Modernization of engineering support of crop cultivation

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Abstract. This paper gives substantiations to a system of effective engineering support of crop cultivation for improving competitiveness of produced goods. Considering the modernization of plant cultivation techniques and technical facilities to carry out agricultural practices, the optimal system of machines for mechanizing crop cultivation was proposed. In substantiating the system of machines, the method of analysis and synthesis of existing and proposed agricultural practices with their engineering support, the methods of modeling and optimization of production processes were proposed to determine the parameters and operating modes of the proposed machines in the system, the planning of a multifactorial experiment according to the $2^k$-plan was used. As a result of the research, the original engineering support system of crop cultivation for lowland agricultural landscapes is proposed, which, according to calculations conducted, allows increasing labor productivity by at least a factor of two. It became possible due to modernization of tillage processes, sowing and harvesting, by combining separate previously technological operations in multifunctional units. The modernization of machine-tractor units was accomplished using original devices for serial machines according to the inventions of the authors. The proposed multifunctional units without a break in time, in a single stream and pace carry out production processes that coincide in calendar terms in the technology of a cultivated agricultural crop, contributing to the quality of work and higher yields.

1. Introduction

The urgency of further modernization of crop husbandry engineering support is connected with the need to increase labor productivity and reduce production costs. These are the main factors of product competitiveness and survival of agricultural enterprises in the agricultural sector. In addressing this issue an important role belongs to the engineering support of the industry, including crop production. The quality of work, productivity, yields and costs depend on what machines perform mechanized processes in crop production. Combined with resource-saving cultivation technologies [1–4], this is the basis of the competitiveness of agricultural enterprises. Technologies in crop production are constantly being improved. New agricultural practices, new means of mechanization contribute to increasing productivity and lower costs, but tangible result from new developments may be obtained only in a systemic application - from all the engineering support of crop production, the basis of which is a system of machines for mechanizing all processes of soil cultivation, sowing, and harvesting. The system of machines is a set of equipment interconnected in technology and productivity which ensures timely and high-quality implementation of the entire volume of fieldwork with minimal labor and money costs. This problem is solved in this article for the mechanization of the cultivation of field crops within the Krasnodarskiy Krai.
2. Materials and methods
To substantiate the system of machines, the method of analysis and synthesis of existing prospective engineering support for agricultural enterprises of the agro-industrial complex of the Krasnodarskiy Krai, the methods of modeling and optimization of production processes were used, the parameters and operation modes of the machines are substantiated by the experiment planning method. Valid OSTs and GOSTs are also used in the work.

3. Results and discussions
The engineering support of crop production is determined by a scientifically based system of machines for mechanization of production processes. Unfortunately, the current set of equipment for crop production in our region ought not to be considered as a justified system. It took shape in the region without proper calculations at the discretion of professionals of agricultural enterprises and coordination of mechanical equipment, taking into account the streaming character and rhythm of the processes. It resulted in an unjustifiably overestimated range of technical tools having been developed, as well as non-compliance with multiple requirements of the agricultural system and economy.

