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The effectiveness of modern mechanized potato cultivation technologies

Mikhail Karpukhin
Vegetable and Fruit Growing Department n.a. Prof. N.F. Konyaev
Ural State Agrarian University
Ekaterinburg, Russia
mkarpukhin@yandex.ru

Igor Krupskiy
Executive director of "Uralskiy kartofel" Selection and Seed-production Company
Sverdlovsk Region, Russia
krupski-igor@yandex.ru

Fode Keyta
Faculty of Agricultural Technologies and Land Management
Ural State Agrarian University
Ekaterinburg, Russia
keitafode2016@gmail.com

Yevgeny Yushkin
Faculty of Agricultural Technologies and Land Management
Ural State Agrarian University
Ekaterinburg, Russia
djonio13@mail.ru

***Abstract*— Studies on the effectiveness of modern mechanized technologies of potato cultivation were carried out under production conditions in company "Belorechensky" Agro-Industrial Plant of the Beloyarsky urban district of the Sverdlovsk Region. In the experiments, one of the most common and highly productive varieties of potato – Impala variety – was used. The studied variants included separate ridge and combined ridge methods and bed technology with different areas of potato nutrition. According to the results of field experiments, it was found that, on average, over three years of research, the yield of seed potato varied from 18.5 to 23.4 t/ha in different planting variants. Among ridge planting technologies, the highest yield of 23.4 t/ha was recorded when using a separate technology. It is also the highest yield among all methods used. Among bed planting technologies, the highest yield of 22.9 t/ha was noticed when using 3-row technology. When comparing ridge and bed planting technologies, it is worth noting that the marketability of tubers when using ridge technologies was higher than when using the bed ones. Among ridge planting technologies, the most cost-effective due to lower production costs is a combined method. Among bed technologies, 3-row method is the most cost-effective due to the high gross output cost and low production costs. When comparing ridge and bed planting technologies, it is worth noting that combined ridge one is the most cost-effective among all these technologies due to the lowest production costs. According to the results of experiments, it was established that all studied cultivation technologies have a high level of profitability, except for 4-row bed technology. However, in order to reduce costs and increase the net income of enterprise, we recommend using 3-row bed technology and combined ridge technology.**

***Keywords*— potato, ridge technology, combined technology, bed technology, comparative analysis, phenology, biometrics, yield, cost effectiveness, product quality.**

I. INTRODUCTION

Potato is an important food and technical crop which occupies one of the leading places in the global crop production. Potato is the raw material for many industrial productions where starch, alcohol, artificial rubber, plastics, lactic acid, dextrin, glue and many other things are produced. Tubers and industrial wastes are used for livestock feeding (1 kg of potato contains 0.3 feed units).

In the Russian Federation, potato is cultivated on the area of more than 2.2 million hectares, the largest volumes of this production are concentrated in the Central, Volga and Siberian Federal Districts. In recent years, in agricultural organizations and peasant (farmer) households there has been a tendency to increase the area of potato planting and its yield. However, it should be noted that, based on modern machine technology, potato cultivation in the public sector is carried out on the area of 388 thousand hectares what is 17.8% of the total planted area in farms of all categories. The remaining 82.2% fall on farm household sector where small-scale production dominates, with limited opportunities for mechanization and a significant share of manual labor.

The Dutch technology includes pre-planting rotary tillage to a depth of 2-3 cm, planting tubers to a depth of 6 cm, carrying out mechanical processing with surface layer tillage to a depth of 2-3 cm, forming a high ridge 10-15 days after planting and two-three days before emergence or when plants reach a height of 5-7 cm. This technology involves the use of KFG-3.6 rotary cultivator and KVK-4 cultivator which helps to form ridges.

A bed-strip technology allows obtaining high yield in the conditions of high or insufficient moisture through special preparation of the field for planting tubers during the entire crop rotation, as well as through its cultivating in wide (140) and high (up to 35 cm) beds with a planting pattern of 110+30 cm. It has several advantages over potato cultivation on ridges. Massive beds are less affected by the environment. At high temperatures, the soil here heats up in a less degree and better retains moisture. With increased humidity, a higher bed allows better drainage of excess moisture from tuber layer. Beds are destroyed by heavy rains more rarely than ridges. This technology allows weed control in rows and spacings during the entire processing period what completely eliminates the use of herbicides for the cultivation of potato and previous crops. Localization of mineral and organic fertilizer distribution reduces the required amount at least 2 times.

