Intellectual multi-functional plowing unit

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Abstract. A multi-functional plowing unit, combining the operation of the base fertilizer application in one pass, the moldboard plowing, the additional crumbling and the soil leveling is proposed and its efficiency is substantiated. A distinctive advantage of the new unit is the separate fertilizer application to a required depth in the arable layer in accordance with the requirements of a scientifically based farming system: phosphorus fertilizers are applied with a special plow attachment to the bottom of the ploughed furrow, potash and nitrogen fertilizers are distributed throughout the layer by plow moldboards. Additional crumbling and leveling of the plowed surface are carried out simultaneously with plowing by the attachment consisting of a combination of annular-spur and wedge-shaped discs. A prior-art plow body with right- and left-side plowshares was used in the design, which allows discerning the field board, reducing plowing resistance and increasing productivity of the unit. Technical and economic indicators of the multi-functional unit were calculated and analyzed. The qualitative indicators of plowing were also analyzed in comparison with conventional serial plows. Fulfilling the main objective of increasing productivity and reducing costs, the proposed multi-functional unit does not increase, but rather reduces the dust content in the arable layer compared to disc implements, thus reducing erosion processes.

1 Introduction

The competitive crop farming production depends on applied technologies [1–3] and intellectual tools of mechanization [4, 5]. Resource-saving environmental technologies contribute to preservation and enhancement of soil fertility, increase labor productivity and reduce costs. In practice, the above requirements are fulfilled with the strict observance of scientifically based farming systems [6], agricultural enterprises achieve high crop yields and are cost-effective. One of the main methods of tillage in agriculture is moldboard plowing. Despite its high energy intensity, prime cost and low productivity, it still remains the basic agricultural method of weed control, plant diseases and agricultural pests [6]. As for the negative impact of plowing on soil erosion, the results of research at KubSAU [7], proved that plowing sprays soil 1.5 times less than disc tools. Before plowing, according to the system of agriculture [6], the base fertilizer is applied. Its elements – nitrogen, potassium and phosphorus – are evenly distributed throughout the entire arable layer. It is negative for phosphorus, since phosphorus fertilizers are especially necessary in the ripening phase of spike crops to obtain high crop yields and should be delivered to the bottom of the furrow during plowing [6]. Thus, for plowing, it is necessary to reduce energy intensity, increase productivity and rational distribution of certain types of fertilizers in layers of plowed soil. We solve this problem in this article.

2 Materials and methods

In the work, the method of mathematical modeling of the plowing process by the proposed multi-functional plowing unit [8] and the results of comparative tests of various plow designs [9] were used.

The total energy costs for the moldboard plowing process, additional crumbling and soil leveling, and the application of base fertilizer into the soil, were used as the target function of the mathematical model for optimizing the parameters of the proposed plowing unit. This process may be represented by the function (1):

$$E = \left(1.3 + \frac{86.4 G_{tr} 0.193}{T_a^{tr} W} + \frac{75 G_{un} 0.38}{T_a^{un} W} + \frac{250}{W} + \frac{0.162 N_{tep} 42.7}{W}\right) \rightarrow \min \quad (1)$$

where $\boldsymbol{E}$ is the total energy costs of the plowing process, MJ/ha; $\boldsymbol{G_{tr}}$ is the mass of the tractor, kg; $\boldsymbol{G_{un}}$ is the mass of the unit, kg; $\boldsymbol{T_a^{tr}}$, $\boldsymbol{T_a^{un}}$ are annual standard load, respectively, of the tractor and machine, h; $\boldsymbol{W}$ is the unit capacity for 1 hour of a shift time, ha/h; $\boldsymbol{N_{tep}}$ is the tractor engine power, kW; 42.7 is the energy equivalent of fuel consumed, MJ/kg; 1.32 is the energy costs of human labor, MJ/h; 86.4 and 75 are the empirical equivalent of the tractor and the agricultural machine, respectively, MJ/kg; 0.193; 0.38; 250 are the empirical coefficients.

The components of the formula (1) are:

The tractor engine power:

$$N_{tep} = \frac{R_{pr} \mathrm{V}_w}{2.88}, \quad (2)$$

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where R_{pr} is the plowing resistance, kN; V_w is the work speed, km/h.

The unit traction resistance:

$$R_{utr} = \kappa_u 0.25 B_w, \quad (3)$$

where κ_u is the unit specific traction resistance, kN/m^2; B_w is the unit working width, m.

