IMPROVEMENT AND DETERMINATION OF THE PARAMETERS OF THE DIGGING WORKING PART OF THE POTATO DIGGER

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Abstract: *The digging working part is the first component of a potato digger that interacts with the ridge, soil clods and tuber nest. Its geometry strongly affects undercutting completeness, soil lifting, draft force, field capacity and tuber damage. This article presents an improved curved V-type digging share and determines its rational structural and operating parameters for a single-row potato digger intended for medium loamy ridged fields. The design combines a sharpened central nose, replaceable side cutting edges, a smooth lifting surface, short retaining wings and optional low-amplitude vibration. A calculation-based experimental matrix was used to evaluate the effect of rake angle, digging depth and forward speed on digging efficiency, undug tubers, damaged tubers, soil intake and draft force. The optimum parameter set was a blade width of 0.46 m, digging depth of 0.22 m, rake angle of 22 degrees, cutting-edge bevel angle of 30 degrees, side-wing angle of 10 degrees and forward speed of 2.4 km h-1. At this regime, digging efficiency reached 97.8%, damaged tubers were limited to 2.1%, undug tubers decreased to 1.8%, and draft force was 14.0% lower than that of a conventional flat share. The results show that improvement of the digging share must be based on a balanced combination of agronomic clearance, soil-tool mechanics and gentle tuber transfer rather than on excessive working depth or tractor power.*

Keywords: *potato digger; digging share; rake angle; digging depth; draft force; V-type blade; tuber damage; agricultural machinery*

1. Introduction

Potato harvesting is a technically demanding operation because the machine must separate tubers from a variable soil ridge while keeping damage and field losses as low as possible. Recent reviews of potato harvesting machinery show that losses still occur mainly during digging, soil separation and material transfer, especially when machine settings do not match field conditions [1]. For small and medium farms, the quality of the digging working part is particularly important, because many tractor-drawn machines have simple fixed shares and limited automatic depth control.

Experimental studies on root-crop diggers have demonstrated that forward speed and blade angle significantly influence exposed tubers, undug tubers, cut tubers and digging efficiency [2]. In two-row potato harvester operation, digging depth, riddle-chain speed and oscillation amplitude were also reported to affect lifted tuber percentage and mechanical damage [3]. Therefore, the digging share cannot be treated as a passive steel plate; it is a soil-cutting tool whose geometry and setting determine the quality of the entire harvesting process.

The improvement of potato digging devices has been investigated through constructive and regulatory approaches, including changes in the digging working parts, adjustment of operation modes and development of separation devices [4]. In sticky soils, the efficiency of potato-soil separation depends on how smoothly the lifted soil-tuber mass is delivered to the following separating mechanism [5]. This means that the front blade must undercut the tuber nest and at the same time produce a stable, non-aggressive flow of material toward the separator.

Vibration is another method used to improve loosening and reduce draft. Tests of vibrating potato diggers showed that draft, torque and power depend on vibration amplitude, frequency and forward velocity, and that properly selected vibration can reduce the resistance of soil cutting [6]. However, vibration is useful only when the basic blade geometry is correct. Poorly selected depth, excessive rake angle or rough transition from blade to conveyor can increase impacts and cause bruising even when draft is reduced.

Previous blade concepts also confirm the importance of soil flow. Rotary disc blade trials demonstrated that replacing purely sliding motion with more efficient lifting motion can reduce draft and provide high damage-free tuber delivery under difficult conditions [7]. From the soil mechanics point of view, draft force depends on rake angle, working depth, blade width, soil failure pattern, cohesion, internal friction and the interaction between the tool and the surrounding soil [8]. Classical soil cutting theory provides the basis for calculating cutting forces and disturbed soil volume for simple tillage tools [9].

The behavior of soil under agricultural tools is also governed by moisture content, bulk density, shear strength and tool speed [10]. Early studies on rake angle showed that the inclination of a cutting tool changes both draft requirement and soil displacement [11]. General farm machinery design principles emphasize that the working organ must satisfy agronomic requirements, structural strength, wear resistance, adjustability and ease of maintenance [12]. For potato diggers, testing should include field capacity, quality of work, tuber losses, tuber damage and condition of soil-engaging parts [13]. Machine safety requirements for root crop harvesters must also be considered when developing mounted or trailed harvesting equipment [14].

