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ECONOMIC AND ENERGY EFFICIENCY OF SOYBEAN GROWING UNDER NO-TILL AND SALICYLIC ACID IN SOUTHERN UKRAINE

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Abstract

The research is devoted to a comprehensive approach to the study of soybean productivity depending on the different tillage technologies and plants' spraying of salicylic acid of climate change in Southen Ukraine. The proposed measures will save water resources up to 30% through the use of portable moisture meters to control soil moisture and the no-till technology; increase the soybean yield by up to 14% by spraying plants of salicylic acid. It was determined that the density of soybean plants during the growing season decreased on variants with traditional technologies in comparison with no-till the deviation makes almost 6%. The soybean water consumption coefficient in the experiment varied significantly in the range from 1,710 to 2,330 m^3/t. Soybean plants used water reserves most rationally in variants where traditional technologies were used. The average increase in yield according to the experiment under traditional technologies was 5.4%, with no-till was 20.3%. In terms of economic and bioenergy efficiency, no-till does not have significant advantages over traditional technologies. Reduction of costs in the introduction of no-till for energy consumption of machinery, fuel, electricity is fully offset by the growth of indirect energy costs, in particular, the cost of herbicides, due to high weed infestation of uncultivated crops.

Key words: *soybean, salicylic acid, yield, economic efficiency, energy efficiency*

INTRODUCTION

Soybean has been actively grown in Ukraine for more than 10 years. Still for now, it has not yet been fully explored and time-tested cultivation technology has not yet been developed. At the same time, interest in soybean cultivation is growing in all soil and climatic zones of Ukraine [40].

The consequences of global climate change are becoming more tangible in the world, and also in Ukraine. Over the last 20 years, the average annual temperature has increased by 0.8 ° C, and the average temperatures in the winter months by 1-2° C. Due to climate change, weather conditions are becoming more severe. In summer, record daytime temperatures up to + 45º C and a sharp decrease at night, sometimes up to + 10-15º C are recorded. The heavy rains are also recorded. Moisture deficiency is one of the main problems in growing agricultural crops, including soybean. Reducing the amount of precipitation in the winter time, increasing the frequency of droughts in the springtime, sharp changes in temperature during the day lead to an increased risk of plant death in the early stages of ontogenesis. The losses of Ukrainian farmers from drought, in the context of climate change, in some years exceed 20 billion UAH per year [19, 31]. But despite this, farmers rely on soybean and consider it the main legume of world agriculture in the XXI century and emphasize that it is the focus of world agricultural science and production [33].

Today, soybean ranks fourth in the world in terms of production after corn, wheat, and rice. According to its chemical composition, the seeds contain an average of 39% protein, 20% semi-drying oil, 24% carbohydrates, 5% ash elements with a predominant content of phosphorus, potassium, and calcium, as well as human and animal bodies, need various enzymes, vitamins (A, B, C, D, E) and other important organic and inorganic substances. Soybean absorbs nitrogen from the air, leaves behind 60-90 kg/ha of biologically fixed nitrogen, improves soil structure, and it is a good precursor for subsequent crop rotations.

Over the past 50 years, world soybean production has grown from 26.9 million tons to 263 million tons, an increase of almost 10 times, with a population growth of only 2.2 times.

Compared to last year, the soybean harvest increased by 500 thousand tons is up to 4.3 million tons. Such volumes will allow Ukraine to take 8th place among world soybean producers, and 7th place of export indicators [41].

Today, scientists are proposing two ways to reduce agricultural losses due to drought (i) the introduction of sustainable crops varieties; (ii) the plants' treatment with substances that increase their resistance to drought [1, 21, 32, 13, 34, 37]. Also, important to develop and implement in the production of scientifically modern, competitive technologies for growing and using the potential of new and promising varieties.

