

## RESEARCH OF CONDITIONS OF RATIONAL CORRELATION OF DESIGN PARAMETERS OF TRACTOR AND PLOUGH AGGREGATE

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**Abstract.** The efficiency of using a general-purpose wheeled tractor as part of an arable machine-tractor aggregate depends to a great extent on a correct ratio of the design parameters. Experimental investigations of arable aggregates with definite traction and operational-technological indicators are implemented using tensometric and other special mechatronic equipment. In the experimental investigations, we applied the version of the arable aggregate, based on the HTZ-170 tractor with 16.6R38 tires. It was found that the performance of such a machine-tractor aggregate at a translational speed of  $2.4 \text{ m} \cdot \text{s}^{-1}$  was  $1.52 \text{ ha} \cdot \text{h}^{-1}$ . In this case slippage of the tractor wheels did not exceed 11%, and the specific fuel consumption was  $14.5 \text{ kg} \cdot \text{ha}^{-1}$ . The use of an arable machine-tractor aggregate as part of an HTZ-170 wheeled aggregating tractor and a five-furrow plough, trailed behind and tuned according to the developed methodology, made it possible to increase its productivity by 13.4% while reducing the specific fuel consumption by 15.2%. The proposed method for setting up an arable aggregate provides an increase in its efficiency by combining the design parameters of the plough and tractor in the direction of achieving the most rational placement of the "center of resistance" and the point of attachment of the plough in relation to the longitudinal axis of symmetry.

**Key words:** ploughing, field board, furrow, aggregation, tractor.

### Introduction

Despite the widespread introduction of minimum and non-moldboard tillage, ploughing is still one of the most common tillage operations in agriculture [1; 2]. The labor and energy costs of this operation in the most countries are enormous, and an increase in the efficiency even by few percents will give large absolute savings. Therefore, the search for the most rational modes of operation, methods of aggregation and optimal design parameters is of high relevance.

The efficiency of using a general-purpose wheeled power tool as part of an arable machine-tractor aggregate largely depends on a correct ratio of their design parameters. Practice shows that the efficiency of using ploughs with different energy sources is different, i.e. the same plough under the same soil conditions with the same working width and working speed, when used with different tractors, has, as a rule, different traction resistance [3; 4].

Such a result is due to the close values of the working width of this plough and the width of the running system of the used tractor. Usually a plough, the design width of which is 1.5 times or more greater than the width of the tractor running system, is attached to it symmetrically. Because of the close values of these parameters, the plough is quite often aggregated with the traction means asymmetrically.

Two versions of a tractor-mounted (as the most common) arable machine-tractor aggregate are currently used. According to the first version the wheels of one of the sides of the tractor (usually the right one) in the aggregate with the plough move along the furrow. According to the second version the plough is attached to the tractor so that the wheels of the latter move outside the furrow.

Each of the versions of an arable machine-tractor aggregate has its own disadvantages and advantages, the subject analysis of which, due to sufficient knowledge and publication [5-10], is not presented in this article. In this article we will consider in more detail the features and conditions of correct aggregation of the plough for each of the versions.

In the Baltic countries, Vilde A., Rucins A. et al. studied the topic of plow aggregation optimization. In particular, they noted that in order to achieve high specific efficiency of the soil tillage aggregates with a minimum consumption of energy machines should be used with a low coefficient of the dynamic resistance, optimal parameters of harrowing, ploughing and cultivation [11; 12].

The purpose of this work is to study possibilities how to improve the operational and technological parameters of an arable machine-tractor aggregate by a rational combination of the design parameters of a plough and an aggregating tractor.

### Materials and methods

Experimental studies of various arable aggregates were carried out in the field conditions of South Ukraine on a dark chestnut soil with a content in the soil layer of 0-20 cm: humus – 2.5%; nitrogen – 21.2; phosphorus – 38.5 and potassium – 295.0 g per 1 kg of soil. Testing of the arable machine-tractor aggregate of such a structure (Fig. 5) was accomplished on an agricultural background, the soil moisture of which in a layer of 0-25 cm was 18.1%. Determination of traction and operational-technological indicators of the arable aggregates involved the use of tensometric and other mechatronic equipment. The method of its application for measuring the estimated indicators (speed and width of the machine-tractor aggregate, towing of the engines of the aggregating tractor, specific fuel consumption, etc.) is described in [3]. The most common option for connecting a plough to a general-purpose power tool is to set up its rear attachment mechanism according to a two-point scheme (Fig. 1, Fig. 2).

