Justification of non-power rotational working body for "STRIP-TILL"

P A Smirnov, M P Smirnov, E P Alekseev and E V Prokopieva

Chuvash State Agricultural Academy, 29 K. Marx Street, Cheboksary 428003, Russia

E-mail: sttmo@yandex.ru

Abstract. In the last decade, the idea of narrow-band tillage for row crops has gained not only material realization, but also a real estimated framework in terms of energy and resource saving. The article presents a variant of the working body for strip tillage, as the simplest and most reliable in construction, at the same time the most effective in terms of achieving the agrotechnical quality of the treated soil. The design of the non-power rotary working body is as follows. At the maximum approaching of two symmetric atradiant and needle disks inclined from the vertical to the crossing of their rolling planes, a zone of soil destruction due to a fixed shift is formed. In this zone, the needles of the first disk make a working stroke approximately perpendicular to the direction of movement, and the needles of the second disk make a similar movement in the opposite direction in the intervals of the needles of the first disk. The soil in this area is first pinched between the needles, then destroyed, including large lumps. To exclude wear on the tips of the needles and the unstable progress of the entire non-driven rotary working body, the manufacture of needles in the self-sharpening mode is proposed, the recommended operating modes are given. An optimal variant of using a non-driven rotary working body as part of the transformer “narrow-band tillage adapter - seeder” is also proposed, on which the adapter can be aggregated with any seeder for row crops.

1. Introduction

The technology of strip tillage "STRIP-TILL" for Russia is currently something new, but research work on the topic is already conducting. Market demand for this technology is justified by reducing the cost of tillage 1.25-1.45 times in the preparation of soil for tillage crops [1-3]. Sowing technology by bandpass processing "STRIP-TILL" (STRIP-TILLAGE) is widely used in the United States and Canada [4]. Agricultural machinery is produced for this technology by the companies – KRAUSE (GLADIATOR) [5], WIL-RICH (series 357) [6], HORSCH (FOCUS) [7], KUHN (STRINGER) [8], JOHN DEERE [9], YETTER (MAVERIK) [10], REMLINGER (PST) [11], BIGHAM BROTHERS [12], Unverferth Primary Tillage (Ripper-Stripper) [13], Orthman (1tripr) [14].

The principal elements of modern technology "STRIP-TILL" are contained in the removal of crop residues on the soil surface from the treated area with a width of 1/3 row spacing (figure 1a) or cutting crop residues with simultaneous loosening (figure 1b), strip main tillage to a depth of 35-40 cm (figure 1c) and 15-25 cm with the formation of a small crest (figure 1d). At the same time, the remaining 2/3 of the aisle width is not processed, is under reliable protection of crop residues on the soil surface, where soil moisture is accumulated and stored. In spring, the micro-comb of processed strip is heated by the solar radiation, there is an opportunity of strip pre-treatment and early planting of crops with a longer growing season.
Figure 1. Recombination of working bodies of strip tillage on the example of machines for strip tillage "AGRIVATOR" [4]: (a) and (b) options of light spring strip processing; (c) option of deep autumn processing; (d) option of processing of the soil of average depth; 1 – rotary removers of stubble and stubble residues; 2 – single wavy disk; 3 – paired spherical disks; 4 – ribbed roller; 5 – double wavy disks; 6 – deep ripper; 7 – spring loosening paw; 8 – roller with jumpers from the chain.

The following working bodies for spring light tillage are recombined for the above mentioned. These are rotary removers of stubble and crop residues (1). Single wavy disc (2) and double wavy discs are used for cutting and loosening the soil to 10 cm for increased width and quality of the treated strip (5). The paired spherical disks are used to align the processed strip with the previous working body (3). A ribbed roller is required to create a smooth field surface (4). For autumn tillage there are the following: subsoiler for soil to 40 cm (6), spring moldering paw for average depth of 25-30 cm treatment (7) and a skating rink with a jumper of chain to create a profile micro-comb (8). An important component of modern technology "STRIP-TILL" is the introduction of multi-depth fertilization. Moreover, the introduction of the necessary fertilizers in the early stages of growth (about the first 15 days) in not a deep channel under the sown seeds takes place. Then it is necessary to insert completely different fertilizers in the stage of forming a strong stem (45 days) – in the channel to a depth of 20 cm. In this case, the dose of fertilizer is set exactly according to the needs of the culture, rationally mastered in comparison with surface or single application [4].

Justification and experimental study of the proposed non-power rotary working body (NPRWB) for the technology "STRIP-TILL" is the purpose of the study. The objectives of the study are as follows:
- to prove quality possibilities of strip cultivation, NPRWB;
- conduct field pilot study, NPRWB processed on energy-saving technologies and stubble agricultural background;
- justify the tillage adapter with NPRWB to seeders for row crops.

