Technologies and Machinery for Tillage on Slopes

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Abstract. With slope farming, land improvement operations shall be adapted to successfully counteract both wind and water erosion, as well as their joint effects. Paraplowing and chisel plowing are considered the most effective for controlling water erosion in the Western Siberia region, where the steepness of slopes in most areas does not exceed 4-6 degrees. However, even relatively small slopes have large areas where the required direction of machinery movement is difficult to determine unambiguously, while incorrect tillage significantly enhances erosion processes on the slopes. A number of disadvantages of existing tools can be eliminated with the help of a rotary-type blade tiller developed by Omsk SAU. As the machinery moves, the tool creates intermittent grooves of a complex configuration on the field surface, which allow to restrain the flow of melt and storm water. With a working depth of over 40 cm in the middle of the furrow, the tool operates partly as a paraplow keeping the crop residue on the field surface. However, this tool needs further modernization. Therefore, research aimed at creating and improving the tool pieces of tillage machinery capable of working on slopes of complex configuration is currently relevant.

1. Introduction

The south of Western Siberia is one of the most vulnerable to erosion regions of the Russian Federation. According to the classification of slope lands of the Omsk region, over 1.5 million hectares (11.3%) are located on slopes vulnerable to erosion. Tools of mass-produced tillage machinery for slope lands do not fundamentally differ in design and have certain disadvantages. Passive tools have high traction resistance, are steerable, designed for intermittent tillage, require significant force to be driven from the wheels or the tractor PTO shaft. It is extremely difficult for existing machines to properly perform operations on slopes of complex configuration. Active tools, auger and disc tillers are inefficient and high energy overheads. However, they are widely used both in the Russian Federation and abroad. Rotary tillers can be used in regions vulnerable to erosion under certain conditions. The development of procedures and equipment systems with the design aimed at
soil protection for high-performance moisture-saving tillage, loosening of heavy soils, contour tillage on slopes is still an urgent task.

2. Materials and methods
Methods of mathematical statistics were used during the research and analysis of the results. Conventional experimental methods were used when determining the quality of soil tillage and measuring tool traction resistance.

3. Results and discussion
One of the techniques contributing to the reduction of melt and storm water runoff is chisel plowing. Chisel plowing is moldboard-free tillage with undercutting of furrow slice along the working width of loosening and V-shaped blades. Chisel plowing is often carried out during the main soil tillage, partially excluding moldboard plowing or moldboard-free plowing with sweep plows. Studies carried out in the central regions of the Non-Chernozem zone have shown that chisel plowing of sod-podzolic soil for row crops and grain crops to a depth of 30–40 cm intensively loosens the compacted subsoil. Chisel plowing significantly improves the water and air regimes of soil, increases the depth of aerated and root layers. It facilitates the removal of excess moisture from the arable layer in the autumn and early spring periods and its accumulation in the underlying layers. Soil hardness at a depth of 30 cm after chisel plowing is lower than after conventional plowing.

Chisel plowing is superior to sweep plowing, but is inferior to moldboard plowing by the degree of loosened soil overturning. The amount of crop residue left on the soil surface after chisel plowing is about 60%. This is enough to protect soil from wind and water erosion. Due to incomplete loosening of the arable layer and at all other conditions being equal, chisel plowing requires less energy consumption than for sweep and moldboard plowing. As a result, the productivity of chisel tools is higher than sweep plows and moldboard plows [1].

In the regions with excessive moisture, agricultural engineering faces heavy dense unstructured soils. When draining mineral heavy soils, closed drainage in wet years and growing seasons is not effective enough. Deep loosening shall be applied under these conditions allowing to accelerate surface and subsurface runoff. Research has shown that deep loosening has approximately the same effect as deep moldboard-free plowing with simultaneous application of 40 t/ha of manure and 4 t/ha of lime [2].

Shank subsoilers are considered to be environmentally harmful. They decrease humus reserves in the arable layer and change the structure of subsurface layers. Professor Ye.P. Ogryzkov notes: “Disturbance of soil structure in the lower part of layers cut by blades occurs as the available pressure and the ultimate compressive strength of soil is exceeded due to action of working surfaces of blades. Subsoilers unevenly till the soil layer by depth. Lumpiness of the upper part exceeds the norm. The structure of the lower part is disturbed to an unacceptable degree. The layer is overcompacted due to significant soil pressure on the tool blades.”

Paraplowing improves the water and infiltration regimes, facilitates loosening of the surface soil layer, reduces water and wind erosion, and increases crop yields. Paraplowing is a versatile technique. It can be used after the winter plowing, over crop residue, irrigated areas of winter crops and perennial grasses, in row spacing of row crops, on slopes with natural grass, before sowing of winter and row crops [3].

The grooves made at intervals of 4–10 m in the direction of the contours, reduce soil washout and facilitate moisture accumulation. To reduce runoff, it is recommended to combine paraplowing with surface tillage. Surface tillage facilitates simultaneous sprouting, while paraplowing helps to accumulate and retain moisture. Paraplowing before sowing creates reservoirs that trap storm water runoff on the slope and accumulate sediment. The positive effects are the loosening of the compacted plow sole, penetration of moisture into the lower layers, as well as the possibility of removing excess moisture in water-saturated areas of the field.
With all the positive effects, paraplowing can be used as seasonal tillage and cannot protect the soil from washout throughout the year. Research by Ye.V. Poluektov confirms that during winter thaws, grooves can be filled with water and not prevent soil washout on the slopes.

