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Influence of Soil Tillage System and Fertilization on Soil Compaction, Water Reserve and Soybean Yield

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ABSTRACT

In recent years, unconventional tillage systems have also experienced a significant expansion in Romanian agriculture. In this context, it was considered appropriate to analyze the impact of the tillage system (conventional-plowed) and conservative tillage (direct seeding), on the degree of soil compaction, water reserve and soybean yield, in a three-year rotation (maize-soybean-wheat). The study was designed and conducted at the Agricultural Research and Development Station (ARDS) Turda and included the following experimental factors: Factor A - tillage system: conventional (plow - SC) and conservative (direct sowing - NT); Factor B - fertilization: unfertilized control and basic fertilization ($N_{40}P_{40}$); Factor C - varieties: Felix and Iris TD. Soybean yield was influenced by the local climatic conditions, the applied agricultural technology and, last but not least, the genetic potential of the varieties. Results indicated that on chernozemic soils with high clay content, soybeans responded less favorably to no-till systems, suggesting that deeper tillage is required to achieve high yields in these soil types.

Keywords: soil, compaction, water, soybean, yield.

INTRODUCTION

Soybean (*Glycine max* L.) is a particularly valuable agricultural crop due to its multiple uses (Singh et al., 2019): in human nutrition (Tripathi and Misra, 2005; Dukariya et al., 2020), in animal feed (Dei, 2011), as well as in industry for obtaining oils used in painting, plastics, margarine etc. (Kok et al., 1999; Güzeler and Özbek, 2016). In addition, the soybean crop contributes to the improvement of the physical properties of the soil (Milson et al., 2023), due to the symbiosis between its roots and the nitrogen-fixing bacteria of the *Bradyrhizobium japonicum* species. This symbiotic relationship (Sprent et al., 2017) generates specialized nodules that fix atmospheric nitrogen for the benefit of the plant. Through this ability to enrich the soil with nitrogen (Herridge et al., 2022), soybeans are an excellent precursor to crops that are not part of the Fabaceae family (www.axereal.hr). Although crop technology can significantly influence the yield potential of soybean varieties, specialized studies suggest that soybeans also perform well when cultivated in unconventional tillage systems (Delbert, 1989; Salar et al., 2021). In order for a soybean variety to be suitable for the unconventional farming system, it must meet certain requirements, including: resistance to diseases, ability to emerge quickly at low temperatures and high vigor in the young stages of development (De Felice et al., 2006; Shea et al., 2020; Gai et al., 2025).

The cultivation system with conservative works is an integrated alternative in the concept of sustainable agriculture (Shah et al., 2025) and has been studied in various pedo-climatic conditions in order to be optimized and adapted to the local specificity (Bran et al., 2008). This system involves, in addition to direct sowing in the stubble of the previous crop, the application of an appropriate crop rotation (Chețan, 2015), chopping and storing plant residues of the previous crop on the soil surface (in this case maize), keeping the soil covered with permanent vegetation between crop cycles (Petcu et al., 2022) etc. Initially, direct sowing in plant debris was designed as an effective technology to protect the soil (Carter, 1994; Alotaibi, 2023). In this

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context, it is necessary to adopt agricultural technologies aimed at contributing to the conservation of water in the soil, in order to ensure optimal productive potential (Fontes, 2020; Chețan et al., 2021). According to the specialized literature, it is recommended to implement measures adaptable to the specifics of each geographical area and local pedoclimatic conditions, in order to limit and counteract the effects of drought (Rusu and Moraru, 2015; Adimassu et al., 2017). These measures include: the use of biological material resistant to water and heat stress; application of agrotechnical technologies that favor the accumulation, conservation and efficient use of rainwater (Alharbi et al., 2024); promoting conservation agriculture (Matei et al., 2024), focused on soil protection, carbon sequestration (Petcu et al., 2022) and the prevention of desertification; identification of areas vulnerable to climate change and use of varieties adapted to the new pedoclimatic conditions specific to these regions (Muhammad et al., 2024).

