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Growth requirements of different potato cultivars

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ABSTRACT

A field trial with four potato cultivars (Faluka, Manitou, Madeleine and Stirling) was conducted in two consecutive years (2012 and 2013) at a laboratory field of Biotechnical Faculty in Ljubljana. The aim of the study was to evaluate different requirements of the selected cultivars in regard to the ridge and tuber cluster. The following parameters were defined and monitored: area of the form surrounding the tubers (ellipse), cross-sectional area of the ridge, vertical and horizontal tuber span in the ridge, the length of semi-axes (a) and (b) of the ellipse, minimum distance of tubers and ellipse from the outer ridge side. The results of 2012 trial indicated that the minimal ellipse method defining the ellipse was not satisfactory as statistical significance was limited due to a large volume of vacant space in the ridge not occupied by potato tubers. Therefore, the mathematical model was upgraded in 2013 and a physical parameter (tuber mass) was incorporated in the equation to better depict the tuber cluster. The trials were designed as a randomized block with five repetitions. The largest ellipse, horizontal tuber span in the ridge and the longest semi-axis (a) were recorded for the cv. Manitou resulting in the highest yield. However, no statistical differences were recorded in the horizontal tuber span, the length of the semi-axis (a) or cross-sectional area of the ridge among cultivars analysed. It was determined that different cultivars require specific growth space in the potato ridge. Moreover, the newly developed method proved efficient for determining growth requirements of potato tubers in the ridge.

Keywords: *Solanum tuberosum* L.; tuberous crop; quality; green tuber; marketable yield

In the present circumstances when the market and the processing industry call for high-quality potatoes the production must focus on diminishing the proportion of non-marketable yields. This can be achieved with planting new potato cultivars, which, in favorable growing conditions, give yields of 50 t/ha or even more. To promote high yields and sufficient quality a ridge of appropriate size must be designed in order to ensure full soil cover of the tubers. Contrary, tubers come to the surface, turn green and fail to reach adequate market/processing quality causing high production costs.

The majority of new tubers develop around and above the seed tuber. Newly formed potatoes push the soil outwards causing cracks on the ridge. This effect is more prominent on loamy soil (Kouwenhoven et al. 2003). Tubers in the ridge are mostly distributed in the form of an ellipse and only a few tubers are located below the seed tuber. Consequently, as tubers grow directly under the surface of small ridges, the possibility of green tuber development is increased (Struik and Wiersema 1999). However, insufficient space in the ridge does not justify the formation of wider ridges per se. Potato tubers only occupy 4.5% of the space in the ridge with a cross-sectional area of 800 cm^2 when considering yields of approximately 50 t/ha. It is therefore crucial that shorter stolons are formed in ridges as this will reduce the number of green tubers (Kouwenhoven and Perdok 2000). Tuber cluster width in the ridge greatly depends on the potato cultivar, as well as general growing and climatic conditions during the vegetation period (Wurr et al. 1997). Tuber cluster width varies from 15 cm in cv. Ulster Beacon to more than triple width (52 cm) in cv. Kerr Pink. As a result, cultivars

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with smaller tuber cluster width are less prone to develop green tubers (Kouwenhoven et al. 2003).

To conclude, green tuber effect can greatly be reduced by increasing the cross-sectional ridge area, by planting the seed tuber directly in the middle of the ridge, by ensuring optimal soil cover of newly formed tubers (at least 3.5 cm of soil above the ellipse), by reducing the cracking of the ridge and by selecting cultivars, which form a narrower tuber cluster. Kouwenhoven et al. (2003) determined that almost no green tubers are formed if a minimum of 7 cm soil cover is maintained. This can be achieved by a draught cultivator with spring tines fixed on a parallelogram framework and wing ridge heads (Vucajnik 2006). The same author also recorded the smallest green tuber yield at 90 cm inter-row width (IRW) as it forms the largest cross-sectional area of the ridge as well as the highest and widest ridge top (Vucajnik 2009). These characteristics are particularly important for cultivars with larger tuber cluster spans (i.e. cultivars with higher yields). On the other hand, 66 cm IRW leads to insufficient soil cover of most of the tubers and increases the possibility of tuber greening (ibid.). Nevertheless, most potato producers in Slovenia still cultivate potato at 66 cm IRW and therefore loss of yield due to green tuber formation is significant. To improve this inappropriate practice, targeted research must be conducted in order to set the requirements of commonly grown potato cultivars in Slovenia. The aim of the study was thus to determine optimal ridge forms and spatial distributions of selected potato cultivars (their tuber clusters) striving towards minimal loss of yield due to green tuber formation.

