Brazilian Journal of Biology®

ISSN 1519-6984 (Print)
ISSN 1678-4375 (Online)

Original Article

Features of the choice of potato (*Solanum tuberosum*) varieties when growing two harvests in the temperate zone of Russia

Características da escolha de variedades de batata (*Solanum tuberosum*) ao cultivar duas safras na zona temperada da Rússia

I. N. Gasparyan[a]*, A. G. Levshin[a,b], O. N. Ivashova[b], N. F. Deniskina[b] and Sh. V. Gasparyan[b]

[a] All-Russian Institute of Agrochemistry named after D. Pryanishnikov, Moscow, Russian Federation

[b] Russian State Agrarian University - Moscow Timiryazev Agricultural Academy, Moscow, Russian Federation

Abstract

The development of potato plants during the cultivation of two crops occurs in a short period. At the same time, field conditions change and do not repeat over time. The formation of the crop during the cultivation of two crops in the Moscow region turns out to be in different growing conditions: the first crop falls on a long day and moderate temperatures, as well as sometimes returning frosts, the second crop falls on a short day and high temperatures, as well as a lack of moisture. The purpose of our research was to substantiate the choice of varieties for cultivation of two crops. Its solution is possible with a certain guaranteed efficiency based on the theory of statistical games. The research was carried out at the Vegetable Experimental Station of the Moscow State Agrarian University named after K.A. Timiryazev and at the Central Experimental Station of the Barybino Research Institute of Agrochemistry of the Moscow Region 2017-2022. The experiment was laid by the method of random placement of plots, the predecessor was a bow. The planting density is 47.6 thousand plants per 1 ha. Germinated tubers were used for planting during the first planting of a large fraction, during the second planting of an average fraction. The second landing was carried out on the vacant place after cleaning the first landing. The cultivation technology is standard. Cleaning was carried out in mid-July and at the end of September. Statistical game theory was used to determine the choice of a variety with a certain guaranteed efficiency. As a result of forecasting in critical climatic conditions, it is necessary to plant 1 crop – varieties Riviera and for 2 crops – varieties Luck.

Keywords: potato, variety, game theory, probability of choice.

Resumo

O desenvolvimento das plantas de batata durante o cultivo de duas culturas ocorre em um curto período. Ao mesmo tempo, as condições de campo mudam e não se repetem ao longo do tempo. A formação da safra durante o cultivo de duas safras na região de Moscou ocorre em condições de cultivo diferentes: a primeira safra cai em um dia longo e com temperaturas moderadas, além de às vezes retornar geadas, a segunda safra cai em um curto dia e altas temperaturas, além de falta de umidade. O objetivo da pesquisa foi fundamentar a escolha de variedades para cultivo de duas culturas. A sua solução é possível com uma certa eficiência garantida baseada na teoria dos jogos estatísticos. A pesquisa foi realizada na Estação Experimental de Vegetais da Universidade Agrária Estadual de Moscou em homenagem a K.A. Timiryazev e na Estação Experimental Central do Instituto de Pesquisa Barybino de Agroquímica da Região de Moscou 2017-2022. O experimento foi realizado pelo método de colocação aleatória de parcelas, seu antecessor foi o arco. A densidade de plantio é de 47,6 mil plantas por 1 ha. Os tubérculos germinados foram utilizados para plantio no primeiro plantio da fração grande, e no segundo plantio da fração média. O segundo pouso foi realizado no local vago após a limpeza do primeiro pouso. A tecnologia de cultivo é padrão. A limpeza foi realizada em meados de julho e no final de setembro. A teoria estatística dos jogos foi utilizada para determinar a escolha de uma variedade com certa eficiência garantida. Como resultado da previsão em condições climáticas críticas, é necessário plantar 1 safra – variedades Riviera, e para 2 safras – variedades Sorte.

Palavras-chave: batata, variedade, teoria dos jogos, probabilidade de escolha.

1. Introduction

The idea of obtaining two potato crops is not new, two or more potato crops are obtained in southern counties, in Egypt, Syria, China, etc. (Birch et al., 2012; Ivashova et al., 2021). The possibility of obtaining a second potato crop in the temperate zone (third light zone) in Russia has become possible only in recent years due to climate warming

*e-mail: irina150170@yandex.ru
Received: September 8, 2023 – Accepted: December 22, 2023

(Gasparyan et al., 2021). According to scientists, over the past 100 years, there has been an increase in the average annual temperature for the whole Earth by 0.75 °C, for the territory of Russia as a whole by 1.0 °C (Gringof and Pavlova, 2013; Nemecek et al., 2012; Delgado et al., 2023), and according to A. Frolov, the head of Roshydromet, the average annual temperature in Russia is growing 2.5 times faster than in the whole world (Diykanova et al., 2020).

