METHODS OF MAINTAINING SOIL DEPTH EVENNESS DURING DISK TILLAGE

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The article examines agro-technical requirements of machine implements with disk working bodies and is aimed to investigate the existing and alternative methods of depth regulation during soil tillage by the mentioned implements. We defined the machines performance indicators significantly affecting the plant potential release not considered previously. The study results were obtained via the soil tilling depth regulation by the disking speed, the change of an incidence angle of the working batteries, and by the use of the additional load mounted on the machine frame. The article presents a two-year research results obtained in 40 different land plots of the Sumy region (Ukraine) using domestic and imported machines, with wheat and buckwheat as crops. To ensure the study accuracy, the methodology was based on the CND 46.16.02.-96. Agricultural Machinery. Quality Indicators Nomenclature (Catalogue of Normative Documents, published in 1997). The research results demonstrate that the tilling depth depends on the manufacturing plant default settings, the speed regime, and the machine load. For the experimental data analysis, the Least Squares Means method was used. The research presents alternative methods of changing the tilling depth applicable for any machine aggregates with disk working bodies, and its results can serve the agricultural machinery designers.

disking, tillage implements, operating conditions, agro-technical requirements, adjustment, performance quality

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INTRODUCTION

Soil tillage working bodies of the agro machines create the necessary conditions for intensive growth and development of plants: due to the correct soil tilling it enables the access of oxygen and moisture into the soil, the root system develops faster and thus the plant is able to absorb the macro- and micronutrients from the soil more intensively.

In practice, as a rule, the configuration of the machines is performed only on those indicators which are recommended by the machine manufacturer. But is there any alternative allowing us to minimize financial cost?

Various researchers indicate such alternatives, however in Ukraine, which is coping with financial scarcity, only large agro holdings (e.g. Kernel Holding S.A.) conduct relevant researches aimed at improving the technological processes. Small and medium farms have neither the financial resources nor the scientific capacity to conduct such researches. Therefore, it is important to undertake relevant studies and to develop recommendations for the effective crops cultivation in regard to the agro machines use.

The main purpose of disking is the stubble demolition and hoeing of the topsoil, thereby reducing the rate of moisture evaporation through the stubble (Yeschenko, 2004). With the help of water, air and heat the plant seeds swell and grow; the growing tissue helps the nutrients to enter into the plant and move through it. A plant organism contains 75–90% of water; that is why all life processes are closely connected with its flow and circulation (Hudz et al., 2010). Still, the soil tillage should be performed in

Table 1. Agro-technical requirements to the machine implements with disk working bodies

Indicators	Requirements and tolerance gaps
Steady depth (each crop needs its own depth parameters to be fulfilled)	no more than ± 20 mm from the specified depth (previously it was not considered to be crucial)
Aggregation state of the soil	clods must not exceed 35 mm
Deviation of an average actual depth of tillage from the planned one (mm)	no more than ± 15 mm
Depth of the depressions or the height of the mounds after tilling (mm)	no more than 40 mm
Cutting of weeds (%)	100%
Allowed amount of stubble not harbored into the ground (%)	4%

a way that would not influence the soil temperature regime (Stipesevic, Kladivko, 2005).

The researchers have defined that for the best water, air, temperature and nutrient conditions in the soil, the compaction must attain 1.1–1.3 g cm^{-3}, the content share of agronomically valuable structural clods (aggregates) with the size of 0.25–10 mm is supposed to be at least 70%, their hardness must be no more than 30 kg cm^{-2}, air intensity qualities – at least 15% of the soil volume, the total soil penetration resistance value up to 50–55%, water conductivity not less than 30 mm per h (Hudz et al., 2007; Bartlova et al., 2015).

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Disking significantly reduces the weeds quantity in the fields and should be conducted simultaneously with the harvesting processes (Yeschenko, 2004). On average, there are 700–800 million of similar seeds of various weeds in the arable soil layer per 1 ha (UDEC, 2017). The assessment of performance quality of machine implements with disk working bodies is carried out according to the figures given in Table 1 (Gevko et al., 2005).