MATERIAL AND METHODS

Potato cultivars form different horizontal and vertical tuber spans and consequently require diverse ridge forms. Tuber spans of four potato cultivars were determined in the study: Faluka, Madeleine, Manitou, and Stirling.

Mathematically defined area of tuber formation (ellipse) revealed that individual cultivars comply with these forms to a greater or lesser degree. In order to evaluate the tuber span of each cultivar vertical and horizontal tuber span area and the form and distribution of tubers in the ridge were monitored. This can only be achieved by determining the position of individual tubers in the ridge. For this purpose a three-dimensional coordinate measuring device was used. A suitable mathematical model for determining the area of the form (ellipse or cluster) surrounding the tubers was developed based on the measurements of individual tubers of selected cultivars (Figure 1). Specific growth characteristics of potato cultivars led to setting up optimal ridge forms, which ensure minimal green tuber formation and highest yields of marketable potatoes. Ridge form is closely related to potato quality (Potrpin and Bernik 2014).

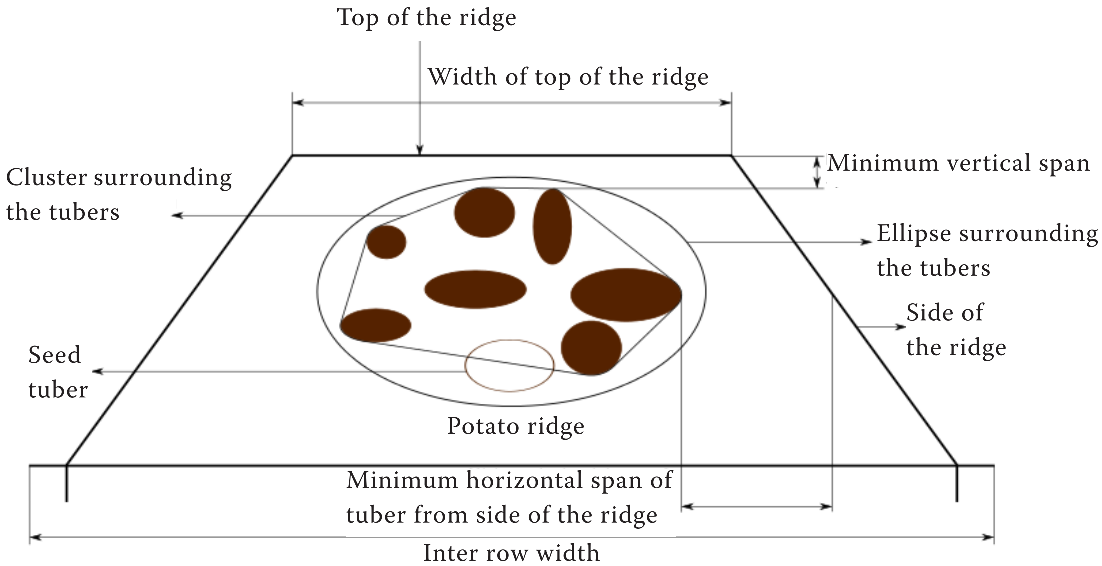

Figure 1. Tuber cluster and ellipse characteristics of potato ridge

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Figure 2. Coordinate measuring device in the field. 1 – ridge; 2 – furrow; 3 – cone tip; 4 – sensor; 5 – supports; 6 – frame; 7 – intersecting support; 8 – cross slide; 9 – device positioning spindles; 10 – bubble levels; 11 – vertical slide

Measuring device. Data on tuber distribution in the ridge are gained in two steps. Firstly, field measurements are conducted with a coordinate measuring device and secondly, the data are further processed with various computer programs (Potrpin and Bernik 2014).

A three-dimensional coordinate device was developed to measure the ridge form and distribution of individual tubers in the ridge (Figure 2). The device enables absolute and relative measurements of the distance in all directions. The device consists of a framework, coordinate leads, measurement converter and computerized measuring system with suitable software (Potrpin and Bernik 2014).

Experimental design. The trial was executed at the experimental field of the Biotechnical Faculty, University of Ljubljana, Slovenia. The soil is silty clay containing 27.5% clay, 58.7% silt and 13.8% sand. The results of the soil analysis are presented in Table 1.

