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SOIL VARIABILITY *VS* POTATO PRODUCTIVITY

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Abstract. This study is based on the results of the field experiment carried out in 1990-1992 on the soil of mechanical composition of light loamy sand. The yield and tuber structure of the crop of potato tubers of 37 varieties were evaluated. A positive effect on the crop and mass of the tubers of ϕ 4-5, 5-6 and >6 cm was exerted by the July and August rainfalls, the May and June rainfalls resulted in enlarging the tuber mass by ϕ <3 cm, and decreasing the share of the remaining tuber size fractions. The increase in atmospheric temperature in July and August caused a drop in tuber yield, and also the tuber mass of ϕ 5-6 and >6 cm in diameter. Heightening by a unit the abundance of assimiable phosphorus and potassium in the soil at its mean level of 15.7 and 21.9 mg/100 g soil, respectively, resulted in an increase of tuber mass in the crop by ϕ <3, 3-4, 4-5 cm, and a lowering of tuber mass in the largest crop. The transition from slightly acid to neutral soil reaction caused a drop in the crop as well as the proportions of small and medium tubers and an increase in the share of marketable tubers.

Keywords: potato, productivity, yield variability, soil variability.

INTRODUCTION

The phenotypical variability of the potato in every detail is an effect of genetic and environmental variability [12]. The share of environmental variability in total is different for particular features. The main reasons of environmental variability are: non-uniformity of weather conditions influence (temperature, isolation, water supply, air humidity, distribution of precipitations), and soil variability within the field and even within the rows. The variations of the environment, in which there are potato plants, cause the modification of the inner regulation processes both within the plant itself and also the stalk of *Solanum tuberosum* L. Therefore, a variety of stalks may be observed within a plant and a variety of plants on a plot, connected with the years and places [4,8,9]. The studies by Keller and Baumgartner [2], Trętowski [10], Ubysz-Borucka [11] and Yildrim and Caliscan [12] reveal that the determination of productivity characteristics of potato plants requires the conducting of studies for at least three years in one place, so as to properly identify the variety of phenotypic components. Thus, the objective of the studies conducted was to determine the phenotypic variety of potato cultivars, singling out genetic and environmental variability, which should enable one to choose for cultivation the cultivars of the greatest stability of the desired feature. Moreover, it is an attempt to describe the connection between the tuber crop and its structure and selected elements of soil and atmospheric viromnent.

MATERIAL AND METHODS

Studies were based on the results of field experiment carried out in 1990-1992 in Parczew, on the soil whose mechanical composition was of a light loamy sand. That soil was characterised by mean to high phosphorus abundance, high in potassium, and light acidic to neutral pH. Studies consisted of 37 potato cultivars including 34 Polish ones (Aster, Atol, Beryl, Bliza, Bogna, Brda, Bronka, Bryza, Bzura, Certa, Ceza, Cisa, Dryf, Duet, Elida, Elipsa, Fala, Fauna, Fregata, Frezja, Heban, Irys, Jaśmin, Lotos, Mila, Orlik, Perkoz, Pilica, Pola, Ronda, Ruta, Sokół, Stobrawa, Tarpan) of every early group, and 3 Dutch cultivars (Premier - early, Escort - middle early, Diamant - middle late), fertilized with manure at the dose 250 dt ha^{-1} and mineral fertilizers at amounts: 100 kg N, 100 kg P_2O_5, 150 kg K_2O ha^{-1}. Material for setting was of super-elite class. Estimation of yield and its structure was made just after the harvest.

Statistical computing of the results was made using variance and regression analyses. Difference significance was estimated using Tukey's test. In order to estimate the particular variability sources and their interactions within total variability of traits under study, estimation of variance components was made, using the following denotations:

σ^2 - the evaluation of environmental variability, connected with the repetition of observation or measurement over many years,

σ^2_G - evaluation of genotypic variability (specific);

σ^2_p - evaluation of phenotypic variability (total).

On the basis of variance component evaluation, their proportional structure was determined.

Functional parameters were found by the least squares method and significance verification by t-Student test. Yield and weight of tubers of <3, 3-4, 4-5, 5-6 and >6 cm diameter were accepted as dependent variable (*y*); independent ones were: mean air temperature during May to June (in °C), mean air temperature during July to August (in °C), precipitation sum during May to June (in mm), precipitation sum during July to August (in mm), soil acidity (pH_{KCl}), soil abundance in available P_2O_5 (in mg/100g soil), soil abundance in available K_2O (in mg/100g soil). Variables for multi-factor linear regression were selected on a base of coefficients from simple regression. Regressions presented in Table 4 were calculated according to the formula: $y = a + b_j x_j$, where y - dependent variable, a - constant, b - regression coefficient, x - independent variable. Partial regression coefficients (b_j) show, how much the yield of tubers and its structure change, if a factor changes by a unit.

