TECHNOLOGICAL EFFECTIVENESS OF TILLAGE UNIT WITH WORKING BODIES OF PARQUET TYPE IN TECHNOLOGIES OF CULTIVATION OF GRAIN CROPS

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Abstract. The article presents the results of experimental studies of the technological operation of tillage in the technology of growing cereals. The authors proved that one of the solutions in soil-saving agriculture is the introduction of parquet-type working bodies for deep loosening. It is proved that the technological process of tillage by working bodies of the parquet type is performed by asymmetric racks and paws, made as separate, sequentially placed broken planes. The influence of the relative position of the working bodies was studied in two variants: frontal with pairwise counter asymmetry; chess arrangement of working bodies. As a result of the experimental research, it is established that in the first variant the energy intensity of the process with the increase of the unit speed by 5.5 $km \cdot h^{-1}$ increased by 22%, in the second variant – by 14.5%. The authors found that in the second variant at the speed of the unit 8 $km \cdot h^{-1}$ traction resistance is reduced by 3.5%, and at the speed of 10 $km \cdot h^{-1}$ the advantage increases to 5.8% compared to the first variant. The article notes that the factor of pinching the soil mass in the space between the paws and their intensive loosening in the frontal performance of the working bodies of the parquet type adds 5% of energy consumption. The authors proved that according to the indicators of slipping by rational modes of tillage in the technology of growing cereals in the unit with a tractor that develops a traction force of 30-40 kN tillage can be carried out at speeds up to 10 $km \cdot h^{-1}$. Under such conditions, the productivity of cultivation will be 3.1 $ha \cdot h^{-1}$.

Keywords: soil, tillage, unit, mode, productivity.

Introduction

The maximum yield potential of cereals depends on the availability of nutrients in the root zone and soil moisture [1]. Tillage in grain growing technologies determines the rate of development of the root system of the plant [2]. The main tillage without rotation of the soil layer helps optimize the water [3] and air condition of the soil [4] and is implemented by tillage units with working bodies of the parquet type [5]. The furrow formed by the loosening paws below the plow sole promotes better penetration of the roots of cereals into the deeper layers of the soil [6]. Branches of the root system of cereals take the root in the cracked walls weakened by cracks [7]. Thus, the plant gains access to moisture and nutrients to realize the biological potential of cereals [8].

The set of technical means for the implementation of the system of basic tillage significantly determines the energy efficiency of a particular technology of growing cereals [9], its environmental and economic orientation [10]. One of the solutions in soil-saving agriculture is the introduction of the parquet-type working bodies for deep loosening of the soil [11]. The original design of the paw of the tillage unit with parquet-type working bodies has seven cutting surfaces [12]. However [13], achieving the technological effect leaves room for finding ways to minimize the energy costs.

Modern studies of the soil ability to accumulate and store productive moisture during the growing season have been established in three tillage systems [14]. The first system, with a canning system or deep loosening, there is an additional accumulation of productive moisture in a meter layer of soil up to 30 millimeters. The second system, for mulching – up to 15 millimeters. The third system, mini-till – up to 20 millimeters.

Insufficient amount of 16-21% preservation of mulch and its uneven distribution on the field surface in all variants of using non-traditional tillage systems cannot effectively prevent the evaporation of moisture under conditions of high ambient temperature [15]. The deep loosening paw loosens the middle and surface layers of the soil, improves soil permeability and aeration [16].

According to French developers, a 3-meter-wide chisel with new parquet-type implements requires 28% less fuel than an asymmetric impeller and 38% less than straight racks [17]. This can be an alternative to choosing a tillage unit with higher productivity compared to traditional plowing [18]. Estimation of operational and technological indicators of deep cultivators, in comparison with initial requirements, reveals possibilities of realization of the constructional and technological potential put in the tillage unit [19].

Energy indicators and characteristics of tillage units with parquet-type working bodies, depending on the layout of the unit with fixed working bodies, have escaped the attention of researchers [20].

The purpose of these studies is to establish the impact of the mutual location of the working bodies on the energy performance and modes of operation of tillage units with working bodies of the parquet type.