Grimme technology includes cleaning the soil layer at the depth of tubers from soil lumps and stones with loosening the subsurface horizon below the level of tubers without removing this layer to the surface, as well as chemical weed control – mechanical treatment of plantings is carried out only when necessary (spreading beds, strong soil compaction). The soil is prepared in two steps before planting in the spring. First, furrows are made to a depth of 25-30 cm at the tractor's track width to form a ridge 140 cm wide with simultaneous loosening of the subsoil horizon to a depth of 10-15 cm using chisel shovels. Then the mass of formed bed is divided by separating machine into three

fractions: crumbly soil comes through the gaps of elevators again on the bed; stones, soil lumps and other foreign objects 30–100 mm in size are placed by a cross conveyor in formed furrow (in tractor's track); and objects larger than 100 mm in size are gathered in a bunker and stacked in headland. For this technology, GO-2 furrow maker and bed former and SU-1.4 separator are used. Plantings are treated with Zenkor herbicide – the norm is 0.7-1.0 kg of the active substance in an aqueous solution (250-300 L/ha) in the period of emergence with the help of a boom sprayer. Planting is performed using KSM-4 planter, cleaning – using KKU-2A combine.

A ridge (European) technology with 75 cm row spacing for clay soils is based on machine complexes produced by the joint Russian-German enterprises "Eurotechnika" and "Kolnag". These companies offer manufacturers a full range of machines and provide their service.

The complex includes: Zirkom 7/300 (Eurotechnika) and Rabewerk RKE 250/300 ("Kolnag") rotate cultivators with vertical working parts (dominators) which are used for pre-plating tillage; VL 20 KLZ ("Eurotechnika") and Hassia KLS 4 BZS ("Kolnag") potato planters; RF-4 ("Eurotechnika") and Rumpstad RSF 2000 ("Kolnag") rotary hillers-ridgers; Amazone UG-3000 ("Eurotechnika") and Agrifacl 302 4 H ("Kolnag") sprayers; DR-1500 ("Eurotechnika") and AVR-220B ("Kolnag") potato harvesters.

In addition to the equipment for potato cultivation and harvesting, these organizations supply equipment for potato storages: loading elevators, sorting tables, pick-ups, ventilation equipment. MTZ-80, MTZ-82 and LTZ-155 universal row wheel tractors are used as power-producing tools for all these devices [1].

In domestic practice there are several types of mechanized technologies for potato production. However, there are conflicting opinions in the system of adaptive landscape farming on the use of different mechanized technologies for potato production in different regions of Russia, on different soil types with different texture, therefore, a comparative analysis for regions of the Russian Federation and the implementation of adapted resource-saving modern mechanized technologies of potato growing are extremely urgent problems at the present stage which require early solution. [2-4] Improving and implementation of such technologies will bring such production to a new modern level, will improve product quality, will significantly reduce the dependence on imports and ensure the country's food security for potato [5].

II. EXPERIMENTAL

Field experiments were conducted in AO "Belorechensky" Agro-Industrial Plant, Beloyarsky urban district, Sverdlovsk Region, on podzolized heavy loamy chernozem (Table 1).

TABLE I. SOIL AGROCHEMICAL CHARACTERISTICS

Soil	Soil texture	Depth of tillage, cm	Content, mg for kg of soil								pH
			N	P_2O_5	K_2O	*Ca*	*Mg*	*Mn*	*Cu*	*Zn*	
Podzolized chernozem	Heavy loamy	28.0-30.0	140	140	180	21.3	5.0	30	8.9	2.8	4.8

Study object – potato, modern technology of potato cultivation.

Study purpose is to conduct a comparative assessment of mechanized seed potato cultivation technologies.

The scheme of experiment 1:

1 variant – Separate ridge technology (k);

2 variant – Combined ridge technology.

The scheme of experiment 2:

1 variant – Bed technology, planting in 2 rows (k);

2 variant – Bed technology, planting in 3 rows;

3 variant – Bed technology, planting in 4 rows.

The placement of variants during experiments was one-layered, systematic. Replication during experiments was fourfold.