In recent years, there has been an increase in the frequency of extreme weather events, manifested by prolonged periods of drought and reduced amounts of precipitation (Dai et al., 2025). These conditions affect the ability of soils to maintain an optimal level of moisture for plants. The situation is even more critical when the lack of water coincides with the periods in which plants have the highest humidity and temperature requirements, negatively influencing physiological processes and, implicitly, their productivity.

The paper presents the results of the research carried out under the conditions of the Agricultural Research and Development Station (ARDS) Turda, located in the hilly area of the Transylvanian Plain, regarding the influence of the tillage system and the fertilization system on the degree of soil compaction, the water reserve available to plants and the yield of soybean crops.

MATERIAL AND METHODS

Location of the experimental field

The experimental fields are located in the western part of the Transylvanian Plain, in a hilly area that dominates the relief (71% of the surface), is characterized by low plateau hills, while being affected by an accentuated erosion process (Chețan, 2020). In the experiment, a three years crop rotation is used (maize-soybean-wheat), thus also achieving root rotation.

Soil description

The experiment was set on a Chernozemic-type soil (SRTS, 2012), with clay texture and favorable hydrophysical properties: porosity of 59% on the surface and 47% in depth, high water holding capacity (32%) and wilting coefficient (WC) of 18%. The agrochemical characteristics of the soil (MESP, 1987), determined at a depth of 0-40 cm, are as follows: pH 7.00; humus content 2.94%; total nitrogen 0.162%; phosphorus 9 ppm; potassium 140 ppm (Chețan et al., 2020). This type of soil settles quickly when subjected to repeated passes by heavy machinery or when agricultural work takes place in conditions of high humidity.

Climatic description

The climatic conditions between April and September 2023 and 2024 are presented in Table 1 (Primary data source: Turda meteorological station, longitude: 23°47’E - latitude 46°35’N, altitude 427 m). Analyzing these data, it can be seen that, in most months, temperatures were higher than the multiannual monthly average and as for the rainfall regime, it had an uneven distribution, with values below the multiannual average in most months.

Compared to the multiannual monthly average over the last 65 years, April 2023 was a cool month, with an average temperature of 8.8°C, and very dry, with only 30.5 mm of rainfall. In May, the average monthly temperature was around the normal value of 15.4°C, but the rainfall regime remained low, with the amount of rainfall being only 33.2 mm, so the month was characterized as excessively dry. This water lack had a negative impact on the development of soybean and maize crops. The month of June was characterized by temperature values above the multiannual average (19.0°C) and abundant rainfall

(144.5 mm), favorable conditions for plant development. In July, temperatures continued to rise slightly, especially in the second decade of the month, with the average monthly temperature reaching 21.8°C. The consistent rains in the last days of July (63.8 mm) contributed significantly to the good development of crops. The months of August (22.1°C) and September (19.0°C) were characterized by high average temperatures, and in terms of rainfall, both months were excessively rainy, with 98.5 mm in August and 116.1 mm in September.

Both at the level of the entire country and in the case of the region where the experiment was carried out, the year 2024 was the hottest in recent decades, the multiannual thermal average being exceeded in most months, and new records of maximum temperatures were also recorded. April was a hot month, with an average temperature of 13.3°C and low rainfall, totaling only 38.8 mm. In May, the average monthly temperature was around 15.8°C, considered normal for this time of year, and the rainfall regime registered a slight increase compared to the previous year, the average amount being 60.7 mm, still indicating a slightly dry month. June was characterized by high average temperature (21.7°C) and a severe lack of rainfall (36.2 mm), being considered excessively dry. In July, temperatures remained high (24.0°C), which made the month warm and very dry, especially compared to the multi-year average (19.8°C and 78.0 mm). August was characterized by a very high average temperature, of 23.4°C, and an excessive deficit of rainfall, totaling only 37 mm - indicating an excessively dry period. In September, temperatures remained at a relatively high level for this period (17.9°C) and the amount of rainfall was significant (64 mm), both values exceeding the multiannual averages of 15.2°C and 42.4 mm.