Materials and methods

The technological process of tillage by working bodies of the parquet type is performed by an asymmetric rack and a paw, made as separate, sequentially placed broken planes. They provide separation and displacement of the chip in the vertical and horizontal planes, creating an extensive network of cracks in the space between the paws. The influence of the relative position of the working bodies was studied in two ways. The first option, frontal with paired counter asymmetry. The second option, chess placement of working bodies. Energy indicators are explained by the processes of compression and relaxation of pinched soil massifs in the space between the paws and their intensive loosening.

Theoretical simplifications were accepted at the beginning of the research. First, the energy consumption for the useful loosening work can be reduced by optimizing the overlap of the zones of volumetric deformation of the soil between adjacent working bodies. Second, the increase in traction resistance to the limit of nominal traction power will be approximated by linear dependences.

To ensure high-performance use of the tillage unit with parquet-type working bodies, it is necessary to solve problems related to the substantiation of rational modes of operation for each of the options for the mutual location of the working bodies, since the energy performance of the tillage unit in general depends on them.

A scientific hypothesis has been put forward, according to which it is possible to increase the efficiency of the use of deep loosening working bodies by their rational mutual arrangement, which ensures optimal overlapping of the zones of volumetric deformation of the soil. Determination of energy indicators was carried out with two variants of the structural design of the tillage unit with working bodies of the parquet type: single-row frontal (Fig. 1,a) and double-row chess arrangement of the working bodies (Fig. 1,b).

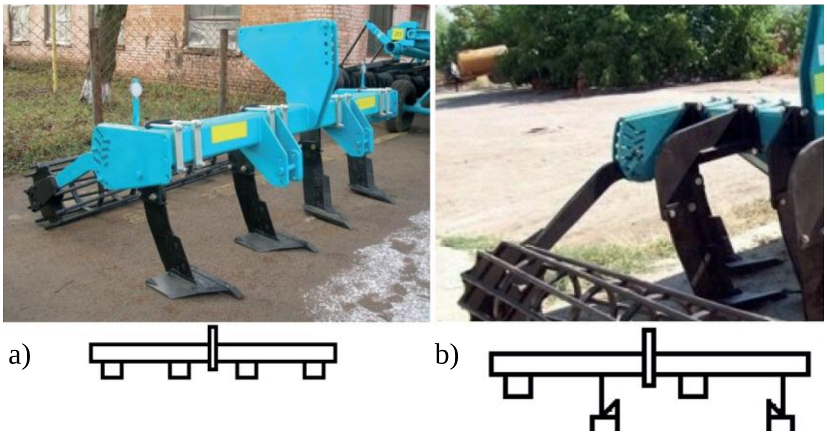

Fig. 1. **Appearance of tillage unit with working bodies of parquet type in single-row front (a) and double-row chess (b) design**

During the research, the tillage unit with parquet working bodies was aggregated with a wheeled tractor HTZ-17221 with a capacity of 128.7 kW, which at a specific fuel consumption of 251.6 g·(kWh)$^{-1}$ develops a traction force of 30-40 kN (Fig. 2).

The experiment was performed on the modes set by changing the gears and gear ranges of the tractor HTZ-17221. The arrangement of the working bodies of the tillage unit in a two-row chess scheme was performed with the use of additional brackets, the distance between the rows was 630 millimeters. The general technical characteristics of the tillage unit with working bodies of the parquet type are given in Table 1.

Fig. 2. **Appearance of tillage unit with working bodies of parquet type in field experiment**

Table 1

General technical characteristics of the tillage unit with parquet-type working bodies

Indicator, characteristic	**Value of indicator or content of characteristic**
Aggregation method	mad
Working width of capture, m	3
Number of working bodies, pcs.	4
Depth of cultivation, mm	250-400
Aggregation with a tractor, kN	30
Deviation of the paw riser from axis, deg.	10
Number of working surfaces of the cutting element, pcs.	7

Energy indicators, taking into account the structure of the information flow of dynamic loads, were measured by the strain gauge. Serial rods in the design of the rear hitch system of the tractor HTZ-17221 were replaced by strain gauges. Calibration of strain gauges was performed by static load. The sensors were connected in a full bridge and connected to the input of a Spider 8 analog-to-digital converter with CatMan Express 4.5 software. The complex performs polling of sensors with a frequency of 50 Hz, conversion of signals for the formation of a digital array in the format * .xls. The translational speed of the unit was recorded by a track measuring wheel equipped with a D4V-1 sensor and attached to the tractor footrest.