The length of test plot was 50 m, width – 60 m, and the area was 300 m2. The surveys were made from the registration plot of 4.2 m^2.

In these experiments, Impala potato variety was used. Impala is a very early ripening table variety. Marketable yield is from 18 to 26 tons per hectare, maximum yield is 36.7 tons per hectare. Root crops reach full technical maturity in 65-75 days from emergence. The plant is upright, well branching, consists of 4-6 crops. The plant is vigorous, densely leafy. The leaves are bright green, small, with a slight waviness along the edge. Abundant blooming, flowers in trusses of 6-10 pieces. 6-10 tubers are usually formed in the rhizome of each plant.

Oval root crops of large size (80-160 g). Skin is thin, light. Flesh is creamy or light yellow. Starch content 10.5-14.6%. Marketability 89-94%, storability 90%.

The variety is resistant to potato nematode, the causative agent of potato cancer, susceptible to late blight and rhizoctoniosis, poorly affected by viral diseases and common scab.

The following agrotechnical steps were carried out during the experiments:

1. Previous crop: perennial herbs;
2. Mineral fertilizers application in the fall – potassium chloride 4 c/ha;
3. Fall plowing using "Lemken" reversible plow;

Mineral fertilizers application in spring – diammophos 4 c/ha, ammonium nitrate 2 c/ha;

4. Planting variants:
   - 4.1. Ridge - separate - cultivation and planting at seeding (tractor - CASE210, cultivator - Baselier, planter - Cramer);
   - 4.2. Ridge - combined - cultivation and planting at seeding with ridge formation (tractor - CASE210, cultivator - Baselier, planter - Wifo, ridge-forming plate - Baselier);

4.3. Bed - in 2 rows - cultivation and planting at seeding with bed formation (tractor - Fendt 936, cultivator - Baselier, planter - Wifo, bed-forming plate - Baselier);

4.4. Bed - in 3 rows – cultivation at seeding and bed formation (tractor - Fendt 936, cultivator - Baselier, planter - Wifo, bed-forming plate - Baselier), manual planting;

4.5. Bed - in 4 rows - cultivation at seeding and bed formation (tractor - Fendt 936, cultivator - Baselier, planter - Wifo, bed-forming plate - Baselier), manual planting.

5. Hilling - only for the first variant – separate ridge technology in fourfold replication (tractor - Case Puma 155, hiller - Baselier);
6. Care of crops:

6.1. Treatment with agents – Shirlan 0.3 L/ha, Titus 0.05 L/ha, Trend 0.2 L/ha (Self-propelled sprayer - Hardi Alpha);

6.2. Treatment with agents – Revus 0.6 L/ha, Scor 0.5 L/ha, Isobion 1 L/hha (Self-propelled sprayer - Hardi Alpha);

6.3. Treatment with agents - Scor 0.3 L/ha, Infinito 1.2 L/ha, Karate 0.2 L/ha (Self-propelled sprayer - Hardi Alpha);

6.4. Treatment with agents - Reglon 2 L/ha, Shirlan 0.3 L/ha (Self-propelled sprayer - Hardi Alpha).

7. Harvesting using DR-1500 harvester;
8. Potato sorting using Miedema equipment.

III. RESULTS AND DISCUSSION

During our research, phenological observations were conducted on the growth and development of potato plants using various cultivation technologies. At present, in the Middle Urals, in connection with new domestic and foreign equipment (tractors, agricultural machines, machine complexes), ridge and bed technologies are used for potato cultivation. Depending on the technology, different conditions and factors appear that affect the growth and development of plants.

Our field experience had the basis of the best potato farming enterprise in the Sverdlovsk region, “Belorechensky” Agro-Industrial Plant, which is the base Department of Agricultural Technology and Land Management Faculty of our University in connection with the high power supply of equipment, required numerous turns and passes, according to the methodology we developed for this research [5-7].

During all years of research, planting was carried out in the first half of June, depending on weather conditions, in moist soil at the optimum temperature for the growth and development of potato.

So, in 2015, due to a large amount of precipitation at the beginning of the month, planting was held on June 18, and in 2016, with a warm beginning of the month, it was carried out on June 3. The beginning of 2017 was rainy, so planting was held on June 14.