Global climate change provides unique advantages for cultivating this valuable crop and getting two potato harvests in one growing season. This is possible due to an increase in the sum of effective temperatures in the region and the growing season, which begins earlier in spring and ends at a later date (Gringof and Pavlova, 2013; Nemecek et al., 2012).

The development of potato plants during the cultivation of two harvests occurs in a short period, early varieties are suitable for cultivation. Tuber formation in a temperate zone when cultivating two crops turns out to be in different conditions: the first crop falls on a long day and moderate temperatures, as well as sometimes returning frosts, the second crop falls on a short day and high temperatures, as well as a lack of moisture (Gasparyan et al., 2021; Bamberg et al., 2023). At the same time, field conditions change and do not repeat over time. The purpose of our research was to substantiate recommendations on the selection of varieties for cultivation of two varieties. Its solution is possible with a certain guaranteed efficiency based on the theory of statistical games.

2. Methodology

2.1. Soils of the field experiment

The experiments were laid in 2018-2022 at the Vegetable Experimental Station of the Russian State Agrarian University - Moscow Timiryazev Agricultural Academy and All-Russian Institute of Agrochemistry named after D. Pryanishnikov, Moscow (55.8385770, 37.5499290). Moscow is located in the central part of the East European Plain, between the Oka and Volga rivers, at an average height of 186 m above sea level. The climate of Moscow is temperate continental, seasonality is clearly expressed; summers are warm, winters are moderately cold. Climate-forming processes increase from the northwest to the southeast.

The typical soils for the Moscow region are soddy-podzolic, in terms of mechanical composition - medium loamy, have a low amount of absorbed bases and degrees of saturation (S = 1.5-3.9 meq/100 g of soil; V = 31.0-46.8%); high content of mobile (available) phosphorus (252-324 mg/kg of soil) and below average content of exchangeable potassium (92-125 mg/kg of soil), low-humus soils - 2.2%, cultivated, pH -. 5.6. The thickness of the arable layer is 20-22 cm.

2.2. Agrometeorological conditions for conducting research

Precipitation fell during the years of research on average 488-880 mm per year, the availability is sufficient for the cultivation of potatoes, but there is a big difference between the years. The period with positive air temperatures was 206-216 days, with average daily temperatures above 5 °C 175-204 days. The duration of the period of active vegetation of plants (with temperatures above 10 °C) was 138-140 days, the total temperature during this period is from 2076 to 2900 °C (Figure 1).

The conditions for potato cultivation are favorable and sufficient for the cultivation of two harvests, since early and medium-early potatoes have an average vegetation period of 70-80 days from planting to harvesting and the required amount of effective temperatures for early varieties is 1000-1100 °C. To obtain two early potato harvests, 1100x2 = 2200 °C is needed. According to the schedule of Davitaya (Gringof and Pavlova, 2013), the heat supply is at least 80%, i.e. in 8 years out of 10. Early potato cultivation can be considered expedient.

Climate change is evidenced by the fact that long-term average ten-day air temperatures have changed upwards, this can be seen in Figure 2. The graph shows two graphs: green indicates the average ten-day air temperature according to 1961-1990 data, blue - 1991-2020 years, they differ by 1-2 °C. The heat was sufficient for the growth and development of potato plants. It should be noted that in 2021-2022, the third decade of June and up to the

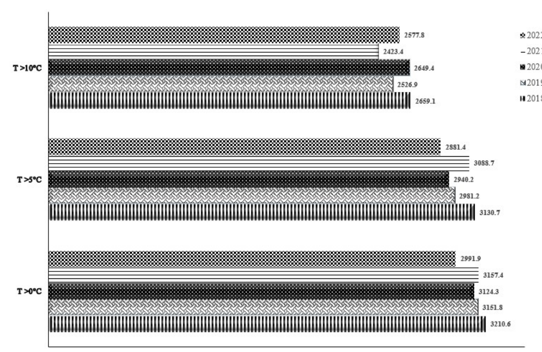
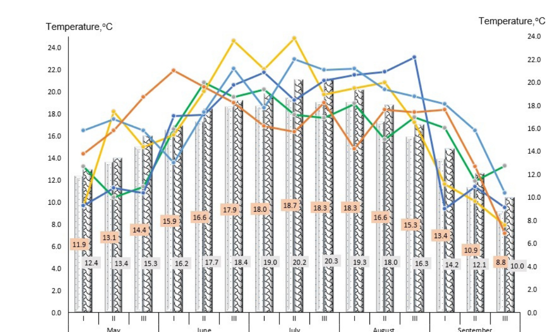


Figure 1. The sums of temperatures above 0 °C, 5° and 10 °C in the studied years (2018-2021).