The research results demonstrate that the optimal clot structure of the soil is formed during the surface tillage by disking (Bartlova et al., 2015). Different authors (Daraghmeh et al. 2009; Boguzas et al., 2010) claim this to be a result of a big quantity of organic elements that appear.

Power consumption and quality performance indexes of tillage machines are determined by constructive peculiarities of their working bodies in general. The loosening and mixing of the soil are influenced by unit's angles, diameter and radius of the disks curvature and the rotation speed (Alam, 1989; Al-Ghazal, 1989; Braginets, Shovkoplias, 2011). Still, the quality of work of tillage implements with disk working bodies depends on the proper set of operation modes, which are determined not only by their construction features, but by the operating conditions, too. Thus, it was proposed to adjust the cultivation depth by the balance between the moment of the disk penetration and the moment of lifting the disk (Kogut et al., 2016). The impaired work quality may be caused by a soil structure within the same soil-climatic zones, not depending on different predecessor crops, and even within the same field (Soht et al., 2014).

Physical-mechanical and technological qualities of the soil are a quite complex system of indicators. The most important of these is the soil hardness. The density of the soil penetration resistance value is formed by its moisture content and these two properties are closely linked (Soht et al., 2014).

Based on field studies of soil-cultivating units performance, it was found that the quality of the machines work is significantly affected by the type of the soil, its humidity, stickiness, condition of its surface, material of the working bodies, and relative speed of their movement. The performance quality of the disk unit is also significantly affected by the post-harvesting residues of stubble and roots, their amount and mechanical-technological properties.

The aim of the research was to study the influencing factors like disking execution speed, angle of attack and additional load on the machine frame and their impact on the efficiency and performance quality of tillage implements with disk working parts.

MATERIAL AND METHODS

The study was conducted using various units during two consecutive years at different farms of the Sumy region: experimental fields of the Sumy National Agrarian University, private enterprise 'Nad', Limited Liability Company 'Vorozhba-Latinvest', Shevchenko agricultural LLC, farming household 'Kuzin V.S.'. Disking of the soil was carried out after such agri-

Table 2. Specifications of the harrow Quivogne APXTL 36

Specifications	Parameters
Type	trailer
Maximum working speed (km h^{-1})	12
Weight (kg)	3 820
Number of disks (pieces)	36
Width of capture (m)	4
Depth of processing (mm)	50–1
Diameter of discs (mm)	660
Aggregation with a tractor	New Holland

cultural crops as winter wheat and buckwheat, which had been harvested from the fields.

Methodology

The study of the execution quality of disking was performed in accordance with standard methodologies defined by the state Ukrainian regulations: (1) CND 46.16.02.-96. Agricultural Machinery. Quality Indicators Nomenclature (published in 1997); (2) CND 46.16.02.08-95. Agricultural Machinery. Methods for Defining the Experiments Conditions (published in 1995); (3) RD 10.4.2-89. Testing of the Agricultural Machinery. Machines and Tools for the Soil Surface Cultivation. Programs and Methods of Testing (Industry standard, published in 1990); (4) GOST-20915-75. Agricultural Machines. Methods for Defining the Experiments Conditions (State All-Union Standard (USSR State Standard specification), published in 1975).

The approaches of the methodology are the simplest for getting the empirical data in real life and their efficiency has been proven for 20 years already. For the experimental data analysis the Least Squares method was used (Dougherty, 2011). The research data were processed using the MS Excel application. The MS Excel table was generated using the arithmetic average of the input data according to the results obtained. To construct the scattering field and a theoretical curve the 'Diagram' option was applied. The option 'To Add the Trend Line' allowed to build the theoretical curve demonstrating the regression equation and the probability of approximation. The approximation was done according to the linear, logarithmic, stage-based, exponential distribution law. As a basic distribution law was chosen the one with the maximal probability of approximation. The measure of the link is shown by the determination coefficient R^2.

