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Dynamics of tuber weight in early potato varieties in the contrasting weather conditions of the Northwestern Russia

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Abstract. Under climate changes, it is particularly important to search for characteristics of varieties that are steady in contrasting weather conditions. The aim of the present research was to study the relationship between the growth of tubers and haulms in early potato varieties in the Northwestern Russia. Fourteen early potato varieties were studied in the field experiments conducted in 2017–2019 in the vicinities of St. Petersburg. The results of three intermediate digs on the 45th, 60th and 75th day from the planting date were analyzed. The correlation analysis, ANOVA, and regression were used. The average haulm and tubers weight significantly differed in the years of the study, while the number of tubers per plant and the haulm to tubers weight ratio did not differ. The relative growth rate of tubers weight from day 45 to 60 and from 60 to 75 did not differ significantly between 2018 and 2019, the years contrasting in terms of weather conditions. On the average, the tubers weight increased 2.6–2.8 times from day 45 to 60, and 1.4 times from day 60 to 75. It has been established that the early prediction of productivity in early potato varieties can be based on the haulm weight on the 60th day after planting; its coefficient of correlation with productivity was 0.72–0.79. Every 100 grams of the haulm weight on day 60 ensures a 100–200 g increment in the tubers weight by the time of harvest on day 80. The obtained results can be used in the development of a morphometric indicator-based automated system for monitoring the growth of potato plants.

Key words: biometric indicators, dynamics, potato, productivity, relative growth rate.

INTRODUCTION

Potato is the third most important food crop in the world after wheat and rice. It is characterized by the ability to grow in various ecological and geographical regions, to yield in unfavorable conditions and on soils with low fertility. In the modern world, where more than two billion people (26% of the world's population) lack a regular food supply (FAO, 2019), potato is regarded as the main crop for combating poverty and malnutrition in developing and underdeveloped countries. The nutritional value of potato and the ability to produce yield in a relatively short growing season have contributed to the development of potato production in most countries in Asia, Africa and Latin America (Chandrasekara & Kumar, 2016; Devaux et al., 2020). Climatic changes and instability of weather factors have a noticeable impact on the potato industry and require adaptation measures (Hijmans, 2003; Menzel et al., 2005; Kaukoranta & Hakala, 2008; Iglesias et al., 2009; Olesen et al., 2011; IPCC, 2014). Depending on the region and climate model, the predicted declines in yield by 2050 range from 2.5% to 23% (Pradel et al., 2019). The climate changes observed in recent decades in the European part of Russia have significantly affected the manifestation of economically important traits of potatoes, including productivity and starch content (Novikova et al., 2017; Maho et al., 2019). For the successful functioning of the industry in conditions with unstable weather factors, there is a need in abiotic stress tolerant varieties, and in appropriate technologies for their cultivation (Hijmans, 2003; Olesen et al., 2011; Dahal et al., 2019; Devaux et al., 2020).

In terms of acreage and gross harvest, Russia's share in world potato production is about 10% (Korshunov et al., 2018). According to the leading Russian breeders, there is a shortage of highly productive table varieties with improved quality characteristics, such as early-maturing, late blight and nematode resistance (Simakov et al., 2016). Testing of new domestic varieties is annually carried out in experimental fields of the ‘Pushkin and Pavlovsk Laboratories’ Scientific and Production Base of the N.I. Vavilov All-Russian Institute of Plant Genetic Resources (P&PL SPB of VIR) located near St. Petersburg (59.7 N, 30.4 E), in the Northwest Federal District of Russia. Conditions in the Northwestern District are favorable for the production of seed potatoes, therefore, testing of new domestic potato varieties in this region is of particular interest for all the parties involved in potato production, including commodity producers and seed producers. However, insufficient knowledge of the mechanisms of potato plants resistance to stress factors, and of their ability to respond to the changing environmental conditions during ontogenesis, complicate the development of a methodology for screening varieties with a high adaptability potential (Eremeev et al., 2003; Dahal et al., 2019).

In breeding of potatoes and other root tubers, the dynamics of growth of roots and tubers, as well as of vegetative mass, is important (Guzhov et al., 2003, p. 179). At the beginning of vegetation, biomass is consumed for the leaf surface formation, and then the biomass produced by the plant is spent on tuberization. To ensure high yields, it is necessary to provide sufficient leaf area by the onset of tuberization. This information is valuable for assessing performance and adaptation particularly in areas with short growing seasons, where harvesting has to be carried out during the bulking period, that is, before leaf senescence. Assessment and documentation of tuber bulking maturity of potential varieties can be useful in the selection of early bulking maturity (Mihovilovich et al., 2014).

Despite the large number of varieties currently available, there is still a need in new early-maturing varieties (Eremeev et al., 2015; Kawar et al., 2018; Ierna & Mauromicale, 2020). Early ripening allows avoiding biotic and abiotic stresses that occur in later periods of the year. Early maturing varieties also ensure an even distribution of potato production over a season (Kawar et al., 2018). Early tuber initiation and growth are necessary for acceptable production in areas where potatoes are often harvested prior to physiological maturity (Mihovilovich et al., 2014).