Planting at the beginning of the first and second decade of June in 2016 and 2017 made all crops under all technologies raise by the end of the month. In 2015, due to a later planting, crops appeared in the first decade of July.

Budding stage in 2016 and 2017 was at the end of the first decade of July and at the beginning of the second decade. In 2015, budding also began later – in late July.

Blooming stage in all years of research came either at the same time as budding stage, or a week later.

The beginning of tuberization in 2016 was already at the end of July what can be explained by earlier planting period. In 2015 and 2017, the beginning of tuberization occurred at the end of the first decade of August and in the middle of the second decade.

In all years of research, harvesting was carried out using continuous lifting method in the second half of September.

To study the growth rate and duration of growing season of potato plants of Impala variety under different cultivation technologies, we calculated the duration of phases and interphase periods of potato plants for all studied variants.

Our research showed that due to the sufficient amount of moisture in soil and optimum temperature for the growth and development of potatoes, the development of plants was within normal.

On average, over three years of research, it has been established that all phases of plant development occurred regardless planting technology.

So, crop emergence occurs 18 days after planting. Budding stage starts 35 days after planting. Blooming stage occurs 41 days after planting. Tuberization stage occurs 55 days after planting. Harvesting was carried out on the same day – 95 days after planting.

On average, over three years of research, it was established that the height of potato plants, depending on cultivation technology, ranged from 49 to 51 cm (Table 2), and it was lower when using ridge planting technologies by 1-2 cm than when using bed ones.

Many researchers associate the yield of tubers with the number of stems per area unit. This method is common in the countries of Western Europe and the USA, and all mechanized potato cultivation technologies in these countries are aimed at creating the optimal number of stems per hectare.

So, it was established that the planting density of seed potatoes should be at least 55 thousand tubers, or 220 thousand productive stems per 1 hectare. Given this fact, we calculated the number of stems per plant for recalculation per area unit.

The number of stems per plant varied from 5 to 7, and it was lower when using combined ridge planting technology than when using a separate one. Among bed planting technologies, the number of stems under 4-row technology was the smallest, and 2- and 3-row technologies showed the same result.

We calculated the number and length of leaves per plant for all studied variants using the parameters of the assimilation surface of potato plants.

The number of leaves per plant varied from 12 to 16, and despite the fact that there were more stems when using separate ridge planting technology, there were fewer leaves than when using combined ridge technology. Among bed planting technologies, the largest number of leaves was noticed when using 2-row technology. 3- and 4-row ones showed the same result.

The length of leaves ranged from 8 to 16 cm on average and was the greatest when using both ridge planting technologies and 2-row bed technology; the difference was only 1 cm. 3- and 4-row technologies showed the length of leaves almost two times smaller.

TABLE II. BIOMETRIC PARAMETERS OF POTATO PLANTS DEPENDING ON CULTIVATION TECHNOLOGY, AVERAGE FOR 2015-2017

Variant	Plant height, cm	Number of stems per plant, pcs	Number of leaves per plant, pcs	Length of leaves per plant, cm
1(k)	49	7	15	16
2	50	6	16	15
1(k)	51	6	16	15
2	51	6	12	9
3	51	5	12	8

According to the results of biometric analysis, it can be concluded that the above-ground part is developed more when using combined ridge and 2-row bed cultivation technologies.

Our research has shown that the yield of seed potato in 2015 varied from 15 to 19.3 t/ha. Among ridge planting technologies, the combined one had yield higher than a separate one, the yield amounted to 18 t/ha. Among bed planting technologies, the highest yield was observed when using 3-row planting technology; it was equal to 19.3 t/ha. 2- and 4-row technologies showed the same yield of 15 t/ha. The highest marketability of 91% was noticed for both ridge technologies, as well as for 2-row bed one. Least significant difference$_{05}$ = 5.28 t/ha.

In 2016, yield varied from 18.6 to 24.2 t/ha. Among ridge planting technologies, the highest yield was noticed when using separate technology and amounted to 23.8 t/ha. Among bed planting technologies, the highest yield of 24.2 t/ha was observed when using 4-row technology. This yield is also the highest among all technologies. 2- and 3-row technologies showed the same yield of 22.7 t/ha. The highest marketability of 91% was noticed for both ridge technologies, as well as for 2-row bed one. Least significant difference$_{05}$ = 0.6 t/ha.

