STUDY OF A PUSH-PULL PLOUGH COMBINATION

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The article presents the results of the study of two plough combinations. One of them included a XT3-16131 tractor, a front-mounted double mouldboard plough and arear-mounted four-furrow plough (*Push-pull* combination '2 + 4').The second combination consisted of the same tractor and five-furrow rear-mounted plough ('0 + 5'combination). According to the experimental data, the working width of '2 + 4' unit was 20.9% higher than the working width of '0 + 5' unit. And although the working speed of the first combination turned out to be 1.5% lower, due to the width advantage the productivity of its work was higher by 19.5%. As a result, the specific fuel consumption of the '2 + 4' unit was lower. Fuel economy made up 11.5 per cent under the conditions of the field experiment. The average square deviation of the ploughing depth in both compared combinations did not exceed agrotechnical requirements (± 2 cm) and made up±1.98 cm for '0 + 5' unit and ± 1.52 cm for '2 + 4' unit. At the same time, the indicated difference between these statistical characteristics (± 1.98 cm and ± 1.52 cm) is not accidental. On these grounds it can be assumed that application of the *Push-pull* '2 + 4'plough combination ensures soil cultivation providing better uniformity of the plough motion in depth.

Keywords: ploughing, combination, push-pull, front-mounted plough, productivity, fuel consumption.

INTRODUCTION

One of the most important tasks of agricultural production is to reduce power inputs on ploughing. The first step in this problem solving is to improve traction of the tractor by increasing its coupling weight.

This can be achieved by using ploughing combinations with the ploughs attached using a *Push-pull* method. According to theoretical studies, due to the vertical component of traction resistance of a front-mounted plough, front wheels load rises. This increases tractor coupling weight. [Nadykto, 1994; Nadykto, Genov, Ayubov, 2003]. As a result, this leads both to a certain decrease in combination slippage and to reduction of specific fuel consumption for the ploughing unit in a whole [Nadykto, 1996].

However, if the front plow is not attached correctly to the power unit, it may not be loaded, but on the contrary the unloading of the tractor front wheels can take place. This causes the inevitable loss of handling and stability of the entire ploughing combination. Theoretical studies have established that in order to avoid this, while using a tractor with 32 kN of traction power, the front-mounted plough should have two bodies and a rear-mounted plough needs four bodies ('2 + 4' combination) [Nadykto, Kistechok, 2015]. The tractor moves in the furrow with its right wheels, the front plough is attached rigidly to the tractor in the horizontal plane, and the supporting wheel of this implement is located outside the furrow.

The purpose of this article is to present and analyze the results of an experimental evaluation of trajectory, traction, power and agrotechnical parameters of the ploughing unit operation according to the *Push-pull* combination with '2 + 4' number of bodies.

MATERIALS AND METHODS

The ploughing unit with '2 + 4' combination consisted of a XT3-16131tractor, front-mounted double-furrow and rear-mounted four-furrow ploughs (Fig. 1a). To compare different combinations '0 + 5' ploughing unit, which included the same tractor and a rear-mounted five-furrow plough ПЛН-5-35 (Fig. 1b), was tested as well.

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a)
b)


Figure 1. ‘2 + 4’ (a) and ‘0 + 5’ (b) ploughing combinations

Ploughing units specification

Engine power of XT3-16131 tractor, kW	132
Operating weight, kg	8100
Track width, mm	2100
Longitudinal tractor base, mm	2860
The size of front and rear axle tires	16,9R38
Front-mounted plough working widtn, m	0,70
Rare-mounted plough, m	1,40
The working widtn of ‘2 + 4’ ploughing combination, m	2,10
The working widtn of ‘0 +5’ ploughing combination, m	1,75

The following parameters were recorded during field tests:

- soil moisture and density;
- longitudinal and vertical profile;
- traction resistance and working width of ploughs (B_p);
- traverse speed (V_p), wheel slip (δ) and hourly fuel consumption of tractors (G_h);
- ploughing depth.