Equipment used

The performance indexes of both foreign and domestic machinery on the fields of the Sumy region (a forest-steppe zone of Ukraine) became the object of the research. The machines implements comprised of the following units: MTZ 892 + UDA-2.4, New Holland + Quivogne APXTL 36, HTZ 17221 + UDA-3.1, Fendt 360 + Fradit 6000, 701 + SOLOKHA, T-150 + UDA-3.8, John Deere 8400 + BDT-10, T-150K + BDT-7.0 A, Fendt 936 + 6.7 BGR, Case of 270 + 4.2 BGR. To be more precise, Quivogne APXTL 36 is a trailer disk harrow produced in France (Quivogne CEE); UDA-2.4, UDA-3.1, UDA-3.8 (universal disking implement) are also the trailer harrows with disks, produced in Ukraine (LLC "Bilotserkovmaz"), and the MTZ harrow is of the Byelorussian origin (Minsk Tractor Plant). The presented machines were used for the investigation of the additional impact tools on the regulation of the soil tilling depth by changing the working speed, the angle of attack and additional load on the machine frame. The variety of the machines applied allowed to diversify the results of the research.

The technical characteristics of the machines studied are given in Tables 2, 3.

Operating conditions

The research data were obtained over the two consequent years (2016–2017) during the tillage of 40 fields of the Sumy National Agrarian University,

Table 3. Specifications of the disk units of the UDA harrow type

Specifications	UDA-2.4	UDA-3.1	UDA-3.8
Type	trailer		
Maximum working speed (km h^{-1})	8–12	8–12	8–12
Weight (kg)	1 750	1 950	3 100
Number of disk batteries	4	4	4
Width of capture (m)	2.4	3.1	3.8
Depth of processing (mm)	50–180	50–180	50–180
Diameter of discs (mm)	650	650	650
Aggregation with a tractor	MTZ-892	HTZ 17221	T-150

Table 4. Operating conditions of disk implements during the research (2016)

Conditions indicators	Case 1 (after harvesting buckwheat)	Case 2 (wheat stubble)
Moisture content in the soil layers (%)		
0–5 cm	12.5	12.9
5–10 cm	17.8	15.5
10–15 cm	17.1	18.2
Hardness in the soil surface layers (mPas)		
0–5 cm	3.05	2.5
5–10 cm	3.98	2.15
10–15 cm	3.17	2.95
Stubble height (cm)	116.0	25.4

private enterprise 'Nad', LLC 'Vorozhba-Latinvest', Shevchenko agrarian LLC, farming household 'Kuzin V.S.'. The fields were used for wheat or buckwheat cultivation. The climate conditions were moderate during the experimental period (Table 4).

Soil moisture in both cases was almost identical in the upper 0–15 cm soil layer (12.5–18.2%). At the same time, the soil penetration resistance value was slightly different – within 2.5–2.95 MPa in Case 2 (wheat stubble), but 2.98–3.17 MPa in Case 1 (after harvesting buckwheat), which was significantly higher than the optimum line, which is 0.4–1.6 MPa for this type of work. Also, Case 2 was marked by the maximum hardness of the soil within the 10–15 cm layer, while this maximum was within the layer of 5–10 cm in Case 1. The stubble height was also different: 116 cm for Case 1, 25.4 cm for Case 2. Previous years working conditions varied within 12%.

Experiments

The required depth of tillage is determined by the plants needs and specifics of soil and climatic conditions (H u d z et al., 2007). The tilling depth adjustment also depends on technological features of the used agro machines with disk working bodies. Thus, the tilling depth adjustment of the Quivogne APXTL36 was fulfilled by means of two hydraulic cylinders with hydro clips, the sectional adjustment and by installing the angle of attack of the disk batteries (Fig. 1). In such a way the tilling depth may be set up at a 40–180 mm level.

The tilling depth of the domestic machines UDA-2.4, UDA-3.1, UDA-3.8, manufactured by LLC 'Belocerkovmaz', is regulated by changing the angle of attack from 12 to 21° as presented in Fig. 2. Thus, the tilling depth varies from 50 to 180 mm.

While conducting the research, the additional method of tilling depth change was used: additional load was fixed on the frame of a disc harrow UDA 3.1 as presented in Fig. 3.

