EXPERIMENTAL STUDIES ON A PLOW WITH A DISK DISINTEGRATOR
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ЕКСПЕРИМЕНТАЛЬНІ ДОСЛІДЖЕННЯ ПЛУГА З ДИСКОВИМ ПОДРІБНЮВАЧЕМ

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ABSTRACT
Studies were conducted on the operation of a plow with a disk disintegrator in a unit with an MTZ-82 tractor on black soil with a flat relief on soybean stubble with the amount of plant residues from 300 to 400 g/m^2. During the research, the following parameters were changed: the disk approach angle, the disk section installation height, and the tractor speed. As a result of the study, it was found that at the speed of a plow with a disk disintegrator from 4 to 5 km/h, the depth of plant residues embedding *is maximum and ranges from 15 to 19 cm, while fuel consumption becomes minimal in the range from 18 to 30 kg/ha.*

ABSTRACT
Були проведені дослідження роботи плуга з дисковим подрібнювачем в агрегаті з трактором МТЗ-82 на чорноземному ґрунті з рівним рельєфом по стерні сої при кількості рослинних решток від 300 до 400 г/м^2. При проведенні досліджень змінювали наступні параметри: кут атаки дисків, висоту установки дискової батареї та швидкість руху трактора. У результаті дослідження встановлено, що при швидкості руху плуга з дисковим подрібнювачем від 4 до 5 км/год глибина заробляння рослинних решток є максимальною і знаходиться в межах від 15 до 19 см при цьому витрати палива набувають мінімального значення в межах від 18 до 30 кг/га.

INTRODUCTION

The use of green manure crops as green organic fertilizers is a widespread agrotechnical measure. Research by scientists has shown that the use of green manure crops leads to an increase in the amount of organic substances in the soil, an improvement in the physical, chemical and biological state of the soil, resulting in an increase in the yield of field crops *(Zhang et al, 2007; Saikia et al, 2019; Israr Khan et al, 2020)*. Studies are also known to determine the effect of green manure and rice straw on rice production *(Zhou et al, 2020)*. Five different types of combinations of their use were applied: no fertilizer; chemical fertilizer; chemical fertilizer plus green manure; chemical fertilizer plus rice straw; chemical fertilizer plus green manure and rice straw. The results of these studies showed that the use of chemical fertilizers and green manure increased rice yields by 4.1%, chemical fertilizers and rice straw by 4.7%, chemical fertilizers, green manure and rice straw by 9.6% when compared to chemical fertilizers. The results of studies (*Nazmus et al, 2013)* showed that the highest yield of corn was with deep embedding of green manure (20-25 cm) compared to the average depth of soil cultivation (10-12 cm) and the minimal one. The *authors (Astier et al, 2006)* conducted studies to determine the effect of using green manure crops (vetch) on the absorption of phosphorus and nitrogen by corn, which showed that the absorption of these substances was better when wrapping green manure in the soil compared to its surface mulching. Therefore, we can conclude that the depth of embedding of green manure crops affects their efficiency of use. The use of plowing when wrapping green manure crops will not allow this process to be carried out as efficiently as possible, depending on the crop and its overall parameters. Therefore, in order to perform a high-quality operation of embedding green manure crops in the soil, they must first be disintegrated (mulched), and then embedded. Step-by-step execution of disking and plowing operations requires high fuel consumption, so the combination of two operations when wrapping green manure crops is very relevant.

Without conducting experimental studies, it is impossible to objectively determine the parameters of working bodies for tillage. The study of the mutual influence of a disk disintegrator, ensuring the green manure stalks disintegration, and a plow on the quality of plant residues embedding and fuel consumption is one of the urgent tasks.

A significant number of publications have been devoted to substantiating the parameters of disks for surface tillage and plows for plowing *(Sineokov et al, 1977; Strelbitsky, 1978; Tsimmerman, 1978; Dubrovin et al, 2007; Kogut et al, 2016)*. A significant part of these works is devoted to the study of the influence of changes in the parameters of the working bodies of machines or the positional parameters of their installation on the quality of tillage, plant residues embedding, fuel consumption *(Zeng and Chen, 2018; Golub et al, 2019; Upadhyay and Raheman, 2018, 2020)*, as well as the dependence on the type of soil *(Gangwar et al, 2006)*. Of interest are combined units that make it possible to reduce the number of passes of equipment through the field by 1.5-2 times, preserve moisture, and reduce the time required to perform technological operations during periods of limited agrotechnical time *(Dubrovin et al, 2004)*. As for combined units for soil plowing, their share in the market of agricultural machinery in Ukraine is still insignificant. At the same time, they require research to determine the quality of plant residues embedding and fuel consumption, since the combination of a plow with a disk disintegrator significantly affects these indicators.