Paraplowing is a promising tillage technique. The positive effect of paraplowing is confirmed by studies conducted by V.N. Slesarev in the conditions of the Omsk region and Kazakhstan. It is most advisable when cultivating slope lands and overcompacted arable land when the soil is slightly frozen. This tillage leaves up to 80% of crop residue, which is enough to protect soil from wind and water erosion [4].

Research conducted by V.N. Slesarev, L.V. Yushkevich and V.Ye. Kovtunov in 1973-1983 in the fields of the Omsk experimental production farm allowed to develop the following agrotechnical requirements for paraplowing: optimal groove spacing — from 1 to 1.5 m, depth — 30-35 cm; paraplowing shall be combined with high-quality, shallow sweep plow loosening to a depth of 10-12 cm, and a compacted tilted surface near the groove edges shall be created; paraplowing shall ensure preservation of up to 80-85% of crop residues on the soil surface and low lumpiness at optimal soil moisture.

GNU SibNIISH proposed a multi-purpose tool — a sweep blade of the mass-produced OПT-3-5 tool outfitted with a multi-shoulder tip (Fig. 1), the tip 1 is installed instead of the original chisel in the front part of the share 5 using two screws 6 and a T-shaped spline key 2.

![Figure 1. Paraplow: 1 — tip; 2 — spline key; 3 — stilt; 4 — stop screw; 5 — share; 6 — screws.](image)

The screws pass through the holes in the share toe. A T-shaped spline key is welded to the frontal surface of the stilt 3, and grooves of the same shape are made on the back side of the tip. This design allows installing the tip in two positions: for sweep plowing with paraplowing — with the long end down; and for sweep plowing when no paraplowing required — with the long end up. If only paraplowing is needed, the tip is installed with the long end down, and the stilt of the tool is tilted back using a stop screw. The tool is installed so that the tip goes to a depth of 30 cm, and the front part of the plowshares — to 3-5 cm to form groove ridges preventing the runoff [5].

Calculation of the coefficients of precipitation utilization for the winter and early spring periods by V.P. Sakhonchik [6] shows that these values are much lower for moldboard plowing than for arable land tilled using additional techniques. Intermittent furrowing and microliming facilitate better utilization of precipitation. The method of dibbing after winter tillage is known using ЛОД-10 dibber and a mass-produced УПЛ-1-40 device, which can be combined with a plow.

In Germany, certain methods and technologies have been developed for decompaction of the subsurface layers. Some scientists believe that the mechanical decompaction of soil and especially the subsurface layers of sandy, humus-poor soils gives only short-term effect due to the instability of their structure, while continuous loosening in the first years has a negative effect due to the penetration of the subsoil into the seed layer. Therefore, the continuous deepening (loosening) was replaced by
intermittent. In this case, the subsoil is periodically extracted and mixed with the subsoil at certain intervals.

The resulting grooves are half-filled with soil from the arable layer, while dense regions remain at the level of its base, thereby increasing the bearing capacity. The grooves improve water and air permeability of the soil, as well as the root system development conditions with a partial deepening of the subsoil layer.

The В-204A-02 unit has paraplow tool pieces located behind the plow bodies and offset to the right. This allows the main tool and paraplow tool pieces to be mounted on twin beams. The subsurface layer of soil from grooves is moved to the left into an open plow furrow (Figure 2). Filling takes place when the soil is overturned and loosened by the main tool. The groove made by this tillage tool has dense walls.

![Figure 2. Soil layers layout after passage of В-204A-02: 1 — paraplowing tool pieces; 2 — plow body.](image)

The variety of paraplowing tools indicates that this method is in demand. Often, paraplowing is carried out together with other tillage types to loosen and facilitate moisture accumulation in soil. For this, various combinations of paraplowing tools with conventional or sweep plows are used.

Active tools are used in cases when soil tillage can be performed in one pass instead of several, which is required when using machinery with passive tools. Active tools crumble the soil by impact action, cutting, and pressure. Tillage machinery with active tools is most often advisable to be used for clay soils in the summer and autumn periods when the soil dries out and becomes lumpy [7].

The best burying ability is observed for passive rotary tools. Simplicity of design, reliability, high performance brings them to take a leading place among surface tillage tools [8].

Rotary tillage is an energy-intensive process. Energy costs for such soil tillage significantly exceed the costs when using other machines. Therefore, it is advisable to used rotary tillage for heavy soils, where soil monoliths shall be intensively ground. Rotary tillage is not recommended for light soils to avoid excessive dusting.