While disking, it is important to control the evenness of the tilling depth (Fig. 4), the height of ridges on the soil surface (if it is within the determined limits) (Fig. 5) and to perform a visual control of pruning and burring the plant residues into the soil.

Fig. 1. The working process of the soil disking by the Quivogne APXTL harrow

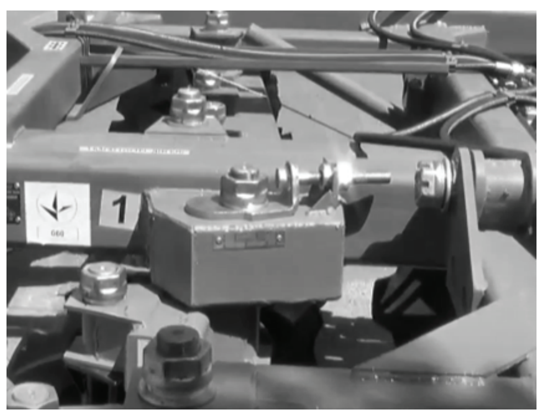

Fig. 2. Adjustment of the disking depth by changing the angle of attack on the UDA-3.1 implement

The depth of the working bodies' penetration was measured by using a preliminary made metal probe with relevant tick marks. The probe was plunged into the soil, as presented in Fig. 4, until it started to contact with the thick sole formed by the disk. The reached mark was assessed by the scale on the probe and fixed in the working materials. The obtained data were used for the analysis of the depth maintenance by the working bodies and of the average deviation of the actual tilling depth from the expected one.

The depressions depth and the ridges height after the soil tillage by agro machines with disk working bodies were defined using a 2-metre rack put on the ridges tops and a scale ruler, which was fixed at the bottom of a furrow (Fig. 5). The obtained data were recorded in the working materials.

The soil's ability to resist the indentation of the working body of tillage machines in it is called the soil penetration resistance value**.** To determine this parameter at a depth of 250 mm, the Revyakin soil penetration resistance value tester was used (Fig. 6), which operated according to the principle of measuring the indentation degree of a working body into the examined soil. Before the soil penetration resistance value tester was applied, a conical shape tip (a cone) with the known diameter of 20 mm (the indentation area) was fixed on it. The soil penetration resistance value tester was also equipped with a flight data recorder, which presented the chart change of the pressure force of the measuring cone into the studied soil. The obtained data were processed into the research results by mathematical statistics methods with the defini-

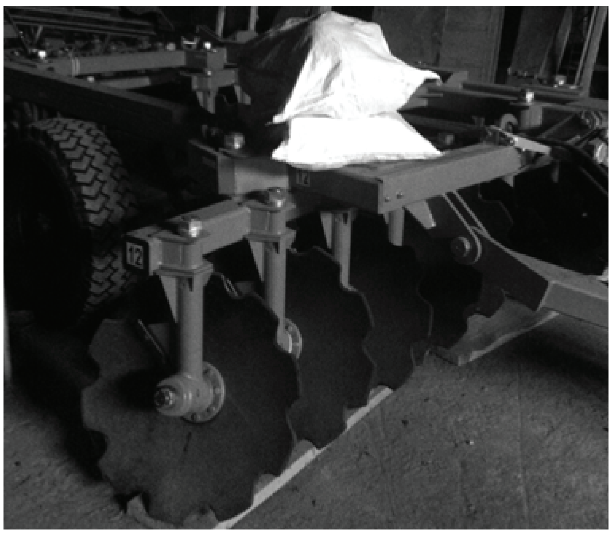

Fig. 3. Adjusting the disking depth with the additional load on the UDA-3.1 implement.
According to the methodology all the data were examined separately

Fig. 5. Determination of the ridges height on the soil surface after disking

Fig. 4. Determination of the depth evenness after disking

Fig. 6. Defining the penetration resistance of the soil

tion of the arithmetic average of the soil penetration resistance value, standard deviation, and coefficient of variation. The soil penetration resistance value was measured by means of the following equation (S a g l a m et al., 2015):

$$PR = \frac{F}{A} \times 0.0981 \quad (1)$$

where:
PR = penetration resistance
F = reading; the value of force (kgf)
A = floor space of the beveled end (K o r u c u , 2002).