It was found that some phytohormones, vitamins, polyamines, phenolic compounds, synthetic compounds of the triazole group, plant extracts, humic acids, etc. may be inducers of drought resistance of plants [17, 35, 36]. Main attention is paid to ascorbic, salicylic acids, and flavonoids, which are natural substances that do not pollute the environment and agricultural products [13, 5, 15].

Salicylic acid in the plant body performs a number of regulating and signaling functions, but its role is most fully expressed by the action of stressors of various natures [20]. In particular, one of the most important effects of salicylic acid is the possibility of tolerance to the damaging effect of abiotic stressors, such as salinity, drought, heavy metals, etc. [17, 29].

There are many studies that have shown that the effects of salicylic acid and other salicylates in many biological processes in plants [16, 22]. Larque-Saavedra [22] used different concentrations of the substance to test the effect on plant leaves. Also, he recorded significant reductions in transpiration and closed of plants' stomata [16, 22]. It was found that soybean respond to drought, especially during the period of flowering to the formation of beans [18], and also confirmed that water stress during the flowering period reduces soybean yield by 43.9% [10].

Salicylic acid used for soybean spraying according to scientists from Tabriz University, Iran showed an improvement in plant biomass of 10% and yield increase to 17% [3].

Likewise, an important feature of soybean growing are soils and fertilizer systems.

According to research [3, 2], deep furrow plowing for soybean after winter wheat growing on soil with heavy mechanical composition improves its aeration, promotes moisture accumulation, better plant growth and development, more incredible leaf surface formation, better branching, and bean formation efficiency, and the result is a yield increase of soybean. For the central areas of the Steppe zone in Ukraine, the following tillage system is recommended peeling to a depth of 6-8 cm after harvesting the predecessor, re-peeling in the event of rain and weed emergence, and deep plowing to 30 cm in III decades of September or I decade of October [2**Error! Reference source not found.**]. The same tillage system of basic tillage operation is proposed by other researchers [25, 6]. However, the main tillage should not allow over-compaction of the arable layer of heavy soils, which bring cracking, changes of soil structure, especially important for the irrigated lands of the south of Ukraine. Recently, most farmers are switching to more economical and ecology-friendly technologies.

In countries of intensive agriculture, the system of minimum tillage (mini-till) has become widesprea. The reduction in tillage intensity differs significantly even in Europe, Great Britain, Denmark, and the Scandinavian countries, where the traditional depth of the main tillage is 15-20 cm, with the most common shallow tillage up to 15 cm [27].

In European countries have the classification of soil suitability for minimum tillage and direct sowing has been developed.

Today is very important to scientific substantiation of the most economical and environmentally friendly tillage systems in combination with other components of the agricultural system and their impact on improving soil fertility and product quality. In recent years, the technology of growing crops without mechanical tillage has been gradually spreading, which is often ineffective on soils of heavy mechanical composition, according to some scientists and explains that this technology is not suitable for all types of soils and climatic conditions. In particular, no-till does not work on soils of heavy mechanical composition in combination with arid conditions [4, 28, 26].

Study results show that the use of direct sowing in such conditions gives a yield of sunflower by 58.6% less than the traditional technology, and sorghum by 36.8%. At the same time, on lighter soils, for example, southern chernozems and especially ordinary chernozems, the use of no-till does not significantly reduce the yield of sorghum and sunflower, and in some wet years, it is even at the yield level when used the deep plowing [4].

MATERIALS AND METHODS

The experimental plot was established at the State Enterprise "Research Farm "Askaniyske" Askaniyska State Agricultural Research Station of the Institute of Irrigated Agriculture of National Academy of Agrarian Science of Ukraine (latitude 46°55'16.72"N, 33°82'20.49"E). The research territory is characterized by low rainfall, low humidity, frequent dry spells, warm autumn, and winter, as well as a long frost-free period. The average annual air temperature in the region is + 9.8 °C, the lowest is in January minus 3.2 °C, the highest is in July + 22.5 °C). The sum of positive temperatures for the warm period of the year (above 0 °C) is 3,800 °C. The sum of positive temperatures for the vegetation period (above + 5 °C) is 2,400 °C, the sum of active temperatures (above + 10°C) is 3,200°C. The average number of days with a temperature of + 25 °C and above is 80. The duration of the frost-free period in the air is 200 days, on the soil surface 180 days.

