УДК 631.316 DOI 10.22314/2073-7599-2018-12-4-48-52

Zone of Soil Loosening with Cultivator Sweeps

Vladimir V. Vasilenko,
Dr.Sc.(Eng.), honored professor,
e-mail: vladva.vasilenko@yandex.ru;

Sergey V. Vasilenko,
Ph.D.(Eng), associate professor;
Vitaliy S. Borzilo,
M.Sc. student

Voronezh State Agrarian University named after Emperor Peter I, Voronezh, Russian Federation

Abstract. Cultivator sweeps are placed remotely relative to each other or as parts of combined working tools with spherical discs, chisels and other parts, so the propagation of a zone of soil deformation during their operation at different depths and at different speeds is studied by designers for the calculation of technological runs in order to avoid their clogging with soil. (*Research purpose*) To determine the dependence of the width of the soil loosening zone with a cultivator sweep on the depth of travel and the speed of travel. (*Materials and methods*) Studies have been conducted on a stubble soil background after harvesting of winter wheat. Humidity and hardness of soil at a depth of 0 to 30 centimeters varied accordingly from 9 to 13 percent and from 0.28 to 0.87 MPa. The structure of the unit has been represented by the tractor MTZ Belarus 1221,2 and the cultivator KRN-5,6. Each section of the cultivator housed a universal sweep with a design working width of 220 mm. (*Results and discussion*) It has been found that a sweep forms a loosened strip and a strip of soil scattering, the width of which depends linearly on the tillage depth ranging from 10 to 22 cm and varies in the range from 31 to 42 and 38 to 58 cm, respectively. The unit travel speed ranging from 3 to 13 km/h does not affect the width of the loosening zone, and the zone of soil scattering increases according to the law of a weakly expressed quadratic parabola. The authors present empirical dependences of the width of the loosening and scattering zones on the tillage depth, the travel speed and the sweep width. (*Conclusions*) It has been found that the interval between the sweeps in one row should not be less than the specified width of the loosening zone, which has been confirmed as exemplified by a successful arrangement of working elements with a width of 410 mm on the combined units of the RVK series. Combined tools work with high technological reliability for sunflower stubble, without being clogged with soil and plant residues during the main field operations performed according to the minimal impact technology.

Keywords: zone tillage, moving apart the soil zone, depth of processing, movement speed, linear dependence, quadratic parabola, cultivators-leveller of the soil.

For citation: Vasilenko V.V., Vasilenko S.V., Borzilo V.S. Zone of soil loosening with cultivator sweeps. *Sel'skokhozyaistvennye machiny i tekhnologii*. 2018. 12(4): 48-52. DOI 10.22314/2073-7599-2018-12-4-48-52. (In Russian)

Combinations of soil cultivating tools mounted on one frame, and sometimes on one rack, require the determination of the minimum possible distance between the component parts, in which the soil can move forward along the technological passages without clogging. Cultivator sweeps are often used in combination with spherical discs and chisel elements. Of great interest to the designers of combined tools are the issues of the propagation of the soil deformation zone to various depths and for different travel speeds to provide for the rational arrangement of the sweeps on cultivator frames or sections for continuous or inter-row cultivation.

The arrangement compactness of working tools is necessary to reduce the size and metal capacity of the product [1]. It is especially important to take into account the trajectories of the soil layer movement when setting up additional working tools for serially produced tillage implements. For example, recent studies on increasing the angle of turnover of soil layers during reversible plowing have proved that to expand the furrow, additional working tools should push the overturned layer only after it has completed its turnover [2, 3]. The subsequent layer will smoothly settle into a wide furrow with a full revolution of 180°. As a rule, when two working tools simultaneously affect the soil layer or area, the deformation zones of the treated medium must not be allowed to overlap. It is necessary to distribute the formation of these zones in time or in space, otherwise the probability of the tool failure will increase because of the obstruction of technological passages for the soil. The only exception is made for active rotating or vibrating tools [3, 4]. With deep loosening of the soil by the cultivator, its deformation spreads forward and sideways. The range of soil movements increases with the travel speed of the unit [5-7]. The greater the travel speed and the depth of the cultivator sweep are, the greater the force of interaction with the soil and the normal stress in the sweep construction are, and this contributes to an increase in the range of soil movement [8].

Research purpose. Experimental study of the width of the soil loosening zone tilled with a cultivator sweep with a change in the tillage depth and the travel speed.