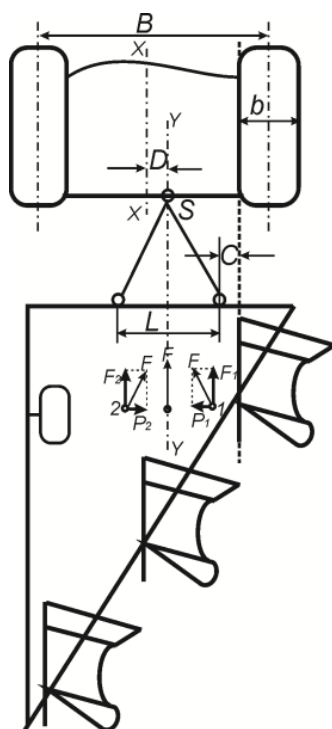


Fig. 1. Scheme of the arable aggregate when the tractor is moving in the furrow

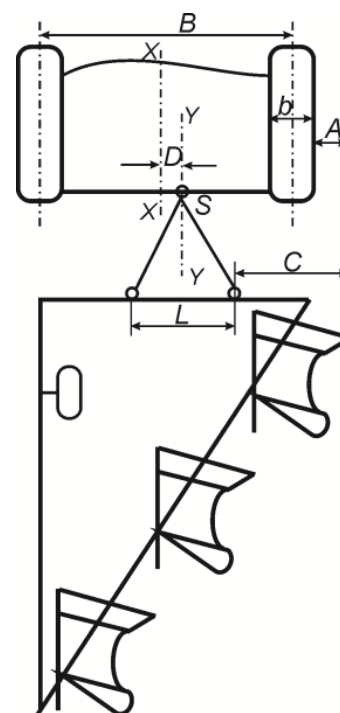


Fig. 2. Scheme of the arable aggregate when the tractor is moving outside the furrow

One of these points ( $S$ ) is the locus of intersection of the lower links of the rear linkage of the tractor. The second point is located at the point of connection of the central link of the rear mounted mechanism of the tractor to its frame. When the plough is properly aggregated, these points should be in the same longitudinal-vertical plane, and preferably on the same vertical axis. Although, this condition is not always met. In relation to the longitudinal axis of symmetry  $X-X$  of the tractor, point  $S$  as a real point of attachment of the plough to it, in principle, can occupy three positions [13]. Namely: 1) it may be to the right of the  $X-X$  axis at a distance  $D$  (as in Fig. 1 and 2); 2) it may be on the axis of symmetry of the tractor; 3) it may be more to the left of this axis at a distance  $D$ . The first and the third positions of point  $S$  are not desirable. In both cases, the plough resistance force (let us denote it as  $P_{KP}$ ) on the arm  $D$  will create an undesirable turning moment  $M = P_{KP} \cdot D$ . With the right-hand location of point  $S$  it will try to turn the tractor clockwise. This is what we often see in the field conditions.

In a left-hand position point  $S$  turning moment  $M$  tends to turn the tractor counterclockwise. In the variant of symmetrical connection of the plough (i.e. when  $D = 0$ ), the turning moment from the action of the force of the traction resistance of the plough disappears. But this takes place only when there is

no angle in the horizontal plane between the longitudinal axes of symmetry of the arable implement (the  $Y-Y$  axis) and the tractor (the  $X-X$  axis). In practice this angle always occurs because the plough and the tractor are constantly turning left/right relative to each other. Because of this the traction resistance of the plough manifests itself in the form of two components: longitudinal and transverse. And if, with a symmetrical attachment of an arable implement to the tractor (when  $D = 0$ ), the longitudinal component of the traction resistance of the plough does not create a turning moment, then the transverse component does. By the way, it is possible to essentially reduce (but not to zero) the turning moment from the action of the transverse component of the traction resistance of the plough precisely by using the three-point scheme of the rear mounted mechanism of the tractor [13]. But the reduction to zero of this moment is possible only with the use of the so-called “pendulum” towing device. Unfortunately, in the design of modern tractors it is practically not provided.