The scientific novelty of the study is:
- band loosening of the soil by the method of pinched shift between a frontal symmetrical needle discs;
ensuring self-sharpening of needle tips;

- preparation of a separate tillage adapter, to which all known seeders for row crops can be attached.

Scientific originality is confirmed by the received Patents of the Russian Federation.

2. Materials and methods

The proposed option way of soil treatment on the basis of non-power rotary working body (NPRWB). The analogue of NPRWB for grinding soil on the trail of the tractor movers is known one, which was developed in by I M Podolko and R M Latypov "Chelyabinsk State Agrarian University" [15]. Combined working body is presented in three separate NPRWB. The use of such NPRWB is possible as a broadband tillage or, with appropriate regulation, in three narrow bands. However, the significant disadvantages of the design are the following: rotation of needle discs on sliding bearings; no individual adjustment and fixation of each pair of discs.

The rotary working body of the direct sowing seeder is the closest to the NPRWB in technical essence, which was designed to remove crop residues in front of the gouter and consisting of a vertical rack and two toothed discs arranged afront and at an angle to the vertical. The disks engage with each other on the soil surface and disengage, shifting the crop residues to the sides [16,17]. The disadvantage of this working body, in our opinion, is that it does not allow loosening the surface layer of soil for sowing. In addition, the lack of adjustment notched discs at the corners of afrontality and vertical tilt does not allow to qualitatively prepare the soil with different physical-mechanical properties and operating speeds of movement of the unit. Modification of the seeder of Rau-Rotosem Company also produces belt sowing [18]. Sowing options with simultaneous milling band processing are interesting [19].

Improving the quality of tillage NPRWB (figure 2) for the band method of sowing [20,21] is achieved due to the fact that the vertical rack 1 mounted transverse adjustable axis 2 with symmetrically curved at an angle $\Theta$ axles 3 and 4 and mounted on the pins needle discs 5 and 6. In this case, the rolling planes of the needle disks 5 and 6 intersect in the zone of interaction with the soil (k-l line). When working NPRWB needle, discs 5 and 6 alternately buried in the treated soil and make a working move in opposite directions. The zone of deformation of the pinched shear between the needles of disks 5 and 6, limited by the k-l chord trajectory of the needle tips, appearing in the treated soil layer, contribute to its destruction. The degree of interaction of needles with the soil is regulated by turning the curved axis at an angle $\phi$ relative to the horizontal position of the bending plane. In the case on figure 1 – this is the part of the segment bounded by the soil surface line.

To adjust the angle $\phi$ and rigid fixation in a given position in the connection "stand-axis" a locking bolt 9 is provided. To control the rotation of the axis, the stand is equipped with a goniometer scale 8, and a pointer 7 is mounted on the axis.

Also the quality of the soil is achieved by breaking down the most durable soil crust and lumps of the local action of the pointed tips of the needles at the edges of the treated strip and the resultant deformation of the entrapped shift in the interplay of forces within the area. Since the movement of needles on the spatial cycloid, the minimum linear velocity of the needles in the zone of interaction with the soil eliminates soil dispersion, and contributes to a significant increase in the translational speed of the tillage unit as a whole. Disc needles are cleaned of crop residues due to the centrifugal force on the upper arc of the cycloid trajectory, where they move at a maximum linear speed [20,21].
3. Results

Since the NRPWB has the ability to control the angle $\phi$ arrangement in the range from 0 to 360°, one of the objectives of the experimental studies was to determine the rational working angle $\phi$. For this purpose, when driving on the length of the rut of 100 m, the clogging and sticking of NRPWB with crop residues, stubble, large unbroken lumps and the execution of the processed strip of agrotechnical quality were determined.

In the experiment, the specified depth 8.5 см stroke, NRPWB was determined. Possible failures are observed in the range $\phi=120-210$° at the same time, NRPWB because of clogging inter disc area stubble and crop residues, as well as solid lumps. In the angle range $\phi=210-330$° installed the unstable course of NRPWB the depth of the partial spontaneous outs. In this case, two loosened strips are formed with insufficient quality of the aggregate composition due to the absence of a pinched shift between the NRPWB needles. Thus, the operating mode of the angle $\phi$ is set to a range from 0 to 90°.

The results of the test of NRPWB on agricultural processing quality of the seed bed on stubble loamy gray forest soils with absolute humidity $\omega_a=22.1\%$ and hardness with a p-value of 1.47 MPa at the depth of 0-10 see in Table 1. Experiments on soil crumbling were carried out by sieving the treated material through a sieve with round hole sizes Ø1 mm and Ø5 mm; with square holes 10×10 mm and 25×25 mm.