The main parameters of an early potato variety are as follows: 60–70 days from planting to tuber bulking, productivity of 12–15 t ha^{-1} on day 60, 6–8 marketable tubers per plant, and 100–120 g average weight of a tuber (Simakov et al., 2016). From the agricultural point of view, an early maturing potato variety implies an ability to produce a high yield of tubers early, however, many varieties that are attributed to early ones, continue increasing the weight of tubers after 75, 80, and even 90 days of growth, which indicates that they have not reached technological ripeness by the time of harvesting (Kiru et al., 2016). Earlier (Kiru et al., 2016), a criterion for true early maturity has been proposed, that is, a decrease in the tuber weight relative growth rate after 60 days from the planting. Growth rate is a characteristic of a time series; it expresses changes in values of a variable between two periods of time (Eliseeva et al., 2006). In our case, it is the relative growth rate in weight of tubers or haulm between two digs (Kiru et al., 2016).

Plant breeders are compelled to screen large numbers of genotypes for their yield potential under field conditions using the time- and cost-intensive methods. The use of easy phenotyping techniques could improve the understanding of potato yield-related mechanisms and allow low-cost predictive assessments (Prey & Schmidhalter, 2020). Knowledge of the biological regularities of plant growth and development allows one to make early forecasts of yield using mathematical, in particular regression models (Guide to agrometeorological forecasting, 1984).

The aim of the present research was to study the relationship between the growth of tubers and haulms in early potato varieties in the Northwestern Russia.

MATERIALS AND METHODS

Site description and materials

Fourteen potato varieties were studied in 2017–2019 in the experimental field of P&PL SPB of VIR, St. Petersburg (Table 1). The soils of the experimental field were medium-loamy, slightly acidic (pH 5.7), and the humus content was 3.4%.

The set represents varieties of different geographical origin, from Germany, the Netherlands, European and Asian parts of Russia; old cultivars and new hybrids (Table 1). The varieties Gala, Red Scarlett and Udacha were used as references, being the most popular early varieties in Russian potato industry (Korshunov et al., 2018).

Each variety was represented by 20 plants planted in three replications on randomized plots. During each growing season, such biometric indicators of plant growth and development as the number of stems, the stems length, the weight of haulm (g), the total weight of tubers (g), the number of tubers (pieces), the weight of marketable tubers (g) and the number of marketable tubers (pcs) were recorded. The records were made on day 45, 60 and 75 after planting by evaluating two plants of each variety in three replications. At the final harvesting on day 80, the total weight and number of all tubers, and the weight and number of marketable tubers were recorded. Tubers weighing 30 g on day 45 and 40 g on day 60 and subsequent days after planting were considered as marketable ones. Marketability was calculated as the marketable tubers weight to the total tubers weight ratio as a percentage.

Table 1. Origin of 14 potato varieties studied in 2017–2019 at P&PL SPB of VIR

Potato variety, hybrid name	Originator (research institute, company)	Year included in the State Register for Selection Achievements
Antonina	Siberian Research Institute of Agriculture and Peat, Russia	2005
Bravo	Urals Research Institute of Agriculture, Russia	2015
Gala	NORIKA GMBH, Germany	2008
Gulliver	A.G. Lorkh All-Russian Research Institute of Potato Farming, Russia	2018
Hybrid S 112-03	Siberian Research Institute of Plant Industry and Breeding, Russia	Not included
Hybrid 3-43-2	Polar Experiment Station, a branch of VIR, Russia	Not included
Zhigulyovsky	A.G. Lorkh All-Russian Research Institute of Potato Farming and N.M. Tulaykov Samara Agricultural Research Institute, Russia	2006
Lyubava	A.G. Lorkh All-Russian Research Institute of Potato Farming and Kemerovo Agricultural Research Institute, Russia	2003
Lux	Urals Research Institute of Agriculture, Russia	2016
Red Scarlett	HZPC HOLLAND B.V., the Netherlands	2000
Sarovsky	Siberian Research Institute of Plant Industry and Breeding, Russia	2014
Start	Smolensk Agricultural Research Institute, Russia	Not included
Udacha	A.G. Lorkh All-Russian Research Institute of Potato Farming, Russia	1994
Yuna	Siberian Research Institute of Plant Industry and Breeding, Russia	2013

Data analysis

The two-way ANOVA was used to analyze the dependence of the final tuber indicators, recorded on day 80 after planting, on the variety and year.

For two years, 2018 and 2019, a more detailed study of the dynamics of haulm and tubers weight increase was carried out using the data of intermediate digs. A comparison of dynamics indicators was carried out using the Student *t-test* for dependent samples, which has greater power than unpaired tests because the random intra-group variation is eliminated (Fradette et al., 2003; Khalafyan, 2010).