Soil moisture was determined by means of a widely known *Hot drying* method. A special method as well as a tool has been developed to measure topsoil density [Kuvachov, Nadykto, Kyurchev, 2008]

Oscillations in amplitude and frequency of the field profile unevenness in longitudinal direction (field profile) were measured with the help of a profile recording instrument – profilograph (Fig. 2).

Figure 2. The instrument which recorders field profile unevenness

The tractive resistance of the ploughs was recorded by means of a strain gauge unit designed for a tractive effort up to 40 kN.

The speed of the ploughing unit during operation was fixed by the use of a track wheel mounted on the tractor. Speed counters were installed on the hubs of the track wheel’s front and rear axles. Electric signals were read with the help of current collectors.

To measure the hourly fuel consumption of the tested tractor a pulse-type flowmeter was used. Electrical signals which were being produced by the profilograph, strain gage, trackwheel, speed counters and a fuel gauge were being recorded by a computer after passing through an analog-to-digital converter.

Tractor wheels skidding was calculated by the formula [Nadykto, 2003]:

$$\delta = 1 - \frac{n_{xx}}{n_p} \cdot \frac{V_p}{V_{xx}},$$

where n_{xx}, n_p is rotating frequency of the tractor wheels when the ploughing unit is being moved without the traction load and with it, respectively; V_{xx},V_p is the ploughing unit speed without the traction load and with it, m·s^{-1}.

It was provided that the ploughing units without load moved along the field with ploughs raised into the transport position.

Productivity of the plough combination (W_a, ha·h^{-1}) and specific fuel consumption (G_u, kg·ha^{-1}) was determined as follows:

$$W_a = 0{,}1 \cdot B_p \cdot V_p;$$
$$G_u = {}^{G_h}/_{W_a}.$$

All the parameters were measured at least 5 times.

RESULTS AND DISCUSSION

Laboratory and field studies were carried out in a field with the following parameters: soil moisture content was 16.5% and density was 1.26 g/cm^3.

Fluctuations in the field profile irregularities were high-frequency ones. This is definitely indicated by the length of the correlation relationship[1] of the ordinates of a given process: it does not exceed 0.3 m (Fig. 3). More over according to normalized autocorrelation function the oscillations in the amplitude of the longitudinal field profile contained a latent periodic component with a period approximately equal to 0.75 m.

Dispersion of the oscillations was also small (1.21 cm^2). It was concentrated in the frequency range of 0 ... 12 s^{-1}. When speed of the ploughing unit is 1.98 m · s^{-1}, frequency is 0 – 24 s^{-1} or 0 – 4 Hz.

According to the correlation and spectral analysis of the Fig. 3 given above, it can be concluded that the relatively high frequency and small dispersion of variations in the unevenness of the longitudinal and vertical profile of the field cannot generate more or less significant oscillations of the traction resistance of the front-mounted and rear-mounted ploughs attached to ХТЗ-160 tractor.

The main changes in this parameter (i.e. traction resistance) will be formed and as a rule are formed by the internal structure of soil environment which is under influence of the tillage working tools.

[1]Abscissa axis of the first zero value of the normalized autocorrelation function ρ (Fig. 1)

The ploughs fort he units with ‘0 + 5’ and ‘ 2 + 4’ implement combination were adjusted on the same working depth of 25 cm.

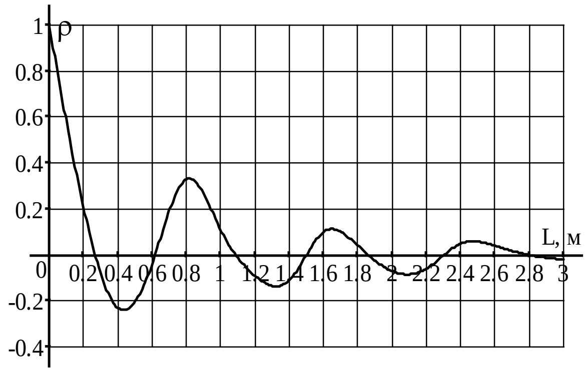

Figure 3. Normalized autocorrelation function (ρ) of field profile oscillations as a function of L path

Traction resistance of the plough unit with ‘0 + 5’ combination varied within the limits of 26.6 – 28.4 kN. Root mean square deviation of this parameter was ± 4.0 – 4.8 kN. As a result, the coefficient of traction resistance variation changed and made up 14.0-18.0%.This indicates the average variability of the process [Dospekhov B.A., 1985].