In 2017, yield varied from 17.9 to 29.2 t/ha. Among ridge planting technologies, the highest yield was noticed when using separate technology and amounted to 29.2 t/ha. Among bed planting technologies, the highest yield was recorded when using 3-row technology; it was equal to 26.7 t/ha. The highest marketability of 93% was observed for the combined ridge planting technology. It is also important to note separate ridge and 2-row bed technologies with the marketability 2-4% lower – 91% and 89%, respectively. Least significant difference$_{05}$ = 9.1 t/ha.

For an average of three years of research (Table 3), the yield of seed potato varied from 18.5 to 23.4 t/ha in different planting variants.

TABLE III. POTATO YIELD DEPENDING ON CULTIVATION TECHNOLOGY FOR 2015-2017

№.	Variant	Yield, t/ha	Increase		Marketability, %
			t/ha	*%*	
1	Separate ridge technology (k)	23.4	-	100	91
2	Combined ridge technology	21.3	-2.1	92	92
1	2-row bed technology (k)	18.5	-4.9	79	88
2	3-row bed technology	22.9	-0.5	98	87
3	4-row bed technology	20.1	-3.3	86	87

Among ridge planting technologies, the highest yield of 23 t/ha was recorded when using separate one. It is also the highest yield among all technologies. The yield of combined technology was lower by 2.1 t/ha and amounted to 21.3 t/ha. The marketability on both technologies was almost the same – 91% for separate technology and 92% for combined one.

Among bed planting technologies, the highest yield was noticed when using 3-row technology; it was equal to 22.9 t/ha. Yield of 4-row technology amounted to 20.1 t/ha, and of 2-row one – to 18.5 t/ha. The marketability for all bed technologies was almost the same. It was 1% higher – 88% – for 2-row technology, and 3- and 4-row methods showed the same value of 87%.

When comparing ridge and bed planting technologies, it is worth noting that the marketability of tubers when using ridge technologies is higher than of bed ones.

In our studies, we evaluated the cost effectiveness of various seed potato cultivation technologies currently used in the advanced farms of our region (Table 4).

TABLE IV. COST EFFECTIVENESS OF SEED POTATO CULTIVATION 2015-2017

Variant	Yield, t/ha	Production costs, RUR/ha	Gross output cost, RUR/ha	Prime costs, RUR/ha	Net income, RUR/ha	Profitability, %
Separate ridge technology (k)	23.4	221070.4	486833.3	9764.6	303203.6	137
Combined ridge technology	21.3	179524.9	441000.0	8657.2	295075.1	164
2-row bed technology (k)	18.5	179157.1	403666.7	9659.7	252882.9	140
3-row bed technology	22.9	201641.8	483500.0	8895.7	318444.9	158
4-row bed technology	20.1	312324.0	433666.7	15530.1	179182.7	57

On average, over three years of research, our calculations showed that production costs ranged from 179 thousand RUR/ha to 312 thousand RUR/ha. The lowest production costs among ridge planting technologies were observed when using combined technology and amounted to 179 thousand RUR/ha. When using separate technology, costs were higher by 42 thousand RUR/ha and amounted to 221 thousand RUR/ha. Among bed planting technologies, the lowest production costs were observed when using 2-row technology and amounted to 179 thousand RUR/ha. It is the lowest value for this parameter among all studied technologies. 3-row technology had production costs higher

by 22 thousand RUR/ha which amounted to 201 thousand RUR/ha. 4-row technology had production costs higher by 133 thousand RUR/ha which amounted to 312 thousand RUR/ha. It is the highest value for this parameter among all studied technologies.

The cost of gross output ranged from 403 thousand RUR/ha to 486 thousand RUR/ha. The highest gross output cost among ridge planting technologies was noticed when using separate technology and amounted to 486 thousand RUR/ha. It is the highest value for this parameter among all studied technologies. Costs for combined technology were lower by 45 thousand RUR/ha and amounted to 441 thousand RUR/ha. Among bed planting technologies, the highest gross output cost was noticed when using 3-row technology and amounted to 483 thousand RUR/ha. 4-row technology showed the gross output cost lower by 50 thousand RUR/ha which amounted to 433 thousand RUR/ha. 2-row technology showed the gross output cost lower by 80 thousand RUR/ha which amounted to 403 thousand RUR/ha. It is the lowest value for this parameter among all studied technologies.

