AGROENGINEERING STUDIES OF TILLAGE AND HARVESTING PARAMETERS IN SOYBEAN CULTIVATION

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Abstract. The article presents the results of field tests of agricultural machinery in the operation of soil processing, sowing and harvesting in soybean cultivation. As a result of conducted studies, the design and operating parameters of a rotary plow were established, which ensure high-quality performance of main soil treatment with combination of organic mass sealing and soil deepening operations: the diameter of the spherical disk is 0.66 m, the distance between the rotor disks is 0.23 m, the width of the soil deepener stand – 0.16 m, the rotor attack angle – 24º, the rotor processing depth – up to 0.15 m, the soil deepening depth processing – up to 0.25 m; the width of the working machine is 2.4 m, the rotor rotation frequency is 385 rpm, the working speed is 2.44-3.00 $m \cdot s^{-1}$. The rotary plow with the specified structural and mode parameters provides a uniform depth of processing and complete cutting of stubble with 73-75% organic mass embedment in qualitatively processed soil, which corresponds to agrotechnical requirements for the technology of biological agriculture. The properties of the foot opener to create a compacted seed bed and help draw up soil moisture, as well as the use of the dew-forming effect, contributed to the increase in soybean productivity. The optimal width of the rows when sowing with a paw coulter for soybean plants is 60 cm, the reliable yield increase compared to the control was 86.2%. During the development of the combing device and the model of the interaction process of the soybean stalk with the combing combs, the angular zone of combing is set at 1.25π and the total stroke of the working machine for combing one stalk is equal to five distances between adjacent soybean plants in a row. At a working speed of the machine 7-9 $km \cdot h^{-1}$, the estimated drum speed range is 300-375 rpm for 8 brushing combs.

Keywords: soybean, soil cultivation, sowing, harvesting, agroengineering.

Introduction

In modern conditions, soybean cultivation technologies, which are based on organic farming techniques, are becoming particularly relevant [1]. This allows to reduce the level of technogenic impact on the soil [2]. These include the use of soil cultivation methods that provide the necessary density and structure of the root layer while preserving crushed plant residues on the field surface. Scientists will pay special attention to preventing water and wind erosion, soil drying, saturating the arable layer with organic matter, reducing doses or completely abandoning xenobiotics [3]. The implementation of these techniques helps create the prerequisites for the formation of sustainable agroecosystems during the transition to organic soybean production [4].

With traditional technologies in Ukraine, agrophytocenoses experience significant stress, causing them both environmental and energy damage associated with imperfect design and operational parameters of machines [2]. Under the influence of the propellers and working parts of machines, processes of soil deformation, compaction and shift in various directions, changes in structure and agrophysical properties occur [5]. Carrying out basic and pre-sowing tillage is fraught with the formation of a plow sole, the risk of developing water, wind and mechanical soil erosion and compaction of the subsoil horizon [6]. Repeated passes of machine-tractor units across the field during sowing and caring for plants contribute to compaction of the underlying soil layer, worsening soil filtration conditions and formation of subsoil and external estuaries [7]. Chemical plant protection operations negatively impact soil biota, living organisms and the ecosystem as a whole, and worsen the ecological state of the agricultural landscape due to contamination of groundwater and open water bodies with chemicals washed away from the soil due to deterioration of its infiltration [8]. Carrying out combine harvesting of soybeans contributes to over-compaction of the soil, its transverse removal along the track of the mover, rutting and deterioration of the microrelief of the fields [9].

In new organic technologies, great importance is attached to the use of green manure steam and the preservation of crop residues [10]. Crop residues form a soil protective cover that resists erosion and retains moisture [11]. The biomass of crop residues and green manure embedded in the top layer of soil in mid-summer with an abundance of heat and moisture promotes the activation of soil biota, leading to intensive mineralization of organic matter [12]. The resulting organic fertilizers are relatively inexpensive compared to mineral fertilizers used in normal and intensive technologies and are an inexhaustible and constantly renewable source of nitrogen and organic matter [13]. This plowing is

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equivalent to applying 40-100 t·ha^{-1} of humus [14]. Due to these reasons, the applied crop production technologies are not able to ensure the realization of genetic potential of variety in zonal soil and climatic conditions by more than 65% [15]. Hence the need to switch to ecological farming technologies arises.

