STUDY OF SPECIALIZED WIDE-RAIL AGRICULTURE UNIT FOR RAIL FARMING

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Abstract. *A promising direction for further sustainable development of agriculture not only in Ukraine but also in the world is the introduction of innovative technologies, which should include the track and bridge systems of agriculture. These systems provide the basis for the automation and robotization of most crop production processes, ensure efficient implementation of "precision" and "digital" farming and provide other significant benefits. Scientists have not sufficiently studied the issue in this regard, and there is currently no effective methodology for implementing the potential technical-operational and technological properties of specialized broad gauge means of agricultural production mechanization for the rutting system of agriculture. Therefore, from the point of view of solving the food problem in the world, especially during the COVID-19 pandemic, as well as developing resource-saving technologies based on the principles of the rutting system of agriculture, in accordance with the trends of scientific and technological progress in the field of mechanization - improving the level of functioning of technical means through integrated mechanization, electrification, automation and robotization - this direction of research is relevant. The aim of the research is to substantiate the main advantages and effectiveness of the use of a specialized vehicle for rutting agriculture by justifying its main parameters. As a result of these studies, it was found that the energy saturation level of specialized agricultural vehicles moving in the tracks of a permanent technological track should be 23.5 kW·t^{-1}, in realizing the traction force at the level of 6.37 kN by 1t of their weight. Losses of the field area for the engineering zone when using agricultural equipment with a wheelbase width exceeding 6 m are 5-6%. The economic effect of the use of broad-wheeled agents in wheat cultivation technology is at least 150 € per hectare.*
KEY WORDS: *TRACK FARMING, BRIDGE AGRICULTURE UNIT, CONSTANT TRAMLINE, ENERGY SATURATION, LAND USE, ECONOMIC EFFECT.*

1. Introduction

At present the most actual problem of soil reconsolidation by running systems of energy means and self-propelled machines remains worldwide [1, 2]. One of the ways to solve this problem is the transition to new farming technologies that allow reducing the area of tractor and machine tracks in the field. Thus, the transition to minimum tillage technologies (No-till) reduces the relative area of wheel motor tracks in the field to 46% [3, 4]. An even greater effect in reducing the compaction effect of the wheels of the running gear of the units on the soil is observed in the tramline system of cultivation (Controled Traffic Farming – CTF). The organization of parallel motion of aggregates along a specially created tramline allows reducing the area of traces from the wheels of machinery in the field to 14% [5, 6].

Farming with a constant tramline is the separation of the zones of movement of agricultural aggregates from the zones of plant processing. In practice, this means that the same transport and technology tracks are used for tillage, planting, spraying and harvesting to move the agricultural aggregates along them. That is, the functional purpose of the field area is divided into fruit-bearing (agricultural) and technological (engineering) zones.

On the basis of duration of use of technological track by scientists of southern branch of National scientific center "Institute of mechanization and electrification of agriculture" (Ukraine) [7] it is offered to classify it on periodic, temporary, constant, long-term and stationary. The practical use of the last three introduces certain difficulties to its implementation by traditional tractor-combine means of mechanization. As in the decision of a problem of optimization of complexes of machines for tramline agriculture there are difficulties in coordination of parameters of running systems of tractors and agricultural machines with parameters of a technological track. On the other hand, the forced coordination of machine units on the parameters of their running systems can lead to an incomplete loading of their engines on various technological operations in the technological cycle of cultivation of agricultural crops, which levels the effect of the implementation of the basic principles of tracked agriculture.

2. Preconditions and means for resolving the problem

For the purpose of practical implementation of the concept of track farming, a number of different technological and technical solutions have been offered worldwide: the use of traditional tractors with extended wheel axles, bridge tractors such as Dohler, Swedish bridge tractor Biotrac with four driving wheels, ASA-Lift WS 9600 WS, etc. [8]. The use of such specialized wide-track agribusinesses to a certain extent solves the problem of reducing soil compaction, because the area from the tracks of their wheels is reduced to 5-10%.

According to scientist V.A. Uleksin [9], the drive of specialized wide-track agricultural units can be fully electric or hybrid. In his opinion, in order to automate driving, these wide-track agricultural units should be four-wheel drive with kinematic-power control, independent for its front and rear wheels.