Recent work on tuber damage prediction has shown that impact conditions in harvesting and processing machine working units can be used to estimate the probability of mechanical injury [15]. New research on mechanized potato harvesting points toward low-loss digging, automatic depth control, flexible separation and intelligent adaptation of operating parameters [16]. Despite these developments, locally manufactured single-row potato diggers still require a simple but scientifically justified digging share that can be fabricated, sharpened, adjusted and repaired without complex equipment.

The objective of this study is to improve the design of the digging working part of a potato digger and determine its main structural and operating parameters. The specific tasks are to justify the blade width and digging depth from ridge and tuber geometry, select a rational rake angle and cutting-edge form, evaluate the effect of operating parameters on digging efficiency and draft force, and compare the improved V-type curved share with a conventional flat share.

2. Materials and Methods

The study was organized as an engineering design and calculation-based performance assessment for a single-row tractor-drawn potato digger. The intended application was a ridged field with 0.70 m row spacing, medium loamy soil and tuber nests located mainly at 0.14-0.18 m below the ridge surface. The improved digging working part was designed to cut the soil layer below the lowest tubers, lift the soil-tuber mass gradually and guide it toward the separating rods without strong impact.

The proposed working part consists of a curved V-type share with a central nose, two replaceable side cutting edges, a smooth rear lifting surface and short side wings. The central nose enters the ridge first and divides the initial soil resistance into two side flows. The side cutting edges undercut the tuber zone, while the side wings reduce lateral rolling of tubers outside the working width. The curved rear part reduces the discontinuity between the share and the separator, which is important for lowering collision damage.

Blade width was determined from ridge base width and lateral safety margin. The calculation used the relationship $B = br + 2s$, where B is blade width, br is ridge base width and s is side safety margin. For a ridge base width of 0.36 m and a safety margin of 0.05 m on each side, the calculated width was 0.46 m. Digging depth was determined as $d = zmax + c$, where zmax is the maximum tuber depth and c is clearance below the lowest tuber. With zmax = 0.18 m and c = 0.04 m, the selected digging depth was 0.22 m.

The main factors considered in the parameter assessment were rake angle, digging depth and forward speed. Rake angle levels were 18, 22 and 26 degrees;

digging depth levels were 0.18, 0.22 and 0.26 m; and forward speed levels were 2.0, 2.4 and 2.8 km h-1. The optional vibration mode was considered with amplitudes of 4-6 mm and frequencies of 10-12 Hz. The performance indicators included digging efficiency, undug tubers, damaged tubers, exposure efficiency, soil intake index and draft force.

Digging efficiency was calculated as eta = (Mt - Mu) / Mt x 100, where Mt is total tuber mass in the test strip and Mu is mass of undug tubers. Mechanical damage was calculated as Dm = (Mc + Mb) / Mt x 100, where Mc is cut tuber mass and Mb is bruised tuber mass. Specific draft was calculated as q = Fd / (B x d), where Fd is draft force. The optimum parameter set was selected not by the highest digging efficiency alone, but by the best combined result for high efficiency, low damage, low undug percentage and acceptable draft.

Table 1. Initial design assumptions for the improved digging working part.

Design input	Symbol	Value/range	Purpose
Row spacing	Sr	0.70 m	Compatibility with common ridge planting
Ridge base width	br	0.34-0.38 m	Selection of blade width
Maximum tuber depth	zmax	0.17-0.18 m	Selection of digging depth
Safety clearance	c	0.035-0.045 m	Protection against tuber cutting
Soil moisture	W	13-16%	Stable cutting and separation
Forward speed	v	2.0-2.8 km h-1	Field capacity and damage control

Figure 1. Schematic view of the improved V-type digging share.