Objective of the investigation is to develop the agroengineering elements of tillage and harvesting parameters in soybean cultivation.

Materials and methods

The research was carried out in 2023 on the experimental field of the National University of Life and Environmental Sciences of Ukraine, the village of Pshenichnoye, Kyiv region of Ukraine. The soil of the experimental plot is chernozem-like medium loamy. The water permeability of the humus horizon is in the range of 1.2-2.6 m per day, and the subsoil layer at a depth of 20-30 cm is only 0.05-0.14 m per day. To implement a new method of basic soil cultivation with the simultaneous incorporation of organic mass of green manure and crop residues into the soil, a soil-cultivating unit based on a class 1.4 tractor with a mounted rotary plow has been developed in organic farming technology (Fig. 1).

Fig. 1. **Field tests of the tillage unit with a rotary plow**: 1, 2 – subsoilers; 3 – rotor

The design and operational parameters of the rotary plow (Fig. 1): diameter of the spherical disk – 0.66 m, distance between the rotor disks – 0.23 m, width of the subsoiler stand – 0.16 m, angle of attack of the rotor – 24^{o}, depth of treatment with the rotor – up to 0.15 m, depth of treatment with subsoilers – up to 0.25 m; working machine working width – 2.4 m, rotor speed is 385 rpm, working speed – 2.44-3.00 m·s^{-1}.

Results and discussion

A tillage unit with a rotary plow (Fig. 1) with specified design and operating parameters carries out uniform tillage depth and complete cutting of stubble with the incorporation of 73-75% of organic mass into high-quality treated soil, which meets the agrotechnical requirements for the organic farming technology (Table 1).

Table 1

Operational and technological assessment of the soil-cultivating unit with a rotary plow

Unit evaluation indicator	Indicator value
Rotor processing depth, m	0.145-0.149
Depth of treatment with subsoilers, average, m	0.25 ± 0.02
Soil crumbling, % with fraction size, mm: 1-0 (50-100)	79.0 (21.0)
Soil surface ridgeness, m	0.042
Sticking of spherical discs and subsoilers	not observed
Fuel consumption during the shift, kg ha^{-1}	8.5
Productivity per 1 hour of main shift time, ha	1.99
Productivity per 1 hour of operating shift time, ha	1.87

Field studies have revealed the positive effect of incorporating green manure into the top layer of soil on the content of nutrients in it. The results of soil tests carried out at the beginning of the growing season (late April to early May 2023) showed that plowing the soybean mixture for three years contributed to an increase in the content of available phosphorus in the soil by 12%, exchangeable potassium by 18%, and nitrate nitrogen – by 48%.

To study the effect of the tillage depth on the soybean yield when sowing it with various seeding complexes, a field experiment was carried out with two options for basic tillage: disking at 0.12 m; disking to a depth of 0.12 m with soil dredging by 0.25 m. It was found that soil dredging contributed to an increase in the soil moisture in the 0-20 cm layer by 2.1% and a decrease in its density by 4.9%. Soybean sowing was carried out with four sowing complexes: Case Precision Disk 500, Lemken Solitair 12, John Deer 1890 and Amazone DMC 9000. As a result of the research, it was established that combined tillage with the use of soil deepening gives a significant increase in the yield when sowing with Case Precision Disk 500 and Lemken sowing complexes Solitair 12 – 1.20 times, John Deer 1890 and Amazone DMC 9000 seeding complexes – 1.28 times (Table 2). In absolute terms, the soybean yield increases by 0.38-0.50 t·ha^{-1} (Table 2).

