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Argo-Economic Evaluation of Main Tillage Methods in the Cultivation of Corn

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ABSTRACT

In agriculture of the steppe zone, there are two main trends associated with the underutilization of the resource potential of maize hybrids and the need to expand the use of minimum tillage methods. Due to the relevance of the issue, field studies were conducted in the steppe zone of Ukraine to study different systems of basic tillage on seed germination, soil agrophysical properties, productivity of corn crops, and economic efficiency. Our study suggests that the use of different methods of main soil tillage affects soil moisture content, penetration resistance and bulk density, biometric parameters as plant height, leaf area. Taking into account the global trend towards minimizing soil cultivation, have been analyzed cost-effective to use mouldboard plough, chisel ploughing, disking, and no-till of main tillage which provide the stable yielding capacity of grain of corn under at the level of 6.11–6.99 t/ha accordingly with the profit of 423.9-488.7 €/ha and grain production profitability 115.2-124.0%. Adapting the main tillage to the soil and climatic conditions makes it possible to obtain high and stable corn yields.

Keywords: Tillage Systems; Economic Evaluation; Corn, Soil Properties; Seed Germination; Crop Yield

Introduction

There are two important trends in steppe zone agriculture that require building a clear theoretical model and shifting it into practical methods of corn growing technology. The first of these is that against the background of rapid growth of the genetic potential of corn grain yield, its realization in production conditions remains frankly insufficient. The second trend is related to the inevitability of minimizing tillage, in which soil regimes are not well understood, and the details of plant responses to agrophysical factors are not fully justified (Tsikov, et al. [1,2]). Corn cultivation technologies based on basic models of minimizing tillage radically change the conditions of plant life, starting from the seed germination phase. The environmental factors formed in the soil are influenced by plant residues of predecessors concentrated in a thin layer of chernozem, enhanced microbiological activity of phytopathogens, compaction of the seed germination zone, nitrogen starvation, positively limited availability of fertilizers in the rhizosphere of the crop, and specific transformation of water and physical properties of the soil environment (Busari, et al. [3]). Based on the existing problems of optimizing the agrocenosis model, which includes «variety - environmental factor - technological method», the purpose of our research was to study the effect of different methods of basic tillage on corn seed germination, growth processes of the initial phases of development and the reaction of the crop to the transformation of agrophysical regimes.

Material and Methods

Field experiments were conducted in 2019, 2020, and 2021 on chernozems soil type (44% clay with a pH of 7.0 and an organic matter content of 4.2) near Dnipro (48°16’ N, 34°56’ E) in Ukraine

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County. This region, which is situated in the northern steppe zone of Ukraine, has a moderate continental climate, with insufficient and unstable moisture supply, and an average annual precipitation of 495 mm (during the growing season of corn - 274 mm), which favors agricultural production. The mean daily air temperatures during the study period did not deviate significantly from the long-term average, while the monthly rainfall varied in total amount and periodicity among the years (Table 1). In particular, June 2021 was a very humid month, with significantly greater amounts of rain during the study periods, except during the 2020, when the monthly rainfall during the whole corn vegetation season was less than the average annual (Table 1). A common cropping practice for corn for grain growing in this region was applied in each study year (Lebed, et al. [4]). Fertilizers were applied using the following recommended rates: 60 kg/ha N, 50 kg/ha P, and 50kg/ha K in autumn, and 30 kg/ha N, 10 kg/ha P, and 10 kg/ha K at planting. The corn hybrid DN Khortytsia was seeded on 25 April following a row spacing of 70 cm, with a planter set to deliver 50.000 seeds/ha.

Table 1: Dnipro, mean monthly air temperatures and precipitation April to September.

Month	Temperature (°C)				Precipitation (mm)			
	2019	2020	2021	average annual	2019	2020	2021	average annual
April	11.2	9.0	8.0	9.4	33.1	11.3	53.6	38.5
May	17.9	14.1	15.8	16.0	48.4	79.5	27.2	46.0
June	24.0	22.5	19.5	19.6	30.8	49.2	202.3	59.4
July	21.5	24.8	23.6	21.3	59.3	30.2	69.4	56.7
August	21.2	22.3	22.8	20.6	58.0	11.1	51.4	37.5
September	16.3	19.5	13.8	15.4	19.1	32.1	23.5	36.0