The purpose of the research is to experimentally determine the quality of plant residues embedding and fuel consumption when embedding plant residues of green manure and energy close-growing crops using a plow with a disk disintegrator.

Fig. 1 - Plow with disk disintegrator in operation

MATERIALS AND METHODS

Field studies of a plow with a disk disintegrator (conventional brand PLN-3-35D) in a unit with an MTZ-82 tractor (fig. 1) was carried out on black soil with a flat relief on soybean stubble with the amount of plant residues from 300 to 400 g/m^2 and the initial surface undulation – from 4 to 5 cm.

The layout parameters of the plow with a disk disintegrator had the following values: working width – 1,050 mm; working width of the body 350 mm; and in the longitudinal-vertical plane – 800 mm, the distance from the disk disintegrator to the point of the rear body – 1,300 mm.

The main design parameters of the working bodies of the disk disintegrator: working width 950 mm (with the disk approach angle of 32 deg.); limits for changing the disk approach angle from 24 to 41 deg., the diameter of the disks is 450 mm; the pitch between the disks is 140 mm.

The installation height of the disk section in relation to the plow point could vary from 20 to 80 cm. At the same time, the depth of tillage increased from 15 to 23 cm when the approach angle of the disk section changed from 24^0 to 32^0. This is due to the fact that the plow body was deepened until the depth force of the disks was balanced with the depth force of the plow bodies. The value intervals and levels of variation of factors are shown in table 1.

Table 1

Value intervals and levels of factors variation

Factor name	Factor levels			Variation intervals
	-1	0	+1	
Disk approach angle, deg.	24	28	32	4
Disk installation height, cm	20	50	80	30
Operating speed, km/h	2	4	6	2

Statistical processing of experimental results was carried out using well-known methods with an assessment of the uniformity of variances according to the Cochrane criterion, an assessment of the significance of regression coefficients according to the Student criterion, and an assessment of the adequacy of the regression equation according to the Fischer criterion (*Golub et al, 2018*).

When embedding green manure and plant residues of energy crops, disk-working bodies disintegrated the stems, loosened the soil, and mixed the disintegrated plant residues with the soil. The plow carried out their final embedding in the soil.

RESULTS

As a result of the implementation of the factor experiment according to the *D*-optimum Box-Behnken second-order design, data were obtained that characterize the depth of plant residues embedding and fuel consumption from the design and technological parameters of a plow with a disk disintegrator: the disk approach angle, the height of installation of disks and the speed of movement of a plow with a disk disintegrator. The average values of the studied ones obtained as a result of the experiment plan implementation, based on three repetitions, are shown in table 2.

Table 2

Results of experimental studies of the unit

Factors			Average values	
disk approach angle, deg.	disk installation height, cm	operating speed, km/h	depth of plant residues embedding, cm	fuel consumption, kg/ha
32	80	4	18	29.38
24	20	4	14	15.90
32	20	4	12	22.05
24	80	4	12	23.39
32	50	6	14	26.73
24	50	2	15	27.88
32	50	2	19	25.09
24	50	6	14	19.64
28	80	6	11	30.76
28	20	2	15	22.45
28	80	2	13	31.98
28	20	1	12	18.51
28	50	4	18	23.15
28	50	4	18	23.15
28	50	4	18	23.15