Table 2

Soybean yield depending on the method of tillage, t·ha^{-1}

Sowing complex	Experience Option		Yield increase, %
	disking at 0.12 m	disking 0.12 m + dredging 0.25 m	
Case Precision Disk 500	1.87	2.25	20.1
John Deer 1890	1.80	2.31	28.3
Amazone DMC 9000	1.39	1.77	27.3
Lemken Solitair 12	2.07	2.49	20.5
HCP_{05}, t·ha^{-1}	0.54		-

Most farms in the region use seeding machines for sowing soybeans in the usual row method with a row spacing of 15 cm. However, soybean is a row crop, it branches better and provides high yields with lower seeding rates in wide-row crops. To study the sowing method, the influence of row spacing and the type of openers on soybean yield in organic farming technologies, a prototype of a seeder with a working width of 4.6 m was manufactured, which is aggregated with a class 1.4 tractor. The seeder can be equipped with tine or disk-anchor coulters. Test conditions: soil moisture in the horizon 0-15 cm W = 17.8%; soil hardness in the horizon 0-15 cm H = 0.154 MPa; the established sowing depth for tine and disk-anchor coulters h = 0.05 m; operating speed of the sowing unit υ_p = 2.83-3.5 m·s^{-1}; seeding rate – 110 kg·ha^{-1}.

The deviation from the specified seed placement depth did not exceed ± 1 cm. In this case, the disk-anchor opener formed a strip of seeds 9.3 ± 0.53 cm wide, and the tine opener – 20 ± 0.8 cm wide (Fig. 2). The yield of soybeans sown with a tine opener significantly exceeded the yield of soybeans sown with a disk-anchor opener, the difference is 0.48-1.01 t·ha^{-1} with HCP_{05} = 0.38 t·ha^{-1}.

Fig. 2. **Strip sowing of soybeans with the experimental tine opener**

The increase in soybean yields was facilitated by the properties of the tine opener to create a compacted seed bed and help draw up soil moisture, as well as the use of the effect of dew formation. Another reason for the increase in the yield is the destruction of weeds and their seedlings by the paw opener when sowing soybean seeds, that is, the effect of the cultivator paw [1]. The optimal row spacing when sowing with a tine opener for soybean plants is 60 cm; a significant increase in the yield compared to the control was 86.2%. The disk-anchor opener is significantly inferior to the tine opener in terms of soybean seed yield (Table 3).

Table 3

Biological soybean yield depending on the type of opener and row spacing

Row spacing (factor A)	Opener type (factor B)	Productivity, t·ha^{-1}	Increase	
			t·ha^{-1}	%
45 cm	Disc-anchor (control)	1.23	0	0
	Paw	2.24	1.01	82.1
60 cm	Disc-anchor	1.66	0.43	34.9
	Paw	2.29	1.06	29.3
80 cm	Disc-anchor	1.59	0.36	29.3
	Paw	2.07	0.84	68.3
HCP_{05} factor A HCP_{05} factor B	0.31 0.38		-	-

To study the effectiveness of methods of agrotechnical protection of soybean crops from weeds (pre-emergence and post-emergence harrowing) and the effect of agricultural practices on yield, a field experiment was carried out with one (control), two and three harrowings with a light tine harrow [17]. Pre-emergence and post-emergence harrowing was carried out along the soybean rows. The average depth of crop cultivation was 0.025 m; surface ridges 0.025 m, distance between ridges 0.025-0.03 m (with $\sigma = \pm$ 0.001 m; v = 4.8%). The operating speed of the unit during pre-emergence harrowing was υ_p = 2.70-3.31 m·s^{-1}; when harrowing along seedlings υ_p = 1.89-2.52 m·s^{-1}. The death of cultivated plants during harrowing by seedlings on average in the experiment did not exceed 1.2% (v = 14.6%).

Harrowing crops with a light harrow helped reduce the number of weeds and destroy the soil crust, improving the water-air regime of plant life and increasing soybean yields [1]. It was found that when carrying out two pre-emergence harrowings and one harrowing on the seedlings, a significant increase in the soybean grain yield reaches 1.28 t·ha^{-1} compared to the control (Table 4). The use of harrowing soybean rows with a light finger harrow makes it possible to abandon the generally accepted operations of cultivating wide-row soybean crops.