| No. | Machinery type             | Machine systems existing | Machine systems prospective |
|-----|----------------------------|--------------------------|----------------------------|
| 1   | Tractors:                  | K-701; K-744; T-150; T-150K; MTZ-1221; KZ180; T-4A; VT-100; DT-75M; T-70C; MTZ-80; MTZ-82; UMZ-6; T-40 | U-450; Belarus-1523; Belarus-892 |
| 2   | Combine harvesters         | TORUM-750; TORUM-740; Acros; Vector; John-Deere; Claas; Tucano; Laverda; Fendt; Massey Ferguson; Challenger; New-Holland | Mn-130; MN-230; KZR-12 |
| 3   | Forage harvesters          | KVK-600; KDP-3000; John-Deere; Claas; Mammut | KVK-800 |
| 4   | Beet combines              | Holmer; CF-10            | VIK+; VIK; CF-10 (PShKO-5-12+PV-2,3+Air) |
| 5   | Plow                       | PLN-5; PLN-4; PLN-8; PNU-8-40; PBS-8; Gregoire Besson; Lemken; John-Deere; Lemken-Opal; Kverneland | BD-6 |
| 6   | Combined machines          | AKP-5; KUM-4; AKP-3      | AKP-8; DGPK-12 |
| 7   | Disc harrows               | BDT-7A; BD-10; B-7T; DMT-4 (Demetra); BDN-2-6 | BZP-27; MRN-6,3 |
| 8   | General-tillage cultivators| KPS-4; KBM-10,8; KBN-14,4 | KBM-10,8; KBM-14,4 |
| 9   | Inter-row cultivators      | KRN-5,6; KRN-8,4; "GASPARDO" | KMO-11 |
| 10  | Sowing-machines            | "GASPARDO"; SUPN-8; SUPN-12; RITM; SST-12; SZ-3,6; SZT-5,4; | FM-7090; Great Plains |
| 11  | Spraying machines          | OPSh-15; OP-24; Kertitox | OP-24 |
| 12  | Mineral fertilizer applicators | MVU-6; Amazon; Accord | |
| 13  | Grass harvesters           | OPT-5; ZKV-1,4; SZT-5,4A; MOHITOU; ES-1+ZHT-9; KPR-9; GVK-6; KIR-1,5; RKM-10; PRF-180; IS-3 | OPT-5; IS-3; 3KVG-1,4; SZT-5,4; MOHITOU; ES-1+ZHT-9; KPR-9; TBM-6; PRF-180; KIR-1,5; PRF-180; USM-1 | PS-6; PS-8; PS-12; PS-15; PS-20 mixed tailgate; PS-60; APV-6; NBP-20 |
| 14  | Transport facilities       | 2 PTS-4; 2 PTS-6; PTS-9; PTS-12; RZHT-4 | |

Table 1. The list of the main machines of the existing and future systems for the conditions of the Krasnodarskiy Krai
In the list of machines for the existing system (Table 1), no equipment allows introducing the resource-saving technologies such as “Neveika” with a trashed heap cleaning at the station, that has successfully proved itself in Canada [5] using trailed non-motorized combine harvesters and stationary vibro-sieve trashed heap separators. The economic benefit of this technology is $80 per 1 ha of the harvested area [5].

The multifunctional plowing unit (Table 1) includes the PShKO reversible plow, a frontal hopper for fertilizer application on the tractor’s front linkage, the PVR-2.3 device for crushing and leveling the soil behind the plow. A multifunctional sowing unit, the prototype of which includes the SZT-3.6 grain-grass seeder, the applicator feet for the basic fertilizer and the helix packer roller.

The harvesting unit is equipped with the TORUM-740 self-propelled combine harvester and the PRF-180 baling machine, also by our invention. The efficiency of the mentioned units in terms of the technical-economic indicators (Table 2) shows how many times these indicators are improved (productivity increases, costs are reduced).

The optimization of the parameters and operating modes of multifunctional units was performed by a simulation method or a three-factor experiment [6]. For example, for a three-factor experiment, when optimizing the parameters of the spring-tine harrow unit, we obtain a regression equation with coded values of factors (1).

\[
y = 432.62 + 2x_1 + x_2 + 2.5x_3 - 15.75x_1x_2 - 18.75x_1x_3 - 14.25x_2x_3 + 1.38x_1^2 + 2.38x_2^2 + 0.88x_3^2, \quad (1)
\]

Where \( y \) is the optimality criterion of minimum of the spring-tooth harrow draught resistance; \( x_1 \) is the angle of tooth point; \( x_2 \) is the harrow operation speed; \( x_3 \) is the tooth inclination angle.

According to the criterion of minimum traction resistance of the spring-tine harrow, the teeth parameters and the operating mode are justified; tooth sharpening angle is 21 degrees; working speed is 11.7 km/h; the angle of inclination of the teeth is 62 degrees. By a similar approach, the parameters of other units have been optimized.