It follows from the foregoing that the optimal attachment of the plough to the tractor will take place under the condition  $D = 0$ . When the tractor moves outside the furrow (Fig. 2), this condition is described by the following fairly simple equation:

$$D = (B + b + 2A - L - 2C) \cdot 2^{-1}, \quad (1)$$

where  $B$  – tractor track,

$b$  – tire width of the rear wheels of the power tool,

$A$  – distance from the edge of the tractor rear wheel tire to the furrow wall,

$L$  – distance between the ploughs, attached by brackets,

$C$  – distance from the right connecting bracket of the plough to the end of its front body.

In the variant of the tractor movement with the right-side wheels in the furrow (Fig. 1), the condition for the symmetrical connection of the plough is described by a simpler equation:

$$D = (B - b - L - 2C) \cdot 2^{-1} = 0, \quad (2)$$

In the process of forming an arable machine-tractor aggregate, conditions (1) and (2) can be achieved by selecting parameters  $B$ ,  $A$ ,  $L$  and  $C$ . Yet, now not all of this is ideal. First, the track of many modern tractors changes in steps. And often this prevents from solving the problem we are discussing. Second, the design of the plough should provide a possibility of transverse movement of the connecting brackets (Fig. 3). Unfortunately, many ploughs do not have such a setting. And this, in its turn, does not allow the correct choice of the parameters  $L$  and  $C$  (Fig. 1 and 2) and thereby to ensure symmetrical connection of the arable implement to the tractor. As regards the parameter  $A$  (the distance from the edge of the tractor rear wheel tire to the furrow wall), the method for choosing it is as follows. On mechanically unstable soils, the  $A$  value is recommended to be taken equal to the ploughing depth [3]. According to experts, this prevents destruction of the furrow wall during the movement of the arable machine-tractor aggregate. According to the results of the conducted research, it is recommended that the value of the parameter  $A$  should be such that it would exclude slipping of the right side wheels of the tractor into the furrow. For this, as long-term practice indicates, the value  $A$  must be maintained within 10-12 cm [3]. It should be noted that the symmetrical connection of the plough to the tractor is not the only and not the main problem of effective aggregation of this tillage tool. The thing is that all the forces, acting upon the plough in a horizontal plane, can be concentrated at one point, which is commonly called the “center of resistance”. The efficiency of the plough aggregation essentially depends on the location of this “center” in the horizontal plane relative to the longitudinal axis  $Y-Y$ , passing through the point  $S$  of attachment of the arable implement to the tractor (Fig. 1, 2). In relation to the indicated  $Y-Y$  axis, the “center of resistance” of the plough can also occupy three positions: 1) to be to the right of it (Point 1, Fig. 1); 2) to be to the left of this axis (Point 2, Fig. 1); 3) to be placed on the  $Y-Y$  axis itself.

With the right-hand placement of the “center of resistance” of the plough relative to the  $Y-Y$  axis (i.e. at Point 1, Fig. 1), the tractor traction force  $F$  can be represented as two components: longitudinal  $F_1$  and transverse  $P_1$ . The first of these components performs useful work by moving the plough in the longitudinal (working) direction. The second component (i.e.  $P_1$  force) is counterproductive as it tries to push the plough further against the furrow wall. As investigations have shown, the friction force of the field boards of the arable tool against the soil in this case increases by 15-20% [13]. As a result, the right-sided transverse displacement of the “center of resistance” of the plough leads to an undesirable

increase in its traction resistance, an increase in the slippage of the tractor wheels, and a corresponding increase in the specific fuel consumption while reducing the productivity of the arable unit.

When the “center of resistance” of the plough is located on the  $Y-Y$  axis (see Fig. 1), then there is practically no additional pressing of the plough against the furrow wall. At the same time, this position of the “center of resistance” of the arable implement is temporary and unstable. After all, as already emphasized above, there is almost always an angle between the  $Y-Y$  axis and the longitudinal axis of symmetry of the  $X-X$  tractor. Because of this the “center of resistance” of the plough occupies a “floating” position, mainly being either to the right or to the left of the  $X-X$  axis.