The aggregate (physical) state of the soil was determined using the following approach (O r m a n d z h i , 1991): a 1 m^2 area frame was put down on ten places along the diagonal of the plot in order to define the boundaries of the area to be studied. The next step was to count the number of aggregates and calculate the average value.

To obtain the data on the weeds number on the studied plot, the 1 m^2 area frame was put down on 5–6 places on the land plot diagonal. The amount of not pruned weeds was calculated within prior determined boundaries and thus the value of the relevant index was received.

To determine the amount of the stubble which was not dug into the soil, the studied area was visually inspected. If necessary, the 1 m^2 area frame was put down on 3–5 places on the land plot diagonal and the amount of the visually fixed stubble was counted. Thus the data regarding the respective indicator were received.

RESULTS

The purpose of the research was to find alternative methods for adjusting the depth of soil processing by disc harrows for an efficient operation of machines in different conditions.

The research also demonstrated that the efficiency of disk aggregates may be increased by applying the harrows with disks being moved by force (N a l a v a d e et al., 2010). Consequently, we investigated namely those machines whose working bodies were driven because of the motion on the field surface.

But there have been also promising methods of modifying the tilling depth. Thus, it is possible to adjust purposefully the movement speed (L e m k e n , 2017). Some researches (e.g. by S e r r a n o et al., 2003; S i n g h et al., 1978) defined the dependence of the motion speed from the angle of attack. Our research is aimed at determining the links between the working speed and tilling depth. It should be mentioned that there exist researches of the disk shape influence on the aggregate productivity (C h a p m a n et al., 1988), which raises the need to investigate relevant issues for the modern machines.

The conducted analysis proved that the tilling depth and the evenness of the machine's working body performance (namely, disking) primarily depends on hardness of the soil, the cultivation of which is carried out. According to different authors (P a n a y i o t o p o u l o s , K o s t o p o u l o u , 1989; C a r a v a c a et al., 2004) penetration resistance of natural soils is more equable within the different layers comparing to those soils that are tilled. While the agricultural enterprises use already tilled soils and their penetration resistance is not equable within the soil layers, the importance of steady tilling depth is undeniable.

Basing on the analysis of regulating methods of the tilling depth it was decided to investigate the influence of the angle of attack, additional load, working speed, and soil hardness on the quality indicators of disking: evenness of the depth, aggregation state, height of ridges and soil friability (crumbliness).

The research of the impact of the angle of attack on the tilling depth was conducted during the operation of the HTZ 17221 + UDA 3.1 implements (Fig. 7). The soil depth was examined according to the four

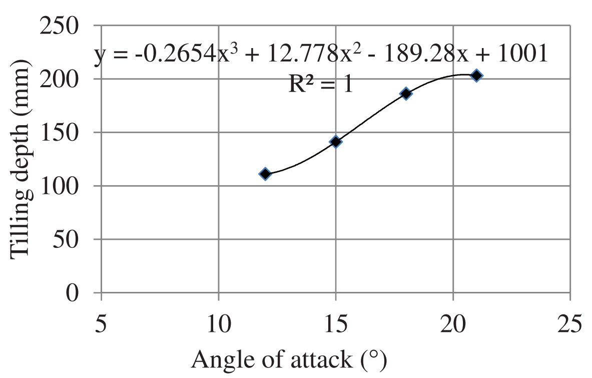

Fig. 7. Change of the disking depth along with changing the attack angle of the machine implement consisting of HTZ 17221 + UDA 3.1