Indicators of the dynamics of haulm and tubers weight increase were calculated according to formula (1) for the periods from day 45 to 60 and from day 60 to 75, that is, the 15-day growth rates were obtained.

$$K_{n/m} = \frac{Y_n}{Y_m} \qquad (1)$$

where Y_n, Y_m – the weight on days *n* and *m* after planting, respectively.

A comparison of dynamics indicators in two contrasting years was carried out using the Wilcoxon matched pairs test.

The dependence of the weight of tubers on day 80 on that of haulm and tubers during intermediate digs was investigated using the correlation and regression analysis.

The statistical analysis was performed using the software package Statistica 13.3 (TIBCO Software Inc., Palo Alto, CA, USA).

Weather conditions

The daily data from the Pushkin meteorological station of VIR were used. During the three years of research, 2018 was the warmest, and 2019 was the coldest year (Fig. 1, a). The average temperature over 80 days of the growing season (from planting to digging up) was 16.5 °C in 2017, 17.5 °C in 2018, and 15.9 °C in 2019. The year 2017 was the wettest, with the total precipitation of 360.4 mm during the growing season (Fig. 1, b). In 2018, it equaled 87.6 mm, and 126.8 mm in 2019.

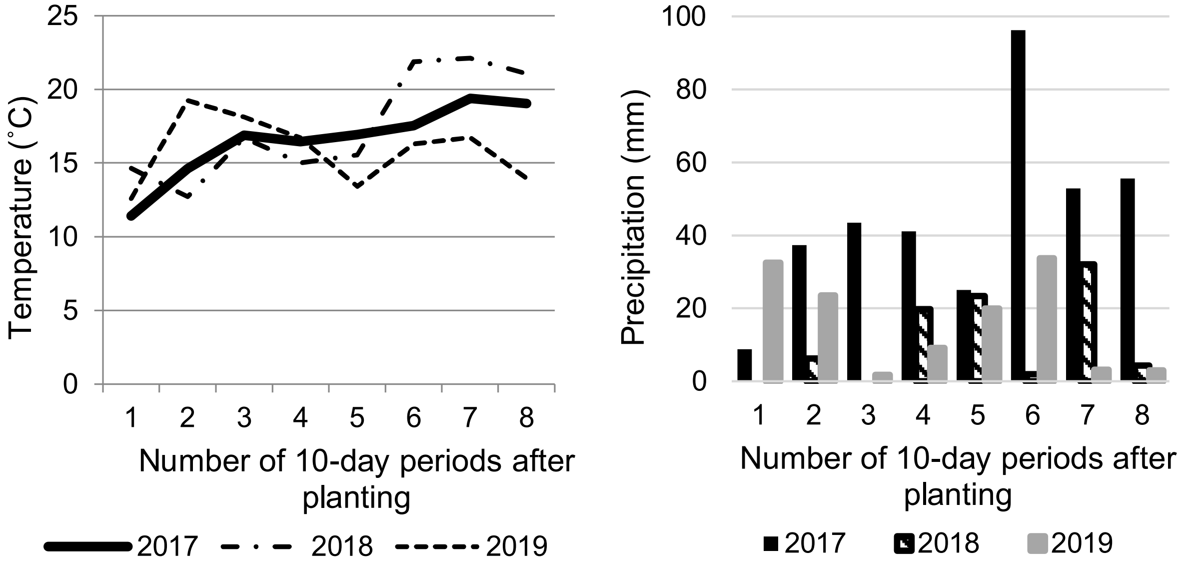

Figure 1. Heat and moisture conditions during potato vegetation per 10-day periods from the planting date: a) average temperature; b) total precipitation.

RESULTSS

Comparison of productivity in three years of research

The two-way ANOVA showed that tuber productivity significantly depends on both the variety ($p < 0.001$) and year ($p < 0.001$). The highest productivity (recorded on day 80 after planting, which corresponds to day 60–65 after emergence) was observed in 2018 (Fig. 2); the average for 14 varieties was 994.7 g plant^{-1}, the lowest of 791.6 g plant^{-1} was recorded in 2019, and in 2017 it averaged 832.3 g plant^{-1}. The productivity amounting to 1 kg of tubers plant^{-1} with 27 thousand plants ha^{-1} and tubers marketability of 75–80%, provides a yield of 20–21 t ha^{-1}, which corresponds to the parameters of an early potato variety.

The number of tubers plant^{-1} did not differ over the years ($p = 0.092$) and amounted to 11.5–12.4 pcs. The number of marketable tubers averaged 6.7–7.1 pcs. plant^{-1} ($p = 0.396$), which corresponds to characteristics of an early variety. Noticeable differences were found in the average tuber weight: the largest (81.9 g) for the studied set of varieties was recored in 2018, the smallest (70.2 g) in 2019, and in 2017 it was 71.2 g ($p < 0.001$). The number of stems plant^{-1} was minimal in 2018 (2.6 pcs.), it was maximal in 2019 (4.3 pcs.), and medium in 2017 (4.1 pcs, $p < 0.001$). The indicator of marketability was the lowest in 2017 (75.5%) compared to 2018–2019 (90, 91%, respectively; $p < 0.001$).