Four potato cultivars were used for the trial: Faluka (medium-early cultivar with very high yields), Manitou (mid-late cultivar with high yields), Madeleine (medium-early cultivar with average yields) and Stirling (mid-late cultivar with average yields). The trial was performed in 2012 and 2013 and organized in randomized blocks (12 × 10 m) with five repetitions. Each block was divided into 30 m^2 plots and planted with individual cultivars. The plots were 10 m wide and consisted of rows with a 75 cm inter-row width. Measurements were only performed within the inner two rows of each plot to minimize the edge effect. Data on soil cultivation prior to planting, fertilization, and weed, pests and disease control are described in Table 2. A conventional method of planting was used, by which the potato is cultivated with a PTO-driven cultivator/ridger immediately before or shortly after emergence. Meteorological data were collected directly on site. The average monthly air temperature in the vegetation period between 1st April and 30th September and the average monthly precipitation are presented in Table 3. All measurements were performed immediately before potato harvest. In addition to data obtained from measuring device (Figure 2) each tuber was labelled and weighed in the laboratory facility. The volume of potato tubers was calculated from mass and average pure density (1.11 g/cm^3). Density of each cultivar was monitored in 2012 but no statistical differences were detected among them (Table 4).

Table 1. Soil analysis for individual years

Year	pH_{CaCl_2}	P	K	Organic carbon
		(mg/kg)		(%)
2012	6.9	59	148	2.2
2013	6.7	41	139	2.6

Methods in data processing. LabView (Austin, USA), Statgraph (Warrenton, USA), Microsoft Excel (Redmond, USA), Octave GNU (Texas, USA) and Matlab software (Natick, USA) were used for data processing. Physical characteristics were elaborated with the aid of the LabView program. Statistical analyses were performed with Statgraph 4.0, according to the method for randomized blocks. Graphical representations were made in Microsoft Excel.

The area of the ellipse encircling the tubers was calculated according to the ME method (minimal ellipse method). A compact mathematical model

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Table 2. Agricultural measures implemented in the trial

Agricultural measure	2012	2013
Fertilization with manure (25 t/ha – 75 kg/plot)	15/9/2011	14/92012
Basic tillage with a 2-bottom turning plow, depth 25 cm	16/9/2011	15/9/2012
Fertilization with NPK 7-20-30 (1540 kg/ha – 4.6 kg/plot) and NPK 15-15-15 (793 kg/ha – 2.3 kg/plot)	30/3/2012	2/4/2013
Additional tillage with a rotary harrow (engine speed 1540 r/min, tractor speed 4 km/h – 2750 r/min at 4 km/h, depth 15 cm) prior to planting	30/3/2012	2/4/2013
Planting (inter tuber width 29 cm, depth of planting 5 cm, tractor speed 3 km/h)	31/3/2012	2/4/2013
Fertilization with 26% Entec (287 kg/ha (72 kg N/ha) – 1076 g N/plot)	24/4/2012	24/4/2013
Spraying against nematodes (Force, 12 kg/ha – 45 g/plot); weed control (Sencor, 1.5 kg/ha – 150 g/plot); against grasses (Stomp, 5 L/ha – 0.5 L/plot)	24/4/2012	24/4/2013
Inter-row cultivating (tractor PTO 540 r/min, tractor speed 1.8 km/h)	24/4/2012	24/4/2013
Ridge formation (20 cm ridge width)	24/4/2012	24/4/2013

was developed in the Octave GNU software environment. It is based on the least square method (Fitzgibbon et al. 1999).

The method was upgraded in 2012 to better define the area of the cluster surrounding the tubers by excluding a large volume of vacant space in the ridge. The method was termed MCP – minimal convex polygon method and developed in the Matlab program software. The mathematical model calculates the area of the form surrounding the tubers in the potato ridge (tuber cluster) in consideration of mass, density and volume of individual potato tubers. The tuber cluster best depicts the area within the ridge occupied by the tubers. The mathematical model calculates the equivalent tuber volume represented by a sphere based on the measured mass and density of individual tubers. In the next step, the radius of the sphere is used to determine the position of each tuber within the ridge and finally, the position and area of the entire tuber span (tuber cluster).

Table 3. Average monthly air temperature (AMAT) in the vegetation period between 1st April and 30th September and the average monthly precipitation (AMP)

Month	2012		2013	
	AMAT (°C)	precipitation (mm)	AMP (°C)	precipitation (mm)
April	11.4	127.7	12.4	91
May	16.1	124.4	14.8	217
June	21.3	129.9	19.8	105
July	22.7	113	23.5	22
August	23.3	66.2	22.5	105

The tuber cluster area represents an upgrade of the ellipse as it considers the physical component of the potato tubers – their mass.

