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Justification parameters of the ripper tooth of combined unit for minimum tillage

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Abstract

The article presents the results of theoretical studies to justify parameters and the angle of entry into the soil of ripper tooth, width and length of the working surface of the ripper tooth of combined unit. Graphs of changes in the working surface length of the ripper tooth depending on the angle of entry of the tooth into the soil at different values of tillage depth and width of combined soil-cultivating unit for minimum tillage, to ensure high-quality loosening of the soil at minimum energy consumption. Based on the results of theoretical and experimental studies, a scheme for placing working bodies on the frame of a combined soil-cultivating unit for minimal tillage has been developed, which contributes to increasing soil fertility with minimal energy and labor costs.

Keywords: combined unit for minimum tillage, ripper tooth, angle of entry into the soil, width, length of the working surface of the ripper tooth, changes in the length of the working surface of the ripper tooth, depending on the angle of entry, depth and width of the tillage of combined unit, scheme of the working bodies

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INTRODUCTION

Vegetable growing is a highly profitable branch of plant growing (Dadoboyev 2009). Under the condition of optimal use of sunny days and soil-climatic conditions of the southern regions of southern Kazakhstan, it is possible to increase the volume of vegetable production at times (Khazimov 2015).

According to international standards, agriculture is considered to be highly productive (Mosalkova 2015), if one person employed in it is able to feed from 30 to 50 people. In Israel, this ratio increased from 1:18 in 1960 to 1:95, ahead of all countries of the world, i.e. each of 80,000 thousand people employed in agriculture is able to feed 95 compatriots. For comparison, in the US this figure is 1: 79, in Russia-1:14.7, in China – 1:3.6, in Kazakhstan – 1: 2.8. Thus, Israeli agriculture is six times more efficient than Russian and almost 30 times more efficient than Chinese agriculture. In South China, many fields produce three major agricultural crops or up to five crops per year (Mosalkova 2015).

Despite the increase in the yield of vegetable and melon crops, the needs of the population of Kazakhstan are not yet fully met, especially in the northern regions. The selling prices of vegetable crops are unreasonably high (Khazimov 2015).

Optimal use of sunny days (210-230 sunny days per year)[1] and soil-climatic conditions of irrigated lands of Maktaral, Keles district and the southern part of Saryagash and Shardara district of Turkestan region allow the implementation of new agricultural technology and obtain a 3-time harvest of vegetable crops during the year in the open ground, by intensifying the production of vegetables.

Turkestan region of the Republic of Kazakhstan is the main supplier of vegetable and melon crops in the northern regions of republic, as well as in the Russian Federation.

The main constraining factors for the further development of vegetable growing are high labor intensity and very little mechanization of cultivation processes of vegetable crops (Golikov et al. 2015). One of the main problems is the quality of soil preparation and mechanized planting of vegetable crops, in optimal agrotechnical terms, especially the ultra-early and early vegetables (Kalimbetov et al. 2018).

World experience shows that the use of highly effective agrotechnical measures and high-producing

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technical means can reduce the level of costs by 30...50%, minimize cash costs (Khazimov 2015).

The relevance of the work. The production and sale of vegetable crops in Kazakhstan has a pronounced seasonal nature, mainly in the summer with an excess of vegetable production. Ultra-early vegetables are grown in a very small volume, so during this period the domestic market becomes import-dependent and, accordingly, the prices for vegetables are too high, although Kazakhstan has a huge potential for vegetable production all year round.

The existing technology and technical facilities do not allow to increase the volume of production of vegetable crops in the year-round cycle, to maximize the use of favorable weather conditions of the southernmost region of the republic. Peasants of the region mainly produce vegetables using primitive methods, i.e. with the involvement of manual labor.

In increasing the harvest of vegetables, it is not only the expansion of crops and the increase in the yield of these crops that matter. Of great importance is also the cultivation of two or three harvests of vegetable crops in one season from the same area.