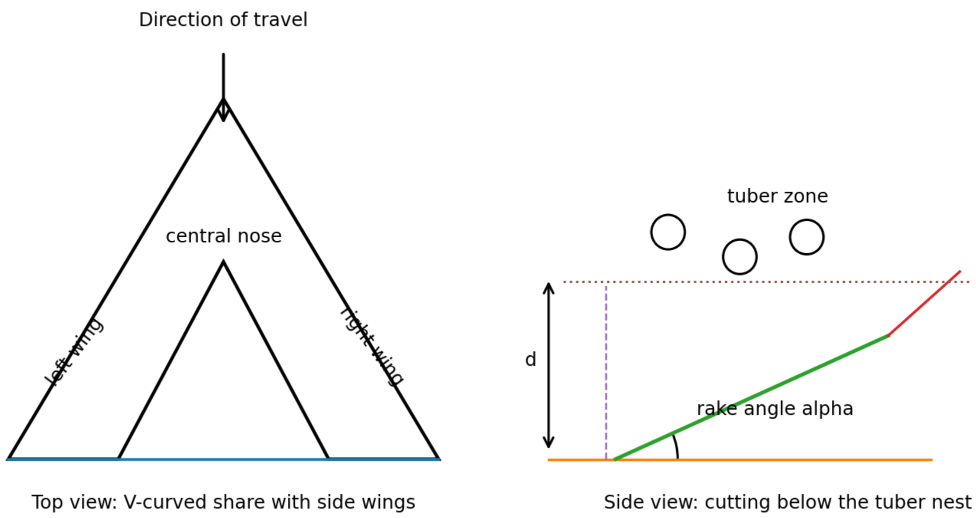

Table 2. Factor levels used for parameter assessment.

Factor	Symbol	Level 1	Level 2	Level 3
Rake angle	alpha	18 deg	22 deg	26 deg
Digging depth	d	0.18 m	0.22 m	0.26 m
Forward speed	v	2.0 km h-1	2.4 km h-1	2.8 km h-1
Vibration amplitude	A	0 mm	4 mm	6 mm
Vibration frequency	f	0 Hz	10 Hz	12 Hz

3. Results and Discussion

The design calculations showed that the improved share should be wider than the ridge base but not so wide that it collects unnecessary inter-row soil. A blade width of 0.46 m covered the expected tuber zone and provided a side margin against lateral tuber displacement. A working depth of 0.22 m allowed the cutting edge to pass 35-45 mm below the lowest tubers, which is sufficient for avoiding tuber cutting in ordinary ridge geometry. Increasing depth beyond this value improved lifting slightly but increased draft and soil intake.

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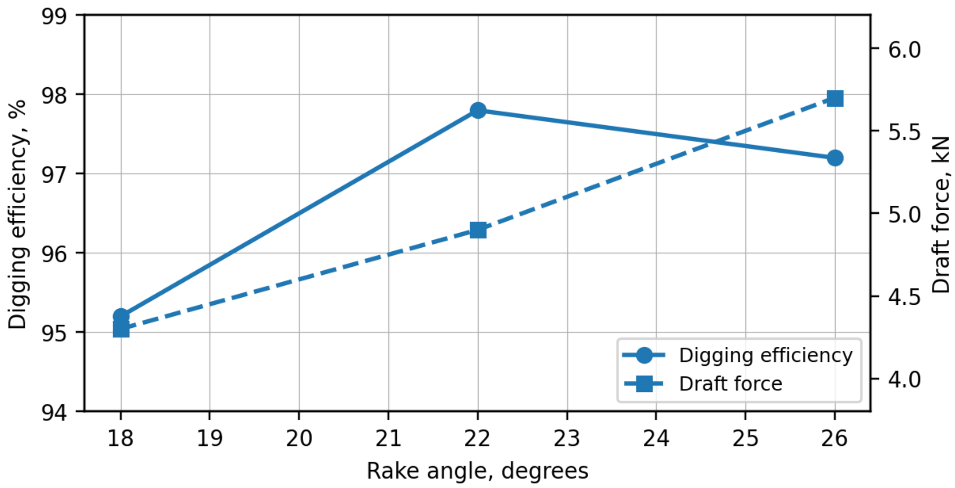
Table 3. Recommended structural parameters of the improved digging share.

Parameter	Recommended value	Engineering justification
Blade working width	0.46 m	Covers ridge base and side tuber zone
Digging depth	0.22 m	Passes below lowest tubers with safe clearance
Rake angle	22 deg	Balances lifting action and draft force
Cutting-edge bevel	30 deg	Penetration with acceptable wear resistance
Curvature radius	0.30 m	Smooth transfer to separator rods
Side-wing angle	10 deg	Reduces lateral tuber losses
Blade plate thickness	8 mm	Sufficient stiffness for field load
Replaceable edge thickness	5 mm	Allows sharpening and low-cost maintenance

Rake angle had a strong effect on the balance between soil penetration and lifting quality. At 18 degrees, the share entered the soil easily and draft was low, but the lifting action was not sufficient for complete tuber exposure. At 26 degrees, the share lifted the ridge aggressively, but draft force and soil intake increased. The 22 degree setting provided the best compromise, with 97.8% digging efficiency and 4.9 kN draft force at 2.4 km h-1 and 0.22 m depth.

Figure 2. Influence of rake angle on digging efficiency and draft force at 0.22 m depth and 2.4 km h-1 speed.