In comparison with ПЛН-5-35 implement, the total traction resistance of the front and rear-mounted ploughs of the unit with ‘2 + 4’ combination under approximately the same value of root mean square deviation (± 5 kN) made up 31.5 – 34.7 kN. Correlation time for these processes varied in this case in the 0.24 – 0.26 s range (Fig. 4).

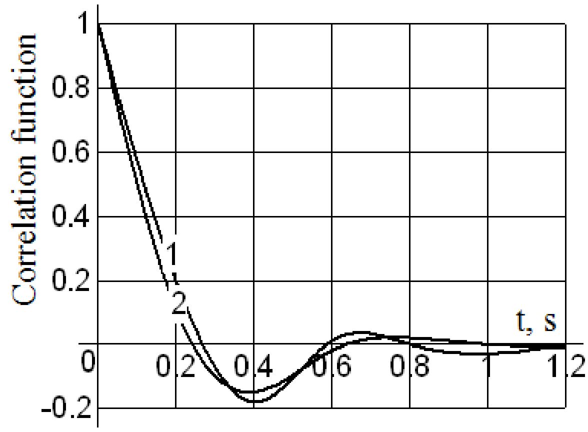

Figure 4. Normalized correlation functions of oscillations for traction resistance of the ploughs for the units with ‘0 + 5’ (curve 1) and ‘2 + 4’ (curve 2) implement combinations

Analysis of hands-on experience for those combinations showed that such duration of the correlation connection (as for time) characterizes the process as high-frequency one [Bulgakov V.M., Kravchuk V.I., Nadykto V.T., 2008; Nadykto V.T., 2017]. Spectrum of variances in the oscillations for plough traction resistance is relevant evidence of the fact. In the machine-tractor assemblies. It is concentrated in the frequency range of 0 – 25 s^{-1} or 0 – 4 Hz.

According to the results of measurements, the unit with a *Push-pull* (i.e. ‘2 + 4’) combination had an actual working width of the implement 20.9% higher than the ‘0 + 5’ploughing unit had.

Operating speed of the ploughing combination with a single five-furrow plough was 1.5% higher due to the smaller working width and therefore less traction resistance of the mounted implement (Table 1).

Table 1

The results of experimental studies for ploughing combinations on the basis of XT3-16131 tractor

Ploughing combination	V_w $^{1)}$, $m \cdot s^{-1}$	B_w $^{2)}$, m	W_u $^{3)}$, $ha \cdot h^{-1}$	h $^{4)}$, cm	δ $^{5)}$, %	P_{tr} $^{6)}$, kN	G_h $^{7)}$, $kg \cdot h^{-1}$	G_u $^{8)}$, $kg \cdot ha^{-1}$
‘0 + 5’	2,01	1,77	1,28	24,9±0,3	13,8	27,4	21,2	16,5
‘2 + 4’	1,98	2,14	1,53	25,1±0,1	14,4	33,1	22,3	14,6

$^{1)}$ – working speed;
$^{2)}$ – working width;
$^{3)}$ – unit productivity per 1 hour;
$^{4)}$ – ploughing depth;
$^{5)}$ – wheelspin of tractor;
$^{6)}$ – tractive resistance of the plough;
$^{7)}$ – hourly fuel consumption;
$^{8)}$ – unit specific fuel consumption.

As a result, the productivity per 1 hour for the unit with ‘2 + 4’ combination was 19.5% more than for the unit with a single rear-mounted five-row plough.

Since the tractive resistance of the ploughs with ‘2 + 4’ implement combination is higher than that of the unit with ‘0 + 5’ combination, it naturally had greater slippage of the tractor wheels (Table 1). In absolute terms it is by 0.6%, and in the relative terms it makes up by 4.3%.