RESULTS

Area of the form surrounding the tubers. In 2012, the data were only evaluated according to the ME method (Table 6). Statistically significant differences in the area of the ellipse encircling the

Table 4. Density of individual tubers of four different potato cultivars in 2012

Tuber No.	Density (g/cm^3)			
	Manitou	Madeleine	Faluka	Stirling
1	1.30	1.25	1.13	1.07
2	1.03	1.11	1.08	1.16
3	1.08	1.17	1.11	1.04
4	1.10	1.03	1.25	1.07
5	1.13	1.11	1.05	1.08
6	1.23	1.09	1.05	1.09
7	1.08	1.20	1.23	1.06
8	1.11	1.23	1.01	1.07
9	1.35			1.16
10	1.15			1.11
11	1.08			
12	1.10			
13	1.15			
14	1.21			
Average density	1.15	1.15	1.11	1.09

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Table 5. The percentage of tuber cluster area in regard to the area of the ellipse (data from the 2013 trial)

Cultivar	% tuber cluster area vs. ellipse area
Stirling	42.00
Manitou	54.20
Madeleine	49.11
Faluka	49.42

Table 6. Area of the form surrounding the tubers in 2012 and 2013

	Cultivar	Area around tubers (cm^2)	
		2012	2013
Ellipse	Faluka	439.74[a]	279.72[a]
	Stirling	378.80[a]	240.03[a]
	Madeleine	387.27[a]	379.18[a]
	Manitou	623.45[b]	346.27[a]
Ridge	Faluka	886.19[a]	770.89[a]
	Stirling	782.03[b]	806.78[a]
	Madeleine	792.26[ab]	855.84[a]
	Manitou	859.43[ab]	839.37[a]
Tuber cluster	Manitou	–	187.69[a]
	Stirling	–	100.81[b]
	Madeleine	–	186.20[a]
	Faluka	–	138.25[ab]

[a,b]Different letters indicate significant differences ($P < 0.05$)

tubers and cross-sectional area of the ridge were recorded among different potato cultivars. The largest area of the ellipse was recorded for the cv. Manitu (623.45 cm^2; 60.75 t/ha) and the largest cross-sectional area of the ridge for the cv. Faluka (886.19 cm^2; 75.75 t/ha). The measurements of the potato crop in 2012 included physical characteristics (mass, density) which were implemented in a new MCP method for data processing. The method was tested and used for calculating the tuber cluster area in the ridge.

Thus, in 2013, the MCP method revealed statistically significant differences in tuber cluster area among the analysed cultivars (Figure 3). This parameter best describes the space requirements of specific cultivars in the potato ridge. The largest tuber cluster area was determined for the cv. Faluka (187.69 cm^2) which also has highest yields (71.29 t/ha). Statistically significant differences in tuber cluster area were also calculated between cv. Stirling and cv. Madeleine, cv. Stirling and cv. Manitou and cv. Madeleine and cv. Faluka. The comparison of the statistical evaluation of the ellipse area reveals a considerable improvement of the MCP method as differences were only recorded between cv. Madeleine and all other potato cultivars. Cv. Madeleine was also characterized by lowest yields (38.12 t/ha).

Tuber span in the potato ridge. In 2012, the ME method revealed statistically significant differences in the length of the semi-axis (b) (vertical span of the ellipse) between cvs. Madeleine and Manitou (Table 7). The length of the semi-axis (b) was significantly smaller in the former (7.45 cm) compared to the latter potato cultivar (9.43 cm). In 2013, statistically significant differences were also determined for the length of the semi-axis [a] (horizontal span of the ellipse) (Figure 4).

Minimum distance from the potato ridge. In 2012, statistically significant differences in minimum distance of tubers from the potato ridge were