The experimental scheme included four systems of main tillage employing: 1) ploughing a PO3-35 mouldboard plough to a depth of 23-25 cm (in autumn); 2) chiseling a Chisel Plow to a depth of 25-27 cm; 3) disking with a BDVP6.3 harrow to a depth of 10-12 cm; and 4) no-till using direct sowing with a Great Plains YP825A planter. Primextra TZGold 500S (Metallochlor, 312.5g/l + Terbuthylazine, 187.5 g/l) pre-emergence herbicide was applied at 4.5 l/ha; inter-row cultivation was carried out; and in the no-till variant, Roundup herbicide was applied at 4 l/ha in the post-harvest period (Tsykov, et al. [5]). The experiment was conducted in with four replicates over a total area of 330 m² using a 30m² accounting plot (Seeds of agricultural crops. (Methods of quality determination [6]). The BBCH-scale was used to identify the phenological development stages of corn by examining 10 consecutive plants selected in each plot. The experiment was determined the agrophysical parameters of the soil, such as penetration resistance, bulk density, and moisture content. During the determination of moisture soil samples were taken every 10 cm from a depth of 0 to 30 cm. The raw weight of the soil samples was determined, after which the samples were dried in an oven at 105 °C for 8 hours. Soil bulk density was determined by the ring method in a layer of 0-30 cm with an interval of 10 cm. Soil penetration resistance was determined by the Lan-M penetrometer. Soil penetration resistance was determined by a Lan-M penetrometer in 8 places on the plot to a depth of 30 cm.

Determination of laboratory and field germination of seeds, indicators of plant growth and development were conducted in accordance with the methodology of field experiments with corn (Seeds of agricultural crops. Methods of quality determination [6]). Crop accounting was carried out by hand-harvesting, taking into account the moisture content and weed infestation of the product at the stage of full grain ripeness. After determining grain contamination and moisture content, the harvest was recalculated for 100% purity and 14% moisture content. The economic efficiency of sweet corn production was determined by using the standard methodology of calculation of the profitability level (Ushkarenko, et al. [7]). Profitability level was calculated as the ratio of the obtained pure profit to the full expenditures required by a certain variant of cultivation technology. The data were analysed using Statistica 12.0 software (StatSoft Inc., USA) and tabulated as x ± standard deviation; differences between values in control and experimental variants were determined using Tukey's test, where differences are considered significant at $P < 0.05$ (with Bonferroni correction). Crop capacity was determined using mathematical statistics (dispersion method) (Ushkarenko, et al. [7]).

Results and Discussion

Modern systems of main tillage of soil are based on significant volumes of use of plant residues of predecessor crops in crop rotations, which solve important problems of regulating fertility conservation, maintaining their optimal agrophysical condition and achieving high crop productivity (Kaminskyi, et al. [8]). At the same time, with the spread of conservation agriculture, problems arise that have new technological and environmental significance. This is confirmed by the experimental field results obtained in different farming zones (Wang, et al. [9,10]). Our study suggests that the methods of main tillage in the cultivation of corn for grain after the winter wheat predecessor significantly influenced the nature of the distribution of plant residues in the cultivated (arable) soil layer. At

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the same time, in field experiments, it was found that with a total mass of organic residues of the predecessor of 4.72 t/ha, the intensity of soil loosening led to different degrees of their concentration in individual soil layers, depending on the vertical movement of this biomass. During mouldboard plough, the highest concentration of winter wheat plant residues was observed in the soil layer of 20-30 cm where 3.68 t/ha was concentrated, which was 78% of the total mass. Minimization of the main tillage when using chisel tillage, disk tillage, and no-till was accompanied by the concentration of winter wheat plant biomass in the upper 0-10 cm soil layer.

In this zone of the cultivated layer, up to 3.17 t/ha-chisel tillage, 4.12 t/ha-disk tillage, 4.58 t/ha-no-till plant residues of the predecessor were accumulated, or 67.2, 87.3, 97.0 per cent of the total straw mass, respectively (Table 2). The world practice of mastering various systems of main tillage of soil proves that this technological factor is the most influential in regulating the agrophysical properties of soils (Dahri, et al. [11]). At the same time, basic tillage raises the most controversial issues regarding moisture supply, soil compaction, erosion processes, and environmentally friendly farming. In more studies, the authors note the deterioration of agrophysical properties of soils with minimization of tillage (Muñoz Romero, et al. [12]). The use of different methods of basic tillage has been impacted on moisture content, penetration resistance and bulk density of soil composition throughout (Table 2). At the beginning of the growing season, the regularities in the ratio of soil moisture, hardness, and density were fully manifested. The best moisture supply was observed on the background of ploughing where in the soil layer 0-30 cm was 23.7%. With the minimization of tillage and the transition to no-till technology, the moisture content status deteriorated significantly to a value of 22.1%. But, in general, the range of soil moisture content fluctuations in the tilth layer at the beginning of the growing season was maintained within the optimal limits for the functioning of corn growth processes against the background of the studied tillage systems.