Processing of experimental data using standard machine software allowed obtaining the following second order mathematical models for each of the response functions:

$$h_P = -23.7917 + 2.1042\,\alpha - 0.1042\,h_D + 6.3542\,v - 0.0391\,\alpha^2 - 0.0038\,h_D^2 - 0.4688\,v^2 + 0.0167\,\alpha\,h_D - 0.125\,\alpha\,v + 0.0042\,h_D\,v; \quad (1)$$

$$q = 13.0999 + 2.016\,\alpha + 0.0817\,h_D - 14.8773\,v - 0.0486\,\alpha^2 + 0.0003\,h_D^2 + 0.6156\,v^2 - 0.0003\,\alpha\,h_D + 0.3089\,\alpha\,v + 0.0114\,h_D\,v; \quad (2)$$

where h_P – depth of plant residues embedding, [cm];

q – fuel consumption when operating a plow with a disk disintegrator, [kg/ha];
α – disk approach angle, [deg.];
h_D – disk installation height, [cm];
v – operating speed of the plow with a disk disintegrator, [km/h].

The study of the influence on the plant residues embedding depth of the disk approach angle and the height of disks installation and the speed of movement of a plow with a disk disintegrator is shown in Figs. 2, 3, 4. The quality of plant residues embedding depends on the dimensional parameters of their disintegration, as stated in some studies, which determined the dependence of wheat straw length (which varied from 130 to 230 mm in 20 mm increments) on the depth of its embedding in the soil of *(Fang et al, 2016)*. These studies have shown that as the length of plant residues decreases, the quality of embedding increases.

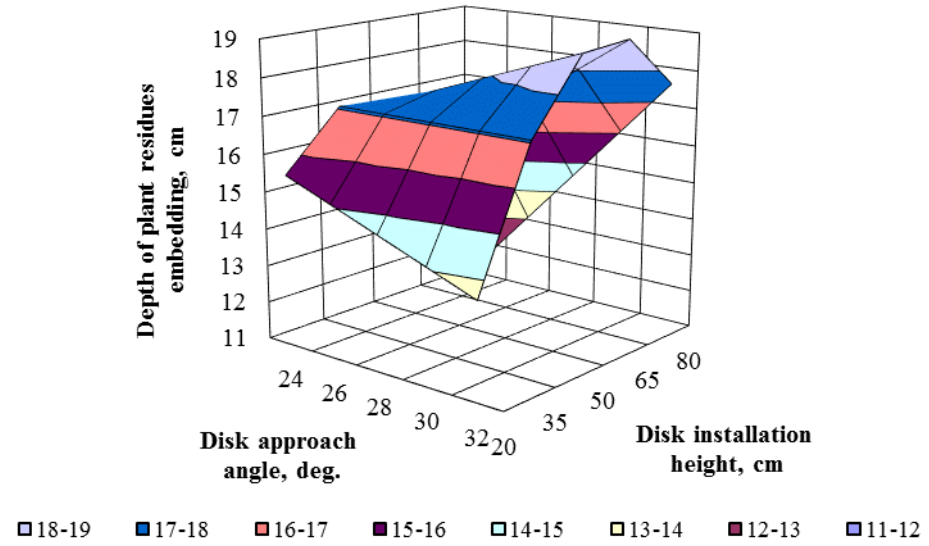

Fig. 2 - Influence of the disk approach angle and the height of disks installation on the depth of residues embedding using a plow with a disk disintegrator

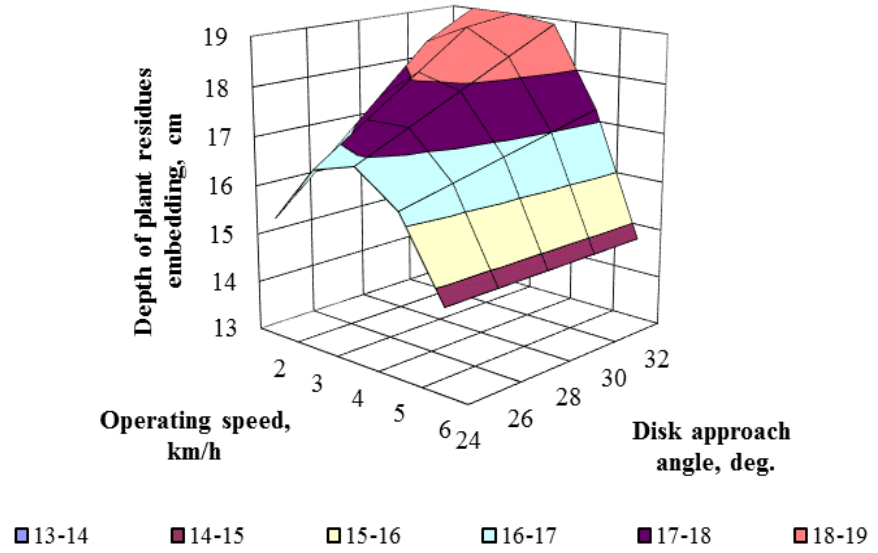

Fig. 3 - Influence of the disk approach angle and operating speed on the depth of residues embedding using a plow with a disk disintegrator