At the same time due to higher productivity the specific fuel consumption of the *Push-pull* unit is 11.5% less. In our opinion this saving is possible due to more effective use of traction properties of the front axle of the tractor. The properties improvement is enabled because of front implement application. Its correct assembly causes loading of the front movers of the power equipment.

One of the main agrotechnical indicators of the ploughing unit work is uniformity of the depth of ploughing. According to the experimental data the mean square deviation of this parameter in both compared machines did not exceed the agrotechnical requirements (± 2 cm) and made up the following values: for the unit with ‘0 + 5’ combination it was±1.98 cm and for the ‘2 + 4’ implement combination it was ±1.52 cm.

According to results of a variance analysis difference between these mean square deviations is not random at a statistical significance level of 0.05. It is explained according to Fisher’s F-criterion [Lurie, 1970] the null hypothesis as for the equality of the compared statistical estimates is not rejected.

It may be stated that with a confidence level of 95%, the‘2 + 4’ ploughing combination performs ploughing with a higher stability in the depth of tillage. One of the reasons for this result may be the fact that the front axle of the tractor XT3-160 performs less vertical vibrations when it moves in the furrow due to front-mounted plough application. As a result it positively affects the smoothness in operation of both the front and rear-mounted ploughs.

It should be emphasized that the normalized correlation functions and spectral densities of the oscillations of the working depth for compared ploughing combinations differ a little among themselves (Figure 5). For both versions of the implements, the length of the correlation is at least 21 m.

Moreover actual fluctuations in the depth of ploughing do not contain any latent periodic component. This result can be explained by the fact that the surface of the field was leveled before ploughing with the help of a disc harrow. Small variance of fluctuations in the field unevenness, which is only 1.24 cm^2, proves this.

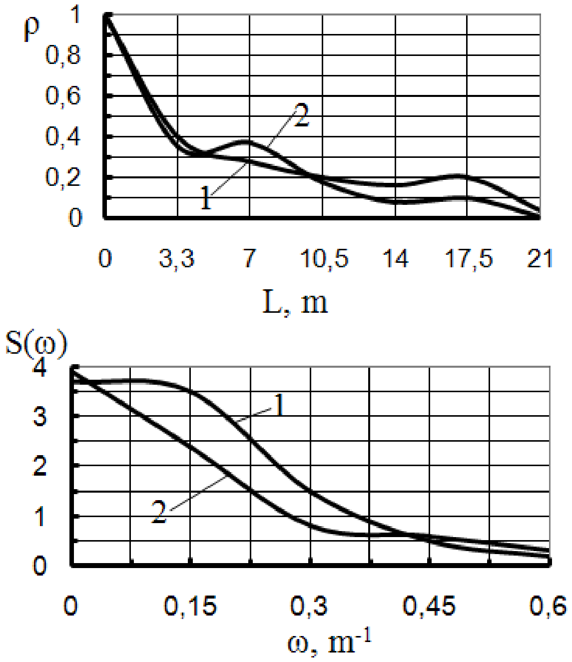

Figure 5. Normalized correlation functions (ρ) and spectral density [S (ω)] for oscillation of ploughing depth for the units with '0 + 5' (curve 1) and '2 + 4' (curve 2) implement combinations

Moreover during the operational movement the tractor wheels have a certain slippage. And since this process is accompanied by the cutting of the soil by the soil-hooks of the movers, an additional alignment of the power unit path takes place. The amplitude of its vertical oscillations decreases in this case. This causes decrease in vertical oscillations of the ploughs which are mounted on a tractor. The final consequence of this is increase of ploughing depth stability for the *Push-pull* system.

CONCLUSIONS

The advantages of front mounted agricultural machines make it possible to create a basis for highly efficient *Push-pull* implement combinations.

Push-pull ploughing unit with ХТЗ-16131 tractor, two-furrow front and four-furrow rear ploughs ('2+4') in comparison with the combination of the same power unit and a rear five-furrow tillage implement ('0+5') has a 19.5% increase in productivity and a lower (by 11.5%) fuel consumption.

The use of the '2+4' ploughing unit provides higher stability of plough motion while tilling.

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