So, the number of tubers was relatively constant, while the growing season conditions significantly influenced the average tuber weight. The indicators of productivity, tuber weight and stem number were the most contrasting in 2018 and 2019.

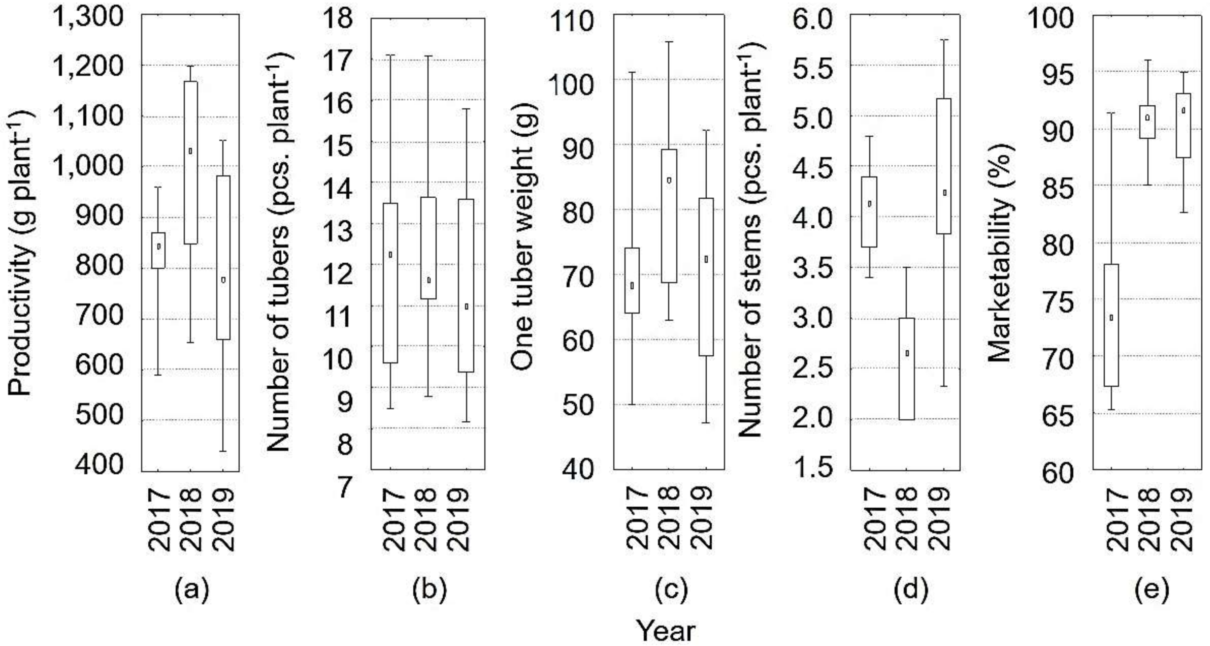

Figure 2. Productivity and its components for a set of 14 early potato varieties within three years of research: a) productivity; b) number of tubers; c) one tuber weight; d) number of stems; e) marketability. The median, qsuartiles, minimum and maximum values are presented.

Comparison of the haulm and tubers weight from day 45 to 75 in contrasting 2018 and 2019

To analyze the dynamics of haulm and tubers weight increase during the growing season, 2018 and 2019 were chosen as the most contrasting years (Fig. 3).

Haulm. The small size of seed tubers determined formation of a smaller number of stems on plants in 2018 compared to 2019 (Fig. 3, a), 2.6 pcs. *vs*. 4.3 pcs. on an average, respectively. The differences between the years were significant, with $p = 0.004$ on day 45; $p < 0.001$ on day 60, and $p < 0.001$ on day 75, according to the Student *t-test* for dependent samples. The stem length did not vary significantly between different years (Fig. 3, b) on day 45 and 60, and amounted to 44.0 and 46.2 cm on day 45 ($p = 0.137$), and to 49.6 and 48.7 cm on day 60 ($p = 0.713$). On day 75, the stem length was significantly lower in 2018 than in 2019 due to the faster development, and amounted to 40.9 cm and 49.0 cm, respectively ($p = 0.004$). The haulm weight (Fig. 3, c) was higher in 2018 than in 2019 on day 45 (349.0 g *vs*. 269.2 g, $p = 0.047$) and on day 60 (376.1 g *vs*. 298.3 g, $p = 0.026$), while on day 75 there were no significant differences (301.8 g *vs*. 276.4 g, $p = 0.376$).

Tubers. The dynamics of the number of tubers did not depend on the year. The final number of tubers that had formed by the first dig (Fig. 3, d) was 10.9 *vs*. 11.8 tubers plant^{-1} on an average on day 45 in 2018 and in 2019, respectively (p = 0.341), 12.1 *vs*. 11.7 on day 60 (p = 0.494); and 12.8 *vs*. 12.3 on day 75 (p = 0.603).