Table 1. Weather condition during soybean growing season, 2023-2024

Month/ Year	Rainfall (mm)			Temperatures (°C)		
	2023	2024	65 years	2023	2024	65 years
April	30.5	38.8	45.6	8.8	13.3	10.0
May	33.2	60.7	69.4	15.4	15.8	15.0
June	144.5	36.2	84.6	19.0	21.7	18.0
July	85.8	49	78	21.8	24	19.8
August	98.5	37	56.1	22.1	23.4	19.5
September	116.1	64	42.4	19.2	17.9	15.2
Sum (mm)	508.6	285.7	376.1	-	-	-
Average (°C)	-	-	-	17.7	19.4	16.3

Field management

In the experiment, three years crop rotation was used (maize-soybean-wheat), thus also achieving root rotation.

The experimental factors implemented in the experimental field are:

- Factor A - Tillage system

a_1 - conventional plough tillage system (SC)

a_2 - direct seeding system (no-tillage, NT)

- Factor B - fertilization level:

b_1 - without fertilization

b_2 - fertilization with $N_{40}P_{40}$

- Factor C - soybean variety (000 maturity group):

c_1 - Felix

c_2 - Iris TD

- Factor D - year (climatic conditions):

d_1 - 2023

d_2 - 2024

Soybean sowing was carried out in April, in the third decade (2023) and in the first decade (2024), taking into account the evolution of climatic conditions.

In general, in soybean cultivation technology, the application of herbicide in pre-emergence, followed by a post-emergence intervention, ensures a crop that is effectively protected against weeds. However, in order to implement effective measures as early as possible, it is essential to know the spectrum of weed species present. In the experimental field, both annual and perennial weeds have been identified, such as: *Galeopsis tetrahit, Cirsium arvense, Cardaria draba, Solanum nigrum, Xanthium strumarium, Chenopodium album, Convolvulus arvensis, Amaranthus retroflexus, Tragopogon dubius, Polygonum convolvulus, Agropyron repens, Rubus caesius, Picris echioides, Hibiscus trionum, Capsella bursa-pastoris, Setaria glauca, Sonchus oleraceus* and *Echinochloa crus-galli*.

During the experimental period, soybean plants were affected by *Peronospora manshurica* (soybean downy mildew) and bacterial blight caused by *Pseudomonas savastanoi* pv. *Wisteria.* However, no chemical treatment was applied, as the degree of attack (GA%) remained below 2%.

Sampling and methods

The determination of the momentary water reserve in the soil was carried out by the classical method, on the appropriate depth and drying the samples in the oven for 8 hours at 105°C. Soil moisture was determined in the two tillage systems: conventional (CS) and direct seeding (NT), at a depth of 0-50 cm.

After harvesting and weighing each experimental variant, samples were taken in order to establish the moisture content of the beans (with the Granomat PERTEN laboratory moisture meter). On the basis of the bean’s moisture, the soybean yield was calculated, then it was related to the unit area, after which it was recalculated with the correction for the STAS moisture (13%).

Soil penetration resistance (soil compaction) was measured using a Field Scout penetrometer down to a depth of 40 cm, corresponding to the main rooting zone of soybean. This indicator is important for assessing the extent to which the soybean root system development was influenced or restricted by the tillage system. The measurements were conducted after the soybean harvest each experimental year.

Statistical analysis

The experimental data were analyzed using analysis of variance (ANOVA) and the Least Significant Difference (LSD) was calculated at significance levels of 5%, 1%, and 0.1% (ANOVA, 2015).

RESULTS AND DISCUSSION

Influence of tillage systems on water reserve

The current soil water reserve, determined on the horizon of 0-50 cm (Figure 1), in 2023 was above the value of the minimum limit (1734.8 m^3/ha) throughout the months under study (soybean sowing-harvesting) in both tillage variants. The deficient rainfall regime recorded in 2024, especially in June-August (flowering - soybean filling period) has considerably decreased the water reserve in the soil, with repercussions on yield. Even if the momentary water reserve (m^3/ha) had low values, the threshold at which plants suspend their physiological processes has not been reached (Wilting Coefficient). In contrast to these claims, research by Karlen and Sojka (1985) showed that the CS variant tends to exhibit higher temperatures and lower moisture content compared to NT.

