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OPTIMIZATION OF CONVENTIONAL AGRICULTURE (TILLAGE X FERTILIZATION X PLANT PROTECTION) FOR SOYBEAN IN THE TRANSYLVANIAN PLAIN

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Abstract: The purpose of this study was to improve conventional agricultural technologies in soybean crop to ensure a higher yield and reduced environmental impact under climate conditions specific for the Transylvanian Plain. For the experimental design a three-factorial experiment was set up (tillage x fertilization x plant protection products). Factor interaction was evaluated using formula AxBxC-R:4x4x4-3 to highlight the benefits of the practices. This study examined yield crops and size of the soybean plants in an effort to identify best practices. Yield was highly increased in conventional soil tillage system (3420 kg/ha), whereas for the minimum soil tillage system and for direct sowing there were no significant difference 2755-2995 kg/ha and 2605 kg/ha, respectively. Crop performance in terms of yield was highly influenced by the soil tillage system (57.5%), followed by plant protection treatments (22.9%) and fertilization (11.8%). Fertilization with $N_{40}P_{40}$ + gulle + green fertilizer ensured the highest soybean production (3132 kg/ha). Plant protection treatments during vegetation determined significant yield increases, with high influence of insecticides and a cummulative effect when both fungicides and insecticides were used (3193 kg/ha). Highest size of plants was registered in conventional soil tillage system. Overall crop protection treatments during vegetation (insecticide + fungicide) triggered not significant increases in plant size, except Teo TD soybean cultivar.

Key words*: soil tillage, fertilization, plant protection, soybean crop*

INTRODUCTION

Soybean is one of the most valuable and famous agricultural plants, useful for human and animal food and industry (Muntean et al., 1995; Duda et al., 2008). As soybean is a pulses, contributes to soil fertility. Thermal resources are one of the main limiting factors in extending the crop to northern areas, while in the southern areas, the efficiency of the crop usually depends on hydric resources (Rusu, 2001; Domuta et al., 2012; Moraru & Rusu, 2013; Gawęda et al., 2020).

In soybean crop research and extension of minimum soil tillage systems and direct sowing have become important alongside with decreased production costs and risks of soil compaction, degradation and erosion (Moraru et al., 2015). Actions like fighting against soil erosion (Kováč et al., 2014), preserving water in the soil (Zheng et al., 2009; Llano & Vargas, 2016) and adapting to climate changes (Choi et al., 2016; Ghaley et al., 2018; Wulanningtyas et al., 2021) are currently under the attention.

The application of minimum soil tillage systems and of direct sowing supposes changes in the crop technology specific to the soybean crop (Chețan et al., 2016b). When minimum soil tillage systems are applied, different techniques of integrated management of pest and diseases are required due to changes in the reserve of weed seeds in soil (Cristian & Ball, 1994), their ratios in soil (Cardina et al., 1991) as well as the diversity of species (Bogdan, 1997; Guş et al., 2004; Ozturk & Sogut, 2016), compared to conventional system.

Soybean is especially sensitive to weeds during the first phases of growing up to covering the land, but also later, at senescence, when leaves start falling. Once invaded by weeds, especially during the first phase of vegetation, the crop is compromised, even if subsequently weeds are controlled (Rusu et al., 2012). As soybean is a small-size plant, it is easily competed by weeds, with high production losses (30-80%) (Hartzler & Michael, 1997; Berca, 2004; Avola et al., 2008; Cheţan et al., 2019a). The most frequent weeds are especially those which germinate late in spring, as: *Echinochloa crus-galli*, *Setaria* sp., *Digitaria sanguinalis, Sorghum halepense, Agropyron repens, Solanum nigrum, Amaranthus retroflexus, Chenopodium album, Galinsoga parviflora*, *Xanthium* sp., *Abutilon teophrasti, Datura stramonium, Polygonum* sp., *Cirsium arvense, Convolvulus arvensis* (Sartorato et al., 1996; Gus et al., 2004).

Specific strategy of integrated weed control in order to reduce their amount under the economic threshold is required. The explosive weeding of soybean crop due to sowing late in spring when the entire vegetation is explosively reborn, the high diverse infestation and variability of weed species ratios are the major factors. The strategy for weed, diseases and pest control (Suciu et al., 2019) should be adapted according to the soil tillage system (Rusu et al., 2014; Cheţan et al., 2019b; Reis et al., 2020). The curently climate changes require the need of specific technological measures of this strategy in soybean. Under these conditions, the most important objective is to preserve water in the soil by minimum soil tillage or direct sowing, ensuring the mulch from the soil surface and preventive control of weeds. Enough moisture in soil is the main condition to obtain good results.

