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The effect of cultivator/ridger type on the physical properties of ridge, power requirement and potato yield

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In 2002, 2003 and 2004, field trials were carried out in Slovenia in the form of random blocks with five replications. Three potato cultivators/ridgers were used on medium textured soil. The aim was to establish which potato cultivator/ridger was the most suitable for inter-row space cultivation, ridge shaping and achievement of the highest possible potato yield, work-rate and productivity. A drawn cultivator/ridger with spring tines on a parallelogram framework and wing ridge heads attached (STC), was compared with a drawn cultivator/ridger with rigid tines on a parallelogram framework and cogwheel ridge discs attached (RTC) and with a rotary, PTO-driven cultivator/ridger (RC). The latter created the largest cross-sectional area of the ridge and proved to be the most efficient at crushing soil aggregates in the inter-row space and at ridge shaping. It also allowed the lowest cone resistance at the ridge centre and in the central part of the ridge side. A higher number of tubers per plant resulted from ridges made by the PTO-driven cultivator/ridger giving a higher total yield of tubers than with the other two cultivators/ridgers. In comparison with the drawn cultivators/ridgers, the PTO-driven cultivator/ridger shaped ridges with better physical properties on medium textured soil; however both drawn cultivators/ridgers had greater work-rates, and also needed less energy to cultivate a unit of area.

Keywords: cone resistance; cultivators; potato; soil aggregates; total power; yield

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Introduction

In order to produce an abundant quality yield of potatoes with the smallest percentage of green tubers an effective soil treatment, particularly in the process of cultivation and ridging, is extremely important. The effective inter-row space cultivation represents the ability of cultivators/ridgers to crush larger clods of soil and cultivate the widest possible inter-row area, which allows enough soil to shape ridges and ensure the smallest possible cone resistance. There is a wide variety of cultivators/ridgers for soil preparation for potatoes available on the market. They differ mainly according to their cultivation and ridging elements and their drive. Drawn cultivators/ridgers are suitable for well-structured light soils (Gerighausen, 1994) while PTO-driven cultivators/ridgers are normally used before the potato emergence on medium textured or heavy soil (Peters, 1999; Wulf, 1995, 1997, 1999; Gerighausen, 1994; Beukema and van der Zaag, 1990). Soil in the ridge is loose, well-structured and with few larger clods. It allows a firm formation of a ridge, thus enabling it to change very little until the time of harvest (Beukema and van der Zaag, 1990). The PTO cultivators/ridgers excel in symmetrical ridge shaping. However, they use much more energy than drawn cultivators/ridgers. Gerighausen (1994) demonstrated that in order to make a ridge, a 4-row drawn cultivator/ridger required 51 kW of power while a PTO-driven cultivator/ridger required as much as 74 kW of power. The operating speed of the drawn cultivator/ridger was between 4 and 6 km/h, while the PTO-driven cultivator/ridger's speed was 1.5 to 3 km/h, resulting in a very large energy difference. The soil in the ridge must be loose in order to enable the emergence of a quality potato. If excessively crushed, heavy precipitation can cause soil particles to unite in larger clods and make the harvest more difficult (Kouwenhoven and Perdok, 2000). A higher percentage of smaller soil aggregates (<2.5 mm) accelerates potato emergence and growth, while, at the same time, enabling a higher potato yield (Kouwenhoven, 1978). At a 75 cm inter-row width (IRW), the cross-sectional area of the ridge, after the ridging and cultivation, must be 900 to 1,000 cm^2 (Gerighausen 1994; Kouwenhoven and Perdok, 2000). Cultivars intended for use in cuisine as chipped potatoes feature longer tubers, give large yields and are thus in need of an even larger ridge (Kouwenhoven *et al*., 2003). So far, little research has been done comparing potato cultivator/ridger types, particularly in the area of ridge shaping, cone resistance in the ridge, distribution of soil aggregate sizes in the ridge, work rate, power consumption, their effect on potato yield and percentage of green tubers.

Since potatoes in South-East Europe are predominantly grown on lighter soil, drawn cultivators/ridgers with spring tines on a parallelogram framework are currently the most frequently used cultivator/ridger type in this area. Other cultivator/ridger types are not being used. Recently, dry spells with no rainfall have occurred during the period of growth. For this reason, producers decided to grow potatoes also on medium-textured and heavy soil where they more easily tolerate the lack of water. These types of soil, however, require ridge formation with a different cultivator/ridger type. We thus decided to compare new cultivator/ridger types, i.e., a PTO-driven cultivator/ridger with trapeze-shaped ridge heads and a drawn cultivator/ridger with rigid tines on a parallelogram framework, with cogwheel ridge discs attached with the most widely used cultivator/ridger. The aim was to establish which potato cultivator/ridger is the most suitable for a quality inter-row space cultivation, ridge shaping and achievement of the highest possible yield, efficiency and productivity on medium textured soil under the conditions of south-east Europe.