The results of the study of NRPWB the crumbling loamy grey forest soil in $\omega_a=23.4\%$ and hardness $R=0.57$ MPa at a depth of 0-10 cm on the chisel processing fields are shown in figure 2.

When strip NRPWB processing of the plot with chisel, there is an intensive crushing of grain sizes of more than 10 mm smaller fractions of 1.0-5.0 mm and 5.0-1.0 mm (figure 3). The most valuable fraction of soil size 1.0-5.0 mm 48.5%, the fraction is 1.0-10.0 mm is 86.7%, which creates good conditions for sowing both small-seeded (for example, carrots, radishes, alfalfa, clover, etc.) and large-seeded (for example, grain) crops.

Erosion hazardous dust fraction of less than 1.0 mm in the treated stubble does not exceed 7.0%; when processing NPWB arable land, there is an increase in the dust fraction, but does not exceed 9.0%. Since such an increase in the dust fraction is observed only on the treated strips of soil, these indicators are not significant for the entire field area.
Table 1. Results of the study, the treated strip NRPWB.

| No. of experiment | Degree of crumbling by fractions, g | The total mass of the sample |
|-------------------|------------------------------------|-----------------------------|
|                   | up to 1.0 mm | 1.0-5.0 mm | 5.0-10.0 mm | 10.0-25.0 mm | more than 25.0 mm |
| 1                 | 95          | 782        | 297         | 411         | 47              | 1632           |
| 2                 | 102         | 803        | 352         | 375         | 62              | 1694           |
| 3                 | 159         | 755        | 422         | 357         | 186             | 1879           |
| 4                 | 79          | 796        | 343         | 376         | 0               | 1594           |
| 5                 | 122         | 734        | 277         | 361         | 111             | 1605           |
| 6                 | 87          | 791        | 312         | 407         | 45              | 1642           |
| 7                 | 145         | 689        | 375         | 428         | 134             | 1771           |
| 8                 | 118         | 751        | 312         | 407         | 59              | 1647           |
| 9                 | 106         | 811        | 402         | 417         | 0               | 1736           |
| 10                | 53          | 613        | 294         | 344         | 126             | 1430           |
| Mean value        | 106.6       | 752.5      | 338.6       | 388.3       | 77              | 1663           |
| Fractional        |             |            |             |             |                 |                |
| composition in %  | 6.41        | 45.25      | 20.36       | 23.35       | 4.63            | 100            |
| Mean square       | 31.20       | 61.52      | 48.79       | 29.12       | 60.57           | -              |
| deviation, δ      |             |            |             |             |                 |                |
| Coefficient of    | 6.41        | 8.16       | 14.41       | 8.61        | 78.66           | -              |
| variation ν, %     |             |            |             |             |                 |                |

Figure 3. Aggregate composition before and after the bandpass processing of NRPWB at the site of treatment chiselcultivator.

High values of the coefficient of variation (78.66 and 26.1%) of the particle fraction of 25.0 mm or more in the samples under study in both cases shows the reverse rolling of large unbroken lumps into
the formed groove. Given the presence of special bolster outers ahead of the openers on some seeders for row crops (e.g., vegetable seeder), approximately 5-percentage of large fraction in the cultivated, NRPWB lane is acceptable.

Studies conducted with NRPWB with needle disks with the number of needles on 12 PCs on each disk. The increase in the number of needles on the discs contributes to more intense crumbling, but it is possible to increase the dust fraction.

For the depth of the seed shoe, especially disc, at a given depth, the state of the hardness of the loosened strip is important. Hardness measurements showed that before loosening the strip on the stubble, the hardness was 1.93 MPa and after passing NRPWB on the treated strip – 0.47 MPa at the entire depth of 7.5-8.0 cm (figure 4). The hardness of the treated field stubble cultivator KST-5.8 was 1.71 MPa, after processing NRPWB – 0.34 MPa.

According to the longitudinal-vertical section of the soil layer (figure 5), it was found that the profile of the groove on the soil surface $y_1$ and the profile of the treated zone $y_2$ is expressed by the parabola equations.

For angle $\phi=0^\circ$:

- $y_1=0.0410x^2-3.325$;
- $y_2=0.08925x^2-9.015$.

For angle $\phi=30^\circ$:

- $y_1=0.107x^2-2.975$;
- $y_2=0.206x^2-7.475$.

For angle $\phi=60^\circ$:

- $y_1=0.180x^2-3.385$;
- $y_2=0.340x^2-10.1$.

For angle $\phi=90^\circ$:

- $y_1=0.173x^2-3.375$;
- $y_2=0.611x^2-9.775$.

![Figure 4](image-url)  Processed NRPWB strip on stubble at $\phi=0^\circ$ and depth of treatment 7.5 cm.