Table 2: Influence of soil tillage methods on its agrophysical soil properties and distribution of crop residues in the soil profile (before sowing corn) (average for 2019-2021, x ± SD, n=8).

Soil agrophysical properties	Soil layer, cm	Tillage			
		mouldboard plough	chisel tillage	disc tillage	no-till
Moisture content, %	0-10	23.4 ± 0.1^{a}	23.7 ± 0.1^{a}	23.2 ± 0.1^{ab}	22.1 ± 0.1^{b}
	10-20	23.8 ± 0.2^{a}	23.7 ± 0.1^{a}	23.0 ± 0.2^{ab}	22.1 ± 0.2^{b}
	20-30	23.8 ± 0.2^{a}	23.7 ± 0.1^{a}	22.9 ± 0.2^{ab}	22.0 ± 0.2^{b}
	0-30	23.7 ± 0.2^{a}	23.7 ± 0.1^{a}	23.0 ± 0.1^{ab}	22.1 ± 0.1^{b}
Penetration resistance, kg/c^{m}2	0-10	8.3 ± 1.8^{a}	10.3 ± 2.0^{a}	12.3 ± 2.4^{ab}	13.0 ± 1.7^{ab}
	10-20	12.2 ± 2.2^{ab}	14.8 ± 2.6^{ab}	15.5 ± 2.6^{b}	15.9 ± 1.6^{b}
	20-30	14.5 ± 2.5^{ab}	16.6 ± 2.7^{b}	19.1 ± 2.9^{bc}	20.6 ± 2.9^{bc}
	0-30	12.7 ± 2.3^{ab}	13.9 ± 2.4^{ab}	15.6 ± 2.5^{b}	16.5 ± 2.6^{b}
Bulk density, g/cm^3	0-10	1.12 ± 0.01^{a}	1.14 ± 0.02^{a}	1.15 ± 0.01^{ab}	1.15 ± 0.01^{ab}
	10-20	1.19 ± 0.02^{ab}	1.20 ± 0.02^{ab}	1.21 ± 0.02^{b}	1.27 ± 0.02^{bc}
	20-30	1.22 ± 0.02^{b}	1.22 ± 0.02^{b}	1.25 ± 0.02^{b}	1.29 ± 0.02^{bc}
	0-30	1.18 ± 0.02^{a}	1.19 ± 0.02^{ab}	1.20 ± 0.02^{ab}	1.24 ± 0.02^{b}
Distribution of crop residues, t/ha	0-10	0.33 ± 0.12^{cd}	3.17 ± 0.15^{b}	4.12 ± 0.16^{a}	4.58 ± 0.17^{a}
	10-20	0.71 ± 0.13^{c}	0.86 ± 0.11^{c}	0.43 ± 0.12^{c}	0.21 ± 0.10^{cd}
	20-30	3.68 ± 0.16^{a}	0.72 ± 0.11^{c}	0.17 ± 0.10^{cd}	0.02 ± 0.01^{d}

Note: Different letters indicate the values significantly differing one from another within an agrophysical soil property of the Table 2 on the results of comparison using the Tukey test ($P < 0.05$) with Bonferroni correction.

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In the arable layer, the indicators of soil hardness and soil density for the period of corn sowing were also transformed under the influence of the intensity of basic tillage and maintained the established optimal parameters at the level of 12,7-16.5 kg/cm2 soil penetration resistance and 1.18-1.24 g/cm3 soil bulk density. The maximum soil compaction was observed on the background of no-till, while on the background of ploughing, the chernozems was more loosened. Methods of soil tillage are becoming increasingly important in regulating soil temperature due to global climate warming. The systems of basic tillage can effectively regulate the temperature at the depth of seed placement and reduce the risk of drought (Haruna, et al. [13]). The methods of basic tillage influenced the projective coverage of the soil surface with plant residues and the average daily soil temperature at the depth of sowing seeds (6-8 cm). More active accumulation of solar thermal energy was observed against the background of mouldboard plough. The presence of plant residues on the surface with minimization of tillage and no-till was accompanied by a decrease in the rate of soil warming in the zone of corn seed germination. This trend persisted during the initial stages of corn plant development (BBCN 00-15). For example, at the stage of plant development according to the BBCH 00 scale, the soil temperature at the depth of seed placement using no-till technology was 1.2 °C lower compared to mouldboard plough.

