CREATION OF COMBINE TILLAGE MACHINE FOR SUPPORTING WIDE ROW SEED POTATO GROWING METHOD

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ABSTRACT: This paper presents a review of papers related to creating, designing and study a sustainable combine tillage machine, supporting wide row seed potato growing method. Present review begins with short description of the wide row seed potato growing method. Then the idea of creation of new machine and the results of preliminary experiments are discussed. The main part of present review is devoted to description the results of mathematical modelling based study the circular link ant the disk-ridging tool and made several recommendations for its structure.

On idea of wide row seed potato growing

Factors such as low reproduction rates and the high cost of seed potatoes have prompted the need for new agrotechnical methods, adjusted to the biological peculiarities of potatoes. The method of wide row seed potato growing was first proposed by Sinijärv (1982) and based on idea of increasing the space available for seed potato growth in a step-by-step fashion. The technology (Olt, 2001a; Olt, Heinloo, 2001f), based to this method, might be just a way to increase the reproduction rates of seed potatoes and to decrease its cost.

Machinery, devices and technical tools that are required for wide row seed potato growing are not yet manufactured. As a result, the development and use of the wide row seed potato growing method has been hindered. However, potato planters, harvesters and other implements currently marketed could be adjusted to support proposed wide row seed potato growing methodology.

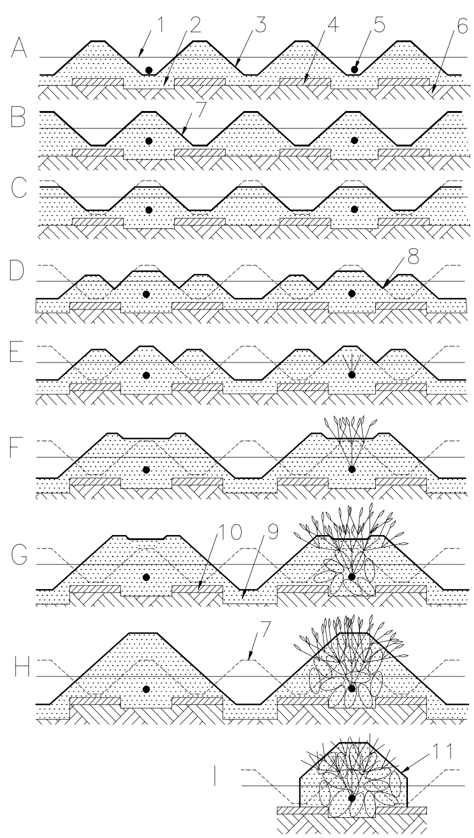

Figure 1. Creation the profile of the seed potato field: A – during the planting period; B – after primary coverage of potato furrows; C – after primary harrowing; D – surface after final coverage of potato furrows; E – profile of the surface before the sprouting of plants; F – profile during the earthing (build) up period; G – profile of the surface after earthing up of new haulm; H – profile of a well developed ridge; I – profile before harvesting; 1 – the level of the field surface before making furrows; 2 – loosened up slits under the rows of potatoes; 3 – profile of the ploughed furrows; 4 – part of the ploughing layer tightened during spring work; 5 – a planted tuber; 6 – tightened layer under the ploughing layer; 7 – profile of the field surface after primary covering it with the soil; 8 – groove for rainwater; 9 – drains for accumulation of a superfluous rain water and direction it into the lower layers of soil; 10 – walls from tightened soil to protect the tuber against the excessive moisture; 11 – profile of a ridge after separating the excessive soil from the sides of a furrow.

According to the wide row seed potato growing method by Sinijärv (1982) the potato tubers must be planted to every second furrow (Fig.1). At the potato tubers planting time the potato field has the profile A. After covering the tubers by ridges the potato field profile changes to the profile B. After first harrowing the tops of ridges this profile changes to profile C. Now the ridges without tubers must be divided into two parts. Then the profile C changes to the profile D. The process of increasing the potato growing space is beginning from profile E. A potato planter could be adjusted for moulding the profiles A, B, C, D.

The problem is in creating a combine tillage machine that would provide potato field profiles E , F, G, H according to wide row seed potato field cultivating technology capable of producing a high-earthed wide ridge or bed that will act as a rainwater accumulator.

New combine tillage machine

New combine wide row seed potato field tillage machine (Fig. 2) supporting wide row seed potato growing method was first proposed by Olt, Stepanov, Normak (1988).

