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Soil cover of tubers and the percentage of green tubers at various inter-row widths

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In the years 2002, 2003 and 2004, a field trial was conducted involving three inter-row widths (66, 75 and 90 cm) and three potato cultivars (Agria, Bright and Carlingford). Increasing the inter-row width (IRW) increased both the cross-sectional area of the ridge and ridge height measured before the harvest. With an IRW of 66 cm the majority of tubers were located directly under the ridge surface (at a depth of < 5 cm), which resulted in the highest percentage of green tubers among the three IRW values. At the 90 cm IRW, in particular, the vast majority of tubers was distributed deeply in the ridge (at a depth of > 5 cm), thus generating the smallest percentage of green tubers. Compared to the other two cultivars, Carlingford produced tubers distributed at a larger ridge depth and subsequently yielded the lowest percentage of tubers covered with less than 5 cm of soil. On the other hand, Agria had a wider horizontal span of tubers than the other two cultivars.

Keywords: cross-sectional area; greening; potato; soil cover

Introduction

The shape of the ridge must allow a uniform soil layer thickness in all directions around a tuber, including the ridge top and ridge sides. In order to gain a quality tuber yield, sufficient soil cover of tubers is particularly important. If such is not the case, tubers will break the soil surface and turn green and thus be unsuitable for sale or further processing. Most new tubers are distributed around and above the seed tuber. By still being able to push

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the soil in the outward direction, they often create cracks in the ridge, especially on loamy soil (Kouwenhoven *et al*., 2003). Generally, tubers are elliptically distributed in the ridge and few of them tend to grow beneath the seed tuber level (Bailey, 1957; Kouwenhoven, 1970). In smaller ridges, the majority of tubers lie directly under the surface, thus increasing the risk of tuber greening (Struik and Wiersema, 1999). Inadequately small tuber-hosting soil volume is not the reason for the creation of bigger ridges. A 50 t/ha yield represents a mere 4.5% of the ridge volume with an 800 cm^2 cross-sectional area of the ridge (Kouwenhoven and Kimmann, 1987). Moreover, large ridges include shorter stolons, consequently contributing to a smaller number of green tubers (Kouwenhoven and Perdok, 2000). Cluster width in the ridge is largely dependent upon the cultivar, growing conditions in the ridge and general weather conditions during the growth period (Wurr *et al*., 1997). As demonstrated by Lacey (1966), cluster width varies from 15 cm with the Ulster Beacon cultivar to 52 cm with the Kerr's Pink cultivar. There is a much smaller probability of tuber greening with cultivars that have a smaller cluster width (Kouwenhoven *et al*., 2003). As established by these authors, reduction in the percentage of green tubers resulted from an increased cross-sectional area of the ridge, distribution of seed tubers in the middle of the ridge, soil cover of new tubers exceeding 3.5 cm in thickness, reduced number of cracks in the ridge and planting cultivars with a narrower cluster width. This can be achieved by changing the ridge shape at the 75 cm inter-row width (IRW) or expanding the IRW to 90 cm. The ridge top at the 75 cm IRW was widened from 18 to 25 cm, the ridge height was expanded and potatoes were planted 4 cm deeper than with the standard 75 cm IRW ridges. The enhanced soil cover of tubers reduced cluster width, while cluster height and tuber thickness increased. The highest percentage of green tubers (60%) was positioned at the ridge top; a smaller percentage (30%) appeared at the ridge top and the ridge side juncture, while the smallest percentage (10%) occurred on the ridge side. The possibility of tuber greening may be minimised by covering tubers with a 7 cm thick soil layer (Kouwenhoven *et al*., 2003). Due to reliance on outdated machinery for potato production, the major part of potato crop in Slovenia is planted at an IRW of 66 cm, resulting in an extremely high percentage of green tubers. This motivated the present study aimed at establishing the effects of IRW (66, 75 and 90 cm) and cultivar (Agria, Bright, Carlingford) on the soil cover of tubers in the ridge and the percentage of green tubers.

Materials and Methods

Trial design

A randomised block split-plot design was used with IRW as the main plot factor and cultivar as the subplot. Each plot was 15 m long and featured a random allocation of three IRW values (66, 75 and 90 cm). At each IRW, 4 rows of potato were planted. All measurements were conducted in the inner two rows. At the 66 cm IRW, the main plot was 2.64 m wide, while at the 75 cm and 90 cm IRW values it amounted to 3 m and 3.6 m, respectively. Within each IRW, 3 cultivars (Agria, Bright, Carlingford) were randomly distributed. Each subplot was 5 m long and its area was 13.2 m^2 at the 66 cm IRW, 15.0 m^2 at the 75 cm IRW and 18.0 m^2 at the 90 cm IRW.