Natural reserves of moisture in soils of steppe and forest-steppe zones of Western Siberia, as well as in a number of other zones with insufficient and unstable moisture, are generally insufficient to obtain high yields. Furthermore, about a quarter of the annual precipitation is carried away off the fields, runs off and evaporates. Data on the soils prone to water erosion in the Omsk Oblast are presented in Table 1.
Table 1. Structure of eroded arable soils in various agricultural zones.

| Natural economic zone       | Type of erosion | erosion-prone soils | | | | | vulnerable to erosion | | | | | | eroded | % of erosion-prone |
|-----------------------------|-----------------|---------------------|----------------|----------------|-----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|
| Steppe outwash              | 16.7            | 0.9                 | 8.3            | 49.7           | 8.4             | 50.3           |
| Southern forest-steppe outwash | 14.4            | 1.9                 | 59             | 5.9            | 41              | 4.1            |
| Northern forest-steppe outwash | 281.3           | 70.6                | 143.4          | 51             | 137.9           | 49.0           |
| North outwash               | 120.2           | 91.7                | 59.3           | 49.3           | 60.9            | 50.7           |

Among the methods aimed at soil washout reduction are field leveling for slopes exceeding 10°, making water-holding reservoirs with dibbers, mulching the soil with crop residues, increasing the moisture absorbing capacity of the soil by using of sweep plowing and paraplowing. Sweep plowing with paraplowing on fallows and sloping lands does not prevent sheet erosion caused by runoff of melt water during snow melting [9].

When agricultural machinery is operating on slopes, the gravity force components of the tool and tractive resistance appear, directed down the slope and parallel to the field surface. Due to these forces, the tool is moved downward. As a result, the tillage process is disrupted, the effective tool width, tillage depth and traction resistance change, the performance of the unit decreases, and the fatigue of the tractor driver increases [10].

A number of disadvantages of existing tools can be eliminated with the help of a rotary-type blade tiller developed by Omsk SAU (Utility model certificate No. 12498. A 01 B 35/16, RF). The considered tool performs moldboard-free loosening to a depth of 8...50 cm. Intermittent furrows are created during machine operation. The tool consists of a stilt 3 with an axle 5 fixed to it in the lower part (Figure 3.). The axle can be tilted at an angle ±α to the direction of travel. A support sleeve 4 is rigidly fixed to the axle to compensate for longitudinal forces. The stilt is attached to the tillage tool frame, which has support wheels and a mechanism for changing vertical position relative to the field surface to change the tillage depth.

Figure 3. Tool stilt: a) side view; b) top view 1 — frame beam; 2 — stilt support plate; 3 — stilt body; 4 — support sleeve; 5 — axle.
A hub with blades is installed on axle 5 (Figure 4). The blade is sharpened and faces towards the travel direction. The tillage depth can be set by changing the position of the tool frame relative to the field surface.

![Blade hub](image)

**Figure 4.** Blade hub.

When the tool moves, at least two blades are always in the ground (Figure 5).

When the blade touches the field surface, the blade deepens since its plane is set at a certain angle to the travel direction. In addition, a forward blade moving at depth creates a significant torque due to the reactive forces of soil resistance. As the sleeve rotates, the blade changes its position to the maximum depth of immersion and then is retracted. The blade cuts the soil layer. The blade plane is set at an angle of attack to the direction of travel, therefore, when the soil layer slides along the blade surface, it is partially deformed and shifted, and is loosened in the area of blade action.

![Rotary tool operation process](image)

**Figure 5.** Rotary tool operation process.
The pressure of the soil layer as it slides along the blade surface creates a force similar to the wing lift. The soil layer pressure force is counteracted by the cutting force generated on the blade as it moves through the soil. Their difference creates a torque around the axis of rotation. After the passage of the machinery with a bladed tool, intermittent dimple-shaped grooves remain on the field surface, located at a certain angle to the direction of movement (Figure 6).

![Figure 6. Track on the field surface after the passage of the rotary tool.](image)

Tracks formed in the soil contribute to the accumulation and retention of moisture. The rotary tool creates ridges on both sides of the groove with a height of 7-9 cm at an angle of attack of 30–35°. This contributes to better retention of melt and storm water. Furthermore, tractor movement direction accuracy relative to the slope is less significant, since the groove has a specific shape. The grooves are located at a certain angle to the machinery travel direction and create closed loops at a certain arrangement of the tool pieces. Agrotechnical assessment of the bladed tool operation involves determining the groove length. The results are shown in Figure 7.

![Figure 7. Dependence of the groove length on the blade attack angle at a working depth of B=22 cm.](image)

The graphs show that the groove length increases with the machinery speed increase. At the same value of the blade attack angle, the groove length values vary in the range of 20–30 cm, depending on the machinery speed. With the blade attack angle increase, the groove length decreases, its openness in the central part increases, while the preservation of crop residue on the field surface decreases.
4. Conclusions
The study led to the following conclusions:

1. Soil washout on slopes with a steepness of up to 3-4° can be limited by reducing the intensity of the flow of melt and storm water by creating intermittent grooves.

2. For tillage of complex slopes, grooves of complex shape located at a certain angle to the machinery travel direction are most suitable, which simplifies the tillage technology and increase performance.

3. Using paraplowing during tilling ensures loose structure of the arable layer, high water permeability of soil and maximum preservation of crop residue on the field surface.

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