	May I	May II	May III	June I	June II	June III	July I	July II	July III	August I	August II	August III	September I	September II	September III
1961-1990	11.9	13.1	14.4	15.9	16.6	17.9	18.0	18.7	18.3	18.3	16.6	15.3	13.4	10.9	8.8
1991-2020	12.4	13.4	15.3	16.2	17.7	18.4	19.0	20.2	20.3	19.3	18.0	16.3	14.2	12.1	10.0
2020	13.2	10.4	11.4	16.6	20.8	19.5	20.2	17.9	17.6	18.9	15.7	17.7	16.7	11.9	13.3
2021	9.6	18.2	15.0	16.1	20.0	24.6	22.0	24.8	19.7	20.3	20.8	17.2	11.6	10.1	7.9
2022	9.7	11.3	10.8	17.8	17.9	20.6	21.7	19.2	21.0	21.5	21.8	23.1	9.4	11.4	9.5
2018	15.8	16.8	15.8	13.0	17.4	21.2	17.8	22.0	21.1	21.2	19.4	18.8	18.1	15.8	10.4
2019	13.8	15.8	18.7	21.0	19.6	18.2	16.2	15.7	18.2	14.2	17.6	17.4	17.6	12.7	6.9

Figure 2. Ten-day air temperatures in the years of research and average ten-day air temperatures.

second decade of July, there is a high temperature, which adversely affects tuberization. Since it is well known that the rate of tuberization decreases sharply with an increase in temperature to 25-27 °C (Gasparyan et al., 2021).

During the years of research (Figure 3), precipitation was sufficient for the growth and development of plants of the first harvest, for the second harvest, planted in early July, there was little moisture in 2021 in the first and third ten days of July, in 2022 - in the second ten days of July, but was replenished for account of the second decade. Budding and flowering of potatoes 2 harvests were in a period of insufficient moisture.

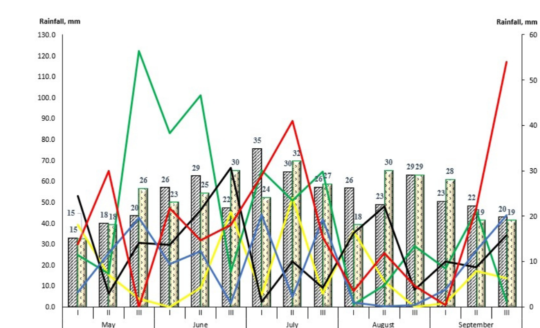
2.3. Research conditions

The objects of research were varieties Udacha, Zhukovsky early, Snegir, Red Scarlet, Riviera, Impala, Lady Clair, Golubizna, Bryansky early.

The options in the experience were placed randomly. The area of one experimental plot is 25 m^2. Planting scheme - 70 × 35 cm. The density of standing is 47.6 thousand plants per hectare.

For planting the first harvest, tubers of a large fraction (more than 80 g), the elite, were used. The timing of planting the first harvest - when the soil warms up to 6-8 °C, as a rule, in late April - early May; second harvest - July 1-6. The planting of the second harvest was carried out immediately after harvesting the first harvest in the vacant place with planting material of the previous year, all planting material was germinated. Planting was carried out with a single-row potato planter for field research.

The basic cultivation technology with row spacing of 70 cm consisted of technological modules, such as tillage, preparation of planting material, planting, care, harvesting. Soil tillage for the first planting consisted of autumn plowing (PLN-3-35 plow), early spring harrowing (BZSS-1.0), milling with a horizontal axis of rotation (FN-1.2) and cutting ridges (CON-2.8), for the second landing from milling (FN-1.2.) and cutting ridges (CON-2.8). Preparation of planting material included light germination, both for the first and second plantings. The planting fraction was different: for the first planting, a large fraction was used, for the second, a medium one. Plant care consisted of inter-row cultivation and hilling with a cultivator. Harvesting was carried out in mid-July and at the end of September manually, in connection with the analysis of the harvest structure, using the method of research on potato culture (Russia, 1967).



	May			June			July			August			September		
	I	II	III	I	II	III	I	II	III	I	II	III	I	II	III
1961-1990	15	18	20	26	29	22	35	30	26	26	23	29	23	22	20
1991-2020	15	18	26	23	25	30	24	32	27	18	30	29	28	19	19
2019	39.1	15.2	4.0	0	9.2	45.4	5.6	52.1	6.2	36.1	12.2	0	1.7	17.0	13.6
2020	24.6	15.7	122.3	83.1	100.9	16.8	65.3	50.8	64.5	1.0	10.2	29.1	18.2	46.0	2.7
2021	52.8	6.4	30.5	29.5	46.1	66.5	2.4	21.7	9.0	35.3	48.0	8.1	21.6	18.9	34.2
2022	6.9	25.7	42.5	20.5	26.6	1.8	43.9	4.9	41.9	2.1	0.1	0.9	8.2	27.0	43.8
2018	13.8	30.0	0.0	21.7	14.6	18.0	28.9	41.0	15.4	3.5	11.8	4.6	0.4	21.7	54.0

Figure 3. Precipitation for the growing seasons in the years of research (2018-2022).