There is a problem of the need for research on the substantiation of new technological processes of progressive technology for the production of a 3-time crop of vegetables per year, on open ground, in combination with the maximum use of sunny days in the regions of southern Kazakhstan.

Development and mastering the production of a complex of simple mounted machines and units for small-scale mechanization of farm-peasant farms, using the best technical solutions and the experience of leading manufacturers of agricultural equipment and with this approach to ensure the country's food security and a sharp rise in the welfare of the rural population is *relevant* (Kalimbetov et al. 2018).

MATERIALS AND METHODS OF RESEARCH

The object of the study are vegetable crops, field relief and soil, a combined unit of minimal tillage and its working bodies.

Calculation methods. Theoretical studies to determine the parameters of ripper tooth of the combined unit were carried out using well-known methods of theoretical mechanics and mathematical analysis.

MAIN RESULTS OF RESEARCH WORK

Soil protection technology of soil preparation in autumn for sowing and planting ultra-early varieties of vegetable and melon crops:

The soil-climatic conditions of the extreme southern regions of the Turkestan region of the republic (about 100 thousand hectares) make it possible to grow and obtain on the fields higher (by 2-3 times) harvests of vegetable crops on repeated harvests *(three turns)*. At the same time, the time factor plays an important role: by quickly preparing the soil, having finished planting vegetable seedlings (previously prepared), can make better use of time, heat and moisture to obtain a high yield of repeated crops in different periods: *the ultra-early period* - from mid-February to 21 March, *early* - from March 21 to April 10, *spring* - from April 10 to May 30, *summer* - from mid-June to August 25, *autumn (late)* - from August 25 to October 20. The slightest delay in carrying out all the work on preparing the soil for planting or sowing or after vegetative irrigation leads to a significant shortage of crop. Consequently, the choice of the correct technology for preparing the soil for repeated sowing and inter-row spacing of vegetable crops, the development of technical means for its implementation are relevant and of great national economic importance. This issue is solved taking into account the characteristics of each region and the re-cultivated culture (Kalimbetov et al. 2018).

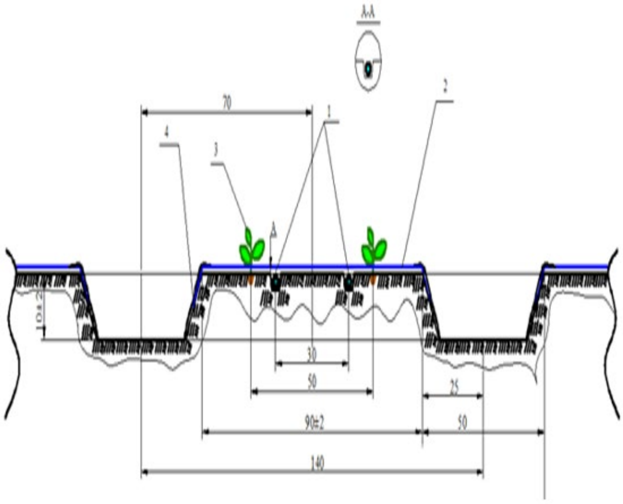
The most important links in the system of agrotechnical measures for the production of a 3-time crop of vegetables throughout the year in open ground are tillage, soil-protective technology for preparing the soil for sowing and planting vegetable and melon crops. Success in the cultivation of vegetable crops largely depends on the timing and quality of tillage, and they, in turn, from the technology of its implementation and the perfection of the design of machines (Kalimbetov et al. 2018).

The existing traditional technology and technical means do not allow preparing the soil and producing mechanized planting of ultra-early varieties of vegetable and melon crops on mulched soil in optimal agrotechnical terms, as a result of which there is an import dependence in ultra-early vegetables (Kalimbetov et al. 2018).

We have developed a new intensive technology of growing ultra-early vegetable crops on mulch soil with simultaneous shelter of sowing rows with a polymer film, creating a "warm greenhouse" (**Fig. 1**), which is an alternative solution to the problem of increasing yield.