Among winter temperatures, the average number of days with a temperature of minus 10°C and below occurs up to 20 days, below minus 25°C is a very rarely to 1-2 days. In winter time there are up to 60 days with thaws. The average of the longest thaws are 22 days.

In summer time, precipitation falls unevenly. Rains are often showers and accompanied by hail, thunderstorms, and storms. On average, rains with thunderstorms are up to 26 days, with hails are up to 2-3 days.

The total evaporation during the summer period is 160 mm, which exceeds the amount of precipitation. The humidity factor is less, so the area belongs to the regions of insufficient natural moisture. The average annual relative humidity is 73%.

The soil of the study area is dark chestnut slightly saline light-clay. The mechanical composition of the arable layer (0-30 cm) is light-hearted. The presence of fractions of coarse dust is 38.18%, silt is 34.10% (Table 1).

Table 1. Mechanical composition of the soil

Depth of soil, cm	Fraction size (mm), quantity,%						
	1.00-0.25	0.25-0.05	0.05-0.01	0.01-0.005	0.005-0.001	< 0.001	< 0.01
0-20	0.15	4.98	38.18	10.84	11.75	34.10	56.69
40-50	0.07	4.53	35.85	10.23	10.39	38.93	59.55
55-61	0.12	2.36	37.09	10.12	12.93	37.38	60.43
80-90	0.08	1.83	39.39	8.96	11.95	37.79	58.70

Source: original data calculated based on the experimental data obtained.

The amount of organic matter in 0-30 cm layer is consist of 3.20% and changes in the deeper soil profile in the range of 3.04-3.24%. The reaction of the soil solution is alkaline (pH 7.4-8.7).

The soil bulk density in 0-30 cm is 1.17-1.26 g/m^3, with deeper layers is fixed increasing the bulk density to 1.52 g/cm^3. The total moisture content of the arable layer is 42.2-47.7%, the maximum field capacity is 26.5-30.4%, which are lower down in profile are decreased to 29.6 and 21.8%, respectively. The coefficient of moisture yield of the arable layer is 40.5-46.0%, aeration is 19.8-20.7%.

The total amount of water absorbed for the first time was 91.2 mm. Water permeability changes gradually from very high (absorption coefficient 0.005166 cm/sec) in the first 10 minutes of determination to medium (absorption coefficient 0.001693 cm/sec) in 7 hours after the start of determination.

The total moisture reserve, with the corresponding maximum field moisture capacity in layer 0-30 cm is 1,000 m^3/ha, for the layer 0-50 cm is 1,700 m^3/ha.

The field experiment was conducted in three replications with the split-plot method. The study was dedicated to the evaluation of the following cultivation technology elements are tillage technologies and spraying treatment of plants. The tillage system, where were compared no-till with the traditional tillage system, the last one included plowing to a depth of 28 cm, disking to 12 cm, pre-sowing cultivation to a depth of seed earning up to 6 cm. Another factor of research treatment was, where compared plots with salicylic acid spraying and non-spraying.

Internet meteorological station from i-Metos of Pessl Instruments was used to collect and analyze weather data during growing season on the research area. The meteorological station records the following indicators: surface soil temperature, solar radiation, precipitation, wind speed, air temperature, relative humidity, dew point and evaporation. Data is recorded every hour and stored on the server. Additionally, the non-uniformity of precipitation was recorded with measuring cups.

The generally accepted methods of conducting field experiments and performing laboratory experiments during the research were guided. The appropriate observations, measurements and analysis of soil and plant samples were accompanied. Remoute sensor (RS) methods was used.

The Least Significant Difference (LSD) test was used to separate the means of the dependent variables in response to predictor variables at $p \leq 0.05$ unless otherwise mentioned.