Scientists have not sufficiently studied the issue in this regard, and there is currently no effective methodology for implementing the potential technical-operational and technological properties of specialized broad gauge means of agricultural production mechanization for the tracked agricultural system. Therefore, from the point of view of solving the food problem in the world, especially during the COVID-19 pandemic, as well as developing resource-saving technologies based on the principles of the rutting system of agriculture, in accordance with the trends of scientific and technological progress in the field of mechanization – improving the level of functioning of technical means through integrated mechanization, electrification, automation and robotization - this direction of research is relevant.

Justification of the main advantages and effectiveness of the use of a specialized vehicle for rutting agriculture, by justifying its main parameters.

3. Results and discussion

In our opinion, the layout scheme of a specialized wide-track agricultural unit for its use in the tramline system of agriculture should contain an electrified chassis 1 with engines 2, driving the wheels of its left and right sides, a set of electrical equipment 3, attaching mechanism 4, retractable supports (jacks) 5, which are attached to the chassis for lifting one of its sides, agricultural implements 6.

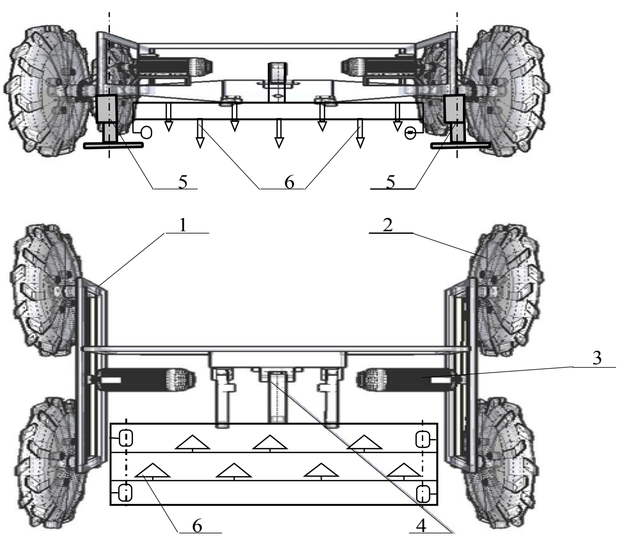

Fig. 1. Specialized wide-track agricultural unit for agricultural work: 1 – chassis; 2 – electric motors; 3 – electrical equipment; 4 – mounted mechanism; 5 – retractable supports (jacks); 6 – agricultural implements

Fig. 1 shows the layout scheme of wide-track agricultural unit is implemented in the construction agricultural unit [10].

For practical realization of the wide-track agricultural unit within the field directly on agricultural operations the issue of realization of its turn, in our opinion, is possible by its rotation on the spot around the center of the turn, which is located in the center of the track on which the agricultural unit itself moves [11, 12]. For this purpose, the is additionally equipped with mechanical retractable supports (Fig. 2) attached to its chassis from left and right side to lift one of them at headland, with respect to the axis coinciding with the longitudinal axis of the support. Such a principle of wide-track agricultural unit turning makes it possible to move it to the next position in a minimum period of time, which increases productivity and requires less area for the engineering field zone.

Fig. 2. Specialised Broad Track Agricultural Unit with hydraulic support for the implementation of on-board turning

In solving the problem of determining the energy content of a specialized wide glue agricultural unit, the power balance equation has been compiled, according to which the power of its energy installation (or power units) is distributed to the drive of its wheels on both its sides and, in certain cases, additional power take-off is possible:

$$N_e = \frac{f \cdot g \cdot V}{\eta_t}\left[\frac{M_l}{1-\delta_l}+\frac{M_r}{1-\delta_r}\right]+\frac{\lambda \cdot \varphi \cdot g \cdot V}{\eta_t}\left[\frac{M_l \cdot \delta_l}{1-\delta_l}+\frac{M_r \cdot \delta_r}{1-\delta_r}\right]+ + \frac{g \cdot V\left(\lambda \cdot \varphi - f\right)}{\eta_t}\left[\frac{M_l}{1-\delta_l}+\frac{M_r}{1-\delta_r}\right]+\frac{N_{PTO}}{\eta_{PTO}}, \quad (1)$$

where V – speed of the wide-track agricultural unit, km·h^{-1}; f – rolling resistance coefficient; g – free fall acceleration, m·s^{-2}; δ – wheel slipping ratio; λ – drive load factor; φ – adhesion coefficient of the wheels of the agricultural unit to the bearing surface of the tramline tracks; δ_l, δ_r – left and right wheel slipping ratios; M_l and M_r – the masses of agricultural unit on his left and right side, kg; η_t – transmission efficiency.