Despite the different temperature conditions till day 45 after planting in 2018 and 2019, the total weight of tubers per plant (Fig. 3, e) on day 45 did not differ significantly and amounted to 241.0 g in 2018 and 214.7 g in 2019 (p = 0.193). On other control dates, the total weight of tubers was higher in 2018 than in 2019, and amounted to 608.2 and 536.3 (p = 0.024) on day 60; and to 874.2 g and 754.2 g on day 75 (p = 0.010).

The haulm to tubers weight ratio (Fig. 3, f) decreased in the seasonal course of development. The differences in years were not significant: the ratio was 1.8 on day 45 in 2018 and 1.3 in 2019 (p = 0.193), 0.6 on day 60 (p = 0.168), and 0.3 and 0.4 on day 75 (p = 0.241).

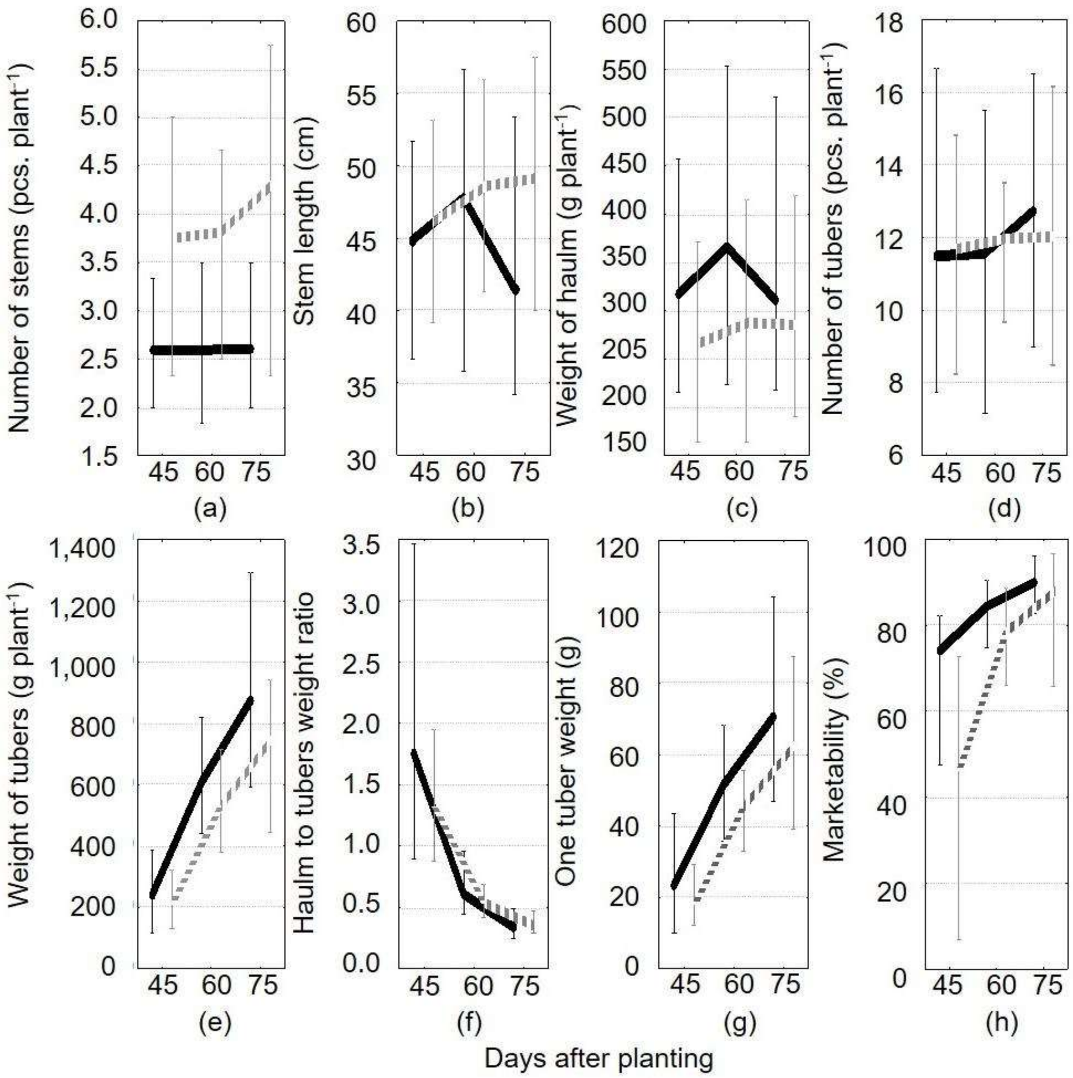

Figure 3. Dynamics of potato growth in 2018 and 2019: a) number of stems; b) stem length; c) weight of haulm; d) number of tubers; e) weight of tubers; f) haulm to tubers weight ratio; g) one tuber weight; h) marketability. Designations: 2018 – solid line, 2019 – dotted line. The average, minimal and maximal values for 14 varieties are presented.