2.4. Methodology for field experiments, observations, analyzes and reports

A field experiment was established, and records and observations were carried out in accordance with the requirements of the methodology of field experiments, the Program and Methodology for Evaluating Potato Varieties (Russia, 1967).

The assessment of agrochemical parameters of the soil was carried out before the laying of field experiments, which meets the requirements. Phenological observations were carried out according to the method of the State assortment. For each variety, the number of days from planting to germination and the beginning of budding, flowering and complete wilting of the green mass was taken into account (Russia, 1967).

3. Results

A study on the cultivation of two harvests of early potato varieties under climate change showed the possibility of implementing this technology, but due to the fact that the varieties used react differently to changing weather conditions for the 1st and 2nd planting, there is a problem of choosing varieties for obtaining a guaranteed harvest (Tables 1 and 2).

4. Discussions

Climatic characteristics for the upcoming growing season are not predictable, they are estimated by a fairly large list of probabilistic indicators, and substantiating recommendations for choosing varieties for cultivation is a difficult task. Its solution is possible with a certain guaranteed efficiency based on the theory of statistical games (Zakharov, 2015; Pisaruk, 2015).

The desire to obtain the highest yield is opposed by the random nature of the appearance of various soil, meteorological and landscape conditions. For the same plot, the difference will be obtained due to differences in the susceptibility of different potato varieties for the actual complex of climatic characteristics. The conducted reasoning notes the presence of contradictions in the strategies of work (selection of varieties for 1 or 2 planting) and the uncertainty of external (natural and climatic) conditions.

The measure of "winning" or "losing" in the production of potatoes of early varieties can be the yield W_{ij} corresponding to the i-th strategy of the performer (selected variety) and the j-th state of the prevailing natural conditions. The yield values for the accepted set of possible producer strategies A_j (i = 1, 2, ..., n) and natural production situations B_j (j=1, 2, ..., m) represent an n x m (Equation 1) ***game matrix*** (Levshin, 2000).

$$A_0 = \left| w_{ij} \right| \tag{1}$$

Table 1. Productivity of 1 planting, average for 2018-2022 years, g/bush.

Variety	Year						
	2017	**2018**	**2019**	**2020**	**2021**	**2022**	**Av.**
Meteor	490	430	515	640	430	645	**525**
Zhukovsky early	675	425	495	540	470	680	**548**
Udacha	470	450	370	500	440	520	458
Snegir	660	470	365	580	465	480	**503**
Red Scarlet	670	490	410	600	420	650	**540**
Riviera	670	535	610	640	680	700	**639**
Impala	550	510	590	600	650	690	**598**
Lady Claire	450	430	435	485	420	530	458
Golubizna	440	403	480	515	480	550	478
Bryansky	400	386	470	505	470	550	464
LSD (P=0.05)	25	22	22	27	23	28	

LSD = the smallest significant difference for 5% significance level.

Table 2. Productivity of 2 planting, average for 2018-2022 years, g/bush.

Variety	Year						
	2017	**2018**	**2019**	**2020**	**2021**	**2022**	**Av.**
Meteor	340	313	224	406	346	413	340
Zhukovsky early	390	436	341	527	308	456	410
Udacha	516	610	625	668	445	603	**578**
Snegir	495	472	461	475	395	584	480
Red Scarlet	543	455	475	575	524	620	**532**
Riviera	495	426	478	505	535	413	475
Impala	544	650	525	625	640	614	**600**
Lady Claire	382	420	385	350	450	400	398
Golubizna	398	510	485	415	465	431	451
Bryansky	315	380	420	435	445	398	399
LSD (P=0.05)	21	23	21	24	22	23	

LSD = the smallest significant difference for 5% significance level.

It should be noted that strategies Aj can be used with different frequency, estimated by the probability pi. Taking into account the theorem on the probability of a complete group of events, pi must satisfy the normalization condition (Equation 2) (Kremlev, 2016; Skorokhodov et al., 2013) .

$$\sum_{i=1}^{n} p_i = 1 \; ; \; \sum_{j=1}^{m} q_j = 1 \tag{2}$$

where ***n*** is the number of possible work execution strategies (number of varieties); ***m*** – ***m*** is the number of groups of climatic characteristics. In practice, it is enough to ask 3 groups: favorable, average and unfavorable.