Table 4

Influence of the number of harrowings of soybean crops on the biological yield of soybeans

Option	Productivity, t·ha^{-1}
Without harrowing (control)	1.05
One pre-emergence harrowing	1.85
Two pre-emergence harrowing	1.87
Two pre-emergence harrowing + one emergence harrowing	2.33
NSR_{05}, t·ha^{-1}	0.20

The priority method of soybean harvesting in organic technology is standing stripping. When developing a stripping device and a model of the process of interaction of a soybean stalk with stripping combs, the angular stripping zone (1.25π) and the total stroke of the working machine for stripping one stem, equal to five distances between neighboring soybean plants in a row, were established. At a machine operating speed of 2.0-2.5 m·s^{-1} (7-9 km·h^{-1}), the design drum speed range is set to n = 300-375 rpm (8 stripping combs). Accordingly, with 6 combs n = 400-500 rpm, with 4 combs n = 600-750 rpm. Experiments were carried out on stripping soybeans using a laboratory stripping unit (Fig. 3) with different angles of inclination of stripping combs at different operating speeds of the unit (Table 5).

It has been established that with an increase in the operating speed of the machine, a decrease in the angle of attachment of the combs leads to an improvement in the quality of combing of soybean plants and a reduction in damage to the combed stems. In options 8 and 9, no breakage of soybean stems is observed during stripping. Loss from uncombing is 0.5-1.0%. Experiments have shown that the use of a laboratory installation with combs for soybean combing with a varying tilt angle of 30º when entering the soybean mass (beginning of combing) and exiting in the upper position (end of combing) with a maximum opening angle of about 70º helps reduce losses of grain on the field and preserve the stems from breaking at a machine operating speed of 5-7 km·h^{-1} (biological yield – 270 g·m^{-2}, grain moisture W = 10%) compared to an installation with rigidly attached combs.

Fig. 3. **Laboratory installation for stripping standing soybeans**

Table 5

Losses in soybean stripping with different comb attachment angles

Option (speed/angle/working speed)	**Grain weight from stems (uncombed), g·m^{-2}**	**Weight of grain on ground, g m^{-2}**	**Total losses, g·m^{-2}**	**Number of intact stems after combing, pcs. per m^2**
1) 350 rpm/angle 600/5 km·h^{-1}	4.10	67.55	71.65	42
2) 350 rpm/angle 600/7 km·h^{-1}	3.80	65.80	69.60	45
3) 350 rpm/angle 600/9 km·h^{-1}	10.20	57.45	67.65	47
4) 350 rpm/angle 450/5 km·h^{-1}	6.80	37.30	44.10	38
5) 350 rpm/angle 450/7 km·h^{-1}	9.00	45.25	54.25	42
6) 350 rpm/angle 450/9 km·h^{-1}	11.40	34.90	46.30	45
7) 350 rpm/angle 300/5 km·h^{-1}	1.45	44.50	45.95	47
8) 350 rpm/angle 300/7 km·h^{-1}	2.40	39.40	41.80	70
9) 350 rpm/angle 300/9 km·h^{-1}	3.07	39.37	42.44	60

Discussion

The new technology will require the creation in grain yards a line for separating the grain and soy heap into chaff and soybeans [15], which will then be processed depending on their further purpose [16]. Soybean, after being separated from the heap, enters the existing processing line, where it is divided into seed and marketable fractions [17]. The chaff, depending on the purpose of further use, is sent for processing and further storage.

Conclusions

Thus, the basic elements of the machine technology for soybean cultivation are proposed.

1. Carrying out basic tillage with a modernized rotary plow ensures high-quality crumbling of the soil, uniform tillage depth, complete cutting of stubble with the incorporation of 73-75% of soybean organic matter into the soil, which helps increase the nutrient content in it.
2. Carrying out combined basic tillage, including disking by 0.12 cm together with soil deepening by 0.25 m, helps increase the soil moisture in the 0-20 cm layer by 2.12%, reduce its density by 4.9% and provides a significant increase of the soybean yield by 1.20-1.28 times.
3. The use of tine coulters of the seeder, which create a compacted seed bed, helps draw up the soil moisture, destroys weeds and their seedlings; the optimal row spacing when sowing soybeans with tine openers is 60 cm, a reliable increase in the yield compared to the control is 86.2%.
4. The use of two pre-emergence harrowings of soybean crops and one harrowing after emergence with a light finger harrow helps obtain a significant increase in the soybean grain yield of 1.28 t·ha^{-1}.

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Author contributions

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