Materials and Methods

Site characteristics

The trial was carried out on a farm located at 46°04' N, 14°31' E in Slovenia. The soil texture was classified as silt loam (SL) including 20% of clay, 15% of course silt, 40% of fine silt, and 25% of sand. Three different potato cultivators/ridgers were used in the trial. Based on random blocks with five replications, it was conducted in three consecutive years: 2002, 2003 and 2004. Each block, 10 m in length and with a one-metre side strip, featured a random allocation of three potato cultivators/ridgers. Each plot with an area of 24 m^2 was 3 m wide and included 4 rows of potatoes at a 75 cm IRW. All measurements were carried out in the inner two rows. All data on primary soil treatment, basic fertilization and spraying are shown in Table 1. Before the process of planting, planting holes were made with a 4-furrow machine. Potatoes were manually planted at a distance of 29.6 cm, creating an exact tuber density of 45,000/ha, and covered with soil by ridge discs. Seed tuber tops remained level with the surface. Ridging was conducted immediately before the potato emergence (i.e., approximately 1 month after the planting).

Potato cultivators/ridgers

The PTO-driven cultivator/ridger with trapezoid-shaped ridge heads (RC) used is shown in Figure 1a and the drawn cultivators/ridgers with spring tines on a parallelogram framework with wing ridge heads attached (STC) and with rigid tines on a parallelogram framework and cogwheel ridge discs attached (RTC) are shown in Figures 1b and 1c, respectively. All machines produced two ridges. Working characteristics of the cultivators/ridgers are presented in Table 2. In comparison with the RTC and STC cultivators/ridgers

Table 1. Primary cultivation process and dates

Cultivation procedure	Year		
	2002	2003	2004
Manure fertilization	15/9/2001	23/9/2002	14/10/2003
Ploughing with 2-furrow reversible plough	16/9/2001	24/9/2002	15/10/2003
Ploughing depth (cm)	25	25	25
Basic fertilization applied with a fertiliser spreader with 2 spreading discs	24/3/2002	26/3/2003	27/4/2004
DURSBANE E-48 (chlorpyriphos) spraying against elaters (*Elateridae*) with tractor mounted sprayer	24/3/2002	26/3/2003	27/4/2004
Soil preparation with rotary harrow	24/3/2002	26/3/2003	27/4/2004
Cultivation depth (cm)	15	15	15
Rotary harrow speed (rpm)	250	250	250
Planting	25/3/2002	27/3/2003	28/4/2004
Planting depth[1] (cm)	5	5	5
Cultivation and ridging	26/4/2002	29/4/2003	26/5/2004

[1] Distance between the lower part of tuber and the soil surface.