The variability of the analysed results were characterized by the following means: arithmetic mean, standard deviation, coefficient of variation (Tables 2 and 3) calculated by the equation: $V = \frac{s}{x}$ 100%, here s - standard deviation, x - arithmetic mean.

The distribution of temperatures and rainfall in the analysed examination was differentiated, which is presented in Fig. 1.

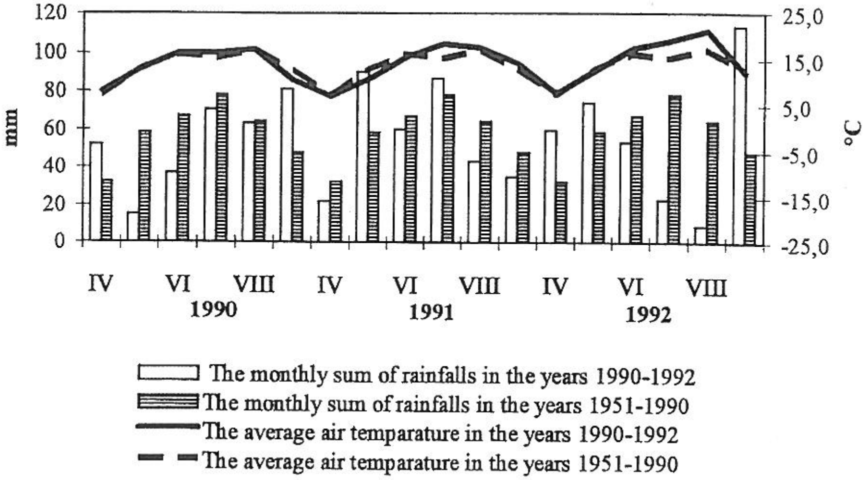

Fig. 1. Rainfalls and air temperature during potato vegetation period in the years 1990-1992 according to IMGW at Włodawa.

RESULTS

Tuber yield appeared to be dependent on cultivar properties (in 4%), vegetation conditions in particular years (in 69.0%) and interactions between cultivars and years (in 26.2%) (Table 1).

Table 1. Influence of cultivars and years on tuber yield and its structure as well as their percentage in total variance

Trait	Significance of effect of			Percentage of variance share in total variance (phenotypical)		
	cultivars	years	cultivars x years	cultivars	years	cultivars x years
Tuber yield	**	**	**	4.0	69.0	26.2
Tuber weight, ϕ <3 cm	**	**	*	4.2	24.0	70.8
Tuber weight, ϕ 3-4 cm	**	**	*	9.8	62.7	7.9
Tuber weight, ϕ 4-5 cm	**	**	*	3.6	64.5	6.4
Tuber weight, ϕ 5-6 cm	n	**	*	1.8	59.8	29.5
Tuber weight, ϕ >6 cm	**	**	**	8.2	64.6	7.8

*significant at $\alpha \leq 0.05$; ** - significant at $\alpha \leq 0.01$; n - not significant at $\alpha \leq 0.05$;

Variation coefficients are the measure of the dispersion of the received results. The lower the value, the more stable the feature: for the yield of tubers the value of this coefficient was 28.1%. Considering the stability (yield verity), the varieties examined may be sequenced as follows: Bryza > Ronda > Irys > Fala > Elida > Orlik > Ruta > Premieur > Diamant > Mila > Ceza > Escort > Bzura > Fauna > Aster > Perkoz > Fregata > Lotos > Stobrawa > Frezja > Elipsa > Bronka > Bliza > Bogna > Pola > Pilica > Dryf > Beryl > Atol > Cisa > Brda > Heban > Sokol > Certa > Duet > Jasmin > Tarpan. The most exact in yield appeared to be semi-late cv. Bryza, the least - late cv. Tarpan. The lowest variability in yield was observed within the group of very early varieties, yet the highest - in the group of late ones.

The structure of tuber yield was found out to be not stable enough, and the components of phenotypic variability (complete) were different. It resulted from various meteorological conditions, and especially from an irregular distribution of rainfall in May - August, determining the number and size of tubers of particular fractions. Years of studies had the dominant role in variability of tubers of 3-4, 4-5, 5-6 and >6 cm. Interaction between cultivars and years was major in total variability within the fraction of <3 cm diameter. Genotype traits had the least contribution in total variability of particular size fractions of tubers. They had a significant effect on the weight of tubers of <3, 3-4, 4-5 and 6 cm diameter.