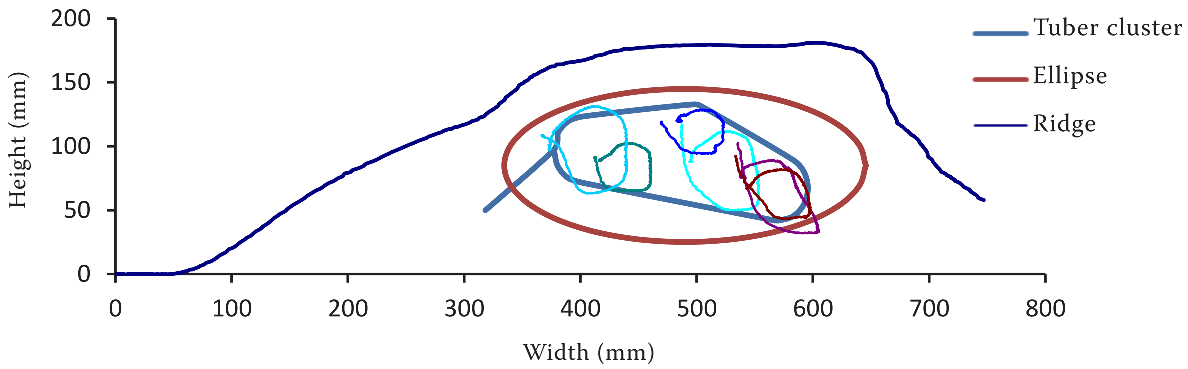

Figure 3. Area of the ellipse and tuber cluster area of the cv. Manitou cultivar in 2013 according to the MCP (minimal convex polygon) method. The image shows the actual form of individual potato tubers based on their measurements. The tuber cluster area is calculated from equivalent tuber diameters, considering mass of potato tubers

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Table 7. Tuber span in the potato ridge in 2012 and 2013

	Cultivar	Tuber span in the ridge (cm)	
		2012	2013
Vertical	Faluka	13.26[a]	16.53[a]
	Stirling	15.72[a]	16.87[a]
	Madeleine	12.85[a]	14.28[a]
	Manitou	15.64[a]	9.39[a]
Horizontal	Faluka	25.68[a]	25.032[a]
	Stirling	23.39[a]	16.22[a]
	Madeleine	24.90[a]	28.40[a]
	Manitou	26.47[a]	26.65[a]
Semi-axis (a)	Faluka	16.32[a]	14.58[ab]
	Stirling	15.04[a]	12.09[a]
	Madeleine	16.31[a]	19.17[b]
	Manitou	20.87[b]	19.19[b]
Semi-axis (b) of the ellipse	Faluka	8.57[ab]	6.14[a]
	Stirling	7.95[ab]	6.06[a]
	Madeleine	7.45[a]	6.36[a]
	Manitou	9.43[b]	5.88[a]

[a,b]Different letters indicate significant differences ($P < 0.05$)

recorded between cvs. Madeleine and Faluka according to the ME method. On the other hand, no differences in the minimum distance of the ellipse from the potato ridge were observed (Figure 5). In 2013, significant differences in the minimum distance of the ellipse from the potato ridge were observed among cultivars; minimal distance was recorded for the cv. Faluka (2.34 cm) and maximum distance for the cv. Manitou (6.69 cm) (Table 8).

DISCUSSION

The trial demonstrated that potato cultivars require different growth space in the ridge. Generally, high-yield cultivars necessitate more space in the ridge as they develop larger tuber clusters. Moreover, the results indicate that the innovative MCP method represents a correct assessment of the potato growth requirements. It namely considers potato tuber mass and calculates the tuber cluster area. All potato cultivars

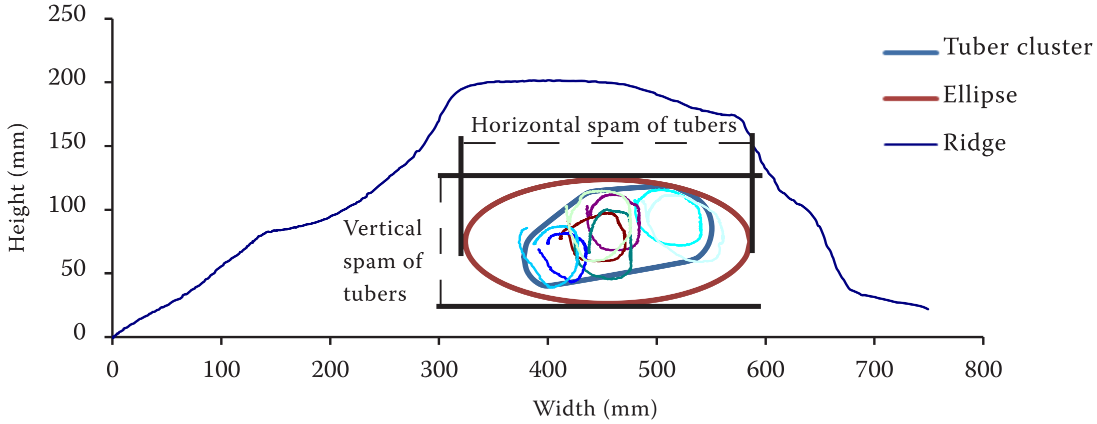

Figure 4. Horizontal and vertical span and semi-axis (a) and (b) of the ellipse (Figure 5) for the cv. Faluka in 2013 according to the minimum ellipse method