The purpose of the present paper is to optimize conventional technology: soil tillage system, fertilization system and plants protection system in soybean crop. The study evaluates the contribution of multiple factors like soil tillage system x fertilization x plant protection treatments in soybean crop, under field experimental conditions.

MATERIALS AND METHODS

The study was conducted during the agricultural year 2019-2020, under the climate conditions from the Transylvanian Plain at the Agricultural Research and Development Station Turda (ARDS Turda) on a Phaeozem soil (Florea et. al., 2012). The experiments were carried out in a soil with neutral pH (between 6.8-7.2), clay texture (clay between 51.8-55.5 %) and humus content between 2.20-3.00 % in the first 30 cm, total nitrogen 0.162-0.124 %; phosphorous 0.9-5 ppm; potassium 126-140 ppm. The potentiometric method was used to establish pH, and the Walkley-Black method was used for humus; total nitrogen was established using the Kjeldhal method; phosphorous and potassium were established through the Egner-Riehm-Domingo extraction method.

The climatic conditions of the experimental field are characterized by a multiannual average of temperatures of 9.2°C and a multiannual average amount of rainfall of 531.4 mm. The agricultural year 2019-2020 had warm months (January, February, March, April, June, July, August, September), except May, which was a very chilly month (recording a deviation of -1.3°C compared to the average of 13.7°C of May). The rainfall regime highly varied, very rainy months (February, March, June, September), alternating with dry ones (January, April, May). These variations triggered phytosanitary risks by increasing the abundance of harmful insects, phytopathogenic agents and weeds.

In order to validate technologies to ensure a higher yield of soybean crop and a reduced impact upon the environment, by optimizing the use of resources and highlighting the factor interaction, a three-factor experiment was proposed, each with 4 graduations, in 3 biological repetitions, the formula of experiment was AxBxC-R:4x4x4-3. The soybean cultivar was Teo TD, obtained at ARDS Turda. The experiment was part of a 3-year crop rotation: autumn wheat - maize - soybean.

The experimental factors were the following:

Factor A – Soil tillage systems (S):

a_1- conventional system with plough (CS used as control): ploughing at 28 cm + preparing the germination bed with a rotary harrow + sowing + fertilizing,

a_2- minimum tillage (MT): chisel (28 cm) + preparing the germination bed with a rotary harrow + sowing + fertilizing,

a_3- minimum tillage (MD): disk (10-12 cm, to chop vegetal debris) + preparing the germination bed with a rotary harrow + sowing + fertilizing,

a_4 - no-tillage (NT): sowing + fertilizing (sowing at the same time with fertilizing with Directa 400; applying gulle - upon the harvest of the pre-emergent crop).

Factor B – The fertilization system (F):

b_1- $N_{40}P_{40}$ at the same time with sowing,

b_2- $N_{40}P_{40}$ at the same time with sowing + gulle,

b_3- $N_{40}P_{40}$ at the same time with sowing + green fertilizer [mustard *(Sinapis alba)* and autumn canola *(Brassica napus)* to fight against compaction],

b_4- $N_{40}P_{40}$ at the same time with sowing + gulle + green fertilizer [mustard *(Sinapis alba)* and autumn canola *(Brassica napus)* to fight against compaction].

Factor C –The system of plant protection (treatments, T):

c_1 - preemergent herbicides on the ground with 0.35 l/ha *metribuzin* 600 g/l + 1.5 l/ha *S-metolaclor* 960 g/l + postemergent herbicides in the soybean phenophase of 2-4 trifoliate leaves with 1.0 l/ha *imazamox* 40 g/l + 1.5 l/ha *propaquizafop*,

c_2 - preemergent herbicides on the ground with 0.35 l/ha *metribuzin* 600 g/l + 1.5 l/ha 8-*metolaclor* 960 g/l + postemergent herbicides in the soybean phenophase of 2-4 trifoliate leaves with 1.0 l/ha *imazamox* 40 g/l + 1.5 l/ha *propaquizafop* + 0.75 l/ha fungicides (*trifloxistrobin* 100 g/l + *tebuconazol* 200 g/l; Nativo 300 SC- 0.75l/ha),