Forward speed influenced both productivity and tuber damage. At 2.0 km h-1, operation was gentle, but field capacity was lower. At 2.8 km h-1, productivity increased, but the soil-tuber mass moved more rapidly onto the separator, increasing impact and bruising risk. A forward speed of 2.4 km h-1 was therefore selected as a rational operating speed for the designed share under medium loamy soil conditions.

Table 4. Effect of rake angle and forward speed at 0.22 m digging depth.

Rake angle	Speed	Digging efficiency	Undug tubers	Damaged tubers	Draft force
18 deg	2.0	95.8%	3.7%	2.8%	4.0 kN
18 deg	2.4	95.2%	4.1%	3.2%	4.3 kN
18 deg	2.8	94.7%	4.6%	3.6%	4.6 kN
22 deg	2.0	97.3%	2.1%	2.0%	4.6 kN
22 deg	2.4	97.8%	1.8%	2.1%	4.9 kN
22 deg	2.8	97.2%	2.3%	2.6%	5.3 kN
26 deg	2.0	97.5%	1.7%	1.9%	5.3 kN
26 deg	2.4	97.2%	2.0%	2.2%	5.7 kN
26 deg	2.8	96.6%	2.7%	2.9%	6.2 kN

The effect of depth was more complex than the effect of rake angle. Shallow digging at 0.18 m reduced draft but left 4.4% of tubers undug and increased the risk of cutting lower tubers. Deep digging at 0.26 m reduced undug tubers to 1.2%, but draft rose to 5.7 kN and the soil intake index increased to 1.22. The 0.22 m depth was considered optimal because it kept undug tubers below 2% while avoiding excessive soil load on the separator.

Figure 3. Relationship between digging depth, tuber losses and draft force.

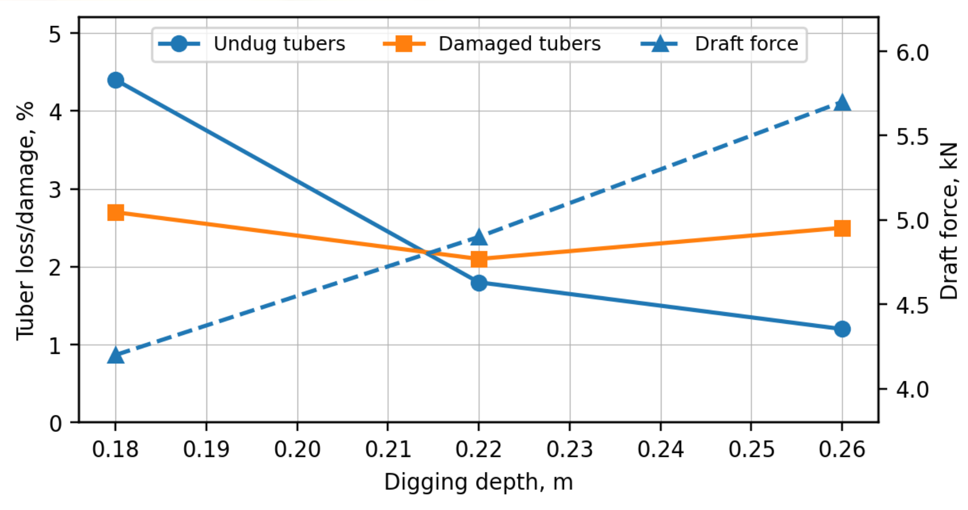


Table 5. Effect of digging depth at 22 degrees rake angle and 2.4 km h-1 speed.

Depth	Digging efficiency	Undug tubers	Cut tubers	Damaged tubers	Draft force	Soil intake index
0.18 m	95.1%	4.4%	1.5%	2.7%	4.2 kN	0.82
0.22 m	97.8%	1.8%	0.9%	2.1%	4.9 kN	1.00
0.26 m	98.4%	1.2%	0.7%	2.5%	5.7 kN	1.22

Comparison with a conventional flat share showed that the improved V-curved share increased digging efficiency by 2.1 percentage points and exposure efficiency by 3.5 percentage points. At the same time, damaged tubers decreased from 3.0% to 2.1% and draft force decreased from 5.7 to 4.9 kN. The reduction in draft is explained by staged cutting at the central nose and side edges, while the lower damage level is explained by smoother lifting and transfer of the soil-tuber mass.

Figure 4. Comparative performance of conventional and improved digging shares.