The masses of the tractor G_{tr} and of the unit G_{un}, respectively:

$$G_{tr} = 10e^{\left(1.46 \ln N_{tep} - 3.54 N_{tep}\right)}, \quad (4)$$

$$G_u = \frac{100}{0.289 \cdot 10^{-5} e^{B_w} - 0.0064 \ln B_w + 0.029} + 906 B_w, \quad (5)$$

The shift time utilization ratio:

$$\tau = \frac{13.6}{13.6 L_f + 0.18 V_w + \frac{0.068 V_w B_w}{V_h} + 0.2}, \quad (6)$$

The unit capacity:

$$W = 0.1 B_w V_w \tau, \quad (7)$$

The optimal working width B_w (m) of the unit, the working speed V_w (km/h), the capacity of the hopper for mineral fertilizers V_h (m^3), the furrow length L_f (km), the specific soil friction factor K_u (kN/m), the shift time utilization ratio τ, are found by the minimum value of the function E (1).

3 Results and Discussion

All progressive structural elements of reversible plows and various devices for fertilizing and additional soil crushing were taken into account in the proposed multifunctional unit [3]. It is possible to compare the plowing quality performed by plowing units without a device for crushing and soil leveling simultaneously with plowing with the device in Figures 1 and 2. The large lumpiness of plowing (Figure 1) will require large expenditures for the soil leveling and completion.

Among the moldboard plows the PShKO (5+1+1) is to be preferred (Fig. 3). The distinctive features of the design of the PShKO-5-60 plow body are shown on the Figure 4.

The PShKO (5+1+1) semi-integral reversible plow (hereinafter “the plow”) is designed for plowing soils for grain and industrial crops to a depth of 30 cm, free from stones, flagstone and other obstructions, with the specific soil reaction up to 0.09 MPa (0.9 kgf/cm^2) and the hardness up to 3.5 MPa (35 kgf/cm^2).

The advantages of these plows are in cutting, spudding, crumbling and wrapping the soil layer at 180 degrees. They contribute to improving the penetration of water, air and nutrients to the plants roots, saving fuel by eliminating tractor idle motion when plowing (fuel savings of up to 9 kg per each hectare). They capture width of one working body – 60 cm, stilt height –70 cm, thickness – 30 mm. There is a sormite surfacing on the knives, which prolongs the service life of the equipment. Knives have two working edges. Plow bodies are protected against overload with protecting shear bolts.

The disadvantage of this plow is the lack of devices for additional crushing of the soil simultaneously with plowing and devices for the basic fertilization according to the requirements of the farming system. Thus, the authors invented and developed the devices missing from this plow.

Plowing with reversible plows is characterized by a good leveling, as the right- and left-handed bodies are mounted on the plow, though the raised soil layer must be crushed immediately and the soil surface must be leveled after the plow passage (Fig. 2).

The industry has developed devices to the plows for soil crushing and leveling, though there are no devices for applying the basic fertilizer simultaneously with plowing, and we are able to introduce our invention for fertilizing [9]. In the last century in Russia, such devices to the plows were used. The PKA-2 device was used for fertilizing, the PVR-3.2 (to the PLN-8-35 plow) was used for soil crushing as well as others.

A similar device can be used to other tillage machines – to cultivators, to spring harrows, rotary and other units. Thus, the multifunctional combined tillage unit DKGP merits attention, but it is not equipped with the above-mentioned devices, which should be taken into account by manufacturers.

Fig. 1. The soil after the passage of the reversible plow without a device

Fig. 2. The plowing unit with a soil crushing device by “LEMKEN” company

Fig. 3. The PShKO (5+1+1) reversible plow

Fig. 4. The design of the PShKO-5-60 plow body without a landside

The need for the basic fertilizer application for the basic cultivation according to the farming system is explained by the peculiarity of phosphorus, potassium and nitrogen fertilizers. The fact is that nitrogen fertilizers are mobile, rapidly soluble in water and, under the influence of moisture, move to the lower soil layers, which is not intrinsic to phosphorus and potassium fertilizers, which must be immediately applied to a predetermined depth during the basic cultivation. When conducting the surface tillage, the phosphorus and potash fertilizers are applied in the latter treatment.

The proposed multi-functional plowing unit (Fig.5) differs not only in the availability of various devices to the plow, but also in the rational distribution of fertilizer elements in depth of the arable layer. Nitrogen and potassium fertilizers enter the scattering disc 6 from their hoppers 4 and 5, are evenly distributed over the field surface and, when a plow passes, they are mixed with its hulls 7 with soil throughout the layer. Phosphorus fertilizers from the hopper 3 enter the collector 8, and then are delivered by the blower 9 through the fertilizer tubes 10 for each dump of the plow bodies to the bottom of the furrow.