During the initial phases of growth and development of corn plants, the smallest difference in soil temperature was found between chisel tillage and shallow disk tillage, which did not exceed 0.2 °C (Table 3). Reduced and soil-protective tillage technologies may represent certain negatives for cultivated crops associated with the biomass of mulch from intermediate crops and post-harvest residues. Sown crops are exposed to impaired soil conditions. The reduced tillage technologies can apparently significantly slow down the germination rate in field crops. Among the factors that negatively affected the field germination of corn with minimization of main tillage, first of all, it is necessary to highlight the heterogeneity of the sowing soil layer in terms of agrophysical properties, the presence of a large amount of plant residues in it, increased phytopathogenic danger, and compaction of mollisol (Johnson, et al. [14,15]). Field experiments shown that mouldboard plough, chisel tillage, disc tillage, and no-till of corn were created different agrophysical, agrochemical and microbiological conditions for seed germination. With high laboratory germination of corn hybrid seeds (99%), field germination was differed significantly depending on the methods of main soil tillage. Thus, the most favorable conditions for seed germination in the field were formed against the background of mouldboard plough, where field germination was 85.6%, and with minimization of tillage and no-till, its indicators decreased to 78.1-82.3%.

Table 3: Influence of main tillage methods and herbicide on germination of corn seeds, %, (average for 2019–2021, x ± SD, n=16).

Seed germination	Tillage			
	mouldboard plough	chisel tillage	disc tillage	no-till
Average daily of temperature at 6-8 cm	11.4 ± 0.3[a]	11.1 ± 0.3[a]	11.0 ± 0.3[a]	10.2 ± 0.2[b]
Field germination without herbicide	85.6 ± 1.2[a]	82.3 ± 1.3[ab]	81.0 ± 1.3[ab]	77.8 ± 1.3[b]
Field germination with Primextra TZGold	86.0 ± 1.3[a]	82.9 ± 1.2[ab]	81.0 ± 1.3[ab]	78.1 ± 1.3[b]
Plant height, cm (BBCH 67-69 stage)	234.3 ± 1.5[a]	232.1 ± 1.5[a]	230.5 ± 1.5[ab]	226.9 ± 1.5[b]
Leaf surface area, thousand m^2/ha (BBCH 67-69 stage)	23.6 ± 0.4[a]	23.2 ± 0.3[a]	23.0 ± 0.3[a]	22.7 ± 0.3[b]

Note: Different letters indicate the values significantly differing one from another within an agrophysical soil property of the Table 2 on the results of comparison using the Tukey test (P < 0.05) with Bonferroni correction.

The use of Primextra TZ Gold 500S soil herbicide did not have a negative impact on corn seeds and seedlings, as evidenced by equivalent field germination rates with variants without weed control products. The difference in field germination with the use of herbicide and without the use of herbicide was 0.3-0.6% (Table 3). At all stages of maize growth and development, some specific depressive effect of minimizing tillage was found in terms of such biometric parameters as plant height, leaf area. The general depression of growth processes was manifested in this case in terms of leaf surface area, which reached 23.6 thousand m2/ha in the phase of completion of linear growth of corn plants in mouldboard plough compared to no-till of 22.7 thousand m2/ha. In order to obtain objective results of the study on yield estimation depending on the methods of basic tillage, it is advisable in all cases to include morphobiological growth characteristics of the crop in the database (Li, et al. [16]). Corn grain yields (Table 4) varied within individual years of the field experiments and depended on the methods of main tillage. The maximum corn grain yield of 8.56 t/ha was formed in 2021 as a result of the most favorable hydrothermal parameters of the steppe climate. At the same time, the climatic factor of 2021 had a positive effect on all methods of main tillage. The minimum yield of 4.92 t/ha was obtained in 2020 using no-till technology due to a deficit in moisture availability during the corn growing season. On average, over the years of research, minimization of soil tillage led to a yield shortfall.

Table 4: Corn grain yield depending on different methods of basic tillage, t/ha (average for 2019–2021, x ± SD, n=8).

Year (factor A)	Tillage (factor B)			
	mouldboard plough	chisel tillage	disc tillage	no-till
2019	6.59 ± 0.13[b]	6.16 ± 0.12[bc]	5.58 ± 0.12[c]	5.44 ± 0.12[c]
2020	5.83 ± 0.12[bc]	5.37 ± 0.11[c]	5.06 ± 0.11[cd]	4.92 ± 0.12[cd]
2021	8.56 ± 0.14[a]	8.34 ± 0.14[a]	8.18 ± 0.13[ab]	7.96 ± 0.13[ab]
Average	6.99	6.62	6.27	6.11
Least significant difference (LSD), t/ha (p = 0.05)				
for factor A	0.09			
for factor B	0.12			
for interaction AB	0.13			

Note: Different letters indicate the values significantly differing one from another within an agrophysical soil property of the Table 2 on the results of comparison using the Tukey test (P < 0.05) with Bonferroni correction.