The trial was established at three different locations – on the Golc family farm in Brnik, on the Cajhen family farm in the village of Pšata near Ljubljana, and on the Vimpolšek family farm in Brežice – and there were 5 replicate blocks at each location. The study was repeated in the years 2002, 2003 and 2004. Soil texture was predominantly classified as silt loam (SL) or loam (L) with 18 to 23% clay content in the soil profile (Table 1).

The crop was planted manually at a uniform depth, allowing the top of a seed tuber to be level with the soil surface. At all three IRW levels, seed density amounted to 45,000 tubers per hectare, thus reducing the distance between the tubers in the rows as IRW increased (33.8 cm at the 66, 29.6 cm at the 75 and 24.7 cm at the 90 cm IRW). Immediately before potato emergence, the field was cultivated and ridged with a PTO-driven cultivator with trapezoid-shaped ridge heads, designed and built at the Biotechnical Faculty, Department of Agronomy, Chair of Agricultural Engineering (see Bernik and Vučajnk, 2008). It is possible to use this two-row machine, with a specially devised simple mechanism, at all three IRW levels by simply shifting individual rotors with knives attached along the main shaft, until the desired bore spacing was achieved, then affixing them with a screw to change the inter-row width. In order to adjust the latter, it is necessary to shift ridge heads as well. These yield ridges with top width of 10, 20 and 25 cm for IRW values of 66, 75 and 90 cm, respectively. Ridge height was about 20, 24 and 28 cm at the 66, 75 and 90 cm IRW levels, respectively. The ridge side angle was 36°, 42° and 41° at the IRW levels of 66, 75 and 90 cm, respectively.

Table 1. Soil characteristics at each trial location in each year

Year	Soil characteristic	Trial location		
		Pšata	Brnik	Brežice
2002	Clay (%)	19.2	21.9	19.7
	Course silt (%)	14.3	11.2	23.4
	Fine silt (%)	40.3	40.3	42.2
	Sand (%)	26.3	26.6	14.7
	Soil texture class[a]	SL	SL/L	SL
2003	Clay (%)	19.7	22.2	18.4
	Course silt (%)	17.0	13.9	25.5
	Fine silt (%)	31.2	35.4	41.8
	Sand (%)	32.0	28.5	14.3
	Soil texture class	L	L	SL
2004	Clay (%)	18.4	23.3	19.4
	Course silt (%)	14.5	16.1	25.8
	Fine silt (%)	44.0	45.0	41.8
	Sand (%)	23.0	15.6	12.9
	Soil texture class	SL	SL	SL

[a] SL = silt loam; L = loam.

Basic and additional fertilisations were carried out on the basis of the previously performed soil analyses. Weed, disease and pest control were conducted in accordance with good agricultural practice.

Measurements

Cross-sectional area of the ridge and ridge height: The cross-sectional area of the ridge and ridge height were measured using the three-dimensional coordinate measuring device described in detail by Bernik and Vučajnk (2008). A single measurement was performed on each subplot; the whole trial involved a total of 45 measurements at each location and these were done immediately before the potato harvest in all test years. These data allowed the calculation of the cross-sectional area of the ridge and ridge height.

Distribution of tubers in the ridge: Distribution of tubers in the ridge was surveyed immediately before the potato harvest using the same three-dimensional coordinate measuring device as described by Bernik and Vučajnk (2008). Measurements were carried out on each subplot, amounting to 45 times in each location in all test years. Due to time limitations, only one measurement was conducted per subplot. Measurements were carried out at the same measuring points, immediately after the cross-sectional area of the ridge had been established. The measuring tip was shifted onto a pole representing the origin (0,0). Soil was carefully removed from the ridge in order to reveal the position of tubers which were left in the exact same position as when uncovered**.** The position of individual tuber was determined by placing the measuring tip on the central top part of a tuber. Then, a special co-ordinate programme (written in the LabView) started recording the measurement process. The measuring tip co-ordinates of the tubers in the ridge (x, y) were registered. Tuber length and thickness were simultaneously determined with a beak-shaped measuring device.

Soil cover of tubers in the ridge: Based on the measurements of the cross-sectional area of the ridge and the distribution of tubers in the ridge, vertical soil cover was calculated for each individual tuber at each measuring point. Vertical soil cover represents the vertical distance between the outer surface of the ridge and the central top part of a tuber in the ridge. Data on the vertical soil cover of individual tubers allowed us to calculate the mean soil cover at each measuring point. Tubers positioned on the ridge surface had a negative vertical soil cover and turned green. Maximum and minimum soil cover were also determined. Maximum soil cover at an individual measuring point represents the absolutely largest vertical soil cover of a tuber in the ridge, while minimum soil cover represents the smallest vertical soil cover of a tuber in the ridge.