According to the technology of cultivating spike crops [6], it is also known that a starter dose of phosphorus fertilizers (50 kg/ha) is applied by the grain seeder's planting attachment along with the seeds and feeds the plants in the early vegetative phases. Considering the plowing process labor intensity and high costs, it is used only after spike crops, especially when they were infected with diseases (root rot) or after perennial grasses by a predecessor [6]. According to the shifting cultivation system, depending on soil types, a part of the spike crops is cultivated after tilled preceding crops using the surface tillage and even without it, using no-till technology [10], but within small field areas.

The advantage of the proposed plowing unit is defined by the combination of technological operations in a single pass through the field, as it provides significant advantage in all technical-economic indicators (Table 1) and quality of work (Table 2).

The analysis of technical-economic indicators of the compared plowing technologies showed a significant advantage of the option using a multi-functional plowing unit. Labor costs decreased from 0.96 man-hour/ha to 0.26 man-hour/ha or 3.7 times, operating costs – 1.6 times, total energy costs – from 581 MJ/ha to – 262 or 2.2 times, metal consumption – 1.9 times. The recoupment period of the proposed unit was 1.5 years.

The advantage of the proposed plowing unit in the quality of plowing and fuel consumption is clearly visible according to the table 2, based on the results of various plow designs comparative tests took place in KubNIITiM (Novokubansk) [9].

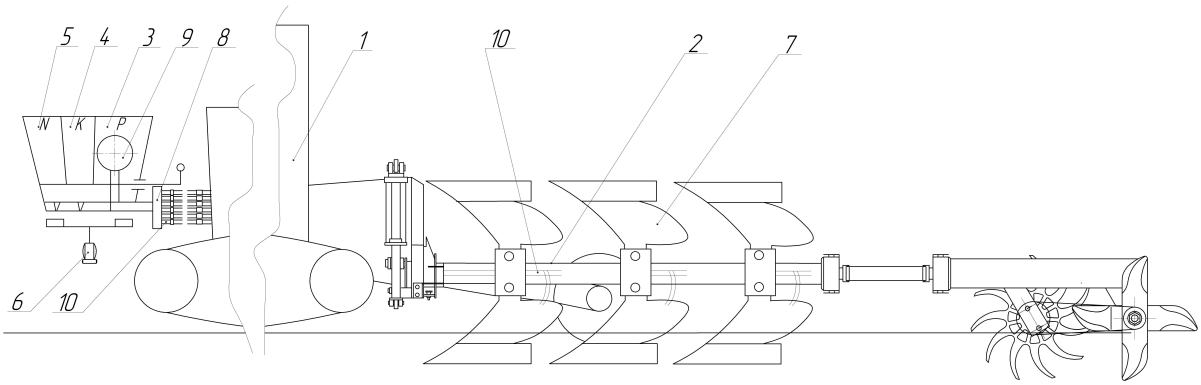

Fig. 5. The multi-functional plowing unit: 1 – the tractor, 2 – the plow, 3,4,5 – the fertilizer hoppers, 6 – the scattering disc, 7 – the plow body, 8 – the collector, 9 – the blower, 10 – the fertilizer tube

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Table 1. The technical-economic indicators of the multi-functional plowing unit

Indicator	Compared technologies		The proposed technology as a percentage of the existing
	existing	multi-functional plowing unit's	
Labor costs, man-hour/ha	0.96	0.26	-269.2
Operating costs, rub/ha	8920.0	1824.7	-388.9
Total energy costs, MJ/ha	581	262	-121.8
Metal consumption, kg/ha	24.8	12.8	-93.8
Recoupment period of the proposed unit, years	-	1.5	-

The most preferable unit was in structure of the K-701 tractor and the PBS-8-55 plow of the compared plowing units. The design of the latter was used in the reversible plow of the PShKO with the main advantage that is the abolition of the left-hand board due to the double-sided plowshare on the hull. The PBS-8-55 plow (Table 2) provided the highest operating speed (8.9 km/h), the lowest fuel consumption (12.3 kg/ha) with a fairly high quality of soil crumbling. Agricultural requirements for the crumbling quality were not met only by PNU-8-40 and SPL plows (Table 2). In addition, these last two units worked at a low speed rate of 6 and 7.7 km/h, which affected their performance. The greater depth of soil plowing (by 2 cm) could explain the low quality of soil crumbling by the PNU-8-40 plow, but it worked at a higher soil humidity (13.6 %). Thus, the construction of the PBS-8-55 plow is the most technologically advanced. In this regard, the hull structure was used in the multi-functional unit proposed.