Due to optimization of agrophysical, morphobiological, and biometric soil parameters depending on the methods of main tillage, mouldboard plough and chisel tillage ensured stable corn grain yields at the level of 6.99-6.62 t/ha. During the years of research, disk tillage and no-till regularly lagged behind by 0.35-0.88 t/ha from the grain productivity of corn obtained from traditionally intensive and chisel tillage. Taking into account the global trend towards minimizing soil cultivation (Tsikov, et al. [1,8]) have been analyzed cost-effective to use mouldboard plough, chisel ploughing, disking, and no-till of main tillage which provide the stable yielding capacity of grain of corn under conditions in the northern steppe zone of Ukraine at the level of 6,11-6,99 t/ha accordingly with the profit of 423,9-488,7 €/ha and grain production profitability 115,2-124,0% (Table 5). The maximum economic efficiency of growing corn is provided by an autumn ploughing with a PO3-35 mouldboard plough to a depth of 23-25 cm. This is expressed in the highest index of profitability level – 124.0%. The lowest index of profitability level was in the variant with disking to 10-12 cm and amounted to 115.2%. Analysis of economic efficiency concerning the production of corn grain showed that cultivation of corn is profitable of agricultural production conditions. The optimization of methods soil tillage is the key to the efficient production of corn grain. Thus, it is important to conduct research work for each area of cultivation, taking into account the range of hybrids, ecological, climatic, soil conditions and the level of agricultural development in the area.

Table 5: Economic indices of corn cultivation depend on the methods of main tillage (average for 2019-2021).

Variant	Corn grain yield, t/ha	Gross product value, €/ ha	Costs per, €/ha	Prime cost, €/t	Net profit, €	Profitability level, %
Mouldboard plough	6.99	882.9	394.2	56.4	488.7	124.0
Chisel tillage	6.62	836.2	375.8	56.8	460.4	122.5
Disc tillage	6.27	792.0	368.0	58.7	424.0	115.2
No-till	6.11	771.8	347.9	56.9	423.9	121.8

Conclusion

The system of regulating the efficiency of corn agrocenoses in the steppe zone of Ukraine has enough soil and climatic resources to ensure high yields of this crop and economic effect. In field experiments was found that with a total mass of organic residues of the predecessor of 4.72 t/ha, during mouldboard plough, the highest concentration of winter wheat plant residues (3.68 t/ha) was observed in the soil layer of 20-30 cm. Minimization of the main tillage was accompanied by the concentration of winter wheat plant biomass (3.14-4.58 t/ha) in the upper 0-10 cm soil layer. The use of different methods of main soil tillage affects soil moisture content, penetration resistance and bulk density during the entire growing season. With the minimization of tillage and the transition to no-till technology, agrophysical parameters deteriorated. The methods of basic tillage influenced the projective coverage of the soil surface with plant residues and the average daily soil temperature at the depth of sowing seeds (6-8 cm). The presence of plant residues on the surface with minimization of tillage and no-till was accompanied by a decrease in the rate of soil warming in the zone of corn seed germination. The most favorable conditions for seed germination in the field were formed against the background of mouldboard plough, where field germination was 85.6 %, and with minimization of tillage and no-till, its indicators decreased to 78.1-82.3 %. The use of Primextra TZGold 500S soil herbicide did not have a negative impact on corn seeds and seedlings.

At all stages of maize growth and development, some specific depressive effect of minimizing tillage was found in terms of such biometric parameters as plant height, and leaf area. On average, over the years of research, minimizing tillage led to a yield shortfall of 0.37-0.88 t/ha compared to mouldboard plough. There have been outlined economically efficient to use mouldboard plough, chisel ploughing, disking, and no-till of main tillage which provide the stable yielding capacity of grain of corn under conditions in the northern steppe zone of Ukraine at the level of 6,11-6,99 t/ha accordingly with the profit of 423,9-488,7 €/ha and grain production profitability 115,2-124,0%. The system of regulating the efficiency of corn agrocenoses in the steppe zone of Ukraine has enough soil and climatic resources to ensure high yields of this crop.

Declaration

The authors declare no conflicts of interest.

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