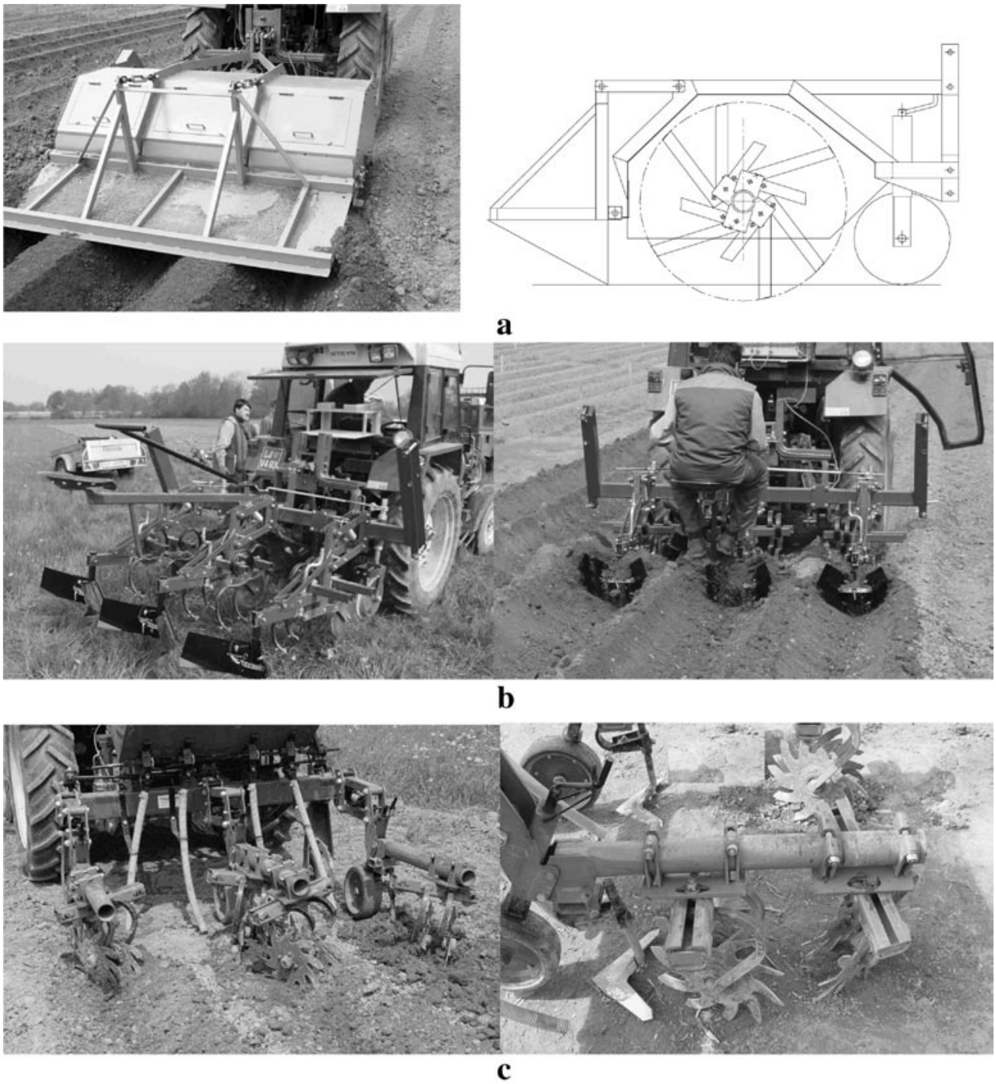

Figure 1. a) PTO driven cultivator/ridger with trapezoid-shaped ridge heads; b) drawn cultivator/ridger with spring tines on a parallelogram framework and winged ridge heads attached; c) drawn cultivator/ridger with rigid tines and cogwheel ridge discs attached.

(width 37.5 cm each), the PTO-driven cultivator/ridger cultivated a wider inter-row space (50 cm). Ten blades with a 5 cm space between one another treated one inter-row space in order to cultivate soil as close to seed tubers as possible. The STC cultivator/ridger had 4 spring tines cultivating one inter-row space, while the RTC cultivator/ridger had a single large winged tine, but additionally cultivated soil by means of its rotary cogwheel disks. The PTO-driven cultivator/ridger, because

Table 2. Working characteristics of the cultivators/ridgers

Characteristic	Cultivator/ridger[1]		
	RC	RTC	STC
Working depth (cm)	15	8	10
Rotor speed at 540 rpm (rpm)	240	–	–
Blade type	Positive rake angle[2]	Rigid tine	Spring tine
Blade tip speed at 540 rpm (m/s)	10.0	–	–
Working width per row (cm)	50	37.5	37.5

[1] RTC = drawn cultivator/ridger with rigid tines on a parallelogram framework and cogwheel ridge discs attached; RC = PTO-driven cultivator/ridger with trapezoid-shaped ridge heads; STC = drawn cultivator/ridger with spring tines on a parallelogram framework with wing ridge heads attached.
[2] Made of spring steel with added manganese.

of its blades, cultivated to a greater depth (15 cm) than the two drawn cultivators/ridgers. For each machine, cultivation depth could be set by means of a wheel. In all test years, cultivation and ridging was conducted immediately before the potatoes emerged. The STC cultivator was not used in 2002.

Standard methodology was applied for the crop production. Immediately before the cultivation, potatoes were additionally fertilised manually with nitrogenous fertilisers. After the ridging, soil herbicide spraying was performed. Subsequent fungicide and insecticide sprayings were carried out in accordance with good farming practice.

The cross-sectional area of the ridge and its relative change

The cross-sectional area of the ridge was measured with a coordinate measuring device (Biotechnical Faculty, Department of Agronomy, Ljubljana, Slovenia) shown in Figure 2 that allows absolute and relative measurements of the distance within the following area: 1,000 mm in the transverse direction, 450 mm in the longitudinal direction, and 600 mm in the vertical direction. All directions include a ± 0.5 mm accuracy.

The cross-sectional area of the ridge was calculated with a LabView computer program (National Instruments, Texas, USA). The 1st measurement was carried out on the day of ridging (immediately after the ridging). This enabled us to get the primary ridge shape serving as a reference point for the later measurements. If measurements had been performed in the days following the ridging, the ridge shape would have already changed considerably. During the period of growth, measurements were always performed at the same measuring point. Depending on the date of planting, growing conditions and the date of harvest, 4 to 5 measurements of the ridge shape were conducted between April and August in 2002 and 2003 and between May and September in 2004. Three measurements were performed per plot. The cross-sectional area of the ridge and its relative change were calculated.

Cone resistance in the ridge

Cone resistance in the ridge was measured after the potato cultivation and ridging on 29 April in 2003 and on 26 May in 2004. A hydraulic penetrometer (Biotechnical Faculty, Department of Agronomy, Ljubljana, Slovenia) was used and consisted of a basic framework,