The economic efficiency of soybean with the generally accepted method using zonal production standards was determined [11, 30 14]. Calculations of bio-energetic efficiency according to the guidelines of bioenergy assessment of crop production technologies were performed [8, 12, 23, 24, 42].

Diona is a soybean variety was sown, which is characterized by increased adaptability to adverse growing conditions. It belongs to the group of very precocious varieties (81-85 days). The variety belongs to the subspecies Manchurian, albo-sublutea variety, approbation glauca group, plant height is 70-90 cm, laying the lower beans up to 12-14 cm bush compressed, and compact. The leaves are narrow, dark green. The color of the flowers is white. The pubescence of stems and beans is gray. Seeds round-oval, yellow, light seed scar with eye. The color of the beans is light yellow, mostly three- and four-seeded.

Soybean growing techniques were generally recognized for the irrigated conditions of the Southern Steppe of Ukraine, with the exception of the studied cultivation techniques. After harvesting the predecessor (corn), double disking of stubble was performed to a depth up to 12 cm. The traditional tillage according to the experimental scheme was performed. Mineral fertilizers at a dose of N_{21} were applied under pre-sowing cultivation. Ammonium sulfate (N-21, S-24%) was used as fertilizer. Pre-sowing tillage was performed at the depth of seed wrapping up to 6 cm using the John Deere 960. There were 13 irrigations with a Renkel sprinkler, the irrigation rate fluctuated in the range of 250-400 m^3/ha, with total irrigation rate of 4,400 m^3/ha. Salicylic acid spraying was carried out in the phase of the appearance of the third trifoliate leaf and the phase of bean formation. Integrated plant protection against weeds, pests, and diseases was used during the growing season. Harvesting was carried out by John Deere T660.

RESULTS AND DISCUSSIONS

Extremely important indicators in the study of tillage technologies are biometric indicators of plants. It gives the opportunity to analyze the condition of the plants and also count the harvest.

The vegetation cover of the territory was quantified using RS and analysis of the Normalized Difference Vegetation Index (NDVI). This index is a simple quantitative indicator of the magnitude of photosynthetic active biomass, commonly referred to as the vegetation index. According to the obtained experimental data, the vegetation density at a certain point in the image is equal to the difference between the intensities of reflected light in the visible and infrared range divided by the sum of their intensities.

It was found that the vegetation density during the season varied in the range of 0.83-0.08. The change in the density of vegetation cover is well traced to the average value (Fig. 1).

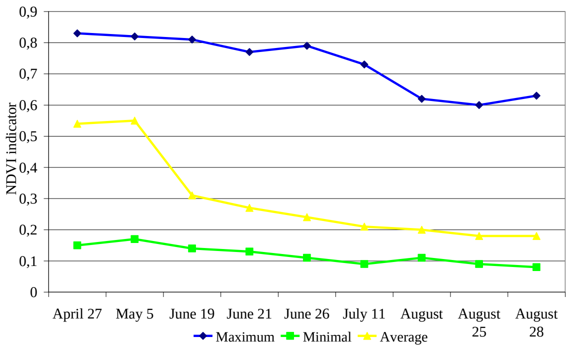

Fig. 1. Dynamics of the Normalized Difference Vegetation Index (NDVI) during the growing season
Source: original data calculated based on the experimental data obtained.

The sharp decline of this indicator in the period of May-June shows the sensitivity of this index and is due to the presence of weeds in the field, which was detected by visual inspection of areas.

The value of total water consumption in our experiments was 4,400 m^3/ha (Table 2).

Table 2. Soybean moisture use efficiency depending on the soil tillage and plant treatment

Methods of soil tillage and plant treatment	Water consumption ratio, m^3/t
Traditional tillage (control)	1,810
Traditional tillage (salicylic acid)	1,710
No-till (control)	2,330
No-till (salicylic acid)	1,860

Source: original data calculated based on the experimental data obtained.