c_3 - preemergent herbicides on the ground with 35 l/ha *metribuzin* 600 g/l + 1.5 l/ha *S-metolaclor* 960 g/l + postemergent herbicides in the soybean phenophase of 2-4 trifoliate leaves with 1.0 l/ha *imazamox* 40 g/l +1.5 l/ha *propaquizafop* + fungal mixture based on *Bauveria bassiana* entomopathogenic fungi,

c_4 - preemergent herbicides on the ground with 0.35 l/ha *metribuzin* 600 g/l + 1.5 l/ha *S-metolaclo*r 960 g/l + postemergent herbicides in the soybean phenophase of 2-4 trifoliate leaves with + 0.75 l/ha fungicide *trifloxistrobin* 100 g/l + *tebuconazol* 200 g/l; Nativo 300 SC) + insecticide 0.5 l/ha (*50 g/l fenpiroximet*; Ortus 5 SC - 0.5 l/ha).

The size of the experimental parcel was 36 m^2. Total number of variables among all three factors was 128. Sowing was made at a distance between rows of 18 cm, seed incorporating depth 5 cm; sowing thickness 65 germinable seeds/m^2; seed quantity 90 kg/ha. Treatment of 0.5 l/ha *fenpiroximat* insecticide (50 g/l) to control the mite *Tetranychus urticae* was applied on warning. Crop was harvested around 10^{th} of October using a Wintersteiger combine with 1.4 m working width. The study was set up on a fertile soil, susceptible of rapid compaction after passing heavy agricultural machines or after mechanical works under high moisture conditions. ANOVA was applied to collected data.

RESULTS AND DISCUSSION

Results show the direct or indirect contribution of each considered factor (soil tillage system x fertilization x plant protection treatments) on yield and size of Teo TD soybean cultivar. For yield, on each experimental parcel, a statistical analysis was made to highlight the influence of each experimental factor, through the mathematical process of decomposing total variance in types of variations based on the causes which they determine (variants, interactions and error).

The variance analysis, as a method chosen to interpret experimental data allowed the separation inside the total variance of the variance components possible to be separated according to the experimental device and numerical expression. The difference between the total variance and the variance of its components is attributed to the error variance (Rusu, 2020). The F test was calculated as a report between two variances, more exactly the variance of the studied factors was divided to the error variance and it serves as a way of interpreting experimental results, respectively to underline the accuracy and precision of the experiment. Data analysis in Table 1 shows that the value of the experimental F is higher than the value of the theoretical F, the test is significant, the differences pass over the limit of errors and the research factors contribute more to the variance of results than the accidental factors.

The interpretation of analysis results of variance, in the case of our polyfactor experiment, based on the values of the F test leads to the preliminary conclusion that among the studied factors, the highest influence upon yield is represented by soil tillage system (S), followed by treatments for plant protection (T). Fertilization (F) also influences significantly yield (F = 165.918, very significantly). S x F, S x T, F x T simple interactions are also of interest, but S x F x T triple interaction has no significance according to F test.

Table 1. Variance analysis and the F test in polyfactor experience for the yield of soybean grains

Source of variation	**Degrees of liberty**	**Medium square**	**F Test**	**Probability**
Soil tillage system (S)	3	6073640	606.877	0.0001
Fertilization (F)	3	1247350	165.918	0.0001
Plant protection treatments (T)	3	2423123	313.967	0.0001
S x F	9	47599	6.332	0.01
S x T	9	43489	5.635	0.01
F x T	9	27784	3.600	0.1
S x F x T	27	14153	1.834	ns (not significant)
Repetitions	2	16749	-	-
Other types of interaction	126	-	-	-
S error	6	10008	-	-
F error	24	7517	-	-
T error	96	7717	-	-
Total	191	-	-	-

To calculate the share of the studied factors in the yield of Teo TD soybean type, sum of squares attributed to each factor and the sum of squares of total deviations are presented (Figure 1). Thus, it was determined that soil tillage system (57.5%) has the highest contribution, followed by plant protection treatments (22.9 %) and fertilization (11.8 %).