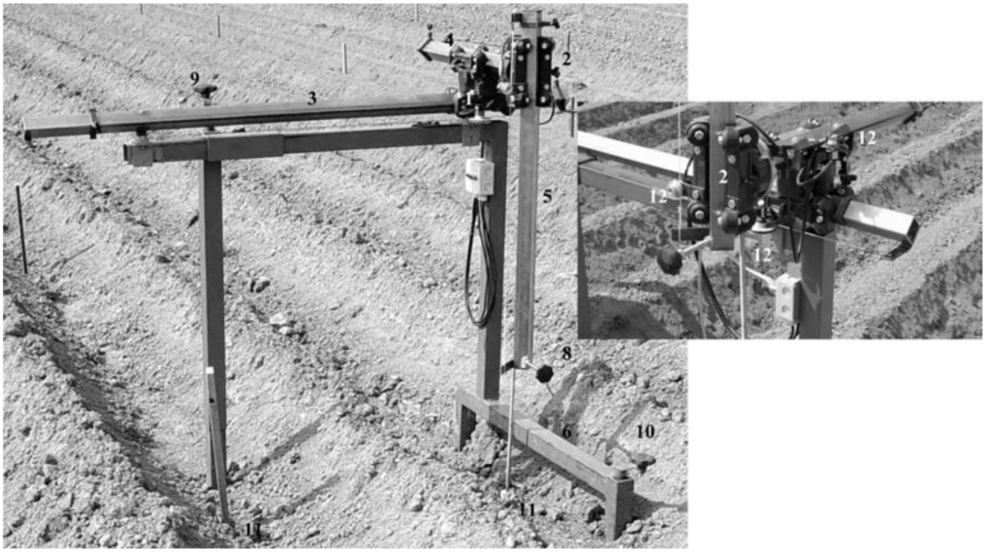

Figure 2. Coordinate measuring device on a test plot: 1. intersecting support, 2. vertical slide support, 3. cross slide, 4. longitudinal slide, 5. vertical slide, 6. framework, 7. cone tip, 8. slide lever, 9. & 10. device positioning spindles, 11. poles, 12. measurement converters.

hydraulic system, measurement sensors and measuring equipment; it contains a special slide on top of the framework, enabling the movement of a two-way hydraulic cylinder, to which a cone with a tip of 30° and a surface of 1.29 cm^2 (in conformity with the ASAE S313.1 Standard) is attached (Chancellor 1994). Measurements were carried out in the ridge centre (measuring point 2 – MP2) and in the central part of the left and the right ridge sides (measuring points 1 & 3 – MP1 & 3) (Figure 3). At each measuring point, the cone tip was shifted close to the soil surface by means of a lever. The computer program for the measurement of cone resistance in the ridge was then started and the penetrometer cone tip was pushed into the soil. A continuously variable measurement of the cone resistance

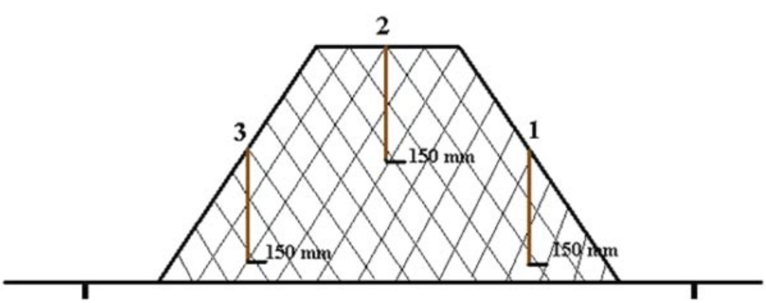

Figure 3. Cone resistance measuring points on the ridge.

was carried out down to a depth of 150 mm. The measured force and shift values were stored to a file. One measurement was performed per plot. The average of each 25 mm layer and, finally, the overall average (150 mm) were calculated with LabView. Results represent the average cone resistance for separate measuring points down to a depth of 150 mm, which allows us to determine cone resistance throughout the ridge.

Soil aggregates

The soil aggregate structure was measured in the ridge immediately after the potato cultivation and ridging in 2003 and 2004. It was determined on the basis of sieving soil samples through different-sized sieves. Soil samples were taken from the upper half of the ridge, all the way down to the ridge centre with a special shovel. Soil sample volume amounted to approximately 5,000 cm^3. Three soil samples were taken per plot. The device for sieving soil samples from the ridge is comprised of eight frames (480 mm × 310 mm) placed one above the other. In accordance with Vučić (1971), each frame includes a sieve with meshes of 50, 30, 10, 5, 3, 1 or 0.5 mm attached to its lower part. The lowest frame has a tin-plate bottom. Frames are attached to a pendulum with a precise swinging angle. Each sample was swung twice to the left and twice to the right. After the sieving, samples within each fraction were weighed. The data obtained enabled calculation of the percentage of each fraction and determination of the differences in percentage of soil aggregates exceeding or being less than 10 mm in the ridge, after the cultivation with the three different cultivators/ridgers.

Efficiency and the power needed for the cultivation and ridging

In both drawn (RTC and STC) cultivators/ridgers, the pulling force and operating speed were measured in 2003. The dynamometer framework for a three-point hitch mechanism was used for measuring the pulling force. In order to establish the operating speed of a tractor and its actual driving distance, a fifth wheel (2.47 m in diameter) attached to the front part of the tractor was used. Besides the pulling force and operating speed, in the PTO-driven cultivator, the torque and rotation speed were also measured. A HBM T30 FN torquemeter (Hottinger Baldwin Messtechnik GmbH, Germany) was used in order to record the measurements. All devices were linked to the HBM SPIDER 8 data acquisition system (Hottinger Baldwin Messtechnik GmbH, Germany) connected to a portable computer. From the data, it was possible to calculate the power required for drawn cultivators or driven cultivators, total power, specific work, and area and time efficiencies. Efficiency represents work rate in terms of hectares per hour.

Yield

Potatoes were harvested from the two inner rows (8 m in length) occupying a total area of 12 m^2. Analyses were carried out at the Agricultural Institute of Slovenia. Each tuber sample was placed into a selection device made of frames, onto which screens were placed one above the other. The screen meshes had a diameter of 65, 45 and 25 mm. Only tubers smaller than 25 mm remained at the bottom of the device. The remaining tubers left on each of the screens were collected, counted and weighed. Market (>45 mm) and non-market (≤45 mm) yields were calculated based on these data. At each plot, green tubers bigger than 45 mm were weighed and the percentage of green tubers per plot was calculated. In addition the number of tubers per plant was analysed.