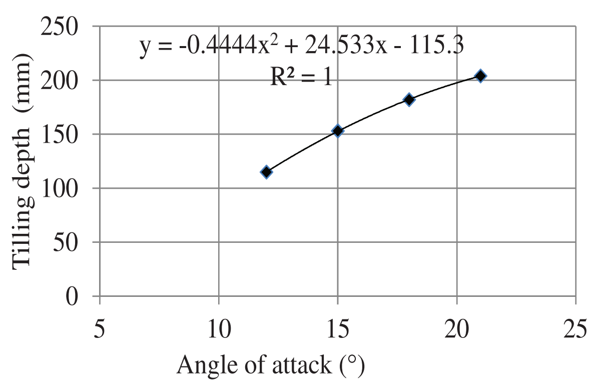

Fig. 8. Change of the disking depth along with changing the attack angle of the machine implement consisting of HTZ 17221 + UDA 3.8

values of the attack angle: 12, 15, 18 and 21° at a constant operating speed of the machine. The design feature of the machine makes it possible to change the attack angle only in the range from 12° to 21°. Therefore, studies with other values of the angle were not conducted.

The presented analysis of the disking depth demonstrates that the increased attack angle directly increases the tilling depth. Thus, when the attack angle increases from 12° to 21°, the depth is increased by 92 mm (75%). A similar trend was observed while studying other machine implements (Figs. 8, 9).

The investigation of the effect of machines operating speed on the soil tilling depth after disking was measured by a depth gauge at ten places of the land plot diagonal. The obtained average value was decreased by the amount of the tilled soil (20%) and was recorded into a database. The research was conducted at minimum speed 4 km h^{-1} and maximum speed 15 km h^{-1}. At lower speeds, the disk does not sink into the ground, and at higher speeds there is high vibration in the tractor cab. A graph presenting the soil tilling depth in dependence on the machine working speed is presented in Fig. 10.

The analysis of the correlation of the soil tilling depth and the machines speed mode showed that by increasing the speed of the implement from 4 to 15 km h^{-1} the tilling depth was increased by 17 mm (18.9%). The corresponding trend of the tilling depth increase in relation to the machines working speed increase suits all the other investigated machines units (Figs. 11, 12).

Fig. 13 presents the research results of the additional load effect on the soil tilling depth provided by the working machine implement consisting of the disc harrow MTZ-892 + UDA-2.4.

The analysis results of the additional load (sandbags) impact on tilling depth (Fig. 13) revealed that with each next kilogram of the additional load, the soil

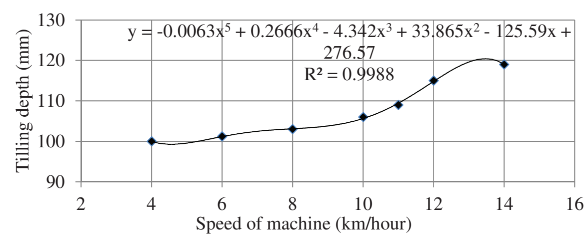

Fig. 11. Change of the disking depth by the speed change of the machine implement consisting of MTZ-892 + UDA-2.4

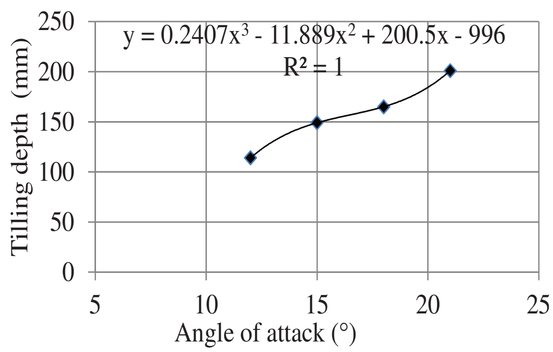

Fig. 9. Change of the disking depth along with changing the attack angle of the machine implement consisting of MTZ-892 + UDA-2.4

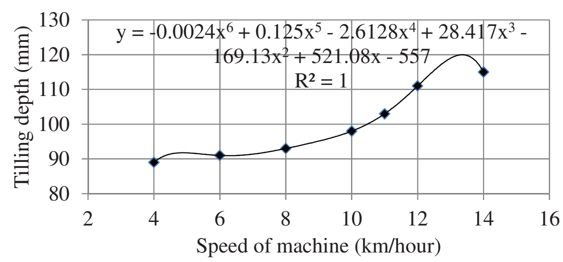

Fig. 12. Change of the disking depth by the speed change of the machine implement consisting of T-150 + UDA-3.8