The work of the tillage unit with the working bodies of the parquet type took place in real field conditions using the technology of growing grain crops in Ukraine (Table 2).

Table 2

Conditions of field experiment of the tillage unit with working bodies of parquet type

Indicator, characteristic	**Value of indicator or content of characteristic**
Soil type and name according to mechanical composition	Deep medium-loam chernozem has little humus
Depth of cultivation, mm	300 ± 20
Relief	plain
Microrelief	smooth
Air temperature, °C	15
Relative humidity, %	64

Table 2 (continued)

Indicator, characteristic	**Value of indicator or content of characteristic**
Soil moisture, % by layers, cm	
0-5	16.7-18.5
5.1-10	18.1-19.2
10.1-15	19.0-20.9
15.1-20	19.4-22.0
20.1-25	21.2-22.4
25.1-30	22.7-23.0
Soil hardness, MPa in layers, cm	
0-5	0.4-0.6
5.1-10	0.7-0.6
10.1-15	1.0-1.9
15.1-20	1.8-2.1
20.1-25	1.9-2.5
25.1-30	2.1-2.5

Results and discussion

Analysis of digital arrays with the results of the research on the implementation of dynamic loading processes with a duration of at least 10 seconds are summarized in tabular form (Table 3).

Table 3

Energy performance of tillage unit with parquet-type working bodies

Range and transmission mode of the tractor	**Translational speed of the unit F_i, km·h^{-1}**	**Skidding δ_i, %**	**Traction resistance v, kN**
in single-row frontal design (Fig. 1,a)			
I – 2	5.8	1.8	25.518
I – 4	7.9	8.3	27.814
II – 1	10.1	11.7	29.414
II – 2	10.8	16.2	28.954
II – 3	11.2	20.2	31.971
II – 4	12.3	28.2	32.078
two-row chess design (Fig. 1,b)			
I – 2	5.8	2.2	23.202
I – 4	7.8	7.0	28.150
II – 1	9.8	9.2	28.227
II – 2	10.9	12.3	28.494
II – 3	11.2	22.2	30.216
II – 4	12.2	24.8	31.239

After processing the experimental data, the regression equations (1) and (2) were obtained, which reflect the dependence of the traction resistance of the tillage unit with working bodies of the parquet type F_i on the translational speed of the unit v:

- in single-row frontal design (Fig. 1, a)

$$F_1 = 0.9874 \cdot v + 19.726\,, \tag{1}$$

- two-row chess design (Fig. 1, b)

$$F_2 = 0.9391 \cdot v + 19.229\,. \tag{2}$$

Statistics of processing the experimental data of expression (1) – polynomial of the first degree, probability level P = 0.95, t_α = 2.013, the regression coefficient is linearized + 19.726, coefficient of multiple determination D = 0.988, coefficient of multiple correlation 0.9818, standard deviation of estimate 0.022, F Fisher's criterion 158.883, the coefficient D is significant with a probability of 0.9998. Statistics of processing the experimental data of expression (2) – polynomial of the first degree, probability level $P = 0.95$, $t_\alpha = 2.013$, the regression coefficient is linearized + 19.229, coefficient of multiple determination $D = 0.898$, coefficient of multiple correlation 0.879, standard deviation of estimate 0.153, F Fisher's criterion 102.313, the coefficient D is significant with probability of 0.9985.