Materials and methods. Experiments have been carried out on one of the farms in the Voronezh Region on a stern background after harvesting of winter wheat. Humidity and hardness of the soil at a depth of 0 to 30 cm varied accordingly from 9 to 13% and from 0.28 to 0.87 MPa. The unit composition was the tractor MTZ Belarus 1221,2 and the cultivator KRN-5,6. Each section of the cultivator was equipped with one pointed universal sweep with a working width of 220 mm. In a field section of 50 × 50 m the unit performed operating runs with the preset tillage depth. The time was measured with a stopwatch, the actual tillage depth and the width of the loosened strips - with metal rulers. During the data processing, average values of the measurement results for all sections of the cultivator were calculated.

Results and discussion. It has been visually established that the sweep wedges out the soil layer into two streams as a result of the deforming effect of a working tool shin. The loosened parts of the formation are displaced in both directions from the sweep axis. Some amount of the soil rises to the front of the rack, then slides off it and is thrown aside. As a result of this action, a groove is formed behind the sweep stand, the dimensions of which increase with the speed and the tillage depth. At a unit travel speed of 10 km/h or more and a tillage depth of 6-8 cm, the furrow bottom is bare.

The results of measurements of the width of the tilled strip have shown that the loosening zone and the soil dispersion zone should be distinguished. Dispersion is always wider than loosening, and if we take it into account when arranging the working tools on the frame, we may get flaws in the process of the soil tillage. The relationship between the loosening zone width and the tillage depth has been determined at a speed of the unit of 9-10 km/h. This relationship has turned out to be a linear dependence (*Fig. 1*), it can be approximated by the expression:

$$b_{рых} = b_{кон} + 0{,}91a, \qquad (1)$$

where $b_{рых}$ is the width of the loosening zone, cm;

$b_{кон}$ – design width of the sweep, cm;

a is the tillage depth, cm.

The dependence of the dispersion zone width on the tillage depth is also linear:

$$b_{разб} = b_{кон} + 1{,}65a, \qquad (2)$$

where $b_{разб}$ is the width of the spreading zone, cm;

The influences of travel speed on the loosening zone width at a tillage depth of 12 cm has not been revealed (*Fig. 2*). The width of the loosened strip remained within

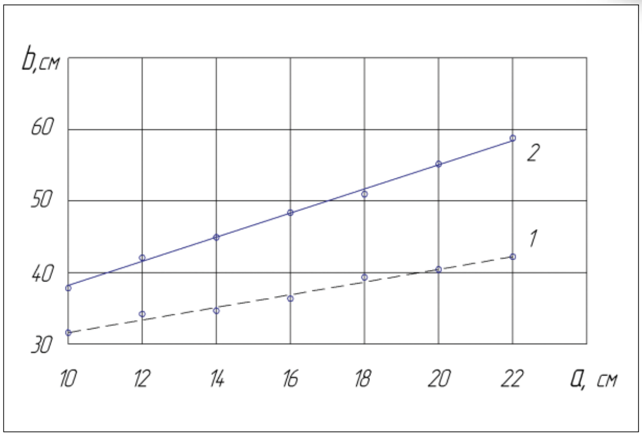

Fig. 1. Dependence of the loosening zone width (1) and the soil dispersion zone (2) on the cultivator sweep depth (experimental data)

33-35 cm, there are no trends to change it. As for the width of the soil dispersion band, its dependence on the travel speed can be approximated by a parabola:

$$b_{разб} = b_{кон} + 15{,}65 + 0{,}056V, \qquad (3)$$

where V is the unit travel speed, km/h.

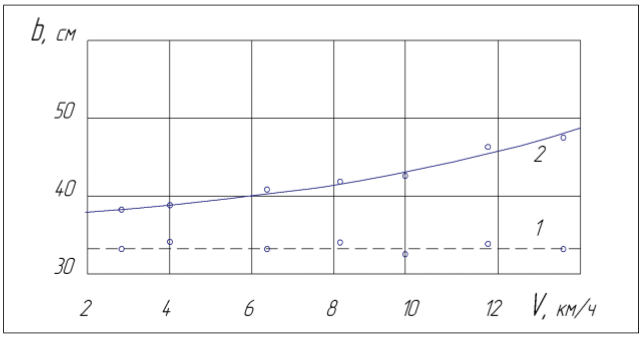

Fig. 2. Dependence of the loosening zone width (1) and the soil dispersion zone (2) on the unit travel speed (experimental data)

The resulting empirical relationships were applied in the design of cultivators-levelers RVK-6, RVK-4, RVK-3. Their production was implemented by joint efforts of Voronezh State Agrarian University and machine-building small enterprises «Aqua-Svar» and «VSZ-Holding», established on the basis of the Voronezh machine-tool plant (*Fig. 3*).