Considering the stability of the share of tuber mass in the crop, the analysed size fractions may be sequenced as follows: <3 cm > above 6 cm > 3-4 cm > 4-5 cm > 5-6 cm. The most variable was the share of the smallest tubers in the crop, the least - the share of large tubers 5-6 cm in diameter. The greatest changes of the most shapely bulbs in the yield, i.e. the lowest stability of the bulb size in the

Table 2. The yield of tubers and the percentage of share in the yield of tubers mass with diameter <3, 3-4, 4-5, 5-6, >6 cm and variability coefficient (V)

Earliness group	Variety	Tuber yield		Tuber diameeter in cm									
		dt ha^{-1}	V	<3		3-4		4-5		5-6		>6	
				x	V	x	V	x	V	x	V	x	V
	Aster	241	23.8	9.6	53.7	23.0	51.9	33.3	30.4	22.4	23.2	11.8	57.1
Very early	Frezja	185	29.9	5.0	66.1	14.8	64.4	28.8	41.2	32.6	45.7	18.8	77.9
	Irys	228	15.4	6.4	49.6	15.4	66.1	32.3	47.7	30.6	28.1	15.2	55.6
	Ruta	219	17.6	5.5	112.7	16.9	63.2	28.7	32.9	32.9	33.1	15.9	80.2
	Orlik	202	16.5	7.4	66.9	17.9	39.8	34.4	44.7	27.8	37.6	12.5	69.5
	Elipsa	259	30.3	6.2	114.4	17.5	84.3	30.9	57.5	30.6	29.8	14.8	47.4
	Jaśmin	281	44.9	5.2	94.5	13.3	88.6	27.4	53.1	30.0	22.2	24.0	69.5
Early	Duet	229	42.0	7.9	99.9	23.9	66.7	31.2	59.3	25.0	39.7	12.0	78.8
	Lotos	208	27.6	6.0	77.2	19.2	56.5	34.9	24.4	27.3	34.9	12.7	89.7
	Perkoz	221	24.4	8.4	65.3	21.7	79.3	37.9	35.5	23.1	44.3	9.0	77.2
	Premieur	197	19.2	10.3	111.6	23.0	67.5	41.1	39.0	20.9	31.5	4.7	89.3
	Beryl	210	35.4	6.7	73.8	13.6	54.1	28.1	46.7	32.1	36.9	19.4	53.2
	Bliza	199	31.9	9.5	50.1	21.8	45.8	32.1	28.6	30.4	29.7	6.2	51.9
	Elida	242	15.6	6.8	82.9	17.5	54.4	36.3	60.8	25.4	23.1	13.9	56.4
Middle early	Fauna	221	23.7	6.5	44.5	21.6	68.1	38.8	49.5	24.9	24.6	8.1	57.1
	Mila	197	21.5	7.7	96.7	26.0	77.5	35.5	47.9	22.2	33.3	8.6	61.6
	Pola	199	32.7	7.9	83.0	17.2	84.9	32.3	57.1	29.3	36.7	13.2	54.8
	Ronda	200	15.2	7.0	77.6	19.5	63.8	32.1	28.5	32.3	30.9	9.1	77.3
	Escort	253	21.8	6.9	56.8	19.0	69.7	29.7	48.4	31.0	24.0	13.4	55.5
	Atol	217	36.2	6.5	66.4	19.7	70.6	30.7	47.9	31.8	45.0	11.3	77.6
	Bogna	238	31.9	5.7	61.3	16.6	34.1	33.2	47.4	29.7	32.8	14.7	56.9
	Brda	249	37.7	9.7	39.1	25.6	38.5	34.0	49.1	19.6	27.7	11.1	73.4
Middle late	Bryza	209	13.8	6.0	68.9	23.6	55.9	37.6	41.3	26.2	21.5	6.7	58.7
	Certa	194	39.9	9.6	92.5	28.4	69.6	35.7	45.2	22.4	35.7	3.8	79.2
	Cisa	218	36.6	9.7	78.7	29.6	64.4	35.7	49.7	20.2	40.5	4.8	55.1
	Fala	219	15.4	8.5	42.9	21.9	38.4	36.7	51.1	22.5	61.2	10.4	83.4
	Fregata	195	24.5	6.5	98.6	21.2	46.8	34.4	53.4	33.9	66.6	4.0	81.7
	Sokół	200	39.7	9.2	98.4	20.3	72.0	30.3	62.2	30.2	31.8	10.0	69.5
	Diamant	259	19.6	9.2	76.3	21.6	43.7	35.7	61.6	22.4	29.3	11.0	60.5
	Bronka	223	31.3	4.0	66.5	13.7	75.8	32.7	69.7	31.0	37.4	18.6	43.2
	Bzura	231	22.2	8.4	80.1	20.2	53.1	33.3	37.3	28.7	24.8	9.4	44.7
	Ceza	219	21.7	13.9	74.8	29.7	54.5	30.7	47.6	17.2	29.9	8.5	77.1
Late	Dryf	204	33.6	7.6	77.9	22.5	45.6	39.8	51.8	22.3	37.3	7.8	85.4
	Heban	223	37.9	12.3	74.2	29.5	70.1	31.1	45.9	17.0	31.7	10.1	69.8
	Pilica	197	33.4	13.1	91.9	24.6	86.7	35.5	36.3	19.8	31.1	7.0	55.6
	Stobrawa	245	29.1	7.2	22.8	21.6	28.6	32.7	33.5	23.0	36.9	15.5	75.6
	Tarpan	203	47.1	6.3	66.6	16.3	55.8	31.4	39.4	29.0	33.5	16.9	90.2
Mean		220	28.1	7.8	74.5	20.8	60.8	33.4	46.0	26.4	34.2	11.5	67.5
LSD $\alpha \le 0.05$;		24	1.6	5.0		5.0		7.6		n*		6.1	