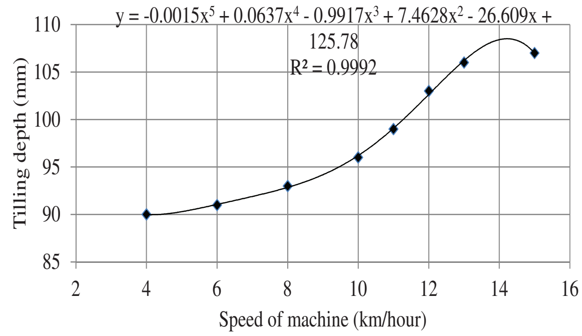

Fig. 10. Change of the disking depth by the speed change of the machine implement consisting of New Holland + Quivogne APXTL 36

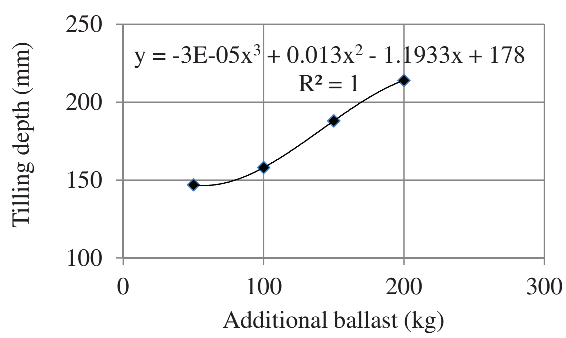

Fig. 13. Change of the disking depth by changing the additional ballast on the machine implement consisting of MTZ-892 + UDA-2.4

tilling depth was increased too. Thus, by increasing the additional load weight up to 200 kg, the soil tilling depth was increased by 70 mm (53%).

DISCUSSION

Unfortunately, usually the study of the machine implements performance is carried out at low speeds within 3–4 km h^{-1} (Kharchenko et al., 2017). Despite this, the operating speed mode for daily operations reaches 15–18 km h^{-1}. Obviously, the quality of the technological operation changes according to the speed and angle of attack with which the disks, under the influence of resistance forces, are pushed out to the surface (Haponenko, 2014). There is an undeniable fact that the evenness of disking directly influences the evenness of sowing. Accurate following of the precise depth is very important in the process of sowing (Paltik et al., 2005).

Our studies have established the dependence of the cultivation depth change on the machine operation speed and an additional ballast (Figs. 10–13). The research results show that it is necessary to increase the operating speed in order to improve the productivity of agrarian machines. The existing machines are not capable of operating at speeds above 14 km h^{-1}. Therefore, there is a need to change theoretical calculations, as well as to design a new approach to consider the dynamics of the aggregate, and to conduct more experimental research (Haponenko, 2014).

So there is a clear need in developing and implementing the devices for the precise determination of the exact soil tilling depth, height of ridges on its surface, its physical state and other parameters (depending on the type of the technological operation), which would fully achieve the crops biological potential.

CONCLUSION

Keeping a stable soil tilling depth becomes obligatory, as this is the basis for a seedbed and thus the relevant conditions for the evenness of sprouts are created.

Our research has proven that the soil tilling depth depends on the operating speed of the machines. With the use of a machines aggregate consisting of New Holland + Quivogne APXTL 36, at the speed increase from 4 to 15 km h^{-1}, the soil tilling depth has increased by 17 mm (18.9%). This trend is legitimate for any sets of machine implements, as has repeatedly been shown in other studies. By a 200 kg increase in the additional load weight on a machine implement consisting of MTZ-892 + UDA-2.4, the soil tilling depth was increased by 67 mm (45.6%).

Thus, in order to meet the needs of different plants and soils after various predecessor crops, it is advisable to the manufacturers to provide the depth adjustment and operating evenness of the machines with disk working bodies also by changing the performing speed of vehicles and the use of the additional ballast. These recommendations ensure not only the quality performance of the machines but also make them more versatile for different operating conditions.

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