Modern Agricultural Science and Technology, ISSN 2375-9402, USA
December 2016, Volume 2, No. 2, pp. 54-63
Doi: 10.15341/mast(2375-9402)/02.02.2016/006
Academic Star Publishing Company, 2016
www.academicstar.us

An Anti-Erosion Strip-Tilling Combined Agricultural Machine

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Abstract: The paper describes an anti-erosion strip-tilling machine, which is capable of performing 5…7 operations simultaneously during one field day. Only those strips with a width of 15…25 cm and depth of 15…25 cm are treated, which are to be seeded. The other strips with a width of 30…40 cm remain unplowed. The expenditures for oils and lubricants and working hours are reduced 2-3 fold, and agrotechnical terms are shortened as well.

The fields with a tilt angle within a range of 0…8 degrees can be treated by the proposed machine. The plowing working tool, which comprises the passive and active (rotary plow or tiller) working members can operate in three modes: (1) On the eroded soils without furrow slice overturning; (2) On the non-eroded soils by crushing and mixing of clod; (3) On the humid soils with partial overturning of furrow slice (when the rotary plow is mounted in the place of tiller).

The tillage tool is mounted on the frame with the possibility of regulating the approach angle towards the soil that allows for reducing plowing resistance of soil.

The mini-firths created by longitudinal windrows are intended for interception of precipitation and irrigation water and wetting the plowed strips that allows for preventing the ablation of the field surface and the development of water erosion processes.

Key words: anti-erosion; combined, tiller, coverer, wedge, mini-firths, slope

1. Introduction

The process, during which the soil fertile particles are washed off by water and detached by wind, is named erosion. Due to fact that there are no arable-cultivated lands with perfectly plane surfaces, since some sections of the arable-cultivated lands are inclined in the different directions and at the different angles, most of soils more or less are eroded. Consequently, all tilling machines must be anti-erosion to one degree or another. In addition, as the anti-erosion machines can be considered only those ones, which perform the operations, the main purposes of which are as follows: soil slitting, terrace building, seed bedding, stubble-mulch tillage, strip tilling and so on [1].

Mostly, soils situated on the slopes are vulnerable to water erosion. The method of soil treatment on the slopes depends on their inclination. At slope inclination up to 6°, there is recommended the stubble-mulch tillage or incomplete plowed-down application, as well as creation of seedbeds on the plowed field.

2. Materials and Methods

At slope inclinations from 6° to 13°, it is expedient to create the windrows, water-collecting furrows and slits filled with an organic substance (peat, manure, straw or their mix, etc.).

The struggle against water erosion includes the system of organizational and agro-technical measures, the main task of which is reduced to interception of water. To this end, at stages of plant cultivation, there are created the conditions and tillage practices, under which both the spring floods and rainfalls do not flow

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down from the fields, but fill the interspace of soil, and remain on a plowed field. This allows not only for excluding water erosion, but moisture accumulates in the soil as well.

These examples include timely treatment of soil, subsoil plowing, tillage with simultaneous formation of bulkheads in furrows, formation of seedbeds and discontinuous furrows, moling, snow capture, snowmelt regulation, strip tilling, bedding, sowing and handling of plants.

Ploughing on the slopes should be carried out in a way that the furrows pass across the slope, horizontally. Such kind of plowing enables to reduce twice washout.

Ploughing across the slope with inclination of 2…3° increases deposit of moisture in a metre-deep layer of soil by 150…200 t for each hectare, and cereal yields by 2…3 metric quintals, as compared to longitudinal ploughing [2].

A good effect in interception of melt waters is made by deep tillage, which increases water absorption capacity of soil. Deep tillage is carried out by using both ordinary moldboard plows and spinner-type plows, which are equipped with subsoil cultivators, mole draining plows or body frames with the curved shellboards.

There is also used combined (step-up) plowing on the slopes with inclination up to 4^0. For this purpose, the moldboard and moldboard-less plows in different combinations are fixed on the body frames, or used plow-body legs of varying height. One body frame with a non-standard lengthened shellboard is mounted on a multi-bottom plow.

After the step-up ploughing across the slope, the field has a rolling surface, and the narrow borders alternate with the smooth wide strips. The rollers detain the water flow.

Paraplough-moling machine, which increases water absorption capacity of soil, is the most efficient tool in the struggle against water erosion of soils on the meadows and pastures. The slits must be cut across the slopes.

Some devices are used for pitting and subsoiling of inter-row spacings of the tilled crops. They are hanging on the tilled crops.