Figure 1. Momentary water reserve (m^3/ha) at 0-50 cm

Influence of experimental factors tillage on soybean yield, 2023-2024

It seems that the conventional tillage system, which allows loosening the land, offers more favorable conditions for the development of soybean plants compared to no tillage, which is materialized in the yields achieved. The yield difference between the two systems, CS-NT, is 1109 kg/ha, in favor of the CS system, the difference being statistically assured as very significantly negative. In the experimental area, soybean cultivation in the NT system is less suitable (the soil has a clay content of over 45%), as shown by the production data (Table 2).

Soybeans, like other legumes, form a symbiotic relationship with the nitrogen-fixing bacterium *Bradyrhizobium japonicum*, through which nitrogen compounds necessary for the plant are generated. However, biological fixation does not provide the full amount of nitrogen the crop needs. For this reason, a fertilization variant (40 kg N/ha + 40 kg P/ha) was included in the experiment, essential for the absorption of nutrients resulting from photosynthesis and for the accumulation of organic compounds with high energy value. The use of these moderate doses of fertilizers has a significant impact on yield, leading to an increase of 352 kg/ha.

As can be seen from the data presented in Table 2, the average yields obtained in the two years of the experimentation had similar values. Thus, the Felix variety recorded a yield of 1592 kg/ha, and in the case of the Iris TD variety, a slight decrease was observed compared to the control variant, of 88 kg/ha, a statistically insignificant difference.

The climatic conditions in the period 2023-2024 had a very significant influence (positive; negative) on soybean yield, compared to the two years average. The climatic conditions in 2023 were slightly more favorable for the soybean crop, compared to the following year, when climatic conditions have led to lower yields. This aspect was reflected in a yield of 1849 kg/ha in 2023, 266 kg/ha higher than the average obtained over the entire experimental period (1583 kg/ha).

Table 2. The influence of experimental factors in the soybean yield, 2023-2024

Experimental factor	Yield, kg/ha	Differences ±, kg/ha
A - Soil tillage system		
a_1 Conventional system (CS)	2138	0.00^{Ct}
a_2 No tillage (T)	1029	-1109^{ooo}
Notes: LSD (5%) = 138 kg/ha, LSD (1%) = 228 kg/ha, LSD (0.1%) = 426 kg/ha; Ct. = control		
B - Fertilization system		
b_1 Unfertilized	1407	0.00^{Ct}
b_2 Fertilized with $N_{40}P_{40}$	1759	352***
Notes: LSD (5%) = 69 kg/ha, LSD (1%) = 100 kg/ha, LSD (0.1%) = 151 kg/ha; Ct. = control.		
C - Variety		
c_1 Felix	1592	0.00^{Ct}
c_2 Iris TD	1505	-88^{ns}
Notes: LSD (5%) = 133 kg/ha, LSD (1%) = 307 kg/ha, LSD (0.1%) = 977 kg/ha; Ct. = control.		
D - Year		
d_0 Mean	1583	0.00^{Ct}
d_1 2023	1849	266***
d_2 2024	1318	-266^{ooo}
Notes: LSD (5%) = 64 kg/ha, LSD (1%) = 106 kg/ha, LSD (0.1%) = 198 kg/ha; Ct. = control.		

In 2023, compared to the CS variant without fertilization (2293 kg/ha), the NT system determined a considerable reduction in soybean yield, by 1209 kg/ha, and in the fertilized version by 1443 kg/ha (2730 kg/ha), the differences being statistically assured (very significantly negative). Analyzing the situation in 2024, referring to the CS, the NT system caused a yield decrease by 786 kg/ha in variant without fertilization and by 992 kg/ha in the fertilized one, these differences being statistically assured as very significantly negative (Table 3).

Table 3. The influence of interaction between the experimental factors (system x fertilization x year) on the soybean average yield

Fertilization	Year	Tillage system	Yield (kg/ha)	Differences ± kg/ha
Without fertilization	2023	SC	2293	$0.00^{Ct.}$
		NT	1085	-1209^{ooo}
	2024	SC	1518	$0.00^{Ct.}$
		NT	733	-786^{ooo}
$N_{40}P_{40}$	2023	SC	2730	$0.00^{Ct.}$
		NT	1288	-1443^{ooo}
	2024	SC	2009	$0.00^{Ct.}$
		NT	1011	-998^{ooo}
LSD (5%) = 175 kg/ha; LSD (1%) = 270 kg/ha; LSD (0.1%) = 456 kg/ha; Significant at 0.1% probability levels, negative values; Ct = control variant.				