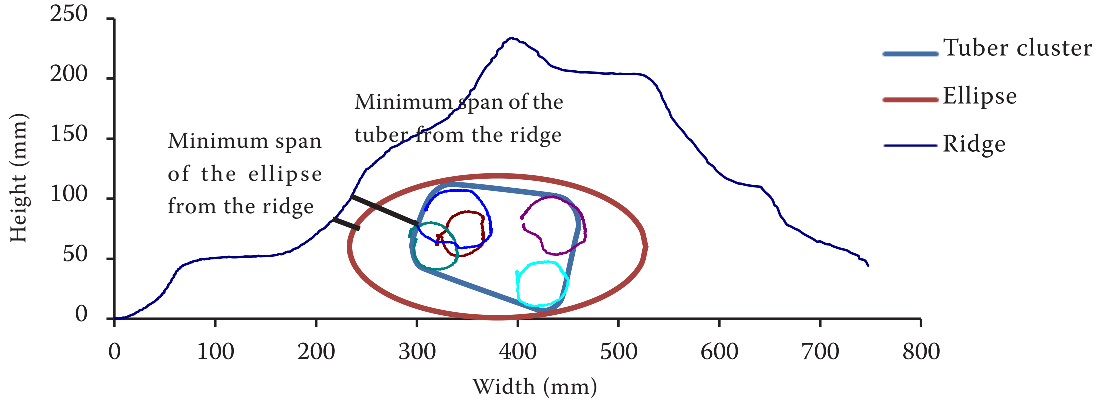

Figure 5. Minimum distance of the tubers and the ellipse from the potato ridge for the cv. Madeleine in 2013 according to the minimum ellipse method

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Table 8. Minimum distance from the potato ridge

	Cultivar	Minimum distance (cm)	
		2012	2013
Tubers from the ridge	Faluka	4.49[a]	4.95[a]
	Stirling	3.30[ab]	3.58[a]
	Madeleine	1.90[b]	4.39[a]
	Manitou	2.35[ab]	4.30[a]
Ellipse from the ridge	Faluka	4.24[a]	2.34[a]
	Stirling	2.67[a]	3.63[ab]
	Madeleine	2.89[a]	5.59[ab]
	Manitou	3.90[a]	6.69[b]

[a,b]Different letters indicate significant differences ($P < 0.05$)

were cultivated according to corresponding technological measures and on the same site. Meteorological conditions however, varied during the two consecutive years. Nevertheless, highest space requirements were detected for the cv. Manitou, which was also characterized by highest yields (75.75 t/ha). Its tuber cluster area was 187.69 cm^2 (Figure 4), its area of the ellipse surrounding the tubers was 224.36 cm^2 in ridge area comparable to other analysed cultivars. The cv. Manitou had the largest horizontal span of the tubers (26.65 cm) (Figure 5) and length of the semi-axis (a) (19.19 cm). The data were processed with the ME method.

The recently developed MCP method revealed statistically significant differences in tuber cluster area and area of the ellipse surrounding the tubers. Up to now, no data on actual position of individual potato tubers (vertical and horizontal span of the tuber cluster) in the ridge have been published. This information is important for defining the space requirements of specific potato cultivars in the ridge. Additional trials are needed to better describe potato growth request in the ridge. It would be interesting to analyse the effect of different pedoclimatic parameters (soil structure, drought) and agrotechnical measures (irrigation, tillage) on potato spatial distribution in the ridge and consequently, its growth requirements in different conditions. Also, cultivation technologies should be examined in future work and their improvements suggested to better suit individual cultivar requirements. By ensuring high yields of marketable potato production costs of this important crop could be decreased.

Each potato cultivar has different growth requirements in the ridge linked to the horizontal and vertical span of the tuber cluster. Optimal potato quality is undeniably connected with an adequate ridge form. If the tuber cluster area exceeds the ridge area the percentage of non-marketable potatoes (green tubers) increases. Generally, high-yield cultivars require more space in the ridge compared to low-yield cultivars. The space requirements in the ridge should be set for individual potato cultivars and specified as a cultivar-specific characteristic affecting technological measures and potato production technology.

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