It is established that the depth of plant residues embedding is most affected by the height of the disk installation and the operating speed of the plow with a disk disintegrator. Some studies indicate that the quality of plant residues disintegration depended more on the operating speed and disk approach angle than on the depth of tillage, since the depth of tillage was relatively small – from 5 cm to 8 cm *(Damanauskas et al, 2019).*

Processing was carried out on loamy and clay-loamy soils. In our research, it was also found that at a low operating speed and a small disk approach angle, the level of quality of plant residues embedding was of poor quality – most of all plant residues were still on the surface, while when cultivating soil with a high operating speed and a large disk approach angle, plant residues disappeared from the soil surface.

With an increase in the installation height of the disk section in relation to the plow point, the depth of plant residues embedding increases. Thus, when the installation height of the disk section in relation to the plow point is from 40 to 60 cm, the depth of plant residues embedding is maximum and is from 17 to 19 cm. This is due to the fact that the plow body attracts a larger volume of soil when deepened. In the future, the trashboard comes into operation, which is equipped with a plow blade and the operation of which makes it possible to change the flight path of the upper soil layer where plant remains are concentrated.

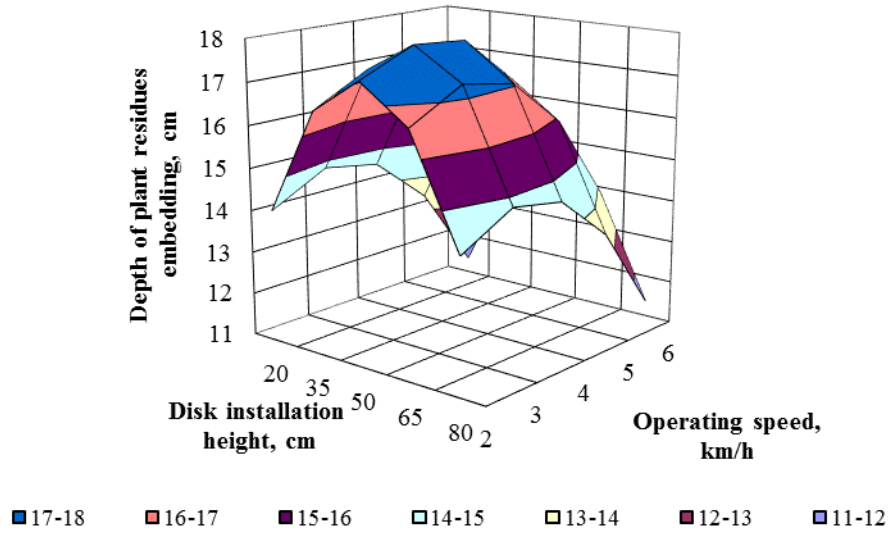

Fig. 4 - Influence of the operating speed and the height of disk installation on the depth of residues embedding using a plow with a disk disintegrator

Plant residues from the upper soil layer can be directed along three possible trajectories. The first is when the residues are placed on the slope of the previous furrow, the second is when the residues enter the bottom of the furrow, and the third is when the residues are placed on the slope of the newly formed furrow. The best option for the trajectory is the one when the residues lie on the bottom of the furrow.

The operating speed of a plow with a disk disintegrator ambiguously affects the depth of plant residues embedding, which is associated with the possible trajectories of their movement when descending from the trashboard. This is due to the influence of the operating speed of the plow with a disk disintegrator on the absolute speed of descent of plant residues from the trashboard, and, accordingly, their laying, either on the bottom of the furrow, or beyond it. The maximum depth of plant residues embedding is from 17 to 19 cm at the operating speed of the unit from 3 to 4 km/h.