Let us analyze the option of placing the “center of resistance” of the plough. In the left-hand case of placing the “center of resistance” of the plough relative to the axis of the plough  $Y-Y$  (Point 2, Fig. 1) the tractive force of the tractor  $F$  is also decomposed into two components. The first component ( $F_2$ ) implements longitudinal movement of the plough, and the second component ( $P_2$ ) tries to push the plough away from the furrow wall. Besides, the force  $P_2$  performs useful work since due to its action the friction force of the field boards of the plough against the ground decreases. Due to this the traction resistance of the plough, the slippage of the tractor wheels and the specific fuel consumption of the arable machine-tractor aggregate are reduced by about the same 15-20% [13]. Considering this, in a left-sided transverse displacement of the “center of resistance” of the plough, all of its floorboards, except for the last one, can be removed (Fig. 4). As the results of the research [1; 10] show, the stability of the plough movement in the horizontal plane does not deteriorate yet, the fuel consumption of the arable aggregate decreases.



Fig. 3. Placement of the plough attachment bracket on the cowl



Fig. 4. View of a plough with a field board on its last cowl

The studies used the HTZ-170 tractor with two types of tires:  $16.9 \times 38$  and  $23.1R26$  (Figs 5-6).



Fig. 5. Arable machine-tractor aggregate based on the HTZ-170 tractor with tires  $16.9 \times 38$



Fig. 6. Arable machine-tractor aggregate based on the HTZ-170 tractor with tires  $23.1R26$

## Results and discussion

From the analysis presented above, it follows that the most efficient use of the plough is possible with a left-sided transverse displacement of its “center of resistance” relative to the longitudinal axis of symmetry of the tractor. When the tractor is moving outside the furrow (Fig. 2), this can be achieved provided:

$$b_k \cdot (n + 1) \geq L + 2C, \quad (3)$$

where  $b_k$  – furrow width of one plough body and  $n$  is the number of these bodies.

In the variant of the movement of the tractor in the furrow (Fig. 1), the condition (3) is different:

$$b_k \cdot (n - 1) \geq L + 2C, \quad (4)$$

These conditions can be met by selecting the parameters  $L$  and  $C$ . The problems associated with this choice have already been mentioned above. If we compare conditions (1) and (2), on the one hand, and (3) and (4), on the other, then the last two are more decisive. Non-fulfillment of conditions (1) and (2) leads to the appearance of the above-considered turning moment  $M = P_{KP} \cdot D$ . Because of this the traction resistance of the plough and the traction and energy indicators of the arable MTA do not change significantly. Failure to comply with conditions (3) and (4) leads to a significant deterioration in the traction and energy performance of the arable aggregate, which is highly undesirable. With this in mind, the method of properly attaching the plough to the tractor is as follows:

- from the technical passport of the selected brand of tractor, determine the track ( $B$ ) and the width of the tires of the rear wheels ( $b$ );
- for the selected plough the following is set: the body width ( $b_k$ ), the number of bodies ( $n$ ), the distance between the connecting brackets ( $L$ ) and the parameter  $C$ . The values of the latter are measured for both supposed options for setting up the arable machine-tractor aggregate, see Fig. 1 and Fig.2;
- the possibility of fulfilling the requirements (1), (2), (3) and (4) is estimated;
- in case of incomplete fulfillment or non-fulfillment of these requirements, a compromise option is chosen, preferring conditions (3) and (4).