Data processing

The following software was used in data processing: LabView (National Instruments, Texas, USA), Microsoft Excel and Statgraph 4.0 (Statistical Graphics Corp., Manugistics, Inc.). LabView allowed us to store measurements (of the cross-sectional area of the ridge, cone resistance in the ridge) and perform the first partial data processing. Statistical analysis was performed with Statgraph 4.0. Firstly, the homogeneity of variance was determined. In the case of non-homogeneity, the data were transformed. Hartley's test of homogeneity of variance was used. The three measurements of the cross-sectional area of the ridge per plot were included. Statistical analysis of these variables was done in random blocks with replications within the test plots. One of the sources of variability is experimental error, which is why the analysis of variance also had to take into account the interaction between the block and the treatment. At a later point in the experiment, the Least Significant Difference (LSD) test with $\alpha = 0.05$ was performed (involving one factor).

The analyses of the yield and the required power, with no replication, carried out within each plot included the analysis of variance in force for random blocks. The measurement of cone resistance took into consideration two factors – cultivator/ridger type and measuring point. Duncan's test was used to determine differences between treatments for cone resistance, as it involved two factors (cultivator and depth).

Results and Discussion

The ridge characteristic that the PTO-driven cultivator/ridger (RC) created was trapezoid, while the drawn cultivator/ridger with spring tines on a parallelogram framework and wing ridge heads attached (STC) shaped ridges in the form of a triangle. A drawn cultivator with rigid tines on a parallelogram framework and cogwheel ridge discs attached (RTC) made lower ridges of a rounder shape (Figure 4).

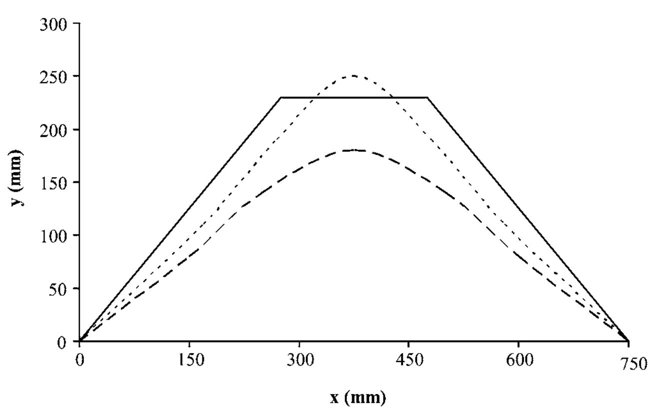

Figure 4. Shape of ridges made with PTO-driven cultivator/ridger (RC, —), drawn cultivator/ridger with spring tines (STC, - - -) and drawn cultivator/ridger with rigid tines (RTC, – –).

The cross-sectional area of the ridge
Since soil was cultivated with a rotary harrow at a depth of 15 cm and the rotation speed of 250 rpm, the intensity of the primary soil treatment did not affect the ridge shape made by each of the three cultivators.

In all test years, statistically significant differences occurred between different cultivators/ridgers at each of the measurement dates (in the period between ridging and harvest) (Table 3). The PTO-driven cultivator/ridger made ridges with the largest cross-sectional area (more than 950 cm^2) when measured after the ridging in all three years. This resulted from the PTO-driven cultivator/ridger's cultivation depth (15 cm), which was greater than that of the other two cultivators/ridgers (10 cm with the STC cultivator/ridger and 8 cm with the RTC cultivator/ridger) and cultivated a greater soil volume to be used for ridge shaping. Due to the rotating movement of its blades, soil treatment in the inter-row space was much more intensive than with the drawn cultivators/ridgers. The cross-sectional area of the ridge that the RTC cultivator/ridger made was the smallest. Gerighausen (1994) states that, at a 75 cm IRW, the cross-sectional area of the ridge after cultivation and ridging should be between 900 and 1,000 cm^2. The RTC cultivator/ridger was not able to shape a ridge of this cross-sectional area on the medium textured soil used in the trial, since ridge discs were unable to cut deep enough into the soil to shape a high-enough ridge. This is also the reason why the RTC cultivator/ridger produced a statistically higher percentage of green tubers (Table 9). The cross-sectional area of the ridge made by the STC cultivator/ridger in 2003 was not large enough. However, this improved in 2004. With spring tines not reaching a sufficient depth and ridge heads not shaping a high-enough ridge, the cross-sectional area of the ridge was not large enough. The STC cultivator/ridger shaped sharply-pointed ridges of considerable height which did not allow

Table 3. Cross-sectional area of the ridge (cm^2) with three different cultivators/ridgers

Year	Measurement date	Cultivator/ridger[1]		
		RTC	RC	STC[2]
2002	26 April	753[a]	948[b]	–
	17 May	645[a]	810[b]	–
	21 June	626[a]	799[b]	–
	6 September	601[a]	794[b]	–
2003	29 April	759[a]	963[b]	803[a]
	30 May	647[a]	902[b]	743[c]
	1 July	713[a]	927[b]	773[a]
	31 July	696[a]	912[b]	737[a]
	27 August	696[a]	923[b]	761[a]
2004	26 May	902[a]	1006[b]	969[b]
	5 July	748[a]	834[b]	832[b]
	29 July	756[a]	850[b]	814[b]
	7 September	753[a]	856[b]	836[b]