The average weight of one tuber (Fig. 3, g) in all three digs was higher in 2018, but the differences were significant only on day 45: 23.4 g in 2018 and 18.4 g in 2019 (p = 0.043), and insignificant on the later dates: 51.6 g *vs*. 45.7 g (p = 0.066) on day 60, and 70.6 g *vs*. 63.1 g (p = 0.247) on day 75.

The marketability was significantly higher in 2018 (Fig. 3, h), that is 75.1% *vs*. 46.6% in 2019 on day 45 (p = 0.000), and 84.4% *vs*. 78.8% on day 60 (p = 0.009). On day 75, marketability reached 89.9% in 2018 and 88.1% in 2019, and the difference between the years ceased to exist (p = 0.527).

Thus, the number of tubers per plant and the haulm to tubers weight ratio on the control dates turned out to be less sensitive to changes in the growing season conditions than the number of stems, the weight of haulm, and the total weight of tubers.

Indicators of the dynamics of the haulm and tubers weight growth from day 45 to 75 in 2018 and 2019

Visually, the lines of the dynamics of tubers weight increase (Fig. 3, e) in 2018 and 2019 are in parallel, despite the differences in the absolute values of the weight on different dates. For a quantitative analysis of the dynamics of the haulm and tubers weight increase, the dynamics indicator was calculated as the 15-day relative growth rate between intermediate digs. The average, minimum and maximum indicators of the dynamics of the haulm and tubers weight increase in the studied group of 14 early varieties in different periods are shown in Table 2.

Table 2. Potato haulm and tubers weight relative growth rates

15-day relative growth rate	Year	Days 45–60			Days 60–75		
		Average	Min	Max	Average	Min	Max
Haulm	2018	1.105	0.825	1.631	0.818	0.586	0.996
	2019	1.143	0.818	1.573	0.941	0.744	1.177
	p*	0.594			0.035		
Tubers	2018	2.750	1.541	5.621	1.443	1.168	1.948
	2019	2.621	1.724	3.665	1.417	1.163	1.745
	p	0.593			0.594		

*p is the significance level of differences between years according to the Wilcoxon test.

Haulm. The relative increment rate of the haulm weight from day 45 to 60 did not depend on the conditions of the year and was 1.105–1.143, i.e. the increment rate was 10.5–14.3% over 15 days (p = 0.594). From day 60 to 75, the haulm weight began to decrease. The process was more intense in 2018 (-18.2% over 15 days) than in 2019 (-5.9% over 15 days; p = 0.035). This was probably due to a higher temperature in this period in 2018 and the faster development of plants.

Tubers. Indicators of the dynamics of tuber weight increase did not differ over the years. On an average, the weight of tubers increased for the studied varieties by 2.621–2.750 times, i.e., by 162.1–175.0% (p = 0.594) over 15 days from day 45 to 60; and by 1.417–1.443 times, i.e., by 41.7–44.3%, from day 60 to 75 (p = 0.594). Thus, the dynamics of tuber weight increase in early varieties was less dependent on the year than that of the haulm weight.

On the 2-year average, the weight of tubers in 14 varieties increased 2.0–3.9 times from day 45 to 60, and 1.3–1.7 times from day 60 to 75.

The tubers – haulm weight relationship

The correlation and regression analysis of the varieties productivity in two contrasting years was carried out.

2018. In 2018, the final productivity of the variety strongly correlated with the characteristics of a variety on day 60 (by which conditions for active growth had formed), that is, with the stem length ($r = 0.83$), the weight of haulm ($r = 0.72$), and with the weight of haulm on day 75 ($r = 0.77$).

2019. In 2019, the varieties could be differentiated by the size of haulm earlier than in 2018, and the final productivity was actually determined by the weight of haulm on day 45 ($r = 0.83$). Productivity was found to strongly correlate with the stem length on day 45 ($r = 0.76$) and the weight of tubers ($r = 0.72$). The final productivity correlated with such variety characteristics on day 60, as the total weight of tubers ($r = 0.88$), the weight of haulm ($r = 0.79$), and the total number of tubers ($r = 0.80$), as well as with such characteristics on day 75 as the total weight of tubers ($r = 0.78$) and the weight of marketable tubers ($r = 0.74$).

In both years with the contrasting temperature profiles, the weight of haulm on day 60 strongly correlated with productivity on day 80 with a coefficient of 0.72–0.79 (Fig. 4).