On one hectare, the device creates about 14 thousand furrows having an area of 100×50 cm, with a depth of 16 cm, and capacity of 250…280 m^3. The cultivator with this device can be also used for making intermittent furrows on the autumn plowing [1].

When using such machines, the value of crop acreage is reduced, and output yield is reduced as well accordingly.

The multiple passages of the tillage outfits across the field, which are associated with the necessity of performing several operations, inevitably lead to the excessive soil consolidation and loosening. Multiple cultivations are exceedingly unwholesome in the areas with insufficient watering, and on the light-textured residual soils. During the intensive cultivation, the organic substance is lost owing to weathering and water erosion, soil structure deteriorates, and losses the moisture. Thus, the system of machines envisages expanding the production of the combined tilling machines allowing for performing several operations simultaneously during one field day.

There are some combined machines with the linked to each other machines, but they are too long and metal-consuming and require a large area for turning.

Most new-generation anti-erosion machines are created and produced by the industry. The design organizations are constantly working on improvements in the machines, thus some changes, which do not influence significantly the nature of their operation, can be introduced in their devices.

The principles of a soil-protective farming system and operating conditions of agricultural machinery exclude application of the machines and tools developed for the classical (moldboard) farming system. This resulted in the creation of the new-type machines for soil protection from wind erosion and for the control of drought.

Wind erosion occurs in the areas with the low rainfall, high spring and summer air temperatures, strengthened eolation, low cohesive properties of soil, and essentially in the arable areas with a weak living soil cover or without plant cover. Strong winds cause soil retirement, and as a consequence, - the dust storms, when microscopic particles of soils are transported at long distances.

Wind erosion not only blasts seeds, but blows away the upper and the most fertile layer of soil as well.

Resistivity of soils without living or dead plant cover depends on a structural composition of the top layer 0…5 cm thick. If this layer contains about 60% of mud balls with a diameter of more than 1 mm, soils are not destructed by wind. When the content of such mud balls is within a range of 60 to 50%, soil is in a fragile state, but at a relative lower values soil is completely unstable to the development of erosion processes. The soil-protective mud balls exhibit different mechanical stability or cohesion (impact resistance or crushing resistance), which mainly depends on their mechanical composition.

Destruction of mechanical mud balls and increasing the amount of erosion dangerous fractions in the soil are affected by weather-climatic conditions.

Occurrence of wind erosion is also fostered by straw burning in the fields. By doing so, stubble often burns up as well, but on the soil surface, mud balls are charred and roots are burnt away. Such sections of the field, as a rule, are becoming the focuses of occurrence of wind erosion.

Thus, the main reasons for occurrence of wind erosion or for its shared occurrence with water erosion are as follows: destruction of mud balls under the action of agricultural machines; the effect of environmental factors (dryness of the climate, broken ground, strengthened wind regime); soaking, drying out and freezing of soil, as well as water defrosting in its capillary tubes; straw burning; “rejuvenation” of hayfields by burning the vegetation; improperly organized pastures [2].

The conservation cropping systems. In various soil-climatic zones, in certain circumstances, almost all types of soils can be destructed by water, wind and machines. Thus, all climatic cropping patterns should facilitate not only the maximum harvest of grain of cultivated agricultural crops, but also provide the soil protection from erosion and increasing its fertility. Herewith, performing any technological operation while growing the cultivated crops on the erosion dangerous soils, must be based on the following principles: minimum dispersion of cultivated soil layer; reducing the air-flow rate in the surface layer; maximum water collection and rational use of moisture at the cost of winter precipitation [3].

The requirement for the minimum dispersion of cultivated soil layer can be met by applying special tillage tools, and by reducing the number of soil cultivations, by using the combined machines and aggregates, as well as by replacing the mechanical treatments by the herbicides.

For reducing the air-flow rate in the surface layer, the ups and downs are created on the field surface (by preserving the stubble and formation of backs during soil treatment), as well as the wind-braking brushes from tall-stalked crops; fallows and cereal crops are located as strips.

Besides, the stubble field is a good remedy for snowfall capture and accumulation, which protects soil from retirement and frost penetration in winter. However, these brushes cannot be considered as a remedy for guaranteed protection of soils from wind erosion on the fallows.

In addition to fallows, cereal and other crops are in need of additional protection from erosion, where their yielding capacity does not exceed 0.6…0.7 t/ha, since in post-harvest period there remain just few stubbles for protection of soil from wind. Thus, in the soils with a light mechanical composition, in addition to soil-protective treatment, there is introduced arrangement of fallows between the seeds of cereal crops. Besides, there are recommended the special soil-protective farming rotations by arranging all non-perennial crops and fallows in rotation with strips seeded by perennial grasses.