Researchers *Liu et al (2010)* determined the effect of the tillage rate on the production of plant residues depending on their length, which varied from 60 to 250 mm. The obtained results showed that an increase in the length of plant residues leads to a decrease in the quality of their embedding, but with an increase in the speed of tillage, the quality of plant residues embedding increases too.

Studies of the influence of factors on fuel consumption during the operation of a plow with a disk disintegrator have shown (figs. 5, 6, 7) that it is partially affected by the disk approach angle. Thus, when the installation height of the disk section in relation to the plow point is 50 cm, fuel consumption ranges from 20 to 24 kg/ha while the disk approach angle changes from 24^0 to 32^0.

When the installation height of the disk section increases in relation to the plow point from 20 to 80 cm, fuel consumption increases from 16 to 29 kg/ha. The paper written by *Damanauskas et al. (2019)* also notes that hourly fuel consumption increases due to an increase in the disk approach angle, the depth of tillage, and the operating speed of the disk harrow. Similar studies have also been conducted which noted that fuel consumption increases due to an increase in disk approach angle, but decreases with operating speed increase *(Damanauskas, 2019)*. The operating speed of a plow with a disk disintegrator has an ambiguous effect on fuel consumption, which is associated with fuel overspending at low operating speeds and an increase in energy consumption when operating at high speeds.

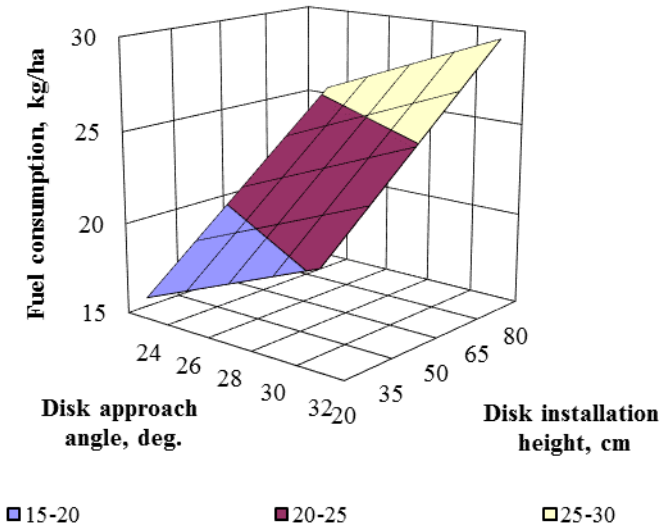

Fig. 5 - Influence of the disk approach angle and the height of the disk installation on fuel consumption when operating a plow with a disk disintegrator

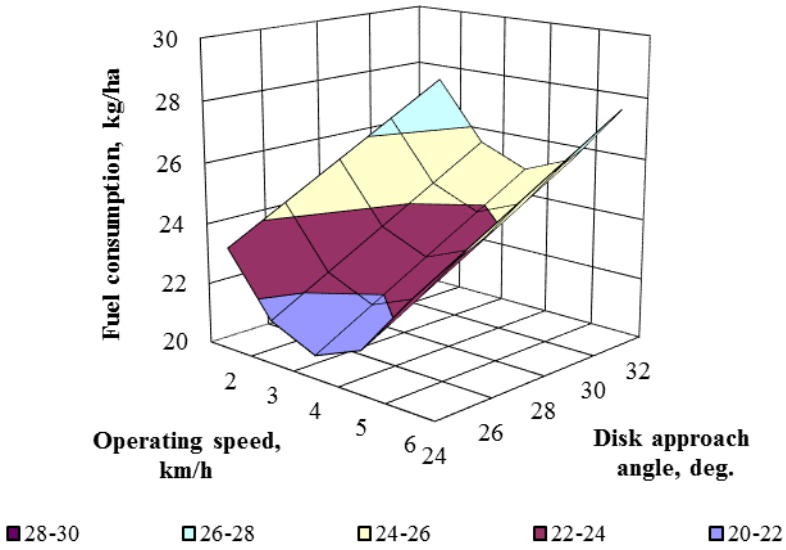

Fig. 6 - Influence of disk approach angle and the operating speed on fuel consumption when operating a plow with a disk disintegrator