![Figure 5](image-url)  Measuring the depth of processing and forming grooves microraster soil treated with a chisel the soil fertility at $\phi=60^\circ$.

The problem of increasing the wear resistance of the needle disk by providing a mode of self-sharpening of the needle blade [20]. For this purpose (figure 6) of a rod of circular cross section are manufactured needle with a beveled tip by cutting. Immediately on the clean plane of the oblique cut, a carbide material with a thickness of 0.7-1.5 mm is deposited, forming a cutting blade. As the carbide material can be, for example, "Sarmite-1". In this case, non-constructive costs of the bar material and unproductive technological operations such as forging are excluded.

All needles 1 are welded with blunt end to the hub 2 on the open circuit 3 arc welding on both sides. In this case, the needle is mounted with the plane of the oblique cut in one direction of the disk. Assembly of discs in a battery produced by a plane oblique cut at the buck, and batteries needle drives installed under an angle of afrontality $\beta$ in the range of 20-35$^\circ$ (figure 6).
In the proposed self-sharpening of the needle drives the bevel angle $\alpha$ must be smaller or equal to the angle $\beta$ of afrontality. This ensures a constant positive occipital angle of the needle tip $EA$ at least 2-3º in the sinking phase (figure 6).

![Diagram of needle disk](image)

**Figure 6.** Image diagram of a needle disk to determine the mode of self-sharpening at an angle $\varphi = 0^\circ$: $\varnothing D$ – diameter of the disk; $D_a$ – horda-level disk tillage; $\alpha$ – the angle of taper of the needle; $\beta$ – the angle of disk afrontality; $\varepsilon$ – occipital angle of the needle; $\varepsilon_a$ – occipital angle of the needle at the entrance level in the soil.

In the course of processing of the soil each needle alternately deepens in the soil, and cuts the layer with a razor blade. With a positive occipital angle $\varepsilon_a$, the plane of the oblique cut of the needle deposited with the carbide material undergoes the least wear out, and the opposite working surface wears out evenly, providing a constant sharp 0.7-1.5 mm sharpening of the blade [22]. The developed technology of production of needle disks can be successfully applied and at repair of the worn-out disks needle harrows in the conditions of repair shop of the agricultural enterprise, and for this purpose the expensive equipment is not required.

Figure 1 shows the recombination of solutions using separate working bodies of soil-cultivating complex "AGRIGATOR", and as permanent in each machine. This can only be beneficial to large agricultural enterprises. At the level of medium and small agricultural enterprises it is more profitable to have transformable machines. To solve this problem, it was decided to use NRPWB on a separate tillage adapter [23], and the adapter, as a transformable unit, is adapted to any seeder (planter) for row crops or transplanters with a wide aisle of 0.6 and 0.7 m (figures 7, 8). Tillage adapter tested with drills-4.2 and other six-row drills.

4. Conclusion

NRPWB according to the experimental performance is quite competitive with the working bodies are represented in figure 1 for loosening the soil, and the discharge of stubble residues. According to the results of production tests, the optimal angle of inclination of the curved NRPWB axis ($\varphi = 0-90^\circ$) was determined. The most valuable structural component of the soil (1.0-25.0 mm) in the loosened strip on the stubble contains 88.96%, washed away (up to 1.0 mm) by erosion – 6.41% (Table 1). When loosening the cultivated field, the most valuable fraction is 91.4%. Hardness measurements before
loosening of the strip on the stubble was 1.93 MPa and after passing of NRPWB – 0.47 MPa at a depth of 7.5-8.0 cm, on the treated field with a stubble cultivator KST-5.8 hardness is 1.71 MPa, after processing of NRPWB – 0.34 MPa. According to the soil longitudinal-vertical section of the treated NRPWB strip, the profiles and sizes of the treated zone and grooves are determined – they are described by parabolas.

**Figure 7.** The scheme of the combination unit in the composition of the tillage of the adapter and seeder: 1 – frame adapter; 2 – lock coupler; 3 – longitudinal bars; 4 – coupler; 5 – bracket section; 6 – suspension section; 7 – spring-loaded rod; 8 – NRPWB; 9 – frame seeders; 10 – seeder.

For effective application of NRPWB developed and implemented tillage adapter to six-row seeders for row crops [23]. Production tests of the adapter in combination with seeders CO-4.2 and SUPN-8 showed stable operation of both the adapter (Ripper) and seeders. For farms at the level of small and medium-sized agricultural businesses, the use of a transformable combined machine is the most
rational option. However, there was a problem for operation – an acute shortage of tractors with hinged systems with increased load capacity up to 30 kN.

To increase the service life and increase the stability of the NRPWB, a method for manufacturing needle discs operating in a self-sharpening mode was developed [22]. This method is also applicable to operated harrows with needle working bodies.

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