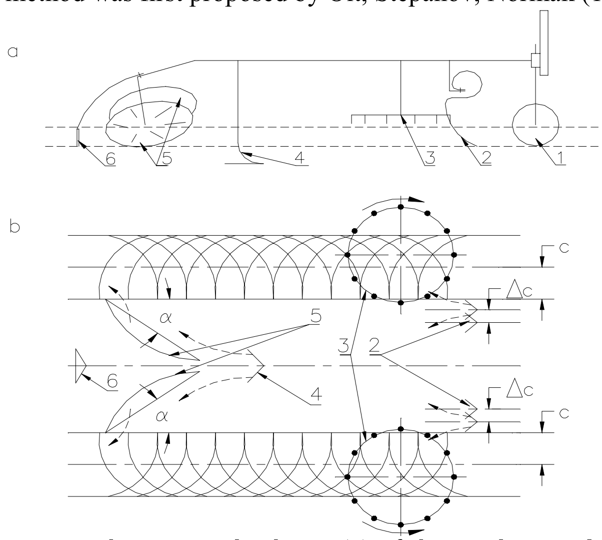

Fig. 2. The principal scheme (a) of the combine wide row seed potato field tillage machine, and its (b) tillage process;
1 – supporting wheel,
2 – S-tine,
3 – circular link,
4 – C-shank with duckfoot shear,
5 – ridging tool,
6 – furrow former, α *- angle of attack,*
c, Δc *– width and the increase of the safety strip.*

The combine machine creates potato ridges of increased profile height of up to 35 – 40 cm during 3 – 5 working strokes. A pair of S-tines (2) loosens soil on the lower border of the ridge's lateral surface. A rotating circular link (3) looses soil, destroys weeds on the top of a ridge and throws a portion of that soil to the lateral surface of the ridge. The spring-reset C-shank with a duckfoot shear (4) loosens the soil, destroys weeds in the bottom of furrow and moves soil to lateral surface of the ridge. The disk ridging tool (5) loosen the soil on the lateral surface of the ridge and lift a portion of the soil from this surface to the top of the ridge increasing its height. The parameters of the ridging tool must be established so that they do not damage new haulms. Solely forces applied to the free-active tool from the soil cause rotation of the circular link and the ridging tool. If the circular link damages new haulms then it must be removed from the machine after earthing up. In order not to destroy potato roots, the S-tines (2) must be moved by Δc towards the midline between furrows (Fig. 2b) before beginning each working stroke. Soil particle moves primarily in the direction shown by the dash lines in Fig. 2b. The solid lines on the top of the ridge in Fig. 2b represent the approximate trajectory of the circular link's spikes. The new combine wide row seed potato field tillage machine is sustainable because its tools do not need additional energy for working in the soil and do not destroy the structure of the soil.

Studies by the experiments

Olt (1999a,b) has studied by experiments with the special device the ability of disk-ridging tool in lifting a part of soil from the lateral surface of the ridge to its top. On the base of statistical treatment the data of the experiments Olt (1999a,b) has concluded that the thickness of the soil, lifted to the top of a potato ridge, is in cubic dependence on the angle of attack and on the velocity of the machine. Olt (1999a,b) found out: in the preliminary working stroke 1. the optimal angle of attack of the disk-ridging tool is between 18^o – 23^o, 2. the optimal velocity of the machine is between 1.9 – 2.4 m/s and in the basic working stroke 1. the optimal angle of attack is between 8^o – 13^o, 2. the optimal velocity of machine is between 2.2 – 2.8 m/s.

Olt (1999c) has studied by experiments the cinematic parameter $\lambda = \omega r/v_m$ of the circular link and the disk-ridging tool. Here ω is the angular velocity of the active tool, r – its radius and v_m – speed of the forward motion of the machine. Olt (1999c) presented the values of the cinematic parameter recorded during the experiments.

Theoretical study of the circular link

The tillage of the soil by a circular link on the top of the potato ridge (Fig. 3) was studied theoretically by Olt, Heinloo (1999), Heinloo, Olt (2000, 2001b).