Table 3. Statistical characterization of independent variables (average in the years 1990-1992)

Independent variables					
x_1	x_2	x_3	x_4	x_5	x_6
Arithmetical means					
103.7	144.7	17.1	15.7	21.9	5.7
Standard deviations					
20.8	46.9	0.4	4.0	4.8	0.6

x_1 - rainfall of period V-VI, in mm; x_2 - rainfall of period VII-VIII, in mm; x_3 - air temperature of period VII-VIII, in ^{o}C; x_4 - content of available phosphorus, in mg/100 g of soil; x_5 - content of available potassium, in mg/100 g of soil; x_6 - pH in KCl.

Table 4. Values of partial regression coefficients for yield traits at significance level $\alpha \leq 0,05$ in relation to the change of independent variable values by a unit

Traits	Independent variables						Determination coefficient (%)
	Precipitation (mm)		Tempe-rature (^{o}C)	Content in soil (mg/100 g of soil)		Soil pH KCl	
	V-VI	VII-VIII	VII-VIII	P_2O5	K_2O		
Tuber yield		+5.14	-4.45		-0.50	-0.94	67.3
Tuber weight, ϕ <3 cm	+0.67	-1.32	+2.13	+2.51	+1.17	-9.56	36.7
Tuber weight, ϕ 3-4 cm			+0.81	+0.88	+0.35	-1.77	57.3
Tuber weight, ϕ 4-5 cm	-0.48	+0.56	+2.95	+1.04	+0.86	-6.62	52.4
Tuber weight, ϕ 5-6 cm	-0.24	+0.48	-1.28	-0.92	-0.42	+4.21	59.5
Tuber weight, ϕ >6 cm	-0.17	+1.21	-5.06	-2.57	-2.43	+7.31	59.8

crop, were characteristic of the following varieties: Ruta (from the very early group), Lotos (from the early group), Ronda (from the middle early), Fala (from the middle late group) and Tarpan (from the late group).

The varieties of the highest stability crop and its share of the tubers > 5 cm in diameter (marketable) in the group of very early varieties was Irys, in the group of early varieties - Elipsa, in the group of middle early - Elida, in the group of middle late - Bryza, in the group of late ones - Bzura.

From the regression equations it follows that environmental factors significantly modified the tuber yield and its structure. Precipitations in July-August at 144.7 mm mean level had a positive effect on tuber yield and weight of tubers of 4-5, 5-6 and >6 cm diameter. Precipitations in May-June (about 103.7 mm) had only an influence on weight increase of tubers of <3 cm diameter but tuber weight of other size fractions decreased. Air temperature increase by 1 degree - in a range of standard deviation from arithmetic mean equalled to 17.1 °C - caused the tuber yield decrease and the weight of tubers of 5-6 and >6 cm diameter by values presented in Table 4. The increase of soil abundance in available phosphorus and potassium - at their mean level of 15.7 and 21.9 mg/100 g soil, respectively - by a unit resulted in increasing the weight of tubers of <3, 3-4, 4-5 cm in crop and decreasing the largest tubers in crop. Soil acidity increase by a unit - at mean pH 5.7 - caused the yield decrease and fine and middle tubers percentage.

