists for many years (Lorkh 1948, Wright et al. 2017).

However, we established that in continuous potato cropping without fertilizer application plants took up 107 kg of nitrogen, 34 kg of phosphorus, 163 kg/ha of potassium, and in crop rotation these indicators were higher – 123, 39 and 187 kg/ha, which resulted from the accumulation of large yield of tubers due to larger reserves of these substances in the soil.

It has to be stated that in one-crop system of potato cultivation with the application of different forms of fertilizers plants take up not nearly enough of nutrition

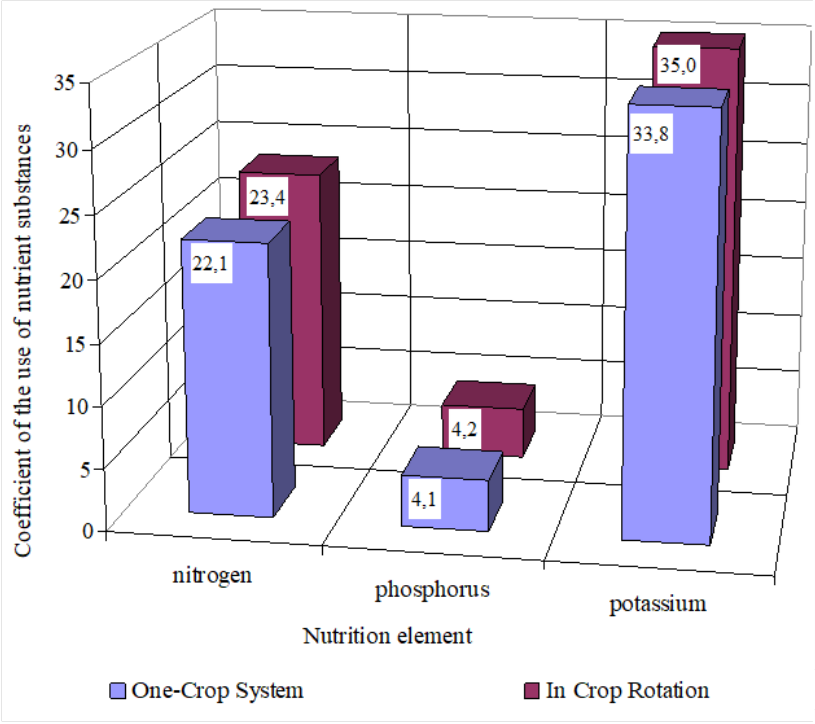

Fig. 1. Effect of potato growing conditions on the coefficient of the use of soil nutrition elements, average in 2012–2015

elements, compared with short-term crop rotation (Lorkh 1948, Lu et al. 2013). This tendency was observed by us in all the years of our experimentation.

Organic and mineral fertilizers, among all the factors studied in the trial, had the most significant effect on the nutrition element uptake by the yield. On the average in the years of experimentation the uptake of nitrogen, phosphorus and potassium by the potato yield in the control variant was 107-123, 34-39, 163-187 kg/ha by elements, respectively; but when 40 t/ha of manure were applied it increased to 146-170; 46-54 and 222-258 kg/ha; when mineral fertilizers were applied on the background of manure it was 170-195; 54-61 and 258-296 kg/ha. With $N_{45}P_{45}K_{45}$ application the indicators were 126-147; 40-46 and 192-224 kg/ha, respectively.

Plowing under of cabbage and grain siderate crops together with $N_{45}P_{45}K_{45}$ application also increased the uptake of main nutrition elements by the potato yield, which varied considerably under continuous cropping and in crop rotation. In the plots where cabbage siderates were used this indicator was 122-146 kg of nitrogen, 38-46 kg of phosphorus and 185-222 kg/ha of potassium, but when grain siderates were applied the uptake increased and ranged from 124 to 147 kg/ha of nitrogen; from 39 to 46 kg/ha of phosphorus and from 188 to 224 kg/ha of potassium. This indicator also increased when mineral fertilizers in combination with cabbage siderates were applied.

The results of the research give all grounds to state that the coefficient of the nutrient use from the soil is very much affected by the elements of potato production technologies (**Fig.1**).

The coefficients of the use of soil nutrition substances changed significantly under continuous potato cropping and in crop rotation. In one-crop system within three years on the average this indicator was 22.1% of nitrogen; 4.1% of phosphorus and 33.8% of potassium. The application of crop rotation made it possible to somewhat increase the coefficients of the use of soil nutrition substances by 01-1.2% on the average by elements, as compared with continuous cropping.

Scientific data confirm that the number of the applied main nutrients and the coefficient of the use of nutrition elements from fertilizers change depending on the kinds of fertilizers. The coefficient of NPK use from organic fertilizers, as compared with mineral ones, is much lower. According to scientists' statistics, the use of nitrogen, phosphorus and potassium from organic fertilizers was 7.7, 3.2 and 6.7%, respectively. When nitrogen and phosphorus with mineral fertilizers were added to manure, applied in term of 100kg/ha of each element, the coefficient of the use of nitrogen from manure increased (Bondarchuk 2010).