Technology of planting of main agricultural crops in the erosion dangerous soils is defined by farming rotations satisfying the soil-climatic conditions of every zone.

The basic agrotechnical requirements for the anti-erosion machines. The anti-erosion machines and tools, when performing any technological operation, should meet the specific requirements, which are conditioned by the following principles of conservation farming:

- To preserve at least 70% of crop residues on the field surface;
- To minimize dispersion of cultivated soil layer, i.e., the number of soil particles of a diameter less than 1 mm;
- To have sufficient passing ability through the stubble backgrounds in case of the existence of significant amount of crop residues;
- To ensure a given rate of stability of the motion of tillage tools in depth during the chisel tillage.

3. Discussions and Results

The new-generation anti-erosion machines must maximally meet not only the specific, but also the common agrotechnical requirements. Besides, the technical level, technical-performance and economic criteria of their operation must be much higher than their technical level.

Operating conditions of the anti-erosion tilling machines are extremely difficult, since their working members move in the soil layer, where the main body of the roots of the plants is located, and herewith, on the field surface there is located a considerable amount of crop residues, but moisture capacity and hardness of soils with different compositions are distinct.

The tilling anti-erosion machines must meet the specific agrotechnical requirements.

So, when treating soils by using the subsurface tillers, deflection from the specified depth (8…16 cm) should no excess ±1 cm. On the field surface, there must remain no less than 85% of crop residues; the height of backs and depth of furrows — no more than 6 cm. The best quality of soil treatment can be achieved with moisture capacity within a range of 16…21% that makes up approximately 55…65% of water field capacity.

So, when treating soils by using heavy cultivators, on the field surface, there must remain up to 55% crop residues. Herewith, the height of backs and furrows should no excess 4 cm. The loosening depth should be even all around the field (20…27 cm). Deflection of the average depth from the specified one is allowed ±2 cm. Herewith, at this depth, weeds should be cut completely. The amount of crop residues on the field surface should be no less than 75%. The field surface must be leveled; the soil fraction size is allowed within a range from 2 to 10 cm. The amount of clods with a diameter of higher than 10 cm should be no more than 20%.

During the surface tillage by using the wheel spiders and other machines at depths of 4…6 cm, the sizes of separate clods and backs should no excess 5 cm [3].

Under conditions of high costs of fuels and lubricants, of essential importance is the problem of fuel economy when performing one of the most power-consuming operations of agricultural production, such as soil plowing and loosening. Pursuant to this, the issue of studying the forms, parameters and integration of their functional surfaces also becomes particularly relevant, but on its basis – the development of the effective, anti-erosion, energy- and resource-saving agricultural and other tillage tools, and, as a whole, strip-tilling farming combined machines corresponding to the nature protection and agrotechnical requirements.

Based on the foregoing, we have developed the diagram of an anti-erosion tilling machine intended for minimal cultivation of soil, or a strip-tilling combined machine (Fig. 1), with which to provide strip tillage of soils with a tilt angle 0…8º, both with furrow slice overturning and without overturning (paring). In the border strips, there would be preserved 90% of stubbles and cover of excised plants, due to which the surface of the unplowed soil retains the thickness of its protective fertile layer that is one of the determining factors of the soil's struggle against wind and water erosion processes and reducing losses of humus layer that in turn is impossible in case of overall tillage with ordinary plows.