By numerical calculations it is proved that for full realization of traction and power properties of specialized wide-track agricultural units at working speeds of their movement to 5 km·h^{-1} their energy saturation should be equal 12.5 kW·t^{-1} and within 10 km·h^{-1} – equal 23 5 kW·t^{-1}. In this regard, under real operating conditions, reducing the operating speeds of such agricultural units is a way to reduce energy consumption for technological processes in rutting agriculture. In conditions of sufficient wheel adhesion of the specialized wide-track agricultural unit with the bearing surface of the soil track of a constant technological track allows it to develop a traction force of 6.37 kN for each ton of its operating weight. This is 1.4 times more than a traditional wheeled tractor can develop while driving on a stubble agrophone. The movement of the agricultural unit on the soil tramline in contrast to agricultural agrophones can increase its coefficient of adhesion up to 0.55. Thus the maximum tangential force of the traction developed by its wheels is reached at smaller slipping value equal to 0.15...0.17. Practically it means that movement of wide-track agricultural unit on the leveled compacted soil track allows to increase its traction and coupling properties at least on 30%.

With the purpose of an estimation of influence of the sizes of wide-track agricultural unit and parameters of their wheels on a factor of land tenure at arrangement of a field by transport technological paths we will consider, as variant, a kind and a way of their movement (Fig. 3) which can be attributed: on the organization of territory – paddock; on a direction of working runs – racing; on the scheme of processing of a paddock - shuttle; on a type of rotation – loopless.

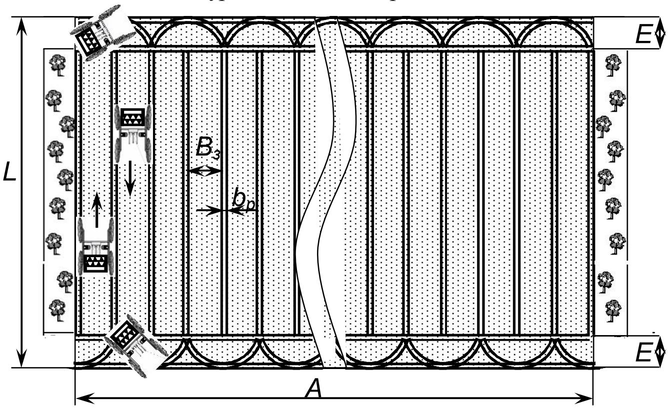

Fig. 3. Field planning scheme for specialized wide-track agricultural equipment: A and L – field width and length; $B_з$ – working width, E_n – swivel lane width; b_p – conveyor belt width

Taking into account the adopted type and method of wide-track agricultural unit movement (see Fig. 3), the conducted researches have established that the influence of its structural parameters on the field area losses under the engineering zone can be estimated by the relative value of the loss factor w_i:

$$w_i = \frac{b_c + c}{L \cdot A}\cdot\left(\left[L - 2\left(K + b_c + c\right)\right]\cdot\left[\frac{A - b_c - c}{K}+1\right]+ +4A+\pi\left[A - b_c - c\right]\right), \quad (2)$$

where b_c – tire track width; c – technological tolerance; K – agricultural track gauge; L and A – field length and width.

The analysis of expression (3) has shown that at a rectangular configuration of a field section the use of wide-track agricultural units with track width about 12 m and wheels with profile width 15,5R or 16,9R determines the value of losses of the field area under engineering zone within 7.5-12.5%. For agricultural machinery with a track width greater than 12 m and wide wheels with a tyre profile width of 23.1R - is not more than 5% of the total area.

The width of the transport technological track of the permanent technological track is significantly influenced by the technological tolerance c, which is caused, in particular, by the amplitudes of transverse deviations of the agricultural unit from the straight-line motion, which directly affects the loss of the field area under the engineering zone. Thus, with the increase in technological tolerance up to 0.3 m the losses of the area for the engineering zone increase by 1.5…1.75 times. Therefore, the practical use of wide-track agricultural units in the rutting system of agriculture requires a justification of the principles of their automatic driving, which will minimize the amplitude of deviations from a given straight-line trajectory and, consequently, the value of technological tolerance.

The economic effect E of the introduction of the tramline system of agriculture and the use of specialized wide-track agricultural units is determined, first of all, by three components:

$$E = \Delta e_h + \Delta e_s + \Delta e_e, \qquad (3)$$

where Δe_h – economic effect of increasing crop yields, €·ha^{-1}; Δe_s – economic effect of saving seed, €·ha^{-1}; Δe_e - the economic effect of saving energy costs, €·ha^{-1}.