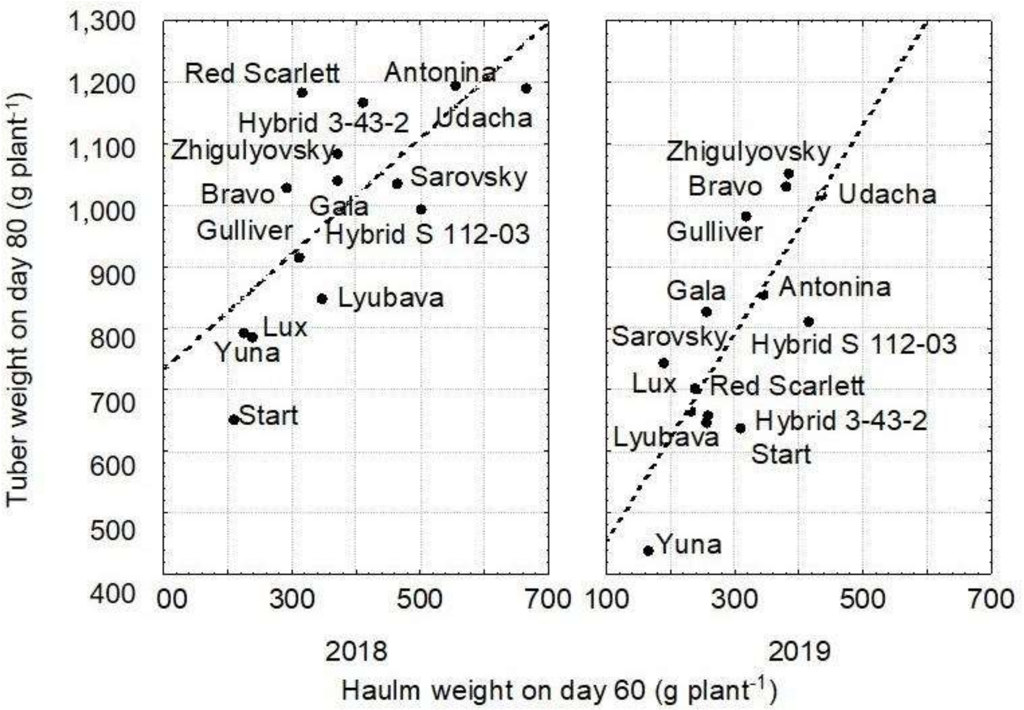

Figure 4. The dependence of the weight of tubers on day 80 after planting on the weight of haulm on day 60.

The final productivity (Y) dependence on the haulm weight on day 60 (V):

$$2018: \; Y = 640.25 + 0.94V \qquad R^2 = 0.52 \qquad (2)$$

$$2019: \; Y = 284.92 + 1.70V \qquad R^2 = 0.62 \qquad (3)$$

where R^2 – the coefficient of determination. It follows from the above that every 100 grams of the weight of potato haulm recorded on day 60 ensures a 100–200 g increment in the weight of tubers by the time of digging up on day 80.

For the average values of two years:

$$Y = 477.75 + 1.23V \qquad R^2 = 0.57 \tag{4}$$

The equation can be improved if the number of tubers per plant on day 60 (N) is known:

$$Y = 236.15 + 0.93V + 28{,}84N \qquad R^2 = 0.69 \tag{5}$$

In the present study, only Udacha variety out of the 14 studied ones, was distinguished by high and stable productivity, regardless of the weather conditions in the growing season (Fig. 4). It is the most common commercial variety in the Russian Federation recommended for cultivation in 8 out of the 12 agro-climatic regions of the country. The rest of the varieties and hybrids have genotypes adapted to different climatic zones (Siberia, the Volga region, the Northern or Central regions of the European part of Russia) and differ in their response to changes in growing regimes.

DISCUSSION

The conditions for potato growth were the best in 2018 and the worst in 2019. The beginning of the growing season in 2018 was cool; the average temperature within 45 days after planting (14.8 °C) was lower than in 2019 (16.3 °C), and medium in 2017 (14.9 °C). The amount of precipitation over 45 days was sufficient: 140.6 mm in 2017, 49.3 mm in 2018 and 86.5 mm in 2019. The period of tuber weight increase from day 45 to 80 was characterized in 2018 by a favorable average temperature (20.9 °C), by the lowest in 2019 (15.3 °C), and medium in 2017 (18.6 °C). The amounts of precipitation in 2018–19 were sufficient (38.3 mm and 40.3 mm, respectively), and excessive in 2017 (219.8 mm). As a result, the highest yield was obtained in 2018; it was 994.7 g plant^{-1} on an average for 14 varieties. The lowest yield was obtained in 2019 (791.6 g plant^{-1}), and it was medium in 2017 (832.3 g plant^{-1}). The productivity amounting to 1 kg of tubers plant^{-1} with 27 thousand plants ha^{-1} and tubers marketability of 75–80%, provides a yield of 20–21 t ha^{-1}, which corresponds to the parameters of an early potato variety.

In 2017, the conditions of the growing season favored early infestation of plants with late blight. Moderate temperatures and the abundance of precipitation, especially their significant increase in the last three 10-day periods (Fig. 1, b), caused a late blight outbreak and a need in early harvesting to prevent losses. Small tubers prevailed in the harvested potato, which is reflected in the marketability indicator, the lowest in 2017. Small tubers developed a smaller number of eyes capable of germinating the next year (Alsmik et al., 1979; Dimante & Gaile, 2018), which led to formation of only 2.6 stems per plant. The tubers harvested in 2018 produced an average of 4.3 stems per plant in 2019.