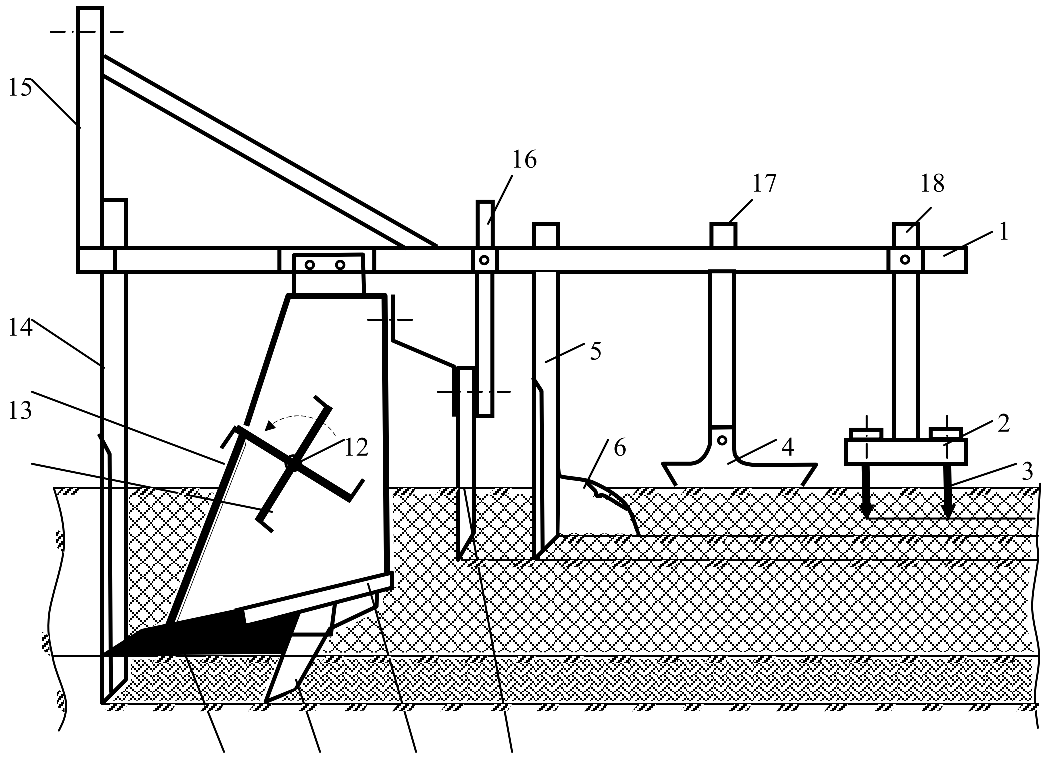

Fig. 1 An anti-erosion strip-tilling machine:
1 – Frame; 2 – Three-toothed harrow; 3 – Harrow teeth; 4 – Earth stratum mover; 5 , 6 – Cutter of a working member of the irrigation mini-channel cutter and a crew-type blade; 7 – Chain harrow; 8 –Main plow blade; 9 – Subsoil plow teeth; 10 – Main plow (wedge); 11 – Rotary plow; 12 - Rotary plow shaft; 13 – Lateral vertical cutters of plowing tool; 14 - Paraplough-deflector; 15 – Trailer; 16 - Chan harrow post; 17 – Coverer post; 18 – Harrow post.

An anti-erosion strip-tilling combined machine consists of passive and active (rotary plough or tiller) working members by separate or simultaneous operation of which there is performed strip tilling of soil. In this case, there is ploughed not the entire area, as is common now, but only that strip of a certain width (20…30 cm) and depth (15…25 cm), where the seeds are setting or seedlings are planting. In the other border strips soil just "rests", and they will be treated in subsequent years (Fig. 2).

During strip-tilling, the capacity of a machine is high. By putting this machine into operation, expenditures for fuels and lubricants and working hours are 2-3 times lower, as well as agrotechnical terms are shortened. The obtained harvest is either the same, or by 10…20% higher than during tilling and sowing with ordinary blade plows.

It is known that the tilling machines' working members are shaped as a wedge, since for breaking material with a wedge, with a relatively lower force, which is directed along a wedge, we may obtain a strong normal force, which crushes material into the particles. Thus, wedge is considered as an economically profitable tillage tool [4] and therefore in this work, we have used a wedge as a main tillage tool.