[abc] Means, within a row, without a superscript in common are significantly different ($P < 0.05$).
[1] See footnote to Table 2.
[2] The STC cultivator/ridger was not used in 2002.

enough space for the tubers to be entirely covered in soil. Tubers which were exposed at the surface turned green, and resulted in a higher percentage of green tubers in the yield. The only cultivator/ridger that met the requirement was the PTO-driven machine. The cross-sectional area of the ridge slightly increased during the growth period, possibly due to the growing tubers, as previously demonstrated by Kouwenhoven *et al*. (2003).

Relative change of the cross-sectional area of the ridge

The largest change in the cross-sectional area of the ridge occurred in the period of 30 to 50 days after ridging. It was substantially smaller in the subsequent period (ending with the harvest). Consequently, it was decided that the relative change of the cross-sectional area of the ridge be analysed between the 1st measurement (after the ridging) and the 2nd measurement as well as between the 2nd and the last measurement (before the harvest). We assumed that, in individual years, the relative change in cross-sectional area of the ridge differed due to a different amount of precipitation during the growth period. In 2002, the annual precipitation was 799 mm, while in 2003 and 2004 it was 536 mm and 861 mm, respectively. In 2003, statistically significant differences occurred in the relative change of the cross-sectional area of the ridge (the ridge area made with the RTC cultivator/ridger (14.7%) was larger than the one made with the STC (7.4%) and RC (6.4%) cultivators/ridgers), while in the other years there were none (Table 4). With its rotating ridge discs loosening the soil in the process of ridging and heaping it up the ridge, the cross-sectional area of the ridge made by the RTC cultivator/ridger was reduced to a larger extent than with the other two cultivators/ridgers. Since soil had not been pressed to the ridge, the ridge was not shaped so firmly and the soil located at the ridge sides collapsed into the inter-row space. The other two cultivators/ridgers used ridge heads to press the soil to the ridge, thus making the ridge shape more firm.

Table 4. Influence of the cultivator/ridger type on the relative change (%) of the cross-sectional area of the ridge between the 1st measurement (after the ridging) and the 2nd measurement and between the 2nd and final measurement (before harvest) in 2002, 2003 and 2004

Cultivator/ridger[1]	Year		
	2002	2003	2004
		Between 1st and 2nd measurement	
RTC	−14.4[a]	−14.7[a]	−16.8[a]
RC	−14.2[a]	−6.4[b]	−17.0[a]
STC[2]	–	−7.4[b]	−14.1
		Between 2nd and final measurement	
RTC	−6.0a[2]	6.6[a]	0.5[a]
RC	−1.6[b]	2.2[b]	2.2[a]
STC[2]	–	2.4[b]	0.6[a]

[ab] Means, within a column for a pair of measurements, without a superscript in common are significantly different (P < 0.05).

[1] See footnotes to Table 2.

[2] The STC cultivator/ridger was not used in 2002.

In 2002, the relative change of the cross-sectional area of the ridge between the 2nd and the last measurement was larger with the RTC (−6.0%) than with the RC cultivator/ridger (−1.6%), which also occurred in 2003, when the change with the RTC cultivator/ridger (6.6%) was larger than with the RC (2.2%) and STC (2.4%) cultivators/ridgers (Table 4). These results partly agree with the conclusions of Kouwenhoven (1978) demonstrating that the relative change of the cross-sectional area of the ridge at a 75 cm IRW in the period between ridging and harvest amounts to 15 to 20%.

Cone resistance in the ridge

The average cone resistance in the ridge down to a depth of 150 mm is presented, because it gave a better measure of the cone resistance in the ridge than values at individual depths (Table 5). Compared to drawn cultivators/ridgers, the PTO-driven cultivator/ridger resulted in lower cone resistance values. Blades attached to this cultivator/ridger and their rotating movements were able to cultivate the soil more intensively than the tines of the drawn cultivators/ridgers. Due to the straight-lined tine movement, the RTC and STC cultivators/ridgers were unable to sufficiently crush the soil.

Cone resistance was lowest at the ridge centre (MP2) with the three cultivators/ridgers (Table 6). Machines cultivate the inter-row space and use this soil to cover the ridge centre, thus making MP2 the measuring point with the lowest cone resistance. The higher cone resistance at the sides was due to an insufficient cultivation of the space nearest to a seed tuber and the pressure of ridge heads on the ridge sides.

The distribution of soil aggregate sizes in the ridge

There were statistically significant differences in the percentage of soil aggregates >10 mm due to the cultivator/ridger type (Table 7). In 2003, the percentage of

Table 6. Influence of measuring point on cone resistance (N/cm^2) up to a depth of 150 mm in the ridge after cultivation

Measuring point[1]	Year	
	2003	2004
1	32.1[a1]	35.8[a]
2	16.9[b]	6.6[b]
3	25.1[a]	43.1[a]

[1] 1 = Central part of the left side of ridge; 2 = centre of ridge; 3 = central part of right side of ridge.
[ab] Means, within a column, without a common superscript are significantly different (P < 0.05).