Table 2. The quality indicators of plowing and specific fuel consumption of various plow designs (KubNIITiM's data)

Indicator	Structures of the plowing units			
	K-701 + PBS-8-55	K-701 + PNU-8-40	Fendt+Kverneland 8 bodies	Buhler 2425 + SPL-9
Plowing depth, m	25.9	27.8	25.4	26.4
Crop residues, g/m^2	312	113	820	286
Operating speed, km/h	8.9	7.7	6.0	6.0
Soil crumbling, %	84.8	63.6	87.0	75.2
Specific fuel consumption, kg/ha	12.3	15.6	15.2	27.0
Soil humidity, %	12.2	13.6	20.6	11.0
Preceding tillage	Disc stubble plowing of winter wheat			

The high quality of soil crumbling with PBS-8-55 and Kverneland plows (Table 2) may be explained by the design features of their plow-dump surface. Plows PNU-8-40 and SPL-9 do not meet agricultural requirements for the quality of crumbling (65.6 and 75.2 percent, Table 2), which indicates the need for a device to the plow for additional crumbling and leveling the soil. Such a device is precisely provided in the design of our multifunctional unit (see Fig. 1). In our fixture for the plow, sections of needle and knife discs are mounted on their shafts, which are interconnected by a chain drive.

Due to the different diameter of the sprockets, the back row of knife discs rotates in the soil with a greater speed. This improves the quality of crumbling and helps to clean the front row discs from crop residues, weeds, and in the case of a high soil moisture – prevents its sticking to the working bodies. The high quality of soil crumbling is especially important when plowing a semi-fallow land, when it is necessary to preserve soil moisture for future crop and provide conditions for the accumulation of new precipitations. On the frame of the device, where the sections of needle and knife discs are fixed, the balance weight is provided, the value of which for better crumbling depends on the firmness and moisture of the plowed soil.

4 Conclusion

As a result of the research, the innovative multi-functional unit was proposed as a part of a reversible energy-saving plow without field planks, consisting of an implement for rational distribution of mineral fertilizers in the arable soil layer and an implement for additional crumbling and leveling the surface behind the plow. The proposed unit makes it possible to improve the technology of plowing compared to a single-operation machines that separately carry out the fertilizing process and layer plowing completion, and due to its advantages it reduces labor costs by 3.7 times, operating costs by 1.6, and energy consumption by 2.2 times. The payoff period of the unit is 1.5 years.

References

1. *The technology of cultivation of corn in Krasnodarskiy krai*, ed. by I. M. Petrenko (Publ. house "Agroprompoligrafist", Krasnodar 2001), 89 p.
2. A.I. Trubilin, V.I. Gayduk, E.N. Belkina, S.A. Kalitko, A.E. Gorokhova, *Infrastructure of the regional agrifood market: Peculiarities of functioning and methods of improvement,* Espacios, **38(33)**, article no. 41 (2017)
3. G.G. Maslov, V.P. Lavrentiev, V.V. Tsybulevsky, E.M. Yudina, V.T. Tkachenko, *Optimization of parameters of a multi-functional unit based on a spring harrow*, Int. J. of Engineer. and Advan. Technol. **9(1)**, 1915–1918 (2019)

* Corresponding author: elena_yudina1963@mail.ru

4. G.G. Maslov, E.I. Trubilin, *The innovative system of mechanization of field cultivation,* Monograph (KubSAU, Krasnodar, 2019), 172 p.
5. D.R. Grifith, J.V. Mannering, W.C. West, *Reduced tillage – what happened in 188 $ plans for 289,* CES Paper No. 209 (Purdue Univ., W / Lafayette, 1N, 1988)
6. *The farming system of the Krasnodarkiy krai on an agrolandscape basis* (Krasnodar, 2015), 352 p.
7. A.S. Naydenov, V.V. Tereshchenko, N.I. Bardak et al., *Minimization of soil cultivation in the field rotation of the Kuban,* Transactions of KubSAU, **1(52)**, 132 (2015)
8. A.A. Zangiev, *Workshop on the operation of the machine and tractor fleet* (Kolos, Moscow, 2006), 320 p.
9. R. Omarov, I. Gorlov, M. Slozhenkina et al., *Applying methods of mathematical modeling in cattle breeding,* Int. J. of Innovat. Technol. and Explor. Engineer., **8(12)**, 185–187 (2019)
10. *Test results of agricultural machinery (collection),* Issue **2**, 40–41 (Rosinformagroteh, Moscow, 2016)
11. M.N. Dudin, V.D. Sekerin, S.V. Bank et al., *Retail branding in food retailers in Russia: Marketing sales and communications tools,* Opcion, **34(85)**, 1654–1663 (2018)