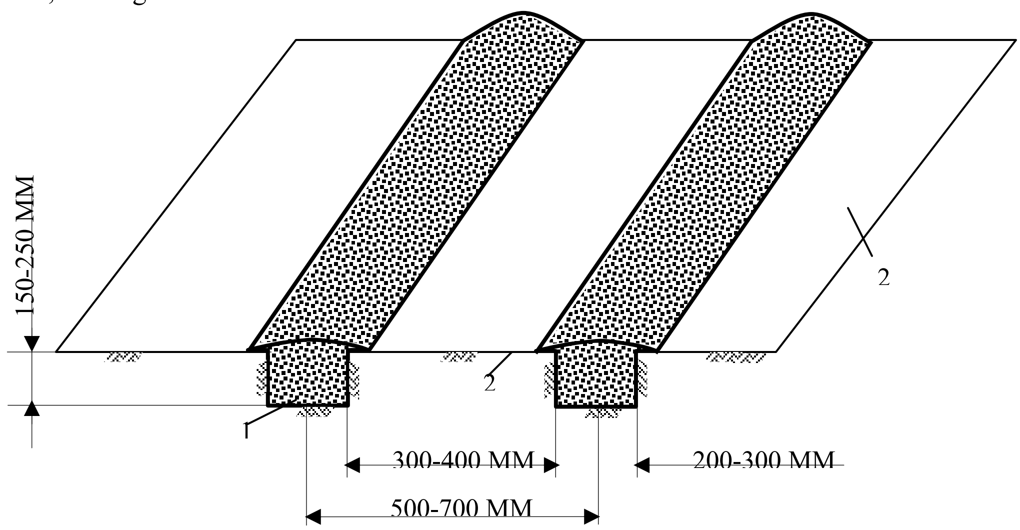

Fig. 2 Strip tillage diagram

1 – Plowed strip; 2 – Unplowed strip

An anti-erosion combined machine consists of the frame of rods having rectangular section, whereupon the tillage tools are fixed by means of supports. In particular: a three-toothed harrow 2, coverer 4, furrow shaper 5 with a screw-type blade 6, chain harrow 7, tillage tool, which consists of passive and active elements, such as a main plowing tool 10, plowing blade 8, subsoil teeth 9, lateral cutters 13 and rotary plow (tiller) 11; milling chisel plow 14 and trailer 15.

The machine, during one field day, performs 5…7 agricultural operations simultaneously, as follows: soil harrowing by milling chisel plow 14; soil layer cutting by vertical cutters 13, main tillage tool (wedge) 10 and lifting it up by blade 8 towards the ground surface, and its loosening without overturning. On the non-eroded soils, between the vertical cutters 13, it is possible to place in the rotary plow (tiller) intended for soil crushing and mixing. The clod cut by rotary plow is thrown away in the opposite direction, and colliding with the chain harrows 7, it will be crushed even stronger and poured down into the empty strip behind the blade 8 of the main tillage tool 10, and then it fills up the empty strip. After reaching the chain harrow 7, it will be located on the plowed strip surface, and we will obtain a smooth fine-grained surface. By means of coverer 4, soil, accumulated by cutter of irrigation channels in the plowed strip moves from the plowed strip into unplowed one for creation of mini-friths; by means of three-toothed harrows, the surface is harrowed to prepare soil for seeding. If necessary, the packing wheels can be mounted on the frame.

In the eroded soils, the machine operates as follows: after adjusting the tillage tools, during the motion of the machine, the main tillage tool (wedge), together with the lateral vertical cutters, digs into the soil and cuts off the soil layer. The cut-off layer of soil moves on the surface of plow and blade, lifts up towards the unplowed surface at a height of 6…7 cm, and then it will be loosened without furrow slice overturning (this time the wedge is off).

By means of tillage tools (8, 9, 10, 11, 13, see Fig. 1), soil treatment can be carried out in three modes: 1. Paring (loosening) of eroded soils without furrow slice overturning, when the rotary plow (tiller) 11 is off, and the main plow 10 is active together with the lateral vertical cutters 13 and subsoil plow 9; 2. Plowing of non-eroded soils by crushing and mixing of clods, when the main plow 10 together with the lateral vertical cutters 13 and subsoil plow 9 and the active working member – tiller 11 are active; 3. Treatment of humid soils with partial furrow slice overturning, when acting the main plow 10 together with the lateral vertical cutters 13 and subsoil plow 9 and the rotary plow 11, which is mounted on the shaft 12 placed between the lateral vertical cutters 13 in the place of tiller.

The tillage tool is mounted on the frame 1 with the possibility of regulating the angle of plow towards the soil that allows for varying the approach angle of the main plow when treating the medium and heavy soils, and by that for decreasing the plowing resistance of the agricultural machine, and as a consequence, reducing the cost of fuels and lubricants.

By means of subsoil plow 9 fixed on the lower surface of the main plow 10, there occurs paring of soil at a depth of 5…7 cm, as a result of what we get the plowed strip at a depth up to 25 cm that in turn fosters more water collection in the plowed strips and the best development of a plant root system.

During the treatment of non-eroded soils, there begins to work the active working member — tiller 11, which crushes the soil layer moved on the main plough and approached to its cutters, and mixes it and then throws into the empty strip cut in the soil. The clods thrown by the tiller's cutters collide with the chain harrows 7 (Fig. 1) and 8 (Fig. 3), but thin ground fraction, after reaching the chain harrow 7 is poured above the plowed soil, and we will obtain a smooth fine-grained surface.

When the mini irrigation channel cutter (5, 6 Fig. 1, and 9, 10, Fig. 3) penetrates into the soil, the drawn soil is thrown away by blade 6 onto the surface of plowed strip, which is cut off by coverer's 11 blade 12 (Fig. 3) and then arranged in longitudinal windrows along the ends of the unplowed strips (19, Fig. 3, and 4, Fig. 4), along the entire length of the field.