Table 5. Influence of the cultivator/ridger type on cone resistance (N/cm^2) up to a depth of 150 mm in the ridge after the cultivation in 2003 and 2004

Cultivator/ridger[1]	Year	
	2003	2004
RTC	25.9[a]	33.1[a]
RC	18.3[b]	20.1[b]
STC	30.0[a]	32.4[a]

[1] See footnote to Table 2.
[2] The means, within a column, without a common superscript are significantly different (P < 0.05).

Table 7. Influence of the cultivator/ridger type on the percentage of soil aggregates, in the ridge, exceeding 10 mm after cultivation

Cultivator/ridger[1]	Year	
	2003	2004
RTC	38.1[a2]	32.4[a]
RC	29.2[b]	23.0[b]
STC	33.9[c]	32.7[a]

[1] See footnote to Table 2.
[abc] Means, within a column, without a common superscript are significantly different (P < 0.05).

soil aggregates exceeding 10 mm in the ridge was less for RC than STC which in turn was less than RTC. In 2004, the percentage of soil aggregates exceeding 10 mm in the ridge was lower for RC than for RTC and STC cultivators/ridgers. These results agree with the findings of Gerighausen (1994) that, on loamy soil, ridges made by a PTO-driven cultivator/ ridger contain almost 50% less of the larger soil aggregates than ridges made by a drawn cultivator.

In Figure 5 a detailed depiction of the influence that cultivator/ridger type had on crushing soil aggregates after the cultivation within each fraction in the ridge is given. The PTO-driven cultivator/ridger proved to be the most efficient in crushing larger soil aggregates, due to the rotary movement of its knives, which enabled

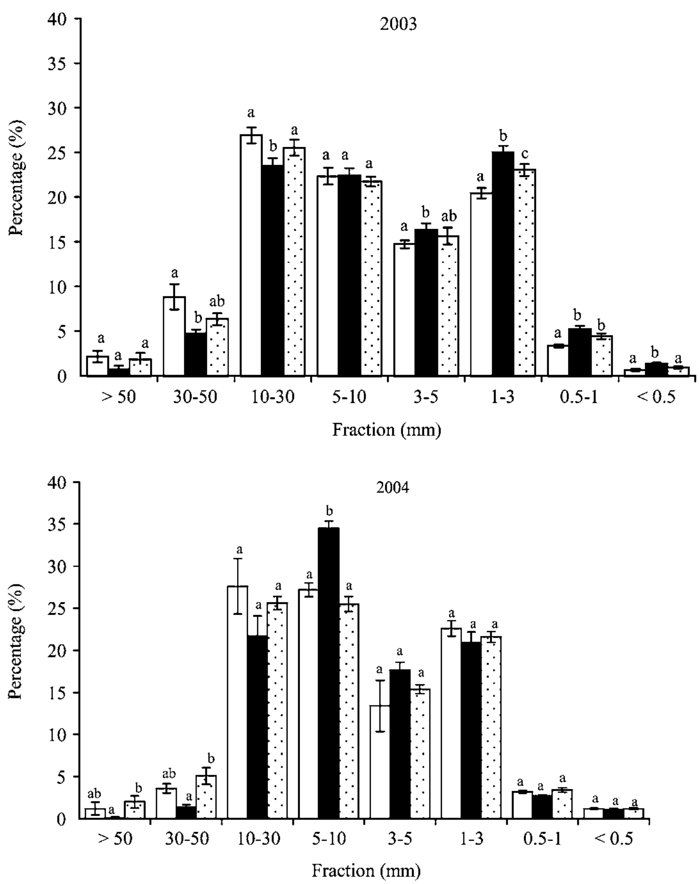

Figure 5. The structure of soil aggregates in the ridge after the cultivation with three cultivators/ridgers in 2003 and 2004 (PTO-driven cultivator/ridger (RC, ■), drawn cultivator/ridger with spring tines (STC, ▩) and drawn cultivator/ridger with rigid tines (RTC, □)). Cultivators, within the same fraction, without a common superscript are significantly different ($P < 0.05$). Vertical bars represent s.e.

effective crushing of larger soil aggregates on medium textured soil. In 2003, the percentage of soil aggregates of 30 to 50 mm and 10 to 30 mm with this cultivator/ridger was lower than with the other two. In 2004, the percentage of soil aggregates exceeding 50 mm and of 30 to 50 mm was lower than with the two drawn cultivators/ridgers.

Power requirements and efficiency of the cultivators

Table 8 shows the power required for operating the drawn and driven cultivators/ridgers and their work rates (ha/h). The pulling force required by the PTO-driven cultivator/ridger was lower than that required by the STC and RTC cultivators/ridgers. This was due to its knives rotating in the driving direction, thus assisting the forward motion of the machine. The RTC cultivator/ridger required more pulling power, followed by the STC cultivator/ridger, while the PTO-driven cultivator/ridger, because of its low speed, required less pulling power. The pulling power needed is related to the pulling force and operating speed during cultivation. Total power for cultivation, was higher for the PTO-driven cultivator/ridger than for the other two drawn cultivators/ridgers. Due to its high operating speed, the RTC cultivator/ridger had the highest work rate (1.13 ha/h), while the PTO-driven cultivator/ridger had the lowest (0.27 ha/h). The PTO-driven cultivator/ridger used the largest amount of energy per unit of cultivated area while the RTC and STC cultivators/ridgers used almost 6 times less energy.