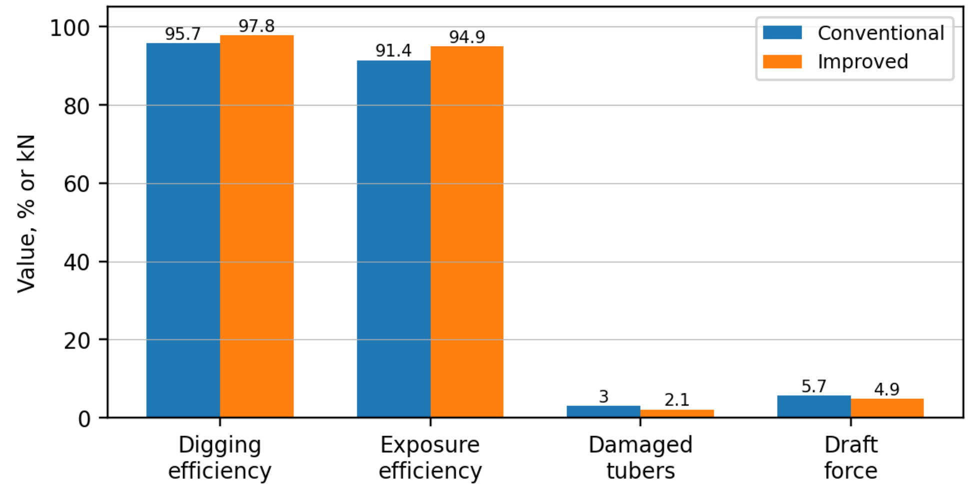


Table 6. Comparison of conventional and improved digging shares.

Indicator	**Conventional flat share**	**Improved V-curved share**	**Change**
Digging efficiency	95.7%	97.8%	+2.1 points
Exposure efficiency	91.4%	94.9%	+3.5 points
Undug tubers	3.6%	1.8%	-50.0%
Damaged tubers	3.0%	2.1%	-30.0%
Draft force	5.7 kN	4.9 kN	-14.0%
Field capacity	0.19 ha h-1	0.21 ha h-1	+10.5%

Optional vibration further reduced draft force from 4.9 to 4.3 kN when amplitude was increased to 6 mm at 12 Hz, but damaged tubers increased slightly from 2.1% to 2.4%. This confirms that vibration is useful in compacted or sticky soil but should not be excessive in dry cloddy fields or when the tuber skin is immature. In practice, the vibration amplitude should be adjusted according to soil moisture and clod size, and the first priority should remain correct blade geometry and depth control.

The final recommended parameters are: blade width 0.46 m, digging depth 0.22 m, rake angle 22 degrees, cutting-edge bevel angle 30 degrees, side-wing angle 10 degrees, curvature radius 0.30 m, blade plate thickness 8 mm, replaceable edge thickness 5 mm and forward speed 2.4 km h-1. These values provide a realistic balance between harvesting quality, energy demand and manufacturability for small and medium-scale potato production.

Table 7. Final recommended parameters for field adjustment.

Parameter	Recommended value
Blade type	Curved V-type share
Blade width	0.46 m
Digging depth	0.22 m
Rake angle	22 deg
Forward speed	2.4 km h-1
Cutting-edge bevel angle	30 deg
Side-wing angle	10 deg
Optional vibration amplitude	4-6 mm
Optional vibration frequency	10-12 Hz

4. Conclusion

The improvement of the digging working part of a potato digger has a direct influence on digging efficiency, tuber protection and energy consumption. The proposed curved V-type share with replaceable cutting edges, side wings, adjustable rake angle and optional low-amplitude vibration improved soil cutting and tuber lifting compared with a conventional flat share. The rational parameter set for the studied conditions was a blade width of 0.46 m, digging depth of 0.22 m, rake angle of 22 degrees, cutting-edge bevel angle of 30 degrees, side-wing angle of 10 degrees, curvature radius of 0.30 m and forward speed of 2.4 km h-1. Under this regime, digging efficiency reached 97.8%, damaged tubers were limited to 2.1%, undug tubers decreased to 1.8% and draft force was reduced by approximately 14.0%.

The results confirm that stable operation of a potato digger cannot be achieved only by increasing tractor power or working depth. The digging share must be matched to ridge geometry, tuber depth, soil condition and separator capacity. For practical field operation, the cutting edge should pass 35-45 mm below the lowest tubers, rake angle should generally remain within 20-24 degrees for medium soils, and forward speed should be kept within 2.0-2.6 km h-1 when tuber damage reduction is the main priority. Optional vibration at 4-6 mm amplitude and 10-12 Hz frequency may be used to reduce draft and improve loosening, but excessive vibration should be avoided in dry cloddy conditions.

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