The space between longitudinal windrows creates mini-friths, which intercept water flowing down the slope pour it into the plowed strip that prevents ablation of soil layer and development of water erosion processes.

The strips plowed as a result of surface loosening by means of three-toothed harrows 2 (Fig. 1) and 13 (Fig. 3) are prepared for seeding. In this case, if we mount the soil packing wheels on the machine's frame, in the place of their passing in the plowed strips, there remains the track with a depth of 2…3 cm (Fig. 4), which additionally fosters water collection in it and its long-term consumption by plant that also prevents development of water erosion processes and fosters preservation of fertile humus layer in soil surface.

By means of paraplough-deflector 14 (Fig. 1) and 3 (Fig. 3), in the unploughed strips, there is performed cutting of grooves with a depth of 25…30 cm and width of 3…5 cm, which are intended for the following operations to be performed by another machine with a milling chisel plough to ensure better orientation (constant track) and increasing operating speeds during the subsequent operations, as well as for the best irrigation of the plant root system during artificial irrigation by precipitation or mini-friths. Thus, the presence of paraplough-deflector in the machines is one of the compulsory elements of this technology.

The per shift effectiveness of the anti-erosion strip-tilling combined machine for tilling and sowing is calculated by formula [5] that was developed by the author of this research (in accordance with Fig. 2)

$$W_s = 0.36\, V_p\, [B_0(n-1)+B_p\, n]\, T_s\, \tau_s\,,$$

where, V_p – is an operating speed of the aggregate, m/sec; B_0 – unploughed row's width, m; B_p – coverage width of one subsoil tiller, m; n – the number of subsoil tillers; T_s – shift duration, h; τ_s – shift period utilization ratio.

The formula indicates that per shift effectiveness of the proposed machine is much higher than during overall tillage with ordinary ploughs, and the expenditures for fuels and lubricants are lower.

Based on the foregoing, it is possible to make the conclusions as follows:

(1) In case of using for soil treatment the wedge as a main ploughing tool in a tilling combined machine, there is required a several times lower force than when using the other tillage tools. Consequently, the ploughing resistance of soil is lower, and, therefore, the expenditures for the tractor engine capacity and for fuels and lubricants are also reduced. The released engine capacity can be used for increasing the coverage width and operating speeds of the machine. Thus, the proposed machine is an energy- and resource-saving one.