The increase in traction resistance occurs in both versions of the design with different intensities, as evidenced by the angular coefficients of (1) and (2). In the single-row front design, the energy intensity of the process increased by 22% with an increase in the speed by 5.5 $km \cdot h^{-1}$, and in the double-row chess design – by 14.5% [16]. In two-row chess at a speed of 8 $km \cdot h^{-1}$, the traction resistance is reduced by 3.5%, and at a speed of 10 $km \cdot h^{-1}$ the advantage increases to 5.8% compared to single-row. However [20], the low value of the coefficient of reliability of dependence (2), relative to the approximation dependence, gives grounds to suggest the significant dependence of traction on the type of soil and its mechanical composition. As the transverse distance between the working bodies did not change, the factor of overlapping of the zones of volumetric deformation of the soil was constant [9]. The factor of pinching of soil massifs in the space between the tillage space of the tillage unit with working bodies of the parquet type adds 5% of energy consumption. Along with obtaining the best technological result, the single-row front-mounted installation of working bodies is more rational.

The increase in traction resistance causes an increase in slip (3) and (4), the mode of movement with a slip coefficient of more than 20% leads to higher fuel consumption and makes the operation of the tillage unit with working bodies of the parquet type economically impractical:

- in single-row frontal design (Fig. 1, a)

$$\delta_1 = 4.0837 \cdot v - 22.959, \tag{3}$$

- two-row chess design (Fig. 1, b)

$$\delta_2 = 3.6631 \cdot v - 21.071. \tag{4}$$

Statistics of processing the experimental data of expression (3) – polynomial of the first degree, probability level $P = 0.95$, $t_\alpha = 2.013$, the regression coefficient is linearized –22.7959, coefficient of multiple determination $D = 0.977$, coefficient of multiple correlation 0.9103, standard deviation of estimate 0.360, F Fisher's criterion 45.529, the coefficient D is significant with probability of 0.9978. Statistics of processing the experimental data of expression (4) – polynomial of the first degree, probability level $P = 0.95$, $t_\alpha = 2.013$, the regression coefficient is linearized –21.071, coefficient of multiple determination D = 0.976, coefficient of multiple correlation 0.8984, standard deviation of estimate 0.612, F Fisher's criterion 49.279, the coefficient D is significant with probability of 0.9995.

According to the slip indicators, rational modes of operation of the tillage unit with parquet-type working bodies in aggregation with a tractor that develops a traction force of 30-40 kN tillage can be carried out at speeds up to 10 $km \cdot h^{-1}$, under such conditions the tillage productivity is 3.1 $ha \cdot h^{-1}$. The productivity is higher compared to shelf tillage, as the width is 3 meters at 10 $km \cdot h^{-1}$ and the plow with five housings is 2 meters and 6 $km \cdot h^{-1}$ is 1.2 $ha \cdot h^{-1}$.

Conclusions

1. In the tillage unit with working bodies of the parquet type with a single-row frontal design, the energy intensity of the process with an increase in the speed by 5.5 $km \cdot h^{-1}$ increased by 22%, double-row chess – 14.5%. In two-row chess at a speed of 8 $km \cdot h^{-1}$, the traction resistance is reduced by 3.5%, and at a speed of 10 $km \cdot h^{-1}$ the advantage increases to 5.8% compared to single-row.
2. Clamping of soil massifs in the space between the tillage unit with working bodies of the parquet type adds 5% of energy consumption, but given the technological result of loosening the soil, it is rational to install single-row working bodies.
3. The optimal modes of movement of the tillage unit with working bodies of the parquet type are the speed up to 10 $km \cdot h^{-1}$, which corresponds to the full load of the tractor relative to the thrust of 85% at the permissible values of slippage of tractors at 15%. Tillage productivity is 3.1 $ha \cdot h^{-1}$.

Author contributions

Conceptualization, I.R.; methodology, L.T.; software, L.T.; validation, I.R. and L.T.; formal analysis, I.R. and L.T.; investigation, I.R., L.T. I.S., L.B. and A.V.; data curation, I.R. and L.T.; writing – original draft preparation, L.B.; writing – review and editing, L.T. and L.B.; visualization, I.S.; project administration, I.R.; funding acquisition, I.R., L.T. I.S., L.B. and A.V. All authors have read and agreed to the published version of the manuscript.

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