Prime costs varied from 8.600 RUR/ha to 15.500 RUR/ha. The highest costs among ridge planting technologies were noticed when using separate technology; they amounted to 9.700 RUR/ha. It is the highest value for this parameter among all studied technologies. Costs for combined technology were lower by 1.100 RUR/ha and amounted to 8.600 RUR/ha. It is the lowest value for this parameter among all studied technologies. Among bed planting technologies, the highest costs were recorded when using 4-row technology and amounted to 15.500 RUR/ha. Costs for 2-row technology were lower by 5.800 RUR/ha and amounted to 9.600 RUR/ha. Costs for 3-row technology were lower by 6.600 RUR/ha and amounted to 8.800 RUR/ha.

Our calculations showed that net income ranged from 179 thousand RUR/ha to 318 thousand RUR/ha. The highest net income among ridge planting technologies was noticed when using separate technology and amounted to 303 thousand RUR/ha. Net income from combined technology was lower by 8 thousand RUR/ha and amounted to 295 thousand RUR/ha. Among bed planting technologies, the highest net income was recorded when using 3-row technology; it amounted to 318 thousand RUR/ha. It is the highest value for this parameter among all studied technologies. Net income from 2-row technology was lower by 66 thousand RUR/ha and amounted to 252 thousand RUR/ha. Net income from 4-row technology was lower by 139 thousand RUR/ha and amounted to 179 thousand RUR/ha. It is the lowest value for this parameter among all studied technologies.

Profitability ranged from 57 to 164%. The highest profitability among ridge planting technologies was observed when using combined technology; it was 164%. It is the highest value for this parameter among all studied technologies. Profitability of separate technology was lower by 27% and amounted to 137%. Among bed planting technologies, the highest profitability was noticed when using 3-row technology; it was 158%. 2-row technology showed the profitability lower by 18%; it was 140%. 4-row technology showed the profitability lower by 101%; it was 57%. It is the lowest value for this parameter among all studied technologies.

Thus, the most cost-effective technology among ridge planting ones is the combined technology due to lower production costs. Among bed technologies, 3-row technology is the most cost-effective due to the high cost of gross output and low production costs.

When comparing ridge and bed landing technologies, it is worth noting that combined ridge technology will be the most cost-effective among all the technologies due to the lowest production costs.

IV. Conclusion

1. Phenological phases and the duration of interphase periods in potato plants grown for seeding does not depend on the cultivation technologies used in experiments.
2. Plant height ranged from 49 to 51 cm, and it was when using ridge planting technologies lower by 1-2 cm than when using bed ones. The number of stems per plant varied from 5 to 7. 3- and 4-row bed technologies showed the smallest number of stems; the difference was 1-2 stems. The number of leaves per plant varied from 12 to 16; 3- and 4-row bed technologies showed the number less by 3-4 pieces than on the others. The length of leaves ranged from 8 to 16 cm on average and was the greatest when using both ridge planting technologies and 2-row bed technology; the difference was only 1 cm. 3- and 4-row technologies showed the length of leaves almost two times smaller.
3. For an average of three years of research, the yield of seed potatoes varied from 18.5 to 23.4 t/ha. Among ridge planting technologies, the highest yield of 23.4 t/ha was recorded when using separate technology. It is also the highest yield among all technologies. Among bed planting technologies, the highest yield was noticed when using 3-row technology; it amounted to 22.9 t/ha. When comparing ridge and bed planting technologies it is worth noting that the marketability of tubers when using on the ridge technologies was higher than when using bed ones.
4. Among ridge planting technologies, the most cost-effective was the combined technology due to lower production costs. Among bed technologies, 3-row one was the most cost-effective due to the high cost of gross output and low production costs. When comparing ridge and bed planting technologies, it is worth noting that combined ridge technology will be the most cost-effective among all the technologies due to the lowest production costs.
5. According to the results of research, it should be noted that all studied cultivation technologies have a high profitability level, except for 4-row bed technology. However, in order to reduce costs and increase the net income of enterprise we recommend using 3-row bed technology and combined ridge technology.

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