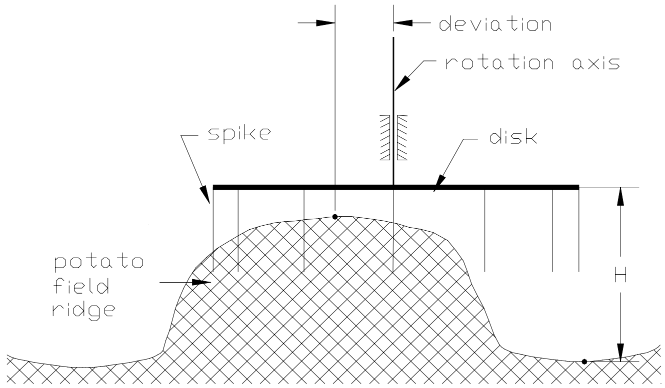

Fig. 3. The working position of the circular link on a ridge

The part of the ridge, to be processed, was modelled by parabolic cylinder (Olt, Heinloo, 1999) or according to the Fig. 1E – by polygonal cylinder (Heinloo, Olt, 2001b). The profile of the last cylinder is shown in Fig. 4, where the lowest points of the spikes of the circular link are on the height 0.05 m. An attempt to find the theoretical dependence of the cinematic coefficient of the circular link from soil resistivity had been made by Heinloo, Olt (2000).

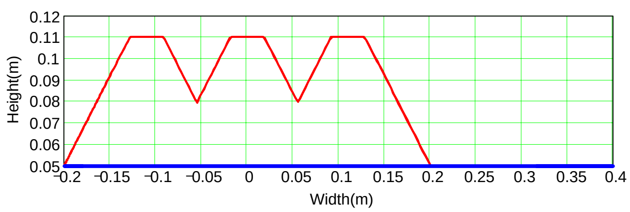

Fig. 4. The polygonal profile of a ridge

The mathematical model for describing the motion of the circular link was made using the following assumptions:

1. the machine begins the motion under acceleration,
2. the modified Goryachkin formula, which takes into account the speed direction (Olt, Heinloo, 1999) of the spikes in motion, determines the amount of forces applied to the spikes
3. the rotation axis of a circular link deviates from the midline of the ridge.

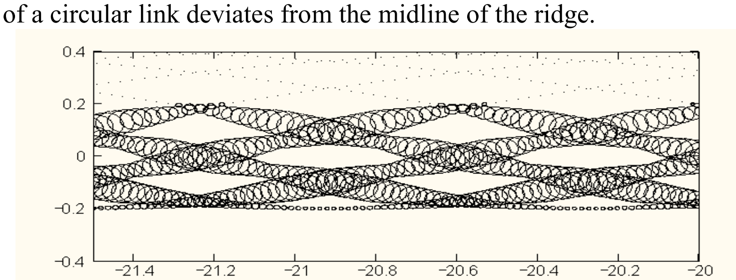

Fig. 5. Processed regions at the maximum working depth of the spikes, when N = 10

Computations were made for certain parameters of the circular link, ridge and soil. The dependence of the angular velocity, resultant moment of applied forces and resultant force, applied from circular link to the frame of the machine, on time were recorded. The region, processed on the top surface of the ridge, was also recorded. Fig. 5 shows a portion of such region (dimensions in metres), when the number N of spikes, clamped rigidly to the circular link is $N = 10$. Each spike processes the region in the circle around it. The radius of this circle depends on the working depth of the spike. Fig. 5 shows that a part of top surface remain unprocessed, when N = 10. Fig. 6. shows the same region (dimensions in metres), when N = 20. One can conclude that practically there are not unprocessed regions on the top of ridge.

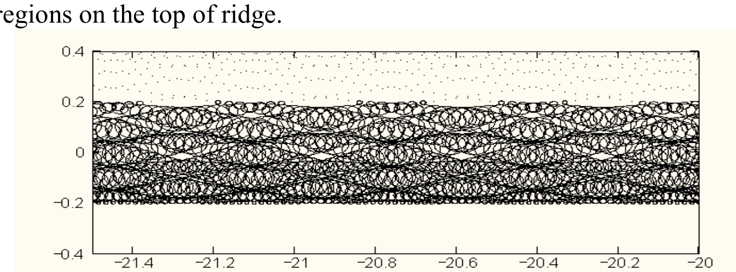

Fig. 6. Processed regions at the maximum working depth of the spikes, when N = 20