These are trailed combination tools with different working widths for attaching to tractors of traction classes from 1.4 to 5. They are designed for minimal

Fig. 3. RVK-6 cultivator-leveler

tillage instead of plowing. The working tools are two rows of spherical cutters with a diameter of 660 mm and an individual frame attachment system, two rows of pointed cultivator sweeps 410 mm wide, a double supporting roller equipped with flat discs, and a rod bar for final leveling of the soil surface. Individual fastening of disks instead of the battery one reduces the longitudinal size of the implement, especially when setting large approach angles. In places where the outer disks are turned with the concave part outward, at a high travel speed, the soil is thrown far aside, so that special screens are mounted on the frame to reflect the dispersing soil inside the operating width. The set of working tools on this combined implement ensures its reliable operation on any soil background. It does not require primary tillage (stubble cleaning) and can prepare the soil from the stubble background in one operating run to the full readiness state for sowing winter crops. The maximum tillage depth is up to 20-22 cm. The advantages of combined cultivators equipped with spherical discs and sweeps are manifested in the reduction of energy consumption and good leveling of the soil surface [10].

It is a common fact that disk tools form a wavy bottom of the furrow. Given the diameter of discs is 660 mm, with a two-row arrangement at intervals of 500 mm in each row, a depth of 20 cm and an approach angle of 25°, the height of residual ridges at the furrow bottom is 18 cm. For leveling the furrow bottom, the cultivator sweeps and disks are adjusted to the same tillage depth.

The width of a loosening zone tilled with the cultivator sweep is 59 cm in accordance with the expression (1). As for the width of the dispersion zone, according to expression (3) it is 65 cm, and taking account of expression (2) it can reach 80 cm. Therefore, when designing the sweeps arrangement, the distance between them in one row was assumed equal to 800 mm (*Fig. 4*). With a 410 mm operating width, the soil is completely cut with minimal overlapping of cutting zones, only 0.5 cm, but this is sufficient given the additional effect of the discs.

The longitudinal distance between the rows of sweeps depends on the calculated speed of motion. To avoid overlapping deformation zones, the soil raised up by the front row should have time to return to the field surface before the approaching of the rear row of sweeps. The vertical speed of soil tossing with a sweep can be calculated from the expression:

$$V_{\text{вер.}} = Vtg\alpha, \text{ m/s},$$

where V – the unit travel speed, m/s;

α is the sweep lifting angle, for universal sweeps $\alpha = 18°$.

The tossed soil is up in the air for:

$$t = \frac{2V_{\text{вер.}}}{g}$$

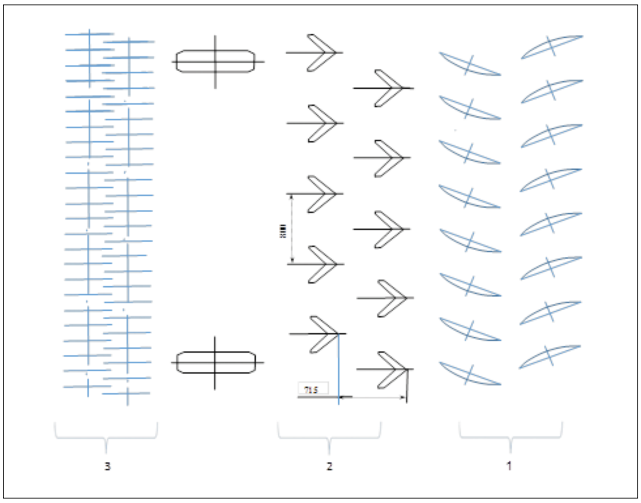

Fig. 4. Diagram of the arrangement of working tools on the cultivator-leveler RVK-4 (top view): 1 – two rows of spherical disks; 2 – two rows of sweeps; 3 – two-shaft needle roller

where g is the acceleration caused by gravity, m/s^2.

Of all the variants of standard cultivator sweeps, the widest widths have been chosen to be as wide as possible in order to avoid the stocking of racks. If on the field there are residues of long-stemmed crops, numerous racks work like a rake, accumulating surviving stalks.