The determined coefficient of water consumption indicates the saving of water consumption by plants to create the unit of yield. Researchers have found that the water consumption rate decreased significantly with the application of fertilizers with a well-balanced ratio of nitrogen, phosphorus, and potassium. In more productive years it is less than in less productive years.

The soybean water consumption coefficient in the experiment varied significantly in the range from 1,710 to 2,330 m^3/t. Soybean plants used water reserves most rationally in variants where traditional technologies were used. Studies have also shown that salicylic acid spraying also affected water consumption.

According to the results of research, the tillage system and treatment of plants with salicylic acid significantly affected the soybean yield. Depending on these parameters, soybean yields ranged from 1.64 to 3.11 t/ha.

The lowest yield was recorded in the variant under no-till 1.89 t/ha, which is 22.2% lower than with traditional tillage (Table 3).

Table 3. Soybean grain yield depending on the method of soil tillage and plants treatment, t/ha

Methods of soil tillage and plant treatment	Yield, t/ha
Traditional tillage (control)	2.43
Traditional tillage (salicylic acid)	2.57
No-till (control)	1.89
No-till (salicylic acid)	2.37
LSD_{05}	0.049

Source: original data calculated based on the experimental data obtained.

Salicylic acid spraying increased soybean yield in all variants. The average yield increase with traditional technology was 5.4%, for no-till was 20.3%. In general, salicylic acid spraying increased yield up to 14%. Effective functioning of any production system is impossible without a rationally built and efficient mechanism for obtaining the financial results of economic activities. At the same time, the only significant source of reproduction of the working capital of an agricultural enterprise is the sale of its main products [38].

In modern conditions of agriculture, an important requirement for the elements of cultivation technology, which are developed and implemented in production, need to reduce energy costs, unit cost and increase profits. Production of crop products in conditions of scarcity of resource potential requires a revision of the approaches that existed in the distribution-planned economy for the distribution of production costs in the development of technologies for growing crops [7]. Improving the efficiency of agricultural production requires radical improvement of technologies for growing crops, providing them with the necessary logistical and financial resources, clear implementation of all technological techniques in the relevant agro-technical terms. Soybean growing technologies are based on the achievements of science and best practices of the best domestic agricultural enterprises, as well as take into account global trends in agricultural production. Technologies are offered and the economic estimation was presented about results at various tillage technologies and plants treating with the use of traditional most widespread samples of domestic techniques with the application of a necessary complex of fertilizers and means of plants protection. The calculation of indicators of soybean economic efficiency growing by different technologies is presented in Table 4.

Table 4. Indicators of economic efficiency of soybean growing with different tillage technologies and plant treatment

Indicators	Traditional technology		No-till	
	Soybean (control)	Soybean (salicylic acid)	Soybean (control)	Soybean (salicylic acid)
Grain cost, UAH/t	8,631.3	8,235.5	9,146.5	7,487.3
Costs and invoices, UAH/ha	20,973.95	21,165.16	17,286.80	17,744.81
Profit, UAH/ha	3,326.05	4,534.84	1,613.20	5,955.19
The level of production profitability, %	15.86	21.43	9.33	33.56

Source: original data calculated based on the experimental data obtained.

There are several reasons for implementing the new system of agriculture (i) economic, which saves spare parts, fuel, wages, and labor, (ii) agronomic, which improves the water regime of the soil, (iii) environmental, which reduces CO_2 emissions from the soil by binding carbon to soil organic matter, as well as reducing degradation soils by stabilizing erosion processes.

During the analysis, the cost of 1 quintal of soybeans in traditional technologies without spraying (control) was 5.6% lower than in no-till, in the variant with spraying on the contrary the cost of products in traditional technologies is 9.1% higher than under no-till.

The profit from the sale of products on the variant under no-till with salicylic acid spraying is higher than on other variants; it was by 44.1% compared to traditional technologies (control) and by 23.9% on traditional technologies with spraying.