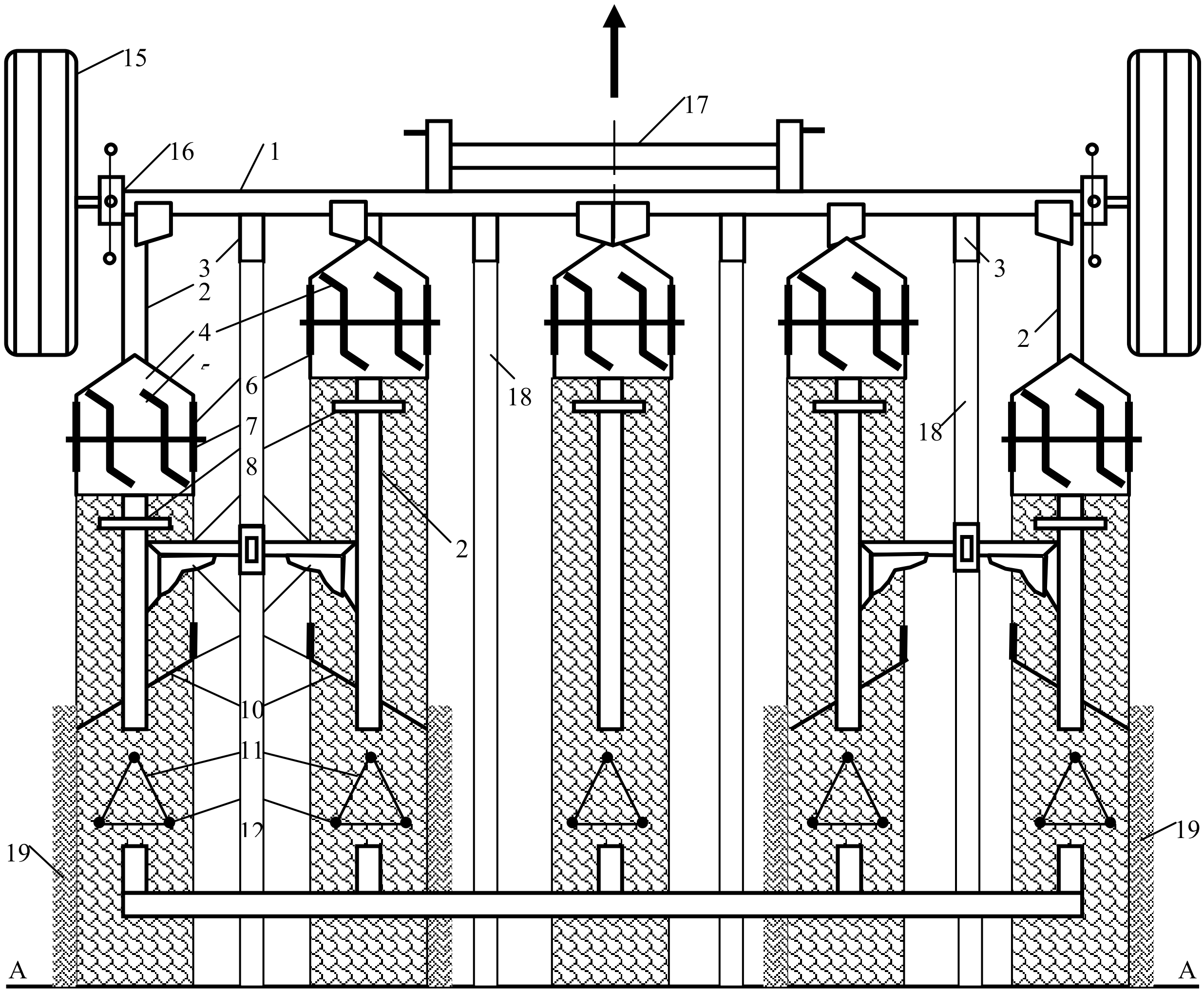

Fig. 3 The layout diagram of working members of an anti-erosion strip-tilling machine on a frame:
1 – Frame; 2 – Frame longitudinal bar; 3 - Paraplough-deflector; 4 – Main plow (wedge); 5 – Tiller (rotary plow) cutters; 6 – Lateral vertical cutters of plowing tool; 7 – Tiller shaft; 8 – Chain harrow; 9, 10 – Cutter of irrigation mini-channels and a screw-type blade; 12 – Coverer's blade; 13 – Three-toothed harrow; 14 – Harrow teeth; 15 – Supporting-adjusting wheels; 16 – Regulating mechanism; 17 – Trailer; 18 – The cutting soil strips moved along the plowed strip edges cutting by the coverer's blade for interception of water; 19 – harrow in the soil; 20 – Soil layer windrow.

(2) The per shift effectiveness of the combined tilling-sowing working machine is much higher than during overall tillage with ordinary ploughs, and therefore, the expenditures for fuels and lubricants are also lower that makes the proposed machine even more effective and profitable for farmers. So, the proposed machine should be considered not only as

the energy- and resource-saving technology, but the nature protection technology (machine) as well.

(3) Combination of passive (main plough and lateral cutters) and active (rotary plough or tiller) working members allows for treating the eroded and non-eroded soils both with and without of furrow slice overturning. Thus, such tilling technology should be considered as an anti-erosion and nature protection technology (machine).