In the proposed prospective system of machines (Table 1), the brand composition of tractors, combines has been completely replaced, disc implements, fertilizer spreaders, sprayers (except for the OP-24 sprayer and fertilizer spreader add-on to the “Tuman” mobile power unit), plows (except for the PShKo-11 reversible model) and cultivators for complete (except for KBO-11) and inter-row cultivations (except for KMO-11) have been eliminated, grain seeders were replaced by universal CF (“Agro-Soyuz”), Great Plains and MPA-3.6 multifunctional sowing unit for sowing grain and legume crops on plowed land (the perennial grasses and grain preceding crops).

| Proposed multifunctional units | Indicators of efficiency (times) |
|-------------------------------|---------------------------------|
|                               | Labor productivity increase | Maintenance costs decrease | Metal consumption decrease | Energy consumption decrease |
| For plowing                   | 3.7                           | 1.6                         | 2.0                         | 2.2                         |
| For harrowing with fertilizer application | 1.7                           | 1.2                         | 4.8                         | 1.7                         |
| For sowing with basic fertilizer application and soil compaction | 3.9                           | 1.5                         | 1.6                         | 1.4                         |
| For harvesting with straw compaction | 1.6                           | 1.2                         | 1.6                         | 1.3                         |
Great efficiency is expected from the use of the multifunctional units in a prospective system of machines that combine several technological operations in one pass on the field. For example, in Table 2, the multifunctional units developed according to our inventions [3] and their effectiveness are presented.

The analysis of the efficiency indicators of multifunctional units allows for the conclusion that they are significantly improved compared to single-operation machines in cultivated crop technologies.

Calculations of the effectiveness of prospective engineering support for labor costs (Table 3) in the field crop cultivation showed that the new system of machines will reduce them by almost two times.

Table 3. The indicators of existing and prospective engineering support for field cultivation in the Krasnodarskiy Krai (labor costs, thous. man-hr.)

| Names of crops                      | Machine systems |
|-------------------------------------|-----------------|
|                                     | existing | prospective |
| Winter, grain                       | 4936      | 2486        |
| Maize for grain and silage          | 4418      | 1273        |
| Spring, grain, and legumes          | 3786      | 2536        |
| Sunflower                           | 2401      | 1209        |
| Sugar beet                          | 1967      | 1279        |
| Perennial and annual grasses        | 3556      | 1609        |
| Total:                              | 20764     | 10397       |

Particularly high efficiency was obtained on the cultivation of corn, perennial grasses. For these crops [3], fundamentally new technological complexes of machines of domestic production and the Republic of Belarus greatly increase labor productivity, quality of work and product competitiveness.

Modernization of engineering support for crop production to increase the competitiveness of the product is especially urgent for improving the design of tillage machines, in particular the moldboard plows. This improvement should be carried out in the following directions: reducing the energy intensity of the plowing process, increasing the productivity of units, reducing specific fuel consumption. Our studies [3] showed a successful example of solving this problem through the multifunctional plowing units (Table 4).

Table 4. Comparative indicators of plowing units’ efficiency

| Make of tractor with plow | Energy consumption of the plowing process, MJ/ha | Output per 1 m of coverage, (ha/h)/m | Specific fuel consumption, kg/ha |
|---------------------------|--------------------------------------------------|-------------------------------------|---------------------------------|
| K744+PLN-8-40            | 305.4                                            | 0.82                                | 15.6                            |
| K744+MFA on the base of PShKO | 184.7                                      | 0.90                                | 11.5                            |
| K-701+PBS-8-55           | 160.0                                            | 0.90                                | 11.5                            |
| Fendt+Kverneland (8 k)   | 290.0                                            | 0.70                                | 15.2                            |
| Buhler 2425 +SPL-9       | 210.0                                            | 0.80                                | 24.0                            |

As appears from the data presented in table 4, the most advanced design of the plows is the reversible wide-grip plow PShKO-5 + 2. The peculiarity of its design due to the reversible part allowed eliminating the field board on each body, reducing traction resistance, specific fuel consumption and increasing machine productivity by 30 ... 50 percent.

4. Conclusion

Modernization of engineering support for crop husbandry through the example of the Krasnodarskiy Krai based on a prospective system of machines for mechanizing production processes will allow improving cultivation technologies, reducing the negative impact of heavy equipment on soil fertility,
reducing costs and increasing labor productivity almost by a factor of two. The proposed compositions of multifunctional units according to the inventions of the authors by combining technological operations give a new idea about the system of mechanization of tillage and sowing, soil and crop maintenance and harvesting. Introduction of the large quantity of the modifier leads to its coagulation and reduction of its influence on the structure.

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