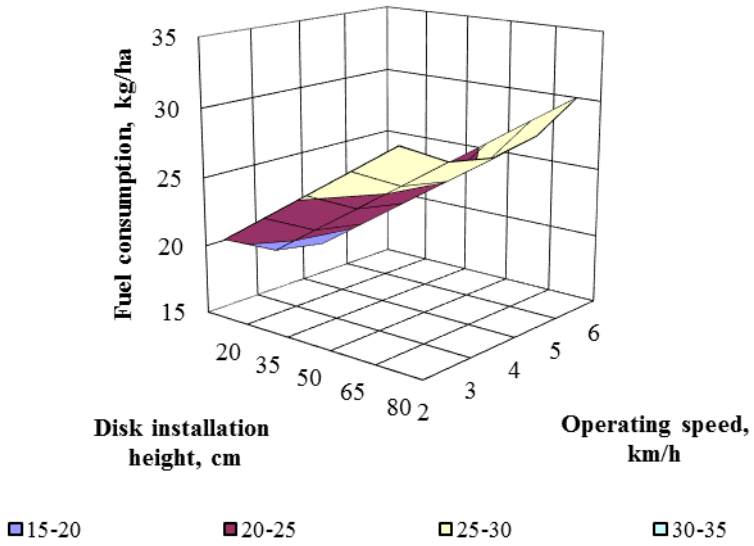

Fig. 7 - Influence of the height of the disk installation and the operating speed on fuel consumption when operating a plow with a disk disintegrator

When changing the operating speed of the plow with a disk disintegrator from 3 to 5 km/h, fuel consumption is minimal and ranges from 19 to 24 kg/ha. Within the same limits of changes in the operating speed of the plow with a disk disintegrator, the minimum fuel consumption is from 18 to 19 kg/ha with a disk section installation height relative to the plow point of 20 cm, from 23 to 24 kg/ha - with a disk section installation height relative to the plow point of 50 cm, and from 28 to 30 kg/ha - with a disk section installation height relative to the plow point of 80 cm.

CONCLUSIONS

- ✓ As a result of studying the influence of the disk approach angle, the depth of disks installation and the operating speed of a plow with a disk disintegrator on the depth of plant residues embedding, it was found that at the operating speed of a plow with a disk disintegrator from 4 to 5 km/h the depth of plant residues embedding is the maximum and is in the range from 15 to 19 cm, respectively.
- ✓ It is established that fuel consumption becomes minimal when the operating speed of a plow with a disk disintegrator is from 4 to 5 km/h and it is in the range from 18 to 30 kg/ha.

REFERENCES

[1] Astier, M., Maass, J. M., Etchevers-Barra, J. D. (2006). Short-term green manure and tillage management effects on maize yield and soil quality in an Andisol. *Soil & Tillage Research*, 88, 153–159. https://doi:10.1016/j.still.2005.05.003

[2] Damanauskas, V. (2019). Dependence of fuel consumption on winter rape stubble tillage quality in clay loam soil, *Proceedings of 18th International Scientific Conference "Engineering for rural development"*, Jelgava, Latvia, 221–226. https://doi: 10.22616/ERDev2019.18.N295

[3] Damanauskas, V., Velykis, A., Satkus, A. (2019) Efficiency of disk harrow adjustment for stubble tillage quality and fuel consumption. *Soil & Tillage Research*, 194, 1–10. https://doi.org/10.1016/j.still.2019.104311

[4] Dubrovin, V. O., Golub, G. A., Skorobogatov, D. V. (2007). Substantiation of diameter of disks of the shredder of stalks of sidereal cultures. *Scientific Bulletin of the National Agrarian University*, 117, 388–392.

[5] Dubrovin, V. O., Sushko, D. S., Skorobogatov, D. V., Roldugin, M. I., Volik, B. A. (2004). Features of the main tillage in the cultivation of corn. *Scientific Bulletin of the National Agrarian University.* 73(2), 55–60.