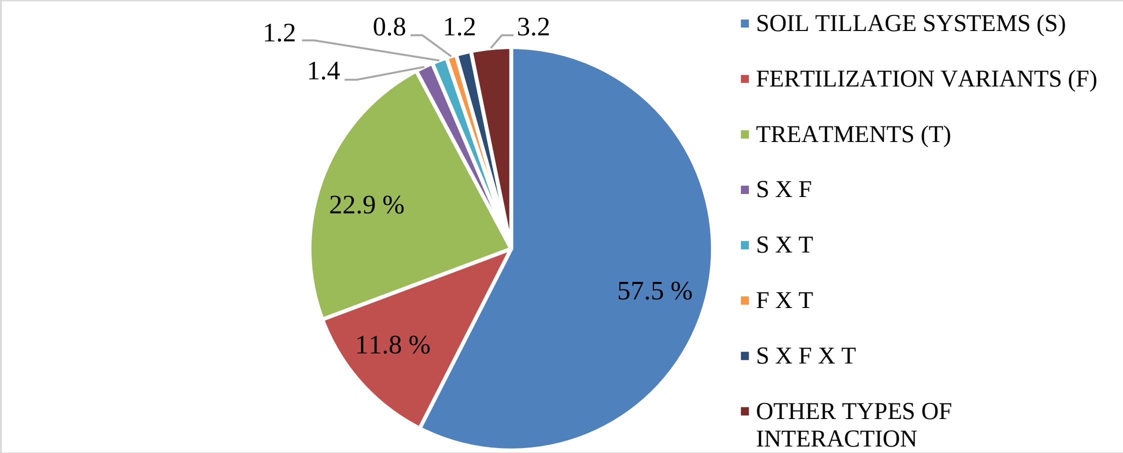

Figure 1. The share of the studied experimental factors for the soybean production

The most efficient soil tillage system is conventional ploughing (Table 2). These results are sustained by other studies where a higher yield was obtained in the conventional system on fertile soils (Moraru et al., 2015; Chețan et al., 2016a) or in minimum system and direct sowing on medium and weak fertile soils (Rusu et al., 2015); similar results were obtained in other pedoclimatic conditions, too (Pielke et al., 2007; Ahumada & Cornejo, 2018). Differences of production among minimum soil tillage systems were recorded, the most efficient is the chisel compared to the disk. In the case of the soybean crop, a difference of 240 kg/ha is important, representing almost 10 % of total production during the last years.

Table 2. Influence of soil tillage system on production for the Teo TD soybean type

Experimental variant	Production (kg/ha)	Production (%)	Difference (± kg/ha)	Significance*	Duncan test**
a_1. Conventional soil tillage system with plough (witness variant) (SC)	3420	100.0	0.00	Mt.	a
a_2. Minimum soil tillage system with chisel (MT)	2995	87.6	425	000	b
a_3. Minimum soil tillage system with disk (MD)	2755	80.6	665	000	c
a_4. Direct sowing system (no-tillage, NT)	2605	76.2	815	000	d

Note: *DL 5% = 50 kg/ha; DL 1% = 76 kg/ha; DL 0.1% = 122 kg/ha; **DS = 40 kg/ha.

The Teo TD soybean type responded positively to organic-mineral fertilization, therefore a significant yield increase was obtained when gulle (345 kg/ha) or green fertilizer (i.e. black radish) were applied. A cumulated effect of gulle and green fertilizer on yield was observed (Table 3). This combination ensured good results on weak fertile soils and in other pedoclimatic conditions (Kubota et al., 2005).

Table 3. Influence of fertilization system on Teo TD soybean cultivar yield

Experimental variant	Production (kg/ha)	Production (%)	Difference (± kg/ha)	Significance*	Duncan test**
$b_1.N_{40}P_{40}$(witness variant)	2745	100.0	0.00	Mt.	d
b_2. $N_{40}P_{40}$ + gulle	2989	108.9	345	***	b
$b_3.N_{40}P_{40}$+ green fertilizer	2908	105.9	163	***	c
$b_4.N_{40}P_{40}$ + gulle + green fertilizer	3132	114.1	387	***	a

Note: *DL 5% = 36 kg/ha; DL 1% = 50 kg/ha; DL 0.1% = 66 kg/ha; **DS = 40 kg/ha.