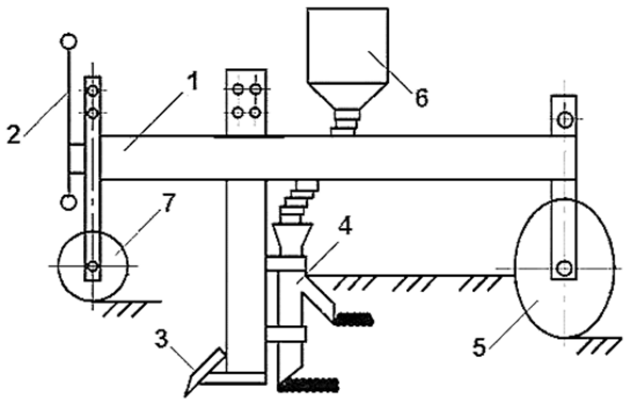
The essence of the new technology is the preliminary preparation of the soil with a combined unit for minimum tillage in the fall, for the earlier spring mulching of the soil in the field of rows with covering materials with further mechanized planting of vegetable crops seedlings on the mulch soil (Kalimbetov et al. 2018).

A feature of the new technology and the combined unit is the preparation of fields in the fall, from under vegetable and industrial crops for planting ultra-early varieties of vegetable crops, which is carried out by forming new ridges instead of existing ridges. At the same time, the top layer of the ridge of each row is processed first by wrapping the ridge soil by 180˚ in its place, by deep ripping the lower soil layer with simultaneous local fertilization along the dual line with



1 - drip irrigation tape; 2 - mulch film; 3 – seedling of vegetable crops; 4 - part of the mulch film embedded by the soil.
B_{or} - the base size of the beds, $в_r$ - the top size of the beds; HM - the minimum allowable
bed height, β - the angle of repose of the bed ridge.

Fig. 1. Technological scheme of cultivation of ultra-early vegetable and melon crops



1 - frame; 2 - hitch; 3 - ripper tooth; 4 - Coulter for two-layer tape fertilizer application; 5 - spherical disk

Fig. 2. Scheme of the combined unit

rippers and fertilizer elements, after which ridges are formed. When the ridge soil is reversed by 180˚, weed seeds and plant residues are embedded in their place (Kalimbetov et al. 2018).

Theoretical study of work process of the ripper tooth of combined tillage unit:

The rippers of the combined unit deeply rip the bottom layer of soil and create optimal conditions for local fertilizer application along the middle of each ridge without disturbing its shape by a special working body (Kalimbetov et al. 2018), for this purpose they are supplied with ripper teeth (**Fig. 2**).

The quality of deep loosening of the soil depends on the parameters and shape, changes in the length of the working surface of the ripper tooth, depending on the angle of *entry of the ripper tooth* at different values of their width and length of the working surface.

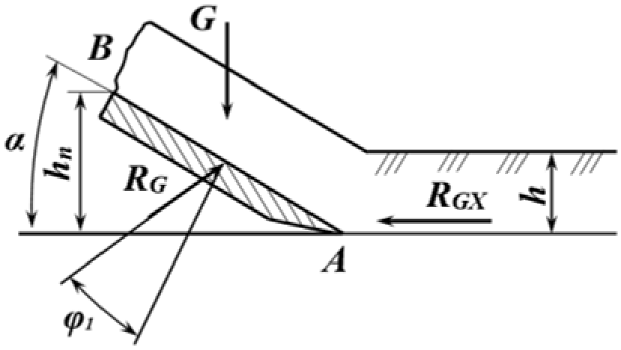


Fig. 3. Scheme for the determination of traction resistance arising from the lifting and moving the soil on the working surface of the ripper

Below are theoretical studies to determine the parameters of ripper teeth of the combined unit, to ensure the qualitative loosening of the soil with minimal energy consumption.