In our experiments the largest number of nutrient substances was taken up in the plots where $N_{45}P_{45}K_{45}$ were applied on the background of manure; however the highest coefficient of the use of nitrogen and potassium from fertilizers was recorded in the plots where only $N_{45}P_{45}K_{45}$ were applied. The coefficient of the use of nutrients from manure was lower, as compared with this

Table 2. Cultivar effect on potato yield capacity and its use of nutrition elements from fertilizers, average in 2012–2015

Trial variants	Yield capacity, cwt/ha	Increase, ц/га	Nutrition element uptake with the yield, kg/ha			Nutrition elements with fertilizers applied, kg/ha			Coefficient of nutrient use, %		
			nitrogen	phosphorus	potassium	nitrogen	phosphorus	potassium	nitrogen	phosphorus	potassium
Cultivar Riviera											
Without fertilizers (control)	177	-	89	27	124	-	-	-	-	-	-
40 t of manure	252	75	126	38	176	140	94	230	26	11	23
40 t of manure + $N_{45}P_{45}K_{45}$	297	120	149	45	208	185	139	275	32	13	31
$N_{45}P_{45}K_{45}$	214	37	107	32	150	45	45	45	40	11	57
Oil-bearing radish	205	28	103	31	144	63	15	69	21	25	28
Oil-bearing radish + $N_{45}P_{45}K_{45}$	239	62	120	36	167	111	63	125	27	14	35
White mustard	207	30	104	31	145	78	23	70	19	17	30
White mustard + $N_{45}P_{45}K_{45}$	243	66	122	36	170	129	73	126	25	13	37
Oat seed	210	33	105	32	147	97	26	67	17	17	34
Oat seed + $N_{45}P_{45}K_{45}$	251	74	126	38	176	152	76	124	24	14	42
Spring wheat	208	31	104	31	146	73	19	88	21	22	25
Spring wheat + $N_{45}P_{45}K_{45}$	251	74	126	38	176	124	67	145	29	16	36
Cultivar Shchedryk											
Without fertilizers (control)	209	-	105	31	146	-	-	-	-	-	-
40 t of manure	304	95	152	46	213	140	94	230	34	16	29
40 t of manure + $N_{45}P_{45}K_{45}$	356	147	178	53	249	185	139	275	39	16	38
$N_{45}P_{45}K_{45}$	258	49	129	39	181	45	45	45	53	17	77
Oil-bearing radish	248	39	124	37	174	63	15	69	29	41	36
Oil-bearing radish + $N_{45}P_{45}K_{45}$	289	80	145	43	202	111	63	125	36	21	46
White mustard	250	41	125	38	175	78	23	70	23	25	38
White mustard + $N_{45}P_{45}K_{45}$	293	84	147	44	205	129	73	126	31	18	49
Oat seed	254	45	127	38	178	97	26	67	21	23	39
Oat seed + $N_{45}P_{45}K_{45}$	304	95	152	46	213	152	76	124	32	19	53
Spring wheat	252	43	126	38	176	73	19	88	25	35	28
Spring wheat + $N_{45}P_{45}K_{45}$	302	93	151	45	211	124	67	145	36	22	43
Factor (AC): SSD_{05}	15,2										

indicator when organic and mineral fertilizers were applied together.

White mustard was the best at accumulating nutrition elements from cabbage siderate crops; however oil-bearing radish had the highest coefficient of the use of nutrient substances. Oat seed was the best at accumulating nutrition elements among grain crops, but spring wheat had the highest coefficient of the use.

When mineral fertilizers and green manure were applied in combination the number of nutrition elements in the soil increased considerably as compared with separate application, but the coefficients of the use of nitrogen and potassium were lower than from mineral fertilizers and higher from organic fertilizers.

It is necessary to state that scientists have established the difference among various cultivars not only by yield capacity but also by unlike influence on the use of nutrition elements from the soil and fertilizers (Pohorilyi et al. 2007, Fedoruk et al. 2017).

The analysis of the crop capacity of the cultivars, used in our trials on the average in 2012–2015, showed that cultivar Shchedryk formed the highest yield capacity in the control variant, which was 209 cwt/ha, i.e., it was higher than that of cultivar Riviera by 32 cwt/ha or 18% (**Table 2**).

When 40 t/ha of manure were applied the crop capacity increase of cultivar Riviera was 75 cwt/ha and that of cultivar Shchedryk – 95 cwt/ha, when 45 kg of NPK were added to manure – 120 and 147 cwt/ha, respectively. Thus, cultivar Shchedryk had the best response to manure and to mineral fertilizers on its background. As to the effect of mineral fertilizers, cabbage and grain siderates alone and in combination with 45 kg of NPK, the yield capacity increase was identical in both cultivars, and a bit higher in favor of cultivar Shchedryk.