Plant protection treatments during crop vegetation determined significant yield increases, higher when insecticides were applied. A cumulated effect of fungicide and insecticide was observed (Table 4). Similar results were recorded in other pedo-climatic areas (Henry et al., 2011; Bergman et al., 2020)

Table 4. Influence of treatments on vegetation on production for the Teo TD soybean type

Experimental variant	Production (kg/ha)	Production (%)	Difference (± kg/ha)	Significance *	Duncan test**
c_1. Preemergent herbicides on the ground+ postemergent (witness variant)	2651	100.0	0.0	Mt.	d
c_2. Preemergent herbicides on the ground + postemergent + fungicide	2930	110.5	279	***	c
c_3. Preemergent herbicides on the ground + postemergent + insecticide	3001	113.2	351	***	b
c_4. Preemergent herbicides on the ground + postemergent + fungicide+insecticide	3193	120.5	542	***	a

Note: *DL 5% = 36 kg/ha; DL 1% = 47 kg/ha; DL 0.1% = 61 kg/ha; **DS = 40 kg/ha.

The experimental factors applied in the experimental field influenced also the size of plants. The highest influence on the size of Teo TD cultivar was represented by the fertilization factor (Table 5). The tillage system also influenced significantly size of plants (F = 45.459 significantly). Among simple interactions, only fertilization x plant protection treatment had a high impact on the size of plants.

Table 5. Analysis of variance and F test in polyfactor experience, for the size (cm) of soybean plants

Source of variation	Degrees of liberty	Medium square	F test	Probability
Soil tillage system (S)	3	1075.31	45.459	0.5
Fertilization variants (F)	3	1615.45	63.123	0.01
Treatments (T)	3	199.54	40.529	0.001
S x F	9	4.62	0.181	ns
S x T	9	8.98	1.824	ns
F x T	9	36.39	7.393	0.5
S x F x T	27	5.72	1.162	ns
Repetitions	2	-	-	-
Other types of interactions	126	141.92	-	-
S error	6	614.20	-	-
F error	24	472.66	-	-
T error	96	-	-	-
Total	191			

Differences in size were recorded among soil tillage systems, the highest size recorded by the conventional soil tillage system. The size of plants could be directly correlated with the grain production (Souza et al., 2016; Matsuo et al., 2018) as higher size implies higher number of branches, beans and finally higher number of grains per plant (Table 6).

Fertilization factor also influences size of plants (Table 7). Plants size increases by 11.2 cm for b_2 ($N_{40}P_{40}$+gulle) and by 13.0 cm for b_4 ($N_{40}P_{40}$ + gulle + green fertilizer), compared to b_1 ($N_{40}P_{40}$).

Table 6. Influence of soil tillage system on the size for the Teo TD soybean cultivar

Experimental variables	Size (cm)	Size (%)	Diff. (± cm)	Significance*	Duncan test**
a_1.Conventional soil tillage system with plough-control (SC)	136	100.0	0.00	Mt.	a
a_2. Minimum soil tillage system with chisel (MT)	129	95.2	6.5	000	b
a_3. Minimum soil tillage system with disk (MD)	127	93.4	8.9	000	bc
a_4. Direct sowing system no-tillage (NT)	125	92.0	10.9	000	c

Note: *DL 5% = 2.4 cm; DL 1% = 3.7 cm; DL 0.1% = 5.9 cm; **DS = 2.4-2.6 cm.

Table 7. Influence of the fertilization system on the size for the Teo TD soybean type

Experimental variant	Size (cm)	Size (%)	Diff. (± cm)	Significance*	Duncan test**
b_1. $N_{40}P_{40}$ (control)	121.3	100.0	0.00	Mt.	c
b_2. $N_{40}P_{40}$ + gulle	132.5	109.3	11.23	***	a
b_3. $N_{40}P_{40}$ + green fertilizer	128.3	105.8	6.98	***	b
b_4. $N_{40}P_{40}$ + gulle + green fertilizer	134.3	110.8	13.06	***	a

Note: *DL 5% = 2.13 cm; DL 1% = 2.89 cm; DL 0.1% = 3.87 cm; **DS = 2.13-2.31 cm.

Plant protection treatments during vegetation determine small, but significant increases in size of plants (Table 8).

Table 8. Influence of treatments during vegetation on Teo TD soybean cultivar plants size

Experimental variant	Size (cm)	Size (%)	Diff. (± cm)	Significance*
c_1. Preemergent herbicides