Ripper tooth (3 combined units made in the form of a chisel and its main parameters are: angle of entry into the soil *α*, width *b* and length of working surface *l*.

The angle of entry of the ripper tooth into the soil was determined from the condition that the traction resistance (see **Fig. 3**) arising from lifting and moving the soil layer along its working surface has the minimum value (Sineokov and Panov 1977).

According to the scheme in **Fig. 1**.

$$R_{GX} = R_G sin(\alpha + \varphi) = bhh_n\rho g\frac{tg(\alpha+\varphi)}{sin\alpha}\left(1+\frac{W}{100}\right) \quad (1)$$

where R_G – the resultant of the normal force and the force of friction arising

on the working surface of the ripper tooth of the weight of the soil, N;

φ –external friction angle of soil, degree;

h – tillage depth, m;

h_n – the height of the soil lifting on the working surface of the ripper, m;

ρ –soil density, kg/m^3;

g – gravitational acceleration, m/s^2;

W – soil moisture, %.

Exploring the expression (1) on the extremum of the angle *α*, we get

$$\alpha = arctg\left[\sqrt[3]{-\left(\frac{b^3}{27a^3}-\frac{bc}{6a^2}+\frac{d}{2a}\right)+\sqrt{\left(\frac{b^3}{27a^3}-\frac{bc}{6a^2}+\frac{d}{2a}\right)^2+\left(\frac{3ac-b^2}{9a^2}\right)^3}}+\sqrt[3]{-\left(\frac{b^3}{27a^3}-\frac{bc}{6a^2}+\frac{d}{2a}\right)-\sqrt{\left(\frac{b^3}{27a^3}-\frac{bc}{6a^2}+\frac{d}{2a}\right)^2+\left(\frac{3ac-b^2}{9a^2}\right)^3}}-\frac{b}{3a}\right] \quad (2)$$

where $a = 1 + tg^2\varphi; b = tg\varphi; c = 2tg^2\varphi; d = -tg\varphi.$

The width of the ripper teeth was determined from the condition of excluding the formation of a compacted groove at the bottom of treated layer using the following transformed formula (Panov et al. 1988)

$$b \geq \frac{(d + ctg\alpha)h}{\left[0{,}1\frac{T_c}{k_c}(1+3tg\varepsilon)-n\right]} \quad (3)$$

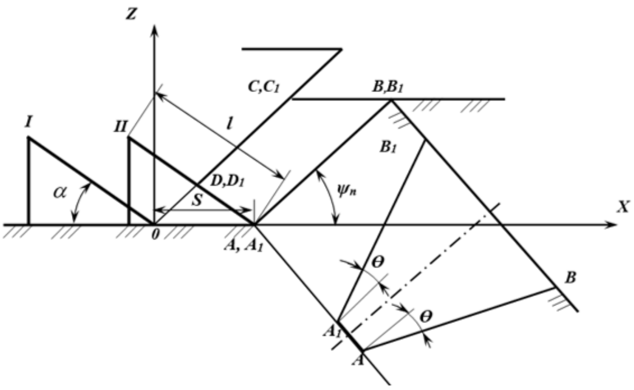


Fig. 4. The process of deformation and destruction of the soil under the influence of ripper

where d, n – dimensionless coefficients depending on physical-mechanical
soil properties;

T_c – *specific resistance of soil to crumple, Pa;*

k_c –specific resistance of soil to shift, Pa;

ε –angle of inclination of the resultant force of resistance of the soil applied to the working surface of the ripper tooth, to the horizon, degree.

To determine the length of the working surface of the ripper tooth, let us consider the process of deformation and destruction of the soil under its influence. It is known (Burchenko 2002, Goryachkin 1965, Klenin and Sakun 1980) that the destruction of the soil under the influence of ripper tooth in the form of a chisel-shaped ripper mainly consists of two phases: when the ripper tooth passes from position I to position II (**Fig. 2**), the soil is compacted under its working surface, and then, when the stresses arising in it reach the ultimate strength, it is destroyed along the ABB_1A_1 plane located to the horizon at an angle ψ_n. As a result, a lump in the form of a prism $ABB_1A_1DCC_1D_1$ is separated from the soil. During the subsequent displacement of the ripper, this process is periodically repeated, i.e. the soil is first compacted (crushed), and then a lump is separated from it.