Theoretical study of the disk-ridging tool

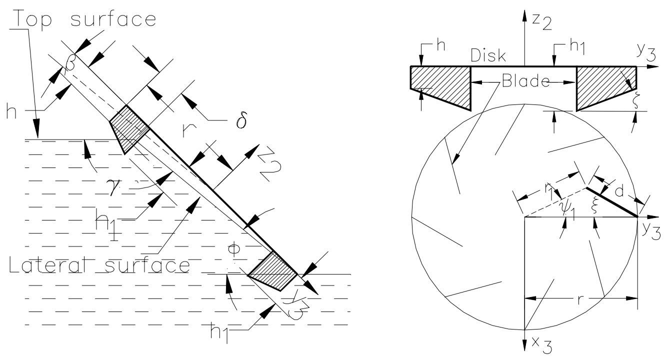

Fig. 7. The schemes of the disk-ridging tool

Fig. 7 shows the schemes of the disk-ridging tool. Heinloo, Olt (2001c, d, e, 2002), Olt, Heinloo (2002) studied the influence of the value of the inclination angle ξ (Fig. 7) to the process of tillage on the lateral surface of the ridge. On the basis of the experiments of Olt (1999b) the value of the average value of the cinematic parameter of the ridging tool (if α = 20° and β = 51°) λ = 1 was recorded. Using of this value of the cinematic coefficient the angular velocity of the ridging tool can be represented by $\omega = v_m/r$, where r is the radius of this tool and v_m – speed of the forward motion.

Computations were made for certain parameters of the disk ridging tool, ridge and soil. The law of motion regulating the ridging tool was discovered. Fig. 8 shows the motion of the blade denoted in Fig. 7 on right side figure by bold line.

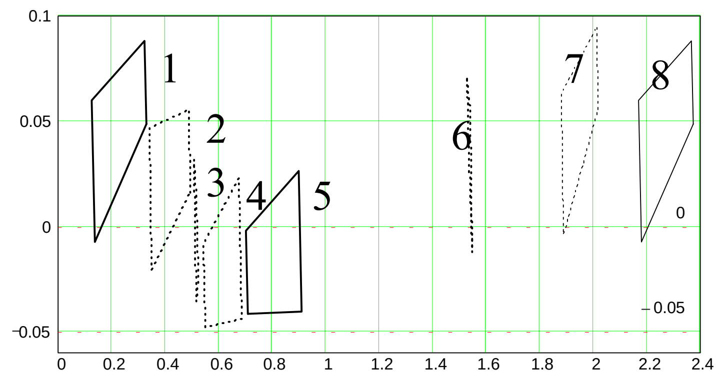

Fig. 8. Positions of a blade in dependence of angle of rotation φ, obtained by graphic features of Mathcad 2000: 1 – φ = 0°, 2 – φ = 45°, 3 – φ = 90°, 4 – φ = 135°, 5 – φ = 180°, 6 – φ = 225°, 7 – φ = 270°, 8 – φ = 315°, 9 – φ = 360°. The processed layer of soil a ridge is between dot lines.

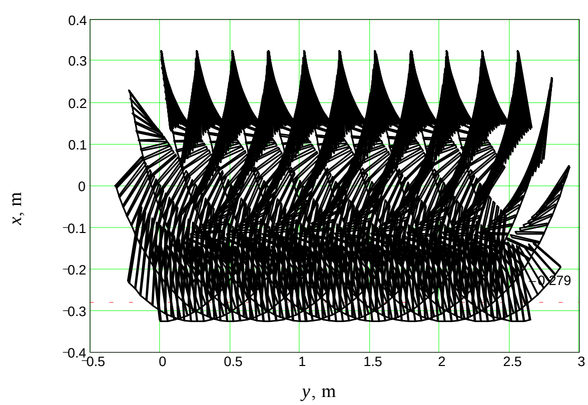

Fig. 9. The processed area of the ridge's lateral surface by the blades of model, shown in Fig. 7 (ξ = -20^o)

The region, processed by blades of the ridging tool on the lateral surface of the ridge, was also discovered. Fig. 9 displays a part of such region, when the number N of spikes, clamped rigidly to the circular link is N = 10.

Analysis of soil resistance forces

Analysis of soil resistance forces of disk-ridging tool were made by Heinloo, Olt (2002) under following assumptions:

- ✓ the forces of friction between soil and blade are small;

- ✓ the system of forces, applied to a blade that has delved into soil, can be changed to the equivalent resultant force, applied to the centroid of the delved part of the blade;
- ✓ the distributed resistance force, applied to the part of the blade that has delved into the soil, is equivalent to the resultant force ***F'***, applied to the centroid of this delved part;
- ✓ the resultant force ***F'*** determines the formula of V. P. Goryachkin in modified form

$$\boldsymbol{F'} = -\left(k_0 + \rho c v^2\right) S_v \frac{\boldsymbol{v}}{v},$$

where k_0 – is a soil resistivity at the beginning of motion, ρ - density of the soil, c – shape parameter of the blade, S_v – the projection of the delved part of the blade into a soil to the direction of absolute velocity $\boldsymbol{v}$ of the centroid of this part, v – the modulus of the absolute velocity.