For better understanding of what was discussed above, we will demonstrate the application of this technique by a concrete example. Let us consider tractors of the HTZ-170 series and a mounted plough PLN-5-35, which are quite common in Ukraine. The wheel track of this power tool is unchanged and is 1860 mm (i.e.  $B = 1.86$  m). The HTZ-170 tractor is equipped with tires 23.1R26, for which  $b = 0.59$  m. The parameters of the plow PLN-5-35 are as follows:  $n = 5$ ;  $b_k = 0.35$  m. The distance  $L$  is practically unchanged and equal to 0.90 m. The value of the parameter  $C$  is chosen from the following logical considerations. Since the width of the plough body PLN-5-35 is 0.35 m, and the tire width of the HTZ-170 tractor is 0.59 m, then the movement of the latter with its wheels in the furrow is technically possible, but technologically, for quite understandable reasons, absolutely not. For the variant of the movement of this aggregating tractor outside the furrow, the parameter  $C$  for the PLN-5-35 plough is 0.75 m. By the way, in the latest design versions of these ploughs this parameter, unfortunately, is also technically unchanged. As for the value of the parameter  $A$ , we take it equal to 0.10 m. Having such initial data, we first check the fulfillment of condition (3). Now we have  $b_k \cdot (n + 1) = 0.35 \cdot (5 + 1) = 2.10$  m, which is less than  $L + 2 \cdot C = 0.90 + 2 \cdot 0.75 = 2.40$  m, condition (3) is not fulfilled. Due to such attachment of the PLN-5-35 plough to the HTZ-170 tractor, the “center of resistance” of the arable implement will be shifted in the transverse direction to the right with respect to the YY axis (Fig. 2) by  $2.40 - 2.10 = 0.3$  m. Due to this, its traction resistance will become significantly greater with all the resulting negative consequences. Verification of condition (1) shows that with such connection of the considered plough to HTZ-170, the value  $D = (1.86 + 0.59 + 2 \cdot 0.10 - 0.90 - 2 \cdot 0.75) \cdot 2 - 1 = 0.125$  m. That is, instead of a symmetrical aggregation we have asymmetric aggregation of this arable implement. As already emphasized above, this will lead to the fact that the traction resistance of the plough (at the level of 30-35 kN) on the arm of 0.125 m will create a permanent turning moment that will try to turn the tractor clockwise (i.e. towards the ploughed part of the field). All this shows that the considered attachment of the plough PLN-5-35 to the tractor HTZ-170 is efficient. It should be added that the T-150K tractor, which had tires by 4.5 cm smaller and whose wheel track was 1.68 m versus 1.86 m of the HTZ-170, was better aggregated with the plough discussed. In the aggregate with it the PLN-5-35 plough, although

it had a right-sided transverse displacement of the center of resistance at the level of 0.30 m, could be attached to the tractor practically symmetrically. The tractor of the HTZ-170 series was equipped with tires 16.9R38, the width of which is 0.43 m. This allows to configure the power tool with a plough PLN-5-35 for the movement with the right-side wheels in the furrow. Although the plow is better suited for this the width of which is 0.40-0.45 m. On the frame of the plough PLN-5-35 its connecting brackets were rearranged so that the parameter  $C$  (Fig. 1) was 0.25 m. In this case, according to condition (4), we obtain  $b_k \cdot (n - 1) = 0.35 \cdot (5 - 1) = 1.40$  m. In such a case, this will exactly correspond to the value  $L + 2 \cdot C = 0.90 + 2 \cdot 0.25 = 1.40$  m. As a result, condition (4) is met. Next, we estimate the value of the parameter  $D$ . According to expression (2)  $D = (1.86 - 0.43 - 0.90 - 2 \cdot 0.25) \cdot 2 - 1 = 0.015$  m (i.e. 1.5 cm). It follows that, according to conditions (2) and (4), the PLN-5-35 plough with displaced brackets can be connected to a tractor of the HTZ-170 series, equipped with 16.9R38 tires practically symmetrically. The PLN-5-35 plough had two settings. The first was with five field boards but the second with one, mounted on the last plough body. The installation depth of ploughing for both plough options was the same and amounted to 25 cm. The aggregating tractor with ploughs in both cases of the settings worked in the same soil conditions and in the same gear. As the results of the field research showed, the average values of the working width and ploughing depth of the ploughs with a different number of field boards practically did not differ from each other. The first indicator was equal to 1.76 m, and the second for both machine and tractor aggregates did not go beyond the confidence interval of  $24.5 \pm 0.3$  cm. At the same time, the traction resistance of the ploughs was different. In the presence of only one field board it was equal to 25.5 kN, which is by 8.9% less than with a plough having all (five) field boards (Fig. 7). As we can see, this confirms the effect that we obtained earlier from such a plough setting option [3]. In further experimental investigations we applied this version of the arable aggregate, based on the HTZ-170 tractor with 16.6R38 tires. It was found that the performance of such a machine-tractor aggregate at a translational speed of  $2.4 \text{ m} \cdot \text{s}^{-1}$  ( $8.64 \text{ km} \cdot \text{h}^{-1}$ ) was  $1.52 \text{ ha} \cdot \text{h}^{-1}$  (Table 1). In this case slippage of the tractor wheels did not exceed 11%, and the specific fuel consumption was  $14.5 \text{ kg} \cdot \text{ha}^{-1}$ . The results of the experimental research of the productivity, fuel consumption, and other indicators are presented in Table 1. The standard deviation of the capture width (1.7 cm) did not exceed the agrotechnically allowed deviation (2 cm). In the performance of the experimental machine-tractor aggregate for 1 hour the main time averaged 1.52 ha. The tractor propeller slippage did not exceed 11%, and the specific fuel consumption was at the level of  $14.5 \text{ kg} \cdot \text{ha}^{-1}$ . When using the HTZ-170 tractor with 23.1R26 tires and the PLN-5-35 plough on the same field without reequipment (Figs. 5-6), the speed of the working movement of this aggregate was less and amounted to  $7.56 \text{ km} \cdot \text{h}^{-1}$  (Table 1) with the efficiency of the basic work at the level of  $1.34 \text{ ha} \cdot \text{hour}^{-1}$ . The tractor propeller slippage was 13%, and the specific fuel consumption was  $17.1 \text{ kg} \cdot \text{ha}^{-1}$ .