In order to ensure the destruction of the soil under the influence of ripper tooth, taking into account the implementation of its bilateral, the following condition must be ensured (see **Fig. 4**)

$$l > 2AD \tag{4}$$

From the scheme in **Fig. 4**

$$AD = \frac{OAsin\psi_п}{sin(\alpha + \psi_п)} \tag{5}$$

or

$$AD = \frac{Ssin\psi_п}{sin(\alpha + \psi_п)} \tag{6}$$

where *S=OA* the distance, passed by the working body from the beginning of the soil crushing before its destruction, m.

Taking into account the expression (6) and that $\psi_п = \frac{\pi}{2} - \frac{1}{2}(\alpha + \varphi_1 + \varphi_2)$ (Goryachkin1965) the expression (4) has the following form

$$l > \frac{2Scos\frac{1}{2}(\alpha + \varphi_1 + \varphi_2)}{cos\frac{1}{2}[(\varphi_1 + \varphi_2) - \alpha]} \tag{7}$$

where φ_2 – angle of internal friction of the soil, degree.

Now we define the distance *S* in the expression (7). To do this, we will express the normal force acting on the soil from the side of the working body through resistance to its shift (Panov et al. 1988, Zelenin 1959) (taking into account the spread of soil deformation in the lateral direction)

$$N = \frac{k_c\left[b + h\,tg(\frac{\pi}{4} - \frac{\varphi_2}{2})\right]\,hcos\varphi_1 cos\varphi_2}{cos^2\frac{1}{2}(\alpha_ю + \varphi_1 + \varphi_2)} \tag{8}$$

and crumpled (Azimov 2011, Kalimbetov et al. 2018)

$$N = \frac{0{,}5q_0 bS^2 cos\frac{1}{2}(\alpha + \varphi_1 + \varphi_2)sin\alpha}{cos\frac{1}{2}(\varphi_1 + \varphi_2 - \alpha)} \tag{9}$$

where q_0 – soil crushing ratio, N/m³.

Equating the right sides of expressions (8) and (9) and solving the resulting expression with respect to *S*, we get

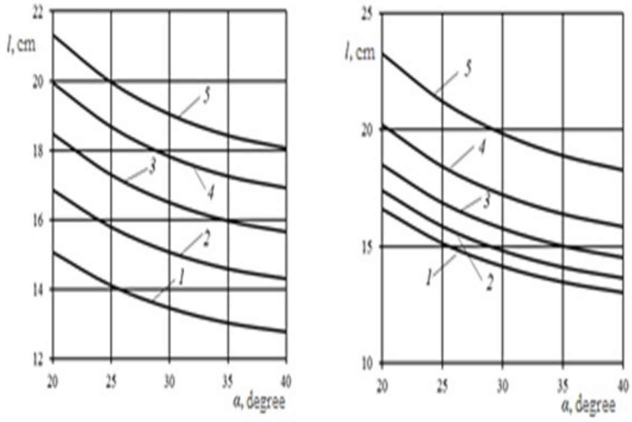
$$S = \frac{\sqrt{2}}{cos\frac{1}{2}(\varphi_1 + \varphi_2 + \alpha)}\left\{k_c\left[b + htg\left(\frac{\pi}{4} - \frac{\varphi_2}{2}\right)\right]hcos\varphi_1 cos\varphi_2 \times \times cos\frac{1}{2}(\varphi_1 + \varphi_2 - \alpha)\right\}^{\frac{1}{2}} : \left\{q_0 bcos\frac{1}{2}(\alpha + \varphi_1 + \varphi_2)sin\alpha\right\}^{\frac{1}{2}}. \tag{10}$$