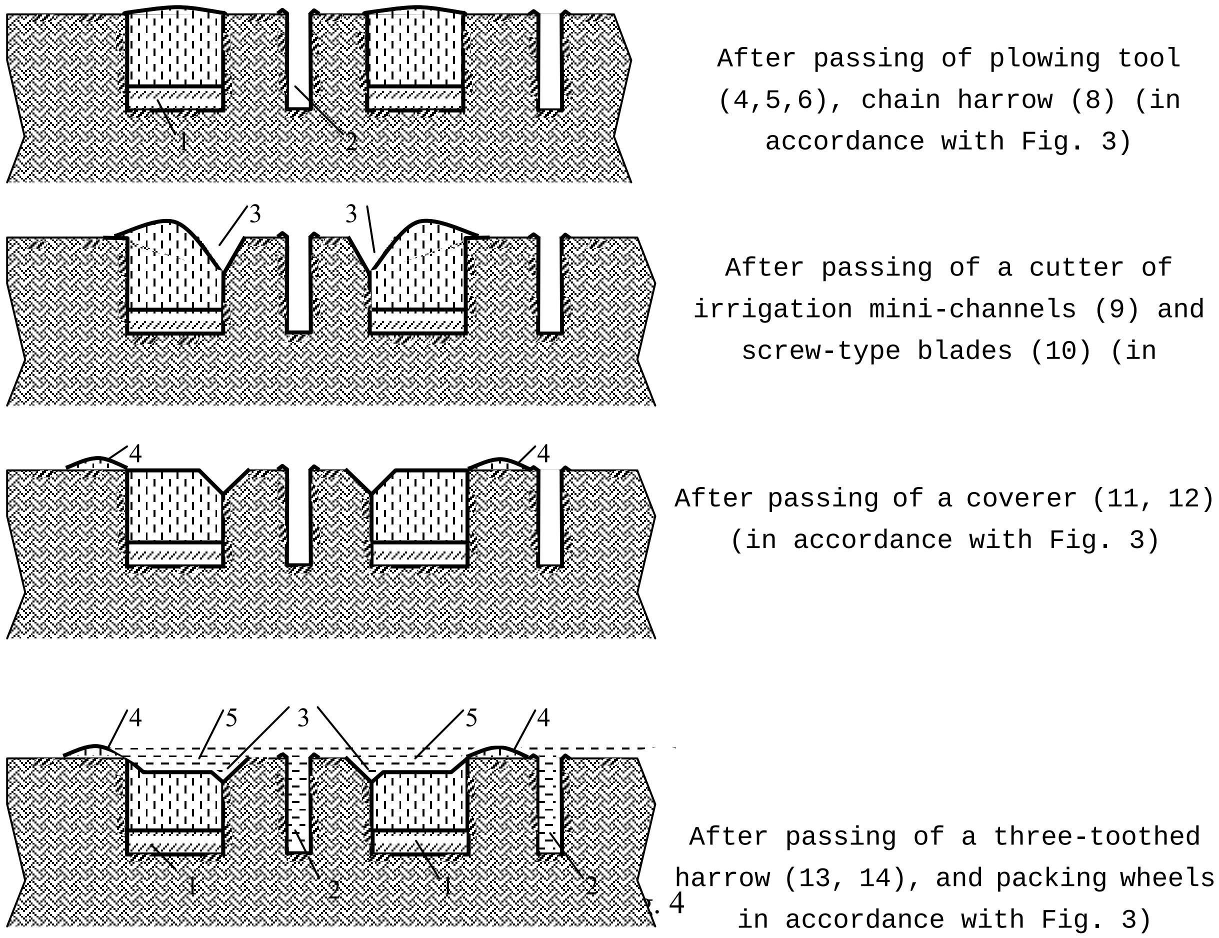

Fig. 4 Vertical section of soil treated after passing of working members of the machine (Section A-A, see Fig. 3)

1 – Deepened soil (5…7 cm); 2 – Slot-deflector; 3 – Irrigation mini-channels; 4 – Soil windrows intended for creation of mini-firths; 5 – Mini-firths.

(4) Since the remained unploughed soil in row spacings "rests" and it will be treated in subsequent years, in its surface layer there will be preserved a thickness of fertile humus layer, reduced the soil erosion processes, and, as a consequence, increased harvesting capacity as well. So, such tilling technology should be also considered as a nature protection technology.

(5) By means of mini-friths created by the proposed machine it is possible to prevent wash-off of the field surfaces and slopes, and as a consequence, the development of the erosion processes in the soil that makes the proposed machine even more profitable for farmers. Thus, such machine to an even greater extent should be considered as an anti-erosion and nature protection machine.

(6) Since the share of the eroded soils throughout the world is large, cultivation of various complexity

soils by the combined tilling machines in the appropriate modes (in above stated three modes and by using the main tillage tool – the wedge, by regulating the approach angle towards the soil) allows for preventing the development of wind and water erosion processes of soil, reducing soil ploughing resistance to agricultural machine, and as a consequence, the tractor engine capacity required for strip tilling will be reduced, as well as expenditures for fuels and lubricants. So, such tilling technology (agricultural machine), as a whole, should be considered as an anti-erosion, energy- and resource-saving, nature protection, rational and advanced technology.

(7) Also high is a level of standardization of the machine. It is easily dismountable, because after removal of some working members from a frame, the other-purpose working members can be mounted in their place, such as: needlelike-gearing rollers; weeder heads; earthling-up ploughs; irrigation mini-channel cutters; cultivator blades for soil treatment in the unploughed strips at a depth of 2…3 cm; moling ploughs working members that enhances mechanical-functional purpose of the machine.

(8) An anti-erosion strip-tilling combined machine is a five-row one. The width between rows is 70 cm, full coverage width — 3.1 m, cyclic efficiency — up to 17.5 ha; it can be aggregated tractors with the capacity of up to 200 KW (drawbar category — 50 kN).

Acknowledgement

This work is supported and funded within the research project №AR/40/9-250/14 granted by Shota Rustaveli National Science Foundation.

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