The results of the evaluation of the efficiency of implementation of the rutting system of agriculture and the use of specialized wide-track agricultural units from saving energy costs, sowing material and increasing yields, on the example of wheat cultivation, by (3) are presented in Figure 1. 4.

Analysis of Fig. 4 indicates that if the loss of the field area for the engineering zone in the rutting system of agriculture is more than 6%, and the absolute value of natural soil compaction will be only 0.1. g·sm^{-3}, it will be impossible to get positive economic effect only by increasing the yield (curve 1, Fig. 4). According to our estimates, it is still possible to achieve a loss of less than 6% of the field area if specialized wide-track agricultural units with their track width of at least 6 m are used.

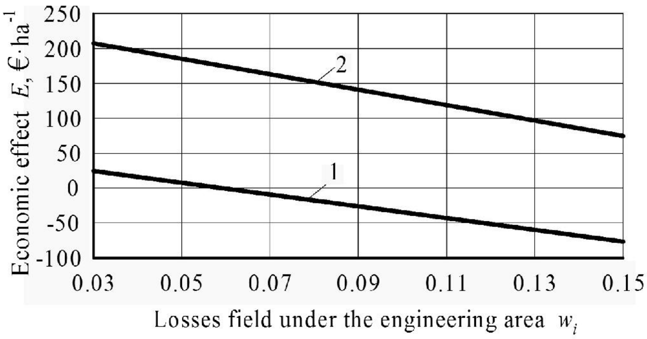

Fig. 4. Results of assessment of efficiency of implementation of tramline system of agriculture and use of specialized wide-track agricultural units from saving energy costs, sowing material and increasing yield of wheat cultivation with different effect of soil compaction: 1 – 0.1 g·sm^{-3}; 2 – 0.2 g·sm^{-3}

A more tangible economic effect from the use of specialized broad gauge agricultural units in the rutting system will be seen if, with traditional farming technology, soil compaction becomes one of the main obstacles to high yields. And if, with the right soil protection practices, natural soil compaction is achieved in rutting agriculture at the level of 0.2 g·sm^{-3}, then, due to a substantial increase in the yield of cultivated plants, the economic effect will be obvious even if the field area under the engineering zone is lost at the level of 10…15% (curve 2, Fig. 4). The economic effect itself will be greater the less the field area is allocated to the engineering zone. With specialty agricultural, the economic effect of saving energy costs, sowing material and increasing wheat yields will be at least 150 € per ha of wheat.

4. Conclusions

1. Carried out researches it is established that for full realization of traction and power properties of specialized wide-track agricultural units at working speeds of their movement up to 5 km·h^{-1} their power saturation should be equal. 12.5 kW·t^{-1}, and within 10 km·h^{-1} – 23.5 kW·t^{-1}. In this regard, under real operating conditions, reducing the operating speeds of such agricultural units is a way to reduce energy consumption for technological processes in rutting agriculture.

2. In conditions of sufficient wheel adhesion of the specialized wide-track agricultural unit with the bearing surface of the soil track of a constant tramline allows it to develop a pulling force of 6.37 kN per each ton of its operating weight. This is 1.4 times more than a traditional wheeled tractor is able to develop when driving on a stubble agrophone.

3. The movement of wide-track agricultural unit on the soil trail in contrast to agricultural agrophones can increase its adhesion coefficient to 0.55. Thus the maximum tangential force of traction, developed by its wheels, is reached at smaller slipping value equal to 0.15...0.17. Practically it means that movement of the agricultural unit on the leveled compacted soil track allows increasing its traction and coupling properties by at least 30%.

4. It is established that losses of the field area under the engineering zone significantly depend on the track width for the movement of specialized wide-track agricultural units, the value of which is directly determined by the width of their wheels. By calculations it is established, that on criterion of the minimum factor of losses of the field area under an engineering zone the rational size of wheel base of the last falls on 7.5 m. In practice, this means that when using tyres of agricultural units with a width of 0.393...0.429 m, the value of losses of the field area under the engineering zone does not exceed 6%. At the same time, at increase of agricultural units track width up to 9 m, that is typical for foreign samples, so-called "bridge" tractors, the amount of area losses decreases up to 5%.

5. The economic effect from the introduction of specialized wide-track agricultural units, which move in the footsteps of a permanent technological track, due to savings in energy costs, sowing material and increasing the yield of cultivated crops is at least 150 € per hectare of wheat cultivation, which allows a return on investment in the development of this promising area of agricultural mechanization.

5. References

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