With this in mind, the expression (7) has the following form

$$l \geq 2\sqrt{2}\left\{k_c\left[b + htg\left(\frac{\pi}{4} - \frac{\varphi_2}{2}\right)\right]hcos\varphi_1 cos\varphi_2\right\}^{\frac{1}{2}} : \left\{0{,}5q_0\, b[cos\alpha + cos(\varphi_1 + \varphi_2)]sin\alpha\right\}^{\frac{1}{2}} \tag{11}$$

In **Fig. 3**, expression (11) shows graphs of the change in the length of the working surface of the ripper tooth as a function of the angle *α* for various values of *h* and *b*. It follows from them that with an increase in the angle *α* the length of the working surface of the ripper tooth decreases, and with an increase in its width and depth of processing - it increases.

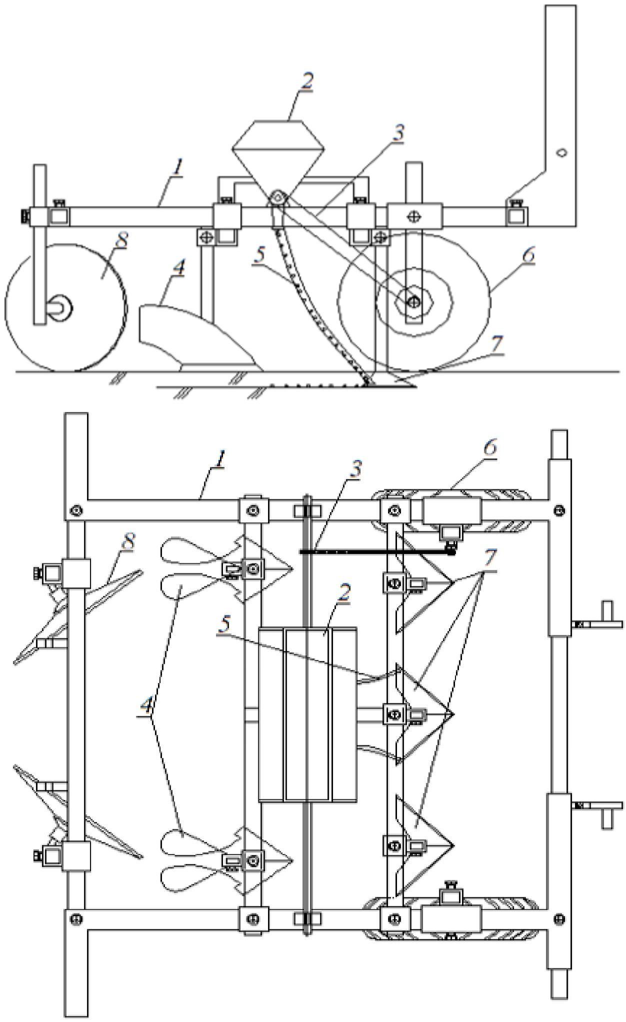
Calculations carried out by expressions (2), (3) and (11) with $\varphi_1 = 30°, \varphi_2 = 40°, d = 4{,}2, n = 2{,}5$, $T_c = 1{,}5 \cdot 10^5$Pa, $k_c = 2 \cdot 10^4$Pa, $q_0 = 1{,}02 \cdot 10^7$N / m³ (Panov et al. 1988, Sergienko et al. 1982, Sineokov and Panov 1977) showed that to ensure good soil loosening with minimal energy consumption, the angle of entry of the ripper tooth in the soil must be 25°, its width is not less than 9.2 cm, and the length of the working surface is not less than 17.3 cm.