Yield

The total yield produced by the PTO-driven cultivator/ridger in 2002 was higher than that produced by the RTC cultivator/ridger, while in 2004 it was higher than that produced by the STC cultivator/ridger (Table 9). The higher total yield was due to an increased number of tubers per plant. We postulate that this was as a result of a larger cross-sectional area of the ridge, a better distribution of soil aggregate sizes in the ridge and a smaller cone resistance. In 2003, yields were much lower due to the low precipitation (536 mm) during the period of growth, while the years 2002 and 2004 had an annual precipitation of 799 mm and 861 mm, respectively. Cultivator/ridger type did not affect the

Table 8. The power requirement and efficiency of cultivators/ridgers

Measurement	Cultivators/ridger[1]		
	RTC	STC	RC
Pulling force (N)	9802[a]	9293[a]	8064[b]
Torque of the PTO shaft (Nm)	–	–	410
Rotation speed of the PTO shaft (rpm)	–	–	518
Operating speed (m/s)	2.1[a]	1.7b	0.5[c]
Pulling power (W)	20421[a]	15488[b]	4032[c]
Rotary power (W)			22274
Total power (W)	20421[a]	15488[b]	26306[c]
Area efficiency (ha/h)	1.13[a]	0.9[a]	0.27[b]
Time efficiency (h/ha)	0.88[a]	1.1[a]	3.70[b]
Specific work (kJ/m^2)	6.5[a]	6.2[a]	35.1[b]

[1] See footnote to Table 2.

[abc] Means, within a row, without a common superscript are significantly different ($P < 0.05$).

Table 9. Influence of cultivator/ridger type on the tuber yield, number of tubers per plant and relative yield of green tubers

Year	Cultivator/ ridger[1]	Total yield (t/ha)	Market yield[2] (t/ha)	Non-market yield[3] (t/ha)	Tubers/plant	Green tubers[4] (% w/w)
2002	RTC	56.6[a]	40.6[a]	16.0[a]	17.8[a]	3[a]
	RC	68.3[b]	49.2[a]	19.1[a]	21.2[b]	0.8[b]
	STC[5]	–	–	–	–	–
2003	RTC	41.8[a]	24.8[a]	17.0[ab]	18.6[a]	2.3[a]
	RC	41.3[a]	25.7[a]	15.6[a]	18.0[a]	0.3[b]
	STC	46.4[a]	27.0[a]	19.4[b]	19.3[a]	1.8[a]
2004	RTC	60.7[ab]	52.6[a]	8.1[a]	13.9[a]	3.3[a]
	RC	62.9[a]	53.2[a]	9.7[b]	15.8[b]	1.0[b]
	STC	57.9[b]	50.6[a]	7.3[c]	13.0[a]	2.5[a]

[abc] Means, within a column for a given year, without a common superscript are significantly different ($P < 0.05$).
[1] See footnotes to Table 2.
[2] Tubers >45 mm diameter.
[3] Tubers ≤45 mm diameter.
[4] Green tubers >45 mm diameter as percentage of total yield.
[5] The STC cultivator/ridger was not used in 2002.

market yield. It did, however, affect the percentage of green tubers in the ridge. The drawn cultivators/ridgers, because of shaping ridges with a smaller cross-sectional area, produced a higher percentage of green tubers. In all test years, the PTO-driven cultivator/ridger produced a lower percentage of green tubers than the other two cultivators/ridgers, which was due to the fact that it created a larger cross section of the ridge allowing enough space for the tubers to be covered in soil. In 2002, the number of tubers per plant with the PTO-driven cultivator was larger than with the RTC cultivator, and in 2004 it was larger than the number achieved by both drawn cultivators.

Conclusion

On medium-textured soil in the climatic situation distinctive of South-East Europe, the PTO-driven cultivator/ridger was justifiable because it produced ridges with better physical properties than the two drawn cultivators/ridgers. This cultivator/ridger type produced ridges with the largest cross-sectional area and reduced the percentage of green tubers due to a better soil covering of tubers in the ridge. It had the lowest cone resistance and the best distribution of soil aggregate sizes in the ridge. However, the two drawn cultivators/ridgers had a better work rate and used less energy due to a less intensive cultivation of a smaller soil volume. It should be noted that in order to reach similar physical properties of the soil as with the PTO-driven cultivator/ridger, drawn cultivators/ridgers need to do more passes (about 4) and, consequently would use much more energy. This was not analysed in this study. However, the PTO-driven cultivator/ridger was not justifiable with regard to the market yield of potatoes. Further research should be performed in order to accurately quantify the number of passes to be done by drawn cultivators to reach similar physical properties of the soil as with the PTO-driven cultivator.

This analysis should use similar parameters as our present research. We assume that it would additionally justify the use of the PTO-driven cultivator in potato cultivation on medium-textured soil in South-East Europe.

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