Determination coefficients of the considered system of equations were, on average, very low, with the exception of tuber crop, which, at simultaneously divergent effects of meteorological and soil factors allows for the conclusion that the tuber yield and its structures affect some features other than those mentioned in the models of function.

DISCUSION

The yield of tubers was determined mostly by vegetation conditions in individual years and on the co-operation of cultivars and years. Studies conducted by Mac Kerron *et al.* [3], Sawicka [5], Yildrim and Caliscan [12] confirm a high variability of yield in the years of study. Silva and Andrew [7] found that differences of yield for the same cultivar can occur and they can be even fourteen-fold. They state that soil variability in a row can cause tuber weight variability to 50% and can be the reason such high variability and, in addition, variability between rows can take place. The studies show that among the meteorological factors, the highest effect on the tuber yield and its structure was exerted by atmospheric temperature of July and August. An increase in atmospheric temperature caused a drop in tuber yield, and also in tuber mass, 5-6 and >6 cm in diameter. Similar results were obtained in earlier studies [4]. According to Mac Kerron *et al.* [3] and Ubysz-Bogucka [11], the structure of tuber yield is subject to high environmental variability, and in subsequent vegetative generations it is even more pronounced. The drop in mean tuber mass and the heightening of the number of small tubers has, according to MacKerron *et al.* [3], been due to drought at tuber creation and flowering.

The co-operation of varieties and years prevailed in total variability within the fraction <3 cm in diameter. The effect of co-operation of cultivars and years on the crop structure was confirmed by MacKerron *et al.* [3] and Sawicka [5,6]. The factors diversifying tuber mass of individual fractions in the yield are also: competition between stalks in a plant; competition for photosynthetic products between individual stolons, emerging from the joints created at various levels of underground part of the stalk. The competition between the sprouts and the domination of the top sprout, main bud, may affect the number of stalks in a plant and the competition between them, which, in turn, influences the size of tubers in the crop [3,5,6,12].

The genotype features had the lowest share in the total variability of individual tuber size fractions (1.8-9.8). Their significant effect was exerted in the mass of tubers <3, 3, 3-4, 4-5 and > 6 cm in diameter. The influence of genetic factors on the yield structure is confirmed by Keller and Baumgartner [2], Teodorczyk [8], Mac Kerron *et al.* [3], Sawicka [4-6], as well as Yildrim and Caliscan [12].

Among the soil factors, greater influence on tuber yield and structure seems to be exerted by soil abundance in assimiable phosphorus in the soil. Such influence is not, however, significant. Fotyma and Grześkiewicz [1] determined, on the basis of 338 experiments, the effect of some agrotechnic and environmental factors and the starch content of the potato and found out that only excessive rainfall causes a decrease in tuber crops and starch content in the conditions of good soils of low soil reaction as well as high assimilable phosphorus.

Demonstrated in the analysis is the negative effect of soil reaction of pH 5.7 ± 0.6 on the tuber yield and its share of small and medium tubers has been partly confirmed by Fotyma and Grześkiewicz [1].

CONCLUSIONS

1. The most stable feature of the potato tuber structure appeared to be the mass of tubers 5-6 cm in diameter with the mean coefficient V = 34.2 %, and the share of the mass of tubers <3 cm in diameter was one of the less stable features of the mean coefficient V = 74.5%.

2. The coefficients of the determinations of the considered systems of equations with the exception of tuber yield were mean on the average, which at simultaneous divergent meteorological and soil conditions allows one to presume that the yield of tubers and their structure is affected by still more factors, not included in the models of functions.

3. The increase of tuber yield, and also the mass of tubers of ϕ 4-5, 5-6 and >6 cm were favoured by the July and August rainfall, at their mean level of 145 mm.

4. Increasing the abundance of soil in assimiable phosphorus and potassium, at its mean level of 15.7 and 21.9 mg/100 g soil, respectively, by a unit, resulted in the increase of the tuber mass share by o <3, 3-4, 4-5 cm, and decrease of the largest tubers in the yield.

5. The change of slightly acid into neutral soil reaction caused the drop in yield and its share and the increase of marketable tuber share.

6. Evaluating the effect of the discussed factors on the yield of tubers and its structure, they may be sequenced as follows: mean atmospheric temperature of July and August > July and August rainfall > May and June rainfall > soil pH > soil abundance in assimiable K_2O > soil abundance in assimiable P_2O_5.

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