At the estimated speed of the unit travel $V = 3.33$ m/s, the initial sped of tossed soil is $V = 1.07$ m/s, the tossing time $t = 0.22$ s, the minimum distance between the sweep rows is $L = Vt = 0.71$ m. This distance is also provided between rows of cultivator sweeps in a series of cultivators-levelers of the RVK type. Such a design allows to avoid clogging with soil and plant residues, even over untouched sunflower stubble, and prepare the soil for sowing grain in one operating run (*Fig. 5*).

Conclusions. The width of the soil loosening zone tilled with a universal cultivator sweep linearly depends on the tillage depth ranging from 10 to 22 cm and varies from 31 to 42 cm with a design operating width of 22 cm. The dispersing zone of the loosened soil also depends linearly on this parameter and varies from 38 to 58 cm at the same tillage depths. The unit travel

Fig. 5. RVK-4 cultivator-leveler operating on sunflower stubble

speed varying from 3 to 13 km/h has no effect on the loosening zone width, and the zone of soil dispersion increases according to the law of a weakly expressed quadratic parabola.

When the cultivator sweeps are placed on the implement frame, the interval between them in one row should be designed to be greater than or equal to the width of the soil dispersion zone (if possible), and necessarily larger than the loosening width determined from the given graphs. The soil dispersion forms a smaller thickness of soil layers, which does not clog technological passages between the sweeps.

A series of unified trailed combination RVK cultivators-levelers with different operating widths designed according to the results of the given calculations, operates with a full coefficient of technological reliability, without clogging with soil and plant residues during the main tillage operations of the minimal impact technology.

REFERENCES

1. Yefremova Ye.N. Agrofizicheskiye pokazateli pochvy v zavisimosti ot razlichnykh obrabotok pochvy [Agrophysical indices of soil depending on various soil cultivation modes] // Izvestiya Nizhnevolzhskogo agrouniversitetskogo kompleksa: Nauka i vyssheye professional'noye obrazovaniye. 2013. N2: 67-72. (In Russian)

2. Bartenev I.M. Udarnoye razrusheniye i aktivnyy oborot pochvennogo plasta pri vspashke [Impact destruction and active circulation of a soil stratum in plowing] // Lesotekhnicheskiy zhurnal. 2016. N1: 98-110. (In Russian).

3. Vasilenko V.V., Vasilenko S.V., Zybin M.V. Uvelicheniye ugla pe-revorota plasta pri vspashke [Increasing the layer revolution angle in plowing] // *Vestnik Voronezhskogo GAU*. Voronezh, 2013. 1 (36): 98-100. (In Russian).

4. Klenin N.I. Sel'skokhozyaystvennyye mashiny [Farm machinery]. M.: KolosS. 2008: 816. (In Russian).

5. Vasilenko V.V., Afonichev D.N., Vasilenko S.V., Timofeyev I. Yu. Obosnovaniye napravleniya vibratsii pochvoobrabaty-vayushchego rabochego organa [Determination of the vibration direction of a tillage tool] // *Vestnik Voronezhskogo GAU*. Voronezh, 2017. 4 (55): 134-139. (In Russian).

6. Hanna H. Mark, Marley Stephen J., Erbach Donald C., Melvin Stewart W. Soil &Tillage Research, Methods for measuring soil velocities caused by a sweep 28 (1994): 315-328. (In English).

7. Rudenko N.Ye., Nosov I.A., Kayvanov S.D., Petukhov D.A. Resurso-sberegayushchiy propashnoy kul'tivator [Resource-saving row-crop cultivator] // *Sel'skokhozyaystvennyye mashiny i tekhnologii*. 2017. 4: 31-36. (In Russian).

8. Rudenko N.Ye., Kayvanov S.D., Zavyalik F.N. Innova-tsionnaya strel'chataya pochvoobrabatyvayushchaya lapa [Innovative sweeps] // *Sel'skokhozyaystvennyye mashiny i tekhnologii*. 2016. 6: 16-20. (In Russian).

9. Chiorescu E., Chiorescu D. The variation of the unitary stresses occurring in the working part in relation to the type of soil, using the finite element method. IOP Conf. Series: Materials Science and Engineering 227. 2017. 1: 20-23. (In English).

10. Fanigliulo R., Biocca M., Pochi D. Journal of Agricultural Engineering 2016; XLVII:519 Effects of six primary tillage implements on energy inputs and residue cover in Central Italy 177-180. (In English).

The paper was submitted to the Editorial Office on 18.05.2018

The paper was accepted for publication on 25.07.2018

Conflict of interest.
The authors declare no conflict of interest.