[6] Fang, H., Zhang, Q., Ali Chandio, F., Guo, J., Sattar, A., Arslan. C., Ji. C. (2016). Effect of straw length and rotavator kinematic parameter on soil and straw movement by a rotary blade. *Engineering in Agriculture, Environment and Food*, 3, 235–241. http://dx.doi.org/10.1016/j.eaef.2016.01.001

[7] Gangwar, K. S., Singh, K. K., Sharma, S. K., Tomar, O.K. (2006). Alternative tillage and crop residue management in wheat after rice in sandy loam soils of Indo-Gangetic plains. *Soil and Tillage Research*, 242-252. https://doi.org/10.1016/j.still.2005.06.015

[8] Golub, G. A., Chuba, V. V., Marus, O. A. (2019). Modeling of transition processes and fuel consumption by machine-tractor unit using biofuel. *INMATEH - Agricultural Engineering*, 58(2), 45–56. DOI:10.35633/INMATEH-58-05

[9] Golub, G. A., Kukharets, S. M., Tsyvenkova, N. M., Golubenko, A. A., Kalenichenko, P. S. (2018). Research on a boiler furnace module effectiveness working on small fracture wastes. *INMATEH-Agricultural Engineering*, 55(2), 9–18.

[10] Israr Khan, M., Suk Gwona, H., Ashraful Alama, M., Ji Songa, H., Dasb, S., Joo Kim, P. (2020). Short term effects of different green manure amendments on the composition of main microbial groups and microbial activity of a submerged rice cropping system. *Applied Soil Ecology*, 147, 1–9. https://doi.org/10.1016/j.apsoil.2019.103400

[11] Kogut, Z., Sergiel, L., Zurek, G. (2016). The effect of the disk setup angles and working depth on disk harrow working resistance. *Biosystems engineering*, 151, 328–337. http://dx.doi.org/10.1016/j.biosystemseng.2016.10.004

[12] Liu, J., Chen, Y., Kushwaha, R. L. (2010). Effect of tillage speed and straw length on soil and straw movement by a sweep. *Soil & Tillage Research*, 109, 9–17. https://doi:10.1016/j.still.2010.03.014

[13] Nazmus, S., Alam, Md. K., Islam, Md. M. Naher, L., Majid, N. (2013). Effects of green manure crops and tillage practice on maize and rice yields and soil properties. *Australian Journal of Crop Science*, 7(12), 1901–1911.

[14] Saikia, R., Sharma, S., Thind, H. S., Sidhu, H. S., Yadvinder-Singh (2019). Temporal changes in biochemical indicators of soil quality in response to tillage, crop residue and green manure management in a rice-wheat system. *Ecological Indicators*, 103, 383–394. https://doi.org/10.1016/j.ecolind.2019.04.035

[15] Sineokov, G. N., Panov, I. M. (1977). Theory and calculation of tillage machines. *Moscow: Mechanical engineering*, 311.

[16] Strelbitskiy, V. F. (1978). Disk tillage machines. *Moscow: Mechanical engineering*, 135.

[17] Tsimmerman, M. Z. (1978). Working bodies of tillage machines. *Moscow: Mechanical engineering*, 295.

[18] Upadhyay, G., Raheman, H. (2018). Performance of combined offset disk harrow (front active and rear passive set configuration) in soil bin. *Journal of Terramechanics*, 78, 27–37. https://doi.org/10.1016/j.jterra.2018.04.002

[19] Upadhyay, G., Raheman, H. (2020). Comparative assessment of energy requirement and tillage effectiveness of combined (active-passive) and conventional offset disk harrows. *Biosystems Engineering*, 198, 266-279. https://doi.org/10.1016/j.biosystemseng.2020.08.014

[20] Zeng, Z., Chen, Y. (2018). Performance evaluation of fluted coulters and rippled disks for vertical tillage. *Soil & Tillage Research*, 183, 93–99. https://doi.org/10.1016/j.still.2018.06.003

[21] Zhang, M., Fang, L. (2007). Effect of tillage, fertilizer and green manure cropping on soil quality at an abandoned brick making site. *Soil & Tillage Research*, 93, 87–93. https://doi:10.1016/j.still.2006.03.016

[22] Zhou, G., Gao, S., Lu, Y., Liao. Y., Nie, J., Cao, W. (2020). Co-incorporation of green manure and rice straw improves rice production, soil chemical, biochemical and microbiological properties in a typical paddy field in southern China. *Soil & Tillage Research*, 197, 1–9. https://doi.org/10.1016/j.still.2019.104499