Cluster width and cluster height: In addition to the tuber distribution data, data on tuber length and thickness were used in order to calculate cluster width and height. Cluster width represents the horizontal distance between the outer sides of the leftmost and the rightmost tubers in the ridge. Cluster height represents the vertical distance between the upper part of the highest-lying and the lower part of the lowest-lying tuber in the ridge.

Green tubers: On the basis of data on the cross-sectional area of the ridge, vertical soil cover of tubers and tuber thickness, the number of green tubers exceeding 35 mm in thickness was determined for each measuring point. The vertical soil cover of green tubers was negative due to their position on the ridge surface. At the same time, tuber thickness was determined with a beak-shaped measuring device. The percentage of green tubers > 35 mm was calculated from the number of green tubers and other tubers exceeding 35 mm in thickness.

Data processing

The following computer programs were used in data processing: LabView, Microsoft Excel and Statgraph 4.0. Statgraph 4.0 was used to fit a statistical model for the split-plot trial with blocks treated as random, for all test years and all trial locations together. The effects of the IRW, cultivar and the IRW x cultivar interaction were evaluated. Firstly, the homogeneity of variance was tested for each of the 9 treatments using Hartley's F_{max} test. Data on the percentage of tubers covered with less than 5 cm of soil and the percentage of green tubers were transformed, using the arcsin transformation, prior to analysis. Where ANOVA yielded a statistically significant effect of IRW or cultivar on a variable Duncan's multiple range test was used to evaluate all pairwise differences among the levels of the factor. Where the interaction was statistically significant, standard error of the mean differences was calculated. A significance level of 0.05 was used for all tests.

Results and Discussion

Cross-sectional area of the ridge and ridge height

Results (Table 2) showed that the IRW significantly affected the cross-sectional area of the ridge and ridge height before the harvest ($P < 0.05$). There was no effect due to cultivar or the IRW x cultivar interaction on these two variables. The largest cross-sectional area of the ridge occurred at the 90 cm IRW and the smallest was at the 66 cm IRW. The results agree with the findings of Kouwenhoven *et al*. (2003) who reported that the cross-sectional area of the ridge at the 75 cm IRW reaches or exceeds 800 cm^2, and exceeds 1000 cm^2 at the 90 cm IRW. The cross-sectional area of the ridge at the 66 cm IRW was not sufficiently large as it should be at least 600 to 700 cm^2 and should exceed 800 cm^2 for cultivars with a large cluster width (Kouwenhoven *et al*., 2003; Kouwenhoven and Perdok, 2000). In accordance with the effects on the cross-sectional area of the ridge, the highest ridge occurred at the 90 cm IRW and the lowest ridge at the 66 cm IRW. This association between ridge height and IRW agrees with Kouwenhoven *et al*. (2003).

Table 2. Influence of inter-row width (IRW) on the cross-sectional area of the ridge and ridge height

IRW (cm)	Cross-sectional area of the ridge (cm^2)	Ridge height (cm)
66	618[a]	18.7[a]
75	810[b]	20.8[b]
90	1072[c]	23.0[c]

[abc] Within each column means without a superscript in common are significantly different ($P < 0.05$).

Mean, minimum and maximum soil cover of tubers

The mean soil cover of tubers was significantly ($P < 0.05$) and positively associated with IRW (Table 3). Kouwenhoven *et al*. (2003) established that soil cover exceeding 70 mm optimally reduces the probability of tuber greening and the present results show that such a soil cover was only achieved at the 90 cm IRW. Cultivar also had a statistically significant effect ($P < 0.05$) on mean soil cover of tubers (Table 3) which was slightly greater with Carlingford compared to the other two cultivars. It can thus be assumed that Carlingford forms tubers at a greater depth in the ridge.

The maximum soil cover of tubers differed significantly among the three IRW values whereas cultivar had no effect on

Table 3. Influence of inter-row width (IRW) and cultivar on soil cover of tubers and on cluster width and height

Factor	Soil cover over tubers (mm)			Cluster dimensions (mm)	
	Mean	Maximum	Minimum[1]	Width	Height
IRW (cm)					
66	45[a]	94[a]	–1[a]	238[a]	128[a]
75	59[b]	109[b]	14[b]	251[a]	135[a]
90	74[c]	122[c]	23[c]	248[a]	139[a]
Cultivar					
Agria	57[a]	107[a]	11[a]	266[a]	134[a]
Bright	56[a]	105[a]	9[a]	224[b]	135[a]
Carlingford	64[b]	112[a]	16[a]	247[c]	133[a]

[abc] Within each column for each factor, means without a superscript in common are significantly different ($P < 0.05$).