The two-way ANOVA revealed that the number tubers did not differ significantly in three years, i.e., turned out to be not very sensitive to changes in the growing regime. Low temperatures increase the number of tubers per plant (Levy & Veilleux 2007), however, in our case, differences in the average temperature of 45 days after planting in 0.5 °C (14.8 °C in 2018 and 16.3 °C in 2019) had less effect on the number of tubers, which was 12 pcs plant^{-1} on an average, but had an effect on the tuber weight, which varied from 70.2 to 81.9 g. The number of tubers is known to be a more stable character of variety than one tuber weight and yield (Petr et al., 1984).

An analysis of dynamics of biometric parameters of the haulm and tubers in potato varieties in 2018 and 2019 showed that on day 60 and 75 they were higher in 2018 than in 2019. Potato is well adapted to a mean temperature of 17 °C: haulm growth optimum is 20–25 °C, tuber growth about 15–19 °C (Tadesse et al., 2001; Levy & Veilleux 2007; Çalişkan, 2016). At a lower temperature (15 °C) and at a higher temperature (25 °C) tuberization is delayed; high temperature above optimum delays tuber initiation and reduces harvest indices (Tadesse et al., 2001; Levy & Veilleux 2007; Çalişkan, 2016). In 2018, favorable growing conditions compensated for the small number of stems, relatively low temperatures at the first part of growing led to more haulm weight. A gradual increase in temperature and precipitation in 2018 ensured the vigorous growth and development of plants. A decrease in temperature that began in the second 10-day period after planting in 2019, and a lack of heat that continued until the end of the growing season negatively affected the biomass increment. Our data are consistent with the previously established differences in optimal temperatures for the growth of the potato haulm and tuberization (Alsmik et al., 1979; Kim & Lee, 2019). The relative growth of various organs in comparable periods of time is similar, i.e., the percentage of dry matter attributable to different organs at certain periods of development is approximately the same in varieties of the same ripening period (Petr et al., 1984).

The use of dynamics indicators made it possible to reveal the relative independence of the tuber weight increase in early varieties from the conditions of the year, in contrast to the haulm weight growth. The haulm to tubers weight ratio (Fig. 3, f) decreased in the seasonal course of development. The differences in years were not significant. The average relative increment rate for a set of 14 varieties did not differ significantly in the contrasting years. The weight of tubers increased on an average 2.6–2.8 times from day 45 to 60, and 1.4 times from day 60 to 75. In studies of a set of 63 early and mid-early varieties at the Polar Branch of VIR (Murmansk Province), the weight of tubers increased from 1.4 to 3.7 times from day 60 to 75, that is, potato varieties of different maturity groups significantly vary in the rate of tubers weight increase in the same conditions (Kiru et al., 2016). In our study of 14 varieties, the average growth rate was 1.3–1.7 from day 60 to 75. Thus, the 14 studied varieties had relative growth rates close to the minimum. The constancy of relative indicators for early varieties is stated in work of Särekanno et al. (2012).

High productivity of potato requires a good development of the haulm. The works of Alsmik (1979) revealed the influence of the potato plant morphobiological type on the productivity and longevity of a variety. The grouping of plants proposed by him according to the shape of the bush, the emergence of stems from soil and the number of stems, has been used by Belarusian breeders to select promising high-yielding varieties (Makhanko & Kolyadko, 1997). A strong relationship between the manifestation of morphological and agronomic characteristics has been established for the early potato varieties developed in Ukraine: it exists between productivity and the leaf weight with the correlation coefficient of 0.83, leaf area size (0.82), total haulm weight (0.84), marketable tubers weight (0.93), and the marketable tubers number (0.73) (Podgaetsky & Kupriyanova, 2008). A conclusion about the possibility of predicting potato productivity on the basis of physiological and morphological parameters of plants was made by Polish researchers based on the results of three-year experiments with early and mid-early varieties. A comparative analysis employed such predictors of potato productivity as the leaf surface index, total chlorophyll content and chlorophyll fluorescence, while the greatest correlation was found between the tuber yield and leaf surface index (Zarzynska & Pietraszko, 2017). Our research revealed, that for the early potato varieties the final productivity of potato plants in contrasting years depended on the weight of haulm on day 60 after planting, and the correlation coefficient was 0.72–0.79. Every 100 grams of the weight of haulm recorded on day 60 ensures a 100–200 g increment in the weight of tubers by the time of digging up on day 80.

CONCLUSIONS

The contrast weather conditions leads to the significant differences in the early potato varieties productivity. But the number of tubers and haulm to tubers weight ratio turned out to be less sensitive to changes in the growing regime.

The use of dynamics indicators made it possible to reveal the independence of the tuber relative growth rate in early varieties (in contrast to the haulm growth) from the conditions of the year.

The revealed relationship between the final productivity of early potato varieties and the weight of haulm on day 60 after planting can be used to advance forecasting the yield. The obtained results can be used for the development of automated systems for recording the morphometric parameters of potato plants.

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