For the best effect, we select a variety (the i-th row of the matrix) for which the maximum of the minimum row-by-row values of $max\left(minW_{ij}\right)$, is reached, and to minimize the negative influence of climatic factors, we select the j-th column with the smallest of the maximum values of min $(\max W_{ij})$. For the matrix of the game, the ratio is valid (Equation 3) (Vorobyov, 1985; Skorokhodov et al., 2013):

$$\max_i \min_j W_{ij} \leq \min_j \max_i W_{ij} \tag{3}$$

If both quantities in this relation are equal, then the game has a saddle point and a unique solution (one price of the game) that determines a ***pure*** optimal strategy. If the ratio represents an inequality, then an upper and lower price of the game will be counted, and the optimal solution is found as a mixed strategy. As an estimated characteristic of the yield, the weighted average value will be taken determined by the Formula 4:

$$W_{cp} \aleph \sum_{j=1}^{m}\sum_{i=1}^{n} p_i \ \ q_j \ \ w_{ij} \tag{4}$$

For mixed strategies, equality will be performed (Equation 5):

$$\max_{p_i}(\min_{q_j} W_{cp}) = \min_{q_j}(\max_{p_i} W_{cp}) = v \tag{5}$$

where v is the price of the game (average yield).

When looking for mixed strategies, the following situations should be considered:

- if the probabilities $q_j = const$, are known, then the mixed strategy allows us to determine the probabilities p^*_i (shares of varieties) with a combination of which we can get the maximum average yield (Equation 6):

$$W_{cp} = \sum_{j=1}^{m}\sum_{i=1}^{n} p_i^* \cdot q_j \cdot w_{ij} \tag{6}$$

- if the probabilities of the group of climatic characteristics q^*_j and the optimal ratio of varieties p^*_i, are unknown, then the maximum average yield evaluates the potential of potato cultivation technology (Equation 7):

$$W_{cp} = \sum_{j=1}^{m}\sum_{i=1}^{n} p_i^* \cdot q_j^* \cdot w_{ij} \tag{7}$$

Optimal strategies p_i^* and q_j^* are defined as solutions to the dual linear programming problem (Equation 8) (Zakharov, 2015; Pisaruk, 2015):

$$A)\ Z = X_1 + X_2 + \ldots + X_n = min \tag{8}$$

with restrictions (Equation 9):

$$A_0^T X_i \geq 1^0, \quad X_i \geq 0\ , i = 1,\ n; \\ B) W = Y_1 + Y_2 + \ldots + Y_m = max \tag{9}$$

with restrictions:

$$A_0 Y_j \leq 1^0,\ Y_j \geq 0,\ \ j = 1,\ m,$$

where A_0 – game matrix; X_i и Y_j - auxiliary variables.

The total price of the game is determined from the ratio (Equation 10)

$$v = \frac{1}{Z_{\min}} = \frac{1}{W_{\max}} \tag{10}$$

The probabilities p_i^* and q_j^* for optimal strategies are calculated by the Formula 11:

$$p_i^* = v \cdot X_i;\ q_j^* = v \cdot Y_j \tag{11}$$

The solution of the problems is given in Table 3.

For the given experimental data on the yield of 10 varieties for 6 years, the division into qualitative groups of climatic conditions at the preliminary stage for 1 and 2 plantings, the total average harvest weight for each year is determined (Table 4).

The range (the difference between the maximum and minimum values) for the 1st and 2nd landings is determined. Given three levels of groups of climatic conditions (favorable, unfavorable and two intermediate groups), the width of the interval (Equation 12) for the group (Table 5) is determined:

$$d = \frac{(m_{максимум} - m_{минимум}}{3} \tag{12}$$

The dominant strategy is the Riviera variety. Varieties Udacha, Snegir, Impala, Lady Claire, Golubizna and Bryansky are inferior in years to the dominant variety, so they can be ignored in the final matrix (Nemecek et al., 2012). With this in mind, the game matrix for 1 harvest will take the form (Tables 6 and 7).

The minimum values for the lines are found and written them down in the 4th column and select the maximum value of 0.608 (for the Riviera variety). Then for groups of climatic conditions (columns 2-4) the maximum values are found and chosen the smallest value - 0.608 (Riviera variety). For the resulting game matrix, the equality of the right and left parts of condition (4) is satisfied, therefore, a saddle point and the best pure producer strategy when choosing the Riviera variety are had. Guaranteed yield (Equation 13) will be at least 0.608 kg per bush without taking into account the probabilities of climatic groups:

$$\max_{i}\min_{j} W_{ij} = \min_{j}\max_{i} W_{ij} = 0.608 \tag{13}$$

Similarly, the results of 6-year experiments for the 2nd harvest are analyzed. The boundaries of the intervals of climatic groups for the average yield of 10 varieties are presented in Table 8.