[1] Negative value represents tubers above the ridge surface, i.e., tubers not covered by soil.

this variable (Table 3). The minimum soil cover of tubers at the 66 cm IRW did not reach the same value as at the 75 or 90 cm IRW. The average minimum soil cover at the 66 cm IRW was negative, which means that tubers were distributed on the soil surface (Table 3) and had turned green. Cultivar did not affect the minimum soil cover. In accordance with previous findings, this showed that the highest risk of tuber greening was with the 66 cm IRW. There was no evidence for any IRW x cultivar interaction for the mean, minimum or maximum soil cover of tubers.

Cluster width and cluster height

Cluster width was mainly dependent on cultivar and was not affected by IRW. Similar findings were reported by Kouwenhoven and Perdok (2000). The cultivar differences comply with the conclusions of Van Mastwijk (1998) that cluster width of cultivars suited for French fries (such as Agria) exceeds that observed with the other cultivars. Based on results, it can be assumed that this reflects Agria's extremely long tubers; tubers are much shorter for the other two cultivars. This implies that Agria requires slightly higher/wider ridges than the other two cultivars. The absence of an effect of IRW on cluster width (Table 3) contrasts with the findings of Kouwenhoven *et al*. (2003) that cluster width was smaller with larger IRW.

Cluster height was not affected by either IRW or cultivar (Table 3) which contrasts with the findings of Van Mastwijk (1998) who reported that cluster height at an IRW of 90 cm was greater than at the 75 cm IRW. The interaction between IRW and cultivar was not significant for either cluster height or width.

Tubers covered with less than 5 cm of soil

Data on the mean soil cover of tubers alone does not offer a full insight into the distribution of tubers in the ridge and, consequently, the percentage of tubers covered with less than 5 cm of soil in the ridge was calculated. The inter-row width had a statistically significant effect on the percentage of tubers covered with less than 5 cm of soil which was highest at the 66 cm IRW and lowest at the 90 cm IRW (Table 4). This is consistent with the results reported by Struik and Wiersema (1999) that, in smaller ridges, tubers are generally distributed directly under the surface, which increases the probability of tuber greening.

Cultivar also significantly affected the percentage of tubers covered with less than 5 cm of soil, with Carlingford having the lowest percentage of this type of tuber (Table 4). The IRW x cultivar interaction had no statistically significant effect on percentage of tubers with < 5 cm of soil cover. Based on these results, it can be concluded that, in comparison with the other two cultivars, Carlingford forms tubers at a slightly deeper position in the ridge, which is consistent with the results on mean soil cover.

Table 4. Influence of inter-row width (IRW) and cultivar on the percentage of tubers covered with less than 5 cm of soil and the percentage of green tubers > 35 mm diameter

Factor	Tubers with soil cover < 5 cm (%)	Green tubers > 35 mm (%)
IRW (cm)		
66	55.9[a]	9.9[a]
75	42.6[b]	3.6[b]
90	28.5[c]	1.3[c]
Cultivar		
Agria	45.3[a]	5.5[a]
Bright	46.1[a]	5.8[a]
Carlingford	35.7[b]	3.4[a]

[abc] Within each column for each factor, means without a superscript in common are significantly different (P < 0.05).

Green tubers

The percentage of green tubers decreased as IRW increased (Table 4). The highest percentage at the 66 cm IRW is consistent with the fact this IRW had the smallest cross-sectional area of the ridge and the highest percentage of tubers directly under the surface of the ridge (at a depth of < 5 cm), in agreement with Struik and Wiersema (1999). For all locations and all years, the percentage of green tubers at the 90 cm IRW (1.3%) was lower than at the 75 cm IRW (3.6%). Similar findings were reported by Spiess *et al*. (2005) and Kouwenhoven *et al*. (2003). There was no evidence for an IRW x cultivar interaction for the percentage of green tubers.

Conclusion

The 90 cm IRW provided the greatest soil cover over tubers and yielded the lowest percentage of green tubers. This was mostly due to having the greatest cross-sectional area of the ridge, ridge top width and ridge height. These characteristics are especially important for cultivars with larger cluster width, such as Agria. The 75 cm IRW did not yield the same results with regard to soil cover due mainly to a poorer ridge geometry and consequently the percentage of green tubers was higher. However, as major potato producers are now starting to adopt the 75 cm IRW, improvements of the latter in terms of ridge shape should be pursued. The 66 cm IRW provides the poorest soil cover and at this IRW the majority of tubers lie directly under the ridge surface, thus increasing the risk of tuber greening.

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