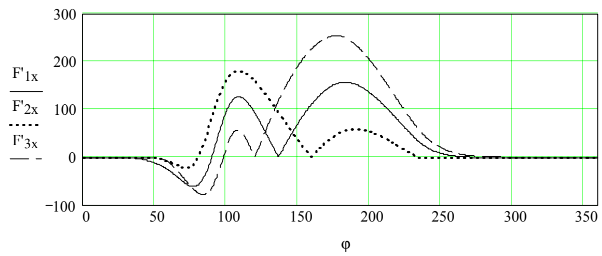

Fig. 10. Dependence of the projections F'_{1x}, F'_{2x}, F'_{3x} (N) on rotation angle φ (deg) of the ridging tool

Computations were made for certain parameters of the disk-ridging tool, ridge and soil. Let us denote the projections of resistance force ***F'***, applied to the bold line denoted in Fig. 7 (right side figure) blade, on the co-ordinate axis x, perpendicular to the direction of forward motion of the tool and directed from top of the ridge to its bottom, by F'_{1x} ($\xi = 0^o$), F'_{2x} ($\xi = 20^o$), F'_{3x} ($\xi = -20^o$). Fig. 10 shows the dependence of these projections on angle of rotation φ. Analogous dependencies for the resistance force $\boldsymbol{F} = \Sigma \boldsymbol{F'}_i$ of whole disk-ridging tool, where i is the number of the blade are shown in Fig. 11.

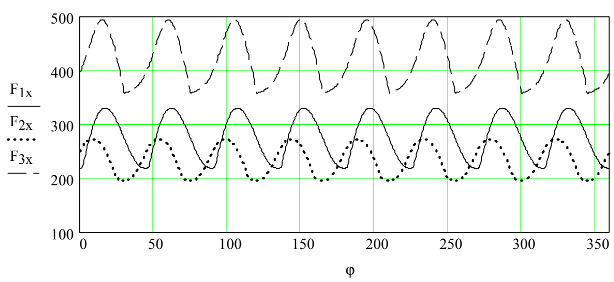

Fig. 11. Dependence the projections of the F_{1x}, F_{2x}, F_{3x} (N) on rotation angle φ (deg) of the ridging tool

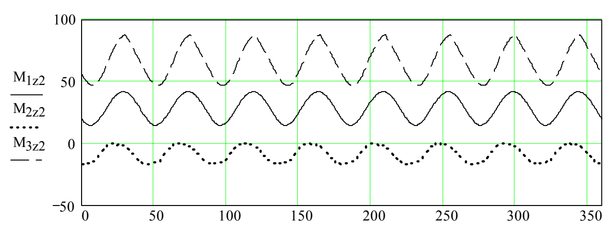

Fig. 12. Dependence of the moments M_{1z2}, M_{2z2}, M_{3z2} (Nm) on rotation angle φ (deg) of the ridging tool

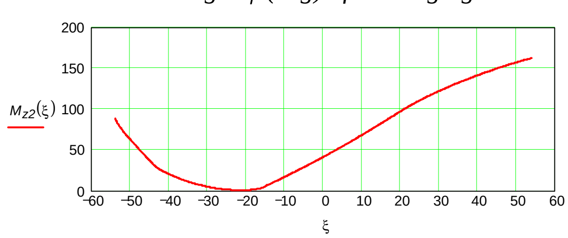

Fig. 13. Dependence of maximum value of the soil resistance moment M_{z2} relative to the axis of rotation of disk-ridging tool on adjustment angle ξ.

Fig. 12 shows the dependence moments M_{1z2} ($\xi = 0^o$), M_{2z2} ($\xi = 20^o$), M_{3z2} ($\xi = -20^o$) of soil resistance forces ***F'*** relative to the axis of rotation of the ridging tool on rotation angle φ.

The oscillation, seen in Fig. 11 and 12, is self-evident because of repetition of the positions of the blades for angle of rotation $\varphi = 2p/M$, where M is the number the blades of the disk ridging tool.

Fig. 13 shows the dependence of maximum value of the soil resistance moment M_{z2} relative to the axis of rotation of disk-ridging tool on adjustment angle ξ. One can conclude from Fig. 13 that the rotation of the blade from its radial positions, where $\xi = 0$ (in Fig. 8) changes the soil resistance force's. In other words, the rotation of blades the ridging tool from their original original positions, where $\xi = 0$ changes the tool´s capability to move soil. At that the clockwise rotation of blades is preferred.

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