For the selected boundaries of the intervals for climatic factors, the year 2019 will be unfavorable and the probability of its occurrence is 0.167. The average years for climatic conditions will be 2017, 2018 and 2021, the probability of the appearance of this group is assumed to be 0.5. Favorable for the production of 2 potato harvests were 2020 and 2022, the probability of this group of climatic conditions is 0.333.

For the 2nd harvest, the game matrix will look like this (Table 9).

For 2nd harvest, the dominant grower strategy will be Udacha. The varieties Meteor, Zhukovsky early, Snegir, Lady Claire, Golubizna and Bryansky are clearly inferior in terms of yield in terms of groups of climatic factors, so they can be ignored in the final matrix. With this in mind, the final matrix of the game for the 2nd harvest will take the form. In this case, a 4x3 matrix is gotten (Table 10).

For the resulting game matrix, equality (4) is satisfied, therefore, the best strategy for the producer is to choose the variety Luck. Guaranteed yield (Equation 14) will be at least 0.570 kg/bush:

$$\max_{i}\min_{j} W_{ij} = \min_{j}\max_{i} W_{ij} = 0.570 \tag{14}$$

Table 3. Results of optimization calculations.

Optimization problem	Solution
Optimal strategy taking into account the likelihood of climatic factors (Equation 8)	
for 1 harvest $p_4 = 1$ variety - Riviera The price of the game is 0.639	**Input data** $0.525*x_1+0.604*x_2+0.590*x_3+0.639*x_4 \rightarrow max$ $x_1+x_2+x_3+x_4=1$ **Decision** $x_1=0, x_2=0, x_3=0, x_4=1, F=0.639$
for 2 harvest $p_1 = 1$ Variety - Udacha The price of the game is 0.631	**Input data** $0.631*x_1+0.532*x_2+0.491*x_3+0.607*x_4 \rightarrow max$ $x_1+x_2+x_3+x_4=1$ **Decision** $x_1=1, x_2=0, x_3=0, x_4=0, F=0.631$
Assessment of critical conditions for obtaining early potatoes (Equation 10)	
1 harvest: Game price: $v = \frac{1}{F_{min}} = 0.608$ $p_i^* = v \cdot F_i;$ $p_4^* = 1;$ Variety - Riviera	**Input data** $x_1+x_2+x_3+x_4 \rightarrow min$ $0.458*x_1+0.563*x_2+0.540*x_3+0,608*x_4 \geq 1$ $0.490*x_1+0.675*x_2+0.670*x_3+0,670*x_4 \geq 1$ $0.642*x_1+0.630*x_2+0.625*x_3+0.670*x_4 \geq 1$ **Decision** $x_1=0, x_2=0, x_3=0, x_4=1.644, F=1.644$
2 harvest: Game price: $v = \frac{1}{F_{min}} = 0.570$ $p_i^* = v \cdot F_i;$ $p_1^* = 1;$ Variety - Udacha	**Input data** $x_1+x_2+x_{3+}\ x_4 \rightarrow min$ $0.570*x_1+0.475*x_2+0.478*x_3+0.525*x_4 \geq 1$ $0.632*x_1+0.507*x_2+0.485*x_3+0.618*x_4 \geq 1$ $0.661*x_1+0.600*x_2+0.507*x3+0.632*x_4 \geq 1$ **Decision** $x_1=1.754, x_2=0, x_3=0, x_4=0, F=1.754$
1 harvest Climatic conditions Game price: $v = \frac{1}{F_{min}} = 0.608$ $q_j^* = v \cdot Y_j$ $q_1^* = 1$ Not favorable	**Input data** $x_1+x_2+x_3 \rightarrow max$ $0.458*x_1+0.490*x_2+0.642*x_3 \leq 1$ $0.563*x_1+0.675*x_2+0.630*x_3 \leq 1$ $0.540*x_1+0.670*x_2+0.625*x_3 \leq 1$ $0.608*x_1+0.670*x_2+0.670*x_3 \leq 1$ **Decision** $x_1=1.644, x_2=0, x_3=0, F=1.644$
2 harvest Climatic conditions $v = \frac{1}{F_{min}} = 0.570$ $q_j^* = v \cdot X_j$ $q_1^* = 1$ Not favorable	**Input data** $x_1+x_2+x_3 \rightarrow max$ $0.570*x_1+0.632*x_2+0.661*x_3 \leq 1$ $0.475*x_1+0.507*x_2+0.600*x_3 \leq 1$ $0.478*x_1+0.485*x_2+0.507*x_3 \leq 1$ $0.525*x_1+0.618*x_2+0.632*x_3 \leq 1$ **Decision** $x_1=1.754, x_2=0, x_3=0, F=1.754$

Table 4. The total average weight of the harvest over the years of research.