The analysis of the received results confirms that cultivar Riviera takes up less mineral nutrition elements with the yield, as compared with cultivar Shchedryk,

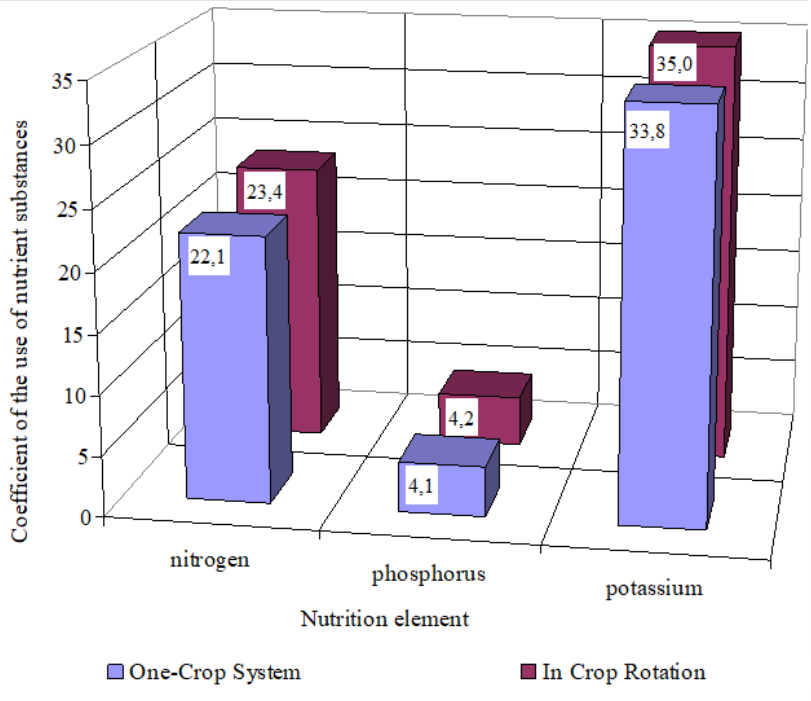

Fig. 2. Efficiency of the use of soil nutrition elements by various potato cultivars, average in 2012–2015

which is due to its biological peculiarities and yield capacity. On the average during three years the uptake of nitrogen in the trial ranged within 87-149 kg/ha in cultivar Riviera, and in cultivar Shchedryk – 105-178 kg/ha, the uptake of phosphorus was 27-45 and 31-53, and that of potassium – 124-208 and 146-249 kg/ha, respectively.

It was found out that cultivars responded to fertilizer application in a different way. Within three years in the trial the total uptake of nutrition elements by the potato yield in the control variant for cultivar Riviera was 240 kg/ha, and for cultivar Shchedryk – 282 kg/ha; however, when 40 t/ha of manure were applied, it increased by 42 (45%), when organic and mineral fertilizers were applied in combination (background + $N_{45}P_{45}K_{45}$) – by 67 (71%), and when only mineral fertilizers were applied ($N_{45}P_{45}K_{45}$) – by 20 (23%), respectively by cultivars.

When cabbage siderates were used, total uptake of the main nutrition elements increased by 16% in cultivar Riviera and by 19% in cultivar Shchedryk, when $N_{45}P_{45}K_{45}$ were applied on the background of siderates – by 36 and 39%. When grain siderates were plowed under, the uptake increased by 18 and 21%, when mineral fertilizers and siderates were applied in combination – by 41 and 45%, respectively by cultivars, as compared with the control.

The research results, received and processed methodologically by us, give every ground to state that the use of soil nutrients by the studied cultivars was different (**Fig. 2**).

Cultivar Shchedryk was characterized with more intensive use of soil nutrients, as compared with Riviera cultivar. When in the control variant on the average during three years the coefficient of the use of nitrogen, phosphorus and potassium from the soil by the first cultivar was 20.8; 3.6 and 30.0%, then by the second cultivar – 24.8; 4.6 and 35.0%, respectively.

If not to take into account the use of nutrition substances by potato from different forms of fertilizers (the issue was considered above), it should be stated that the studied cultivars responded to the assimilation of the nutrition elements identically. The received experimental data show a higher coefficient of the use of nutrients from the soil and fertilizers by cultivar Picasso, which, as it has been mentioned earlier, is associated with its biological peculiarities.

CONCLUSION

1. It was established that the use of short-term crop rotation facilitated the increase of potato yield capacity, as compared with continuous cropping, by 43 cwt/ha, or by 17.3 %.
2. It has been confirmed that in crop rotation the coefficient of the use of nutrition substances from manure increases: nitrogen – by 6%, mineral fertilizers on the background of manure – by 3%, and mineral fertilizers alone ($N_{45}P_{45}K_{45}$) – by 11%; phosphorus – by 2; 2 and 3%; potassium – by 5; 5 and 18%, respectively.
3. It was found out that when cabbage siderates were used in crop rotation, potato yield capacity increased by 40 cwt/ha, grain siderates – by 44, and when mineral fertilizers ($N_{45}P_{45}K_{45}$) were

applied on their background – by 77 and 88 cwt/ha, respectively.

4. The conducted research proves that when siderates are used yield capacity increase is close to the effect of mineral fertilizers at the rate $N_{45}P_{45}K_{45,}$ and when siderates in combination with mineral fertilizers are applied – to the effect of 40 t/ha of manure.
5. The advantage of cultivar Shchedryk was recorded both by yield capacity and by the use of nutrition elements from the soil and fertilizers. Cultivar Riviera is behind it by these indicators.

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