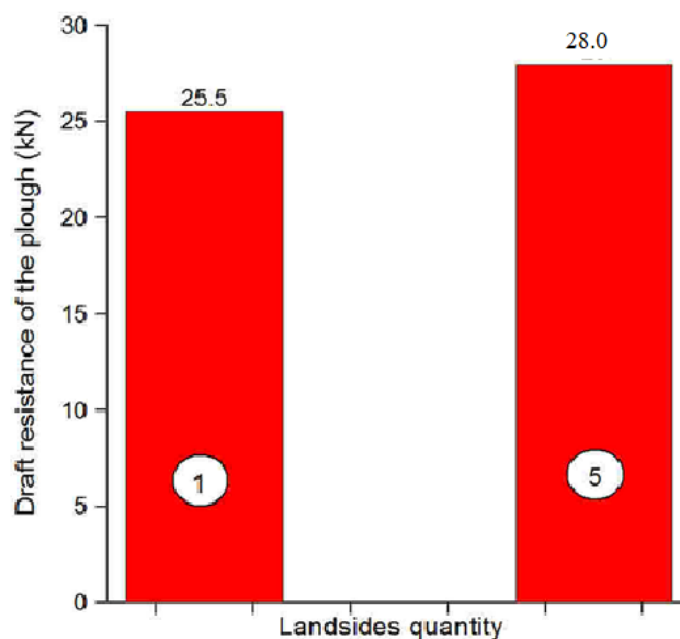


Fig. 7. Draft resistance of a plow with one (1) and five (5) field boards

Obviously, the improvement in the performance of the arable machine-tractor aggregate, based on the HTZ-170 tractor with experimental wheel tires 16.9R38, is determined by an efficient scheme of its aggregation with the plough. The latter, as emphasized above, is characterized by the absence of a right-side transverse displacement of the “center of resistance” of the arable tool with its simultaneous, almost symmetrical attachment to the energy tool.

Table 1

### Operational and technological indicators of performance of the arable aggregates

Indicator	Tire size	
	16.9R38	23.1R26
Mode of performance:		
– capture width, m	1.76	1.77
– speed of movement, km·h <sup>-1</sup>	8.64	7.56
– set ploughing depth, cm	25	
Amount of work performed, per ha <sup>-1</sup>	21	
Work productivity, per · hour <sup>-1</sup>		
– basic time	1.52	1.34
– shift time, ha·hour <sup>-1</sup>	1.34	1.17
Specific fuel consumption, kg·ha <sup>-1</sup>	14.5	17.1
Operational and technological coefficients:		
– use of the shift time	0.88	0.87
– reliability of the technological process	0.99	0.99
– use of the working passages	0.92	0.91
Agrotechnical indicators:		
– average ploughing depth, cm	24.5 ± 0.3	24.9 ± 0.2
– standard deviation from the average ploughing depth	1.7	1.9
– standard deviation from the average width of capture, ± cm	5.3	6.0

### Conclusions

1. A method for setting an arable machine-tractor aggregate is proposed, which involves a combination of the design parameters of a plough, and a tractor, ensuring the most rational placement of the “center of resistance”, and the point of attachment of the first in relation to the longitudinal axis of symmetry of the second.
2. It has been established that the use of the developed technique for aggregating a wheeled energy tool with an arable tool allowed the unit, based on the HTZ-170 tractor with 16.9R38 tires and the PLN-5-35 five-furrow plough, compared to a similar machine-tractor aggregate, based on the same tractor with standard tires 23.1R26, increase the productivity by 13.4%, while reducing the specific fuel consumption by 15.2%.

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