The importance of soybean fertilization is also highlighted in other studies and research including Meese et al. (1991) and Osborne and Riedell (2006), which found that a nitrogen deficit at the beginning of the season can lead to significant yield reduction, losses can reach up to 52%. The results obtained are consistent with previous studies (Kendall et al., 2025), which showed that the CT generated a higher yield compared to NT.

Influence of tillage systems on specific soil resistance to penetration (Rp)

The specific resistance of the soil to penetration (Rp) is one of the main mechanical indicators that reflect the degree of soil particles compaction (Saygin et al., 2023). The evaluation of the degree of soil compaction can be achieved by analyzing the absolute values of penetration resistance. According to the data in Figure 2, significant differences are highlighted both between tillage systems and between years of experimentation. The conditions in 2023 led to lower values of soil resistance to penetration, compared to those recorded in 2024, across all analyzed horizons. It is also noted that the soil resistance increases with the measuring depth in both tillage systems, the maximum values being reached in the NT system. In the CS, the soil resistance in the first 40 cm was between 958-4176 kPa in 2023 and between 1165-4638 kPa in 2024, respectively. For the NT system, the values ranged from 1320-4605 kPa in the first year to 1470-4712 kPa in the second.

According to the scientific literature, a resistance between 2000 and 3000 kPa is considered the acceptable upper limit for the normal development of the root system of plants (Bengough et al., 2011). Exceeding this range can limit root growth, negatively affecting both biomass and crop yields. Kuhwald et al. (2020) also point out that soil resistance to penetration is influenced by soil moisture, increasing significantly in drought conditions.

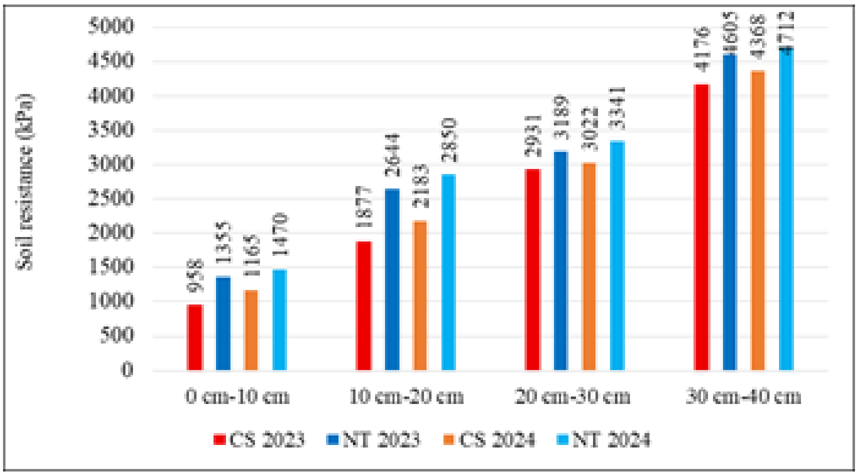

Figure 2. Influence of tillage systems on specific soil resistance to penetration

CONCLUSIONS

- On chernozemic soils with high clay content, soybeans responded less favorably to no-till seeding, requiring deeper tillage to achieve high yields. The yield difference between conventional plowing (CS) and no-till (NT) was 1109 kg/ha, in favor of plowing.
- Moderate fertilization with complex mineral fertilizers applied at sowing increased yield by 352 kg/ha.
- The two soybean varieties showed similar responses to the applied tillage systems, with average yields differing by less than 100 kg/ha.
- High temperatures combined with deficient rainfall during the growing season reduced yields by approximately 500 kg/ha.
- Soil penetration resistance was influenced by both the tillage system and the climatic conditions of the experimental year.

The deficient rainfall in 2024, particularly from June to August (flowering and grain-filling stages), significantly reduced the soil's available water reserve under both tillage systems.

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