(a)
1, 2, 3, 4, 5 - respectively, with
h = 20; 25; thirty; 35; and 40 cm

(b)
1, 2, 3, 4, 5 - respectively, with
b = 5; 7.5; ten; 12.5; and 15 cm

Fig. 5. The process of deformation and destruction of the soil under the influence of ripper



1-frame; 2- fertilizer hopper; 3 – mechanism of fertilizer gear; 4 - right-leftharvester bodies; 5 - opener for double-layer tape fertilizer application;
6-wheel, 7-ripper; 8-spherical disks.

Fig. 6. The scheme of working bodies on the frame of the combined tillage unit for minimal tillage

DISCUSSION OF THE FINDINGS AND CONCLUSION

To implement the technology, taking into account the previous R&D and engineering development work (Kalimbetov et al. 2018) and on the basis of preliminary experiments based on the combined unit of «Bomet» (Poland), the layout of the working bodies was justified (**Fig. 6**).

In the process of preliminary testing of the signal sample of the combined unit, we found soil clumps on the ridges and irregularities of the treated field surface; by calculation-theoretical way, the replacement of the working body of the dumping type with a spherical disk was substantiated (Goryachkin 1965, Kalimbetov et al. 2018, Klenin and Sakun 1980).

In order to prevent these errors, we decided to change the design of the combined unit for minimal tillage: it was decided to use spherical discs as the comb deck; in this case, each ridge is formed by two oppositely mounted disks (Akar et al. 2018, Kalimbetov et al. 2018, Khudayarov and Mamatov 2015, Mamatov and Khudayarov 2015).

The new design of the combined unit, providing high-quality soil preparation in the fall for planting vegetable crops in the early stages for obtaining ultra-early harvest by improving soil fertility, as vegetable crops are responsive to organic fertilizers.

In the early spring period, the combined unit for preplant soil preparation is used for intensive soil crumbling, destroying weeds, chopping plant residues, mixing soil layers, planting fertilizers in the area of future rows of planting vegetable crops under the mulch film and leveling the soil surface to spread the mulch film on the formed ridge (Kalimbetov et al. 2018, Khazimov 2018, Khudayarov and Mamatov 2015, Mirzamasoumzadeh and Mollasadeghi 2013).

There is no need to carry out traditional methods for harrowing, planning, chiseling, mulching soil by combining technological operations: tillage in the planting zone of seedlings of vegetable crops, landless processing - surface loosening of the soil on the right and left sides of the blade, lane subsoil loosening along the planting line local two-tier fertilization (Aghajari et al. 2018, Khozhiyev 1988), preparing the soil for sowing and planting, cutting irrigation furrows.

Due to the use of the proposed combined tool, a significant economic effect is formed, mainly due to an increase in labor productivity and an increase in the yield of vegetable crops.

The increase in the productivity of the implements occurs as a result of combining the operations of tillage and fertilizer application in one pass of the soil tillage implement. Combining operations in one tool reduces the number of passes of the unit across the field, which, on the one hand, reduces fuel consumption, depreciation and labor costs, and on the other hand, significantly reduces compaction of the fertile soil layer, thus this technology can be attributed to the soil-protective.

In accordance with the calendar plan in the scientific center "Mechanization and Automation of Agriculture" of the South Kazakhstan State University named after M. Auezov, the authors developed a new agricultural technology for minimal tillage for the implementation of agrotechnical measures for the production of 3 single harvest of vegetable crops, taking into account previous R&D and engineering development work, on the basis of the grant funding of the scientific and technical program BR 05236680 by the Committee of Science, the Ministry of Education of the Republic of Kazakhstan for 2018–2020[1], has been developed constructive-technological scheme of the combined unit that provides high-quality soil preparation in the fall, for planting seedlings of vegetable crops in ultra-early terms to produce an ultra-early harvest, by increasing soil fertility, as vegetable crops are responsive to organic-mineral fertilizers.

[1]contract №284 of 03.03. dated March 2, 2018. BR05236680 "Intensification of the production of vegetables through the implementation of agrotechnical measures to obtain a 3-time harvest, and the development of a set of agricultural machines and units for this purpose in the conditions of the South Kazakhstan region."

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