Year	2017	2018	2019	2020	2021	2022	Размах	d, Class Width
1 harvest	0.532	0.483	0.488	0.555	0.503	0.579	0.096	0.032
2 harvest	0.463	0.470	0.446	0.498	0.480	0.484	0.052	0.0173

Table 5. Limits of intervals of climatic groups (1 harvest).

	Boundaries of group interval		Years	Class of the year	Probability
	left	right			
1	0.483	0.515	2018, 2019, 2021	Not favorable	0.500
2	0.515	0.547	2017	Medium	0.167
3	0.547	0.579	2020, 2022	Favorable	0.333

Table 6. Game Matrix for 1 harvest.

Variety	Year type		
	Not favorable	Medium	Favorable
Meteor	0.458	0.490	0.642
Zhukovsky early	0.563	0.675	0.630
Udacha	0.453	0.470	0.510
Snegir	0.433	0.560	0.530
Red Scarlet	0.540	0.670	0.625
Riviera	0.608	0.670	0.670
Impala	0.530	0.550	0.595
Lady Claire	0.428	0.450	0.507
Golubizna	0.454	0.440	0.532
Bryansky	0.442	0.350	0.425

Table 7. Final game matrix for 1 harvest.

Variety	Year type			
	Not favorable	Medium	Favorable	$\min_j W_{ij}$
Meteor	0.458	0.490	0.642	0.458
Zhukovsky early	0.563	0.675	0.630	0.563
Red Scarlet	0.540	0.670	0.625	0.540
Riviera	**0.608**	0.670	0.670	**0.608**
$\max_i W_{ij}$	**0.608**	0.675	0.670	

Table 8. Limits of intervals of climatic groups for 2 harvest.

	Boundaries of group interval		Years	Class of the year	Probability
	left	left			
1	0.446	0.463	2019	Not favorable	0.167
2	0.463	0.481	2017, 2018, 2021	Medium	0.500
3	0.481	0.498	2020, 2022	Favorable	0.333

Table 9. Final game matrix for 2 harvest.

Variety	Year type		
	Not favorable	Medium	Favorable
Meteor	0.324	0.333	0.378
Zhukovsky early	0.341	0.411	0.421
Udacha	0.570	0.632	0.661
Snegir	0.461	0.487	0.450
Red Scarlet	0.750	0.507	0.600
Riviera	0.478	0.485	0.507
Impala	0.525	0.618	0.632
Lady Claire	0.385	0.417	0.400
Golubizna	0.485	0.458	0.432
Bryansky	0.420	0.362	0.427

Table 10. The final matrix of the game for the 2nd harvest.

Variety	Year type			
	Not favorable	Medium	Favorable	$\min_j W_{ij}$
Udacha	**0.570**	0.632	0.661	**0.570**
Red Scarlet	0.475	0.507	0.600	0.475
Riviera	0.478	0.485	0.507	0.478
Impala	0.525	0.618	0.632	0.525
$\max_i W_{ij}$	**0.570**	0.632	0.661	

Taking into account the probability of occurrence of climatic characteristics for 1 harvest (Table 4): q_1=0.5, q_2=0.167 and q_3=0.333, when choosing a variety, it is necessary to maximize the average yield $\min_{q_j} W_{cp}$ by optimizing the choice of probabilities p_i^* Substituting in (8) the values of the probabilities of climatic conditions q_i we obtain the equation for optimizing the average yield for 1 harvest (Equation 15):

$$W_{cp} = p_1 \cdot 0.525 + p_2 \cdot 0.604 + p_3 \cdot 0.590 + p_4 \cdot 0.639 \rightarrow max \quad (15)$$

with restrictions: $\sum_{i=1}^{n} p_i = 1;\ p_i \geq 0.$

According to the results of the solution, the choice p_4 = 1 (the probability of choosing the Riviera variety) will be optimal, and the probabilities of choosing other varieties are equal to zero. At the same time, the average yield will increase by 5.1% compared to the pure strategy and will be equal to 0.639 kg per bush.

For the 2nd harvest, the probabilities of occurrence of climatic conditions are equal (Table 6): q_1=0.167, q_2=0.500 and q_3=0.333. The solution is given in summary Table 3.

For the 2nd harvest, the optimal choice will be p_1 = 1 (the probability of choosing the Udacha variety). At the same time, the average yield compared to the pure strategy of 0.570 will increase by 10.8% and will be equal to 0.6315 kg per bush.

The prediction of critical conditions for obtaining the maximum average yield is based on the fulfillment of condition (7). The optimal strategies p_i^* and q_j^* for the given data are given in Table 3.