The highest level of profitability of 33.56% was obtained under the no-till and salicylic acid spraying, the lowest was 9.33% under no-till without spraying (control).

Widespread use of intensive technologies has led to increased consumption of fuel, electricity, chemicals, and protection and, as a result, energy costs. Modern science-based technologies must be energy-efficient and rationally use both non-renewable and natural renewable energy, as well as perform environmental functions [39].

According to the scientists' results [9], the most complete assessment of the effectiveness of technology is the bioenergy methodology, which quantifies and analyzes the processes of transformation of free energy flows in agricultural landscapes. Production technologies should ensure the fullest use of natural agri-energy resources while reducing the specific costs of anthropogenic energy per unit of output and preventing negative impacts on the environment.

Energy analysis allowing to develop and evaluate the effectiveness of resource- and energy-saving technologies. The indicator of energy efficiency in different models of soybean growing technologies can be a decisive and equivalent criterion for the efficiency of grain production of this crop, which was determined by energy analysis. This analysis was performed to determine the degree of using fertilizers, pesticides, irrigation water, fuels and lubricants, various types of units of the machine-tractor fleet, natural resources, soil and climatic conditions, solar radiation, and other factors affecting soil fertility and crop formation.

Indicators of bioenergetic efficiency of soybean growing with salicylic acid spraying are much higher than in the control. The energy efficiency ratio in the version with no-till and spraying is 1.57, which on 9.6% higher than under traditional technologies with spraying. The energy intensity of 13.4 GJ/t was obtained on the variant under no-till (control), which is 3.7% less than on the variant with traditional technologies (control).

From the energy point of view, the technology is considered effective if the planned level of crop yield provides the condition Ev> Eo; Ke≥1.0, which is confirmed by the data presented in Table 5.

Table 5. Indicators of bioenergy efficiency of soybean growing with different tillage and plant treatment

Indicators	Traditional tillage		No-till	
	Soybean (control)	Soybean (salicylic acid)	Soybean (control)	Soybean (salicylic acid)
Energy yield, GJ/ha	42.99	45.46	33.43	41.93
Energy consumption, GJ/ha	31.34	32.03	25.40	26.69
Increse of energy, GJ/ha	11.64	13.44	8.04	15.24
Energy efficiency ratio	1.37	1.42	1.32	1.57
Energy consumption, GJ/t	12.9	12.5	13.4	11.3

Source: original data calculated based on the experimental data obtained.

At the same time, it should be noted that energy costs for tillage are not crucial. They range from 20-30%, and the fuel component is only 10-20%, and their reduction by excluding certain technological operations, or using no-till does not have a decisive impact on the total amount of total anthropogenic energy used in crops.

CONCLUSIONS

Large losses of traditional technologies accompained by soil plowing, repeated deep pre-sowing and post-sowing cultivation, encourage the establish under no-till, which have no mechanical impact on the soil, and all plant residues remain on the surface, which in turn will increase yields and reduce costs.

It was determined that the density of soybean plants during the growing season decreased in two ways; on variants with traditional technologies in comparison with the variant without processing the deviation makes almost 6%. In addition, the data was confirmed using RS.

The soybean water consumption coefficient in the experiment varied significantly in the range from 1,710 to 2,330 m^3/t. Soybean plants used water reserves most rationally in variants where traditional technologies were used.

It was determined that the factors in the research, namely tillage, and treatment of plants with salicylic acid significantly affected the soybean harvest. The average increase in yield according to the experiment with traditional technologies was 5.4%, with no-till was 20.3%. Salicylic acid allowed an increasing yield of 14%.

In terms of economic and bioenergy efficiency after one year of research, no-till do not have significant advantages over traditional tillage. The reduction of costs in the introduction of no-till for energy consumption of machinery, fuel, electricity is fully offset by the growth of indirect energy costs, in particular, the cost of herbicides, due to high weed infestation of uncultivated crops. It should be noted that with the long-term use of no-till, the situation may change for the better.

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