For critical conditions, the varieties for 1 crop – Riviera and for 2 crops – Luck will be optimal (Table 3).

5. Conclusion

The proposed method can be used when choosing early varieties of potatoes when cultivating two harvests to obtain a guaranteed yield for possible climatic conditions. Game theory methods allow you to get a guaranteed result when choosing and implementing a certain strategy.

References

BAMBERG, J., DEL RIO, A., KINDER, D., LOUDERBACK, L., PAVLIK, B. and FERNANDEZ, C., 2023. Mother tubers of wild potato *Solanum jamesii* can make shoots five times. *American Journal of Potato Research*, vol. 100, no. 5, pp. 407-412. http://dx.doi.org/10.1007/s12230-023-09927-1.

BIRCH, P.R., BRYAN, G., FENTON, B., GILROY, E.M., HEIN, I., JONES, J.T., PRASHAR, A., TAYLOR, M.A., TORRANCE, L. and TOTH, I.K., 2012. Crops that feed the world 8: potato: are the trends of increased global production sustainable? *Food Security*, vol. 4, no. 4, pp. 477-508. http://dx.doi.org/10.1007/s12571-012-0220-1.

DELGADO, J.A., BARRERA, V.H., ALWANG, J.R., CARTAGENA, Y.E., ESCUDERO, L.O., NEER, D., D'ADAMO, R. and ZAPATA, A.C., 2023. Nitrogen management can increase potato yields and food security for climate change adaptation in the Andean Region. *American Journal of Potato Research*, vol. 100, no. 3, pp. 221-232. http://dx.doi.org/10.1007/s12230-023-09912-8.

DIYKANOVA, M.E., LEVSHIN, A.G., GASPARYAN, I.N., DENISKINA, N.F., IVASHOVA, O.N. and MEKHEDOV, M.A., 2020. Eff ect of temporary covering on early potato yield in the conditions of the Moscow region. *Agricultural Engineering*, vol. 6, no. 100, pp. 31-38. In Russian. http://dx.doi.org/10.26897/2687-1149-2020-6-31-38.

GASPARYAN, I., LEVSHIN, A., IVASHOVA, O., DYIKANOVA, M. and DENISKINA, N., 2021. Agrotechnical requirements for the cultivation of potatoes in a two crops culture. *Research on Crops*, vol. 22, suppl., pp. 1-4. http://dx.doi.org/10.31830/2348-7542.2021.001.

GRINGOF, I.G. and PAVLOVA, V.N., 2013. *Fundamentals of agricultural meteorology. Volume III. Part 1: fundamentals of agroclimatology. Part 2: impact of climate change on ecosystems, agrosphere and agricultural production*. Obninsk: FGBU "VNIIGMI-MTsD", 384 p.

IVASHOVA, O.N., GASPARYAN, I.N., LEVSHIN, A.G., DYIKANOVA, M.E., DENISKINA, N.F. and GASPARYAN, S.V., 2021. *Cultivation of two crops of early potato varieties in the conditions of the Moscow region: monograph*. Moscow: RGAU-MSHA, 132 p.

KREMLEV, A.G., 2016. *Basic concepts of game theory: textbook*. Yekaterinburg: UFU Publishing House, 144 p.

LEVSHIN, A.G., 2000. *Development of methods to improve the efficiency of using mobile agricultural aggregates as human-machine systems.* Moscow: MGAU named after V.P. Goryachkin, 277 p. Doctoral Dissertation in Mechanization of Agricultural Production.

NEMECEK, T., WEILER, K., PLASSMANN, K., SCHNETZER, J., GAILLARD, G., JEFFERIES, D., GARCÍA-SUÁREZ, T., KING, H. and MILÀ I CANALS, L., 2012. Estimation of the variability in global warming potential of worldwide crop production using a modular extrapolation approach. *Journal of Cleaner Production*, vol. 31, pp. 106-117. http://dx.doi.org/10.1016/j.jclepro.2012.03.005.

PISARUK, N.N., 2015. *Introduction to game theory*. Minsk: BGU, 256 p.

RUSSIA, 1967. *Methods of research on potato culture*. Moscow: NIIKH, 263 p.

SKOROKHODOV, A.N., LEVSHIN, A.G., UVAROV, V.P. and DIDMANIDZE, R.N., 2013. *Modeling and optimization of technological processes in crop production: a tutorial*. Moscow: RGAU-MSHA, 145 p.

VOROBYOV, N.N., 1985. *Game theory for economists*. Moscow: Nauka, 272 p.

ZAKHAROV, A.V., 2015. *Game theory in social sciences: textbook for universities National research University "Higher School of Economics"*. Moscow: Ed. House of the Higher School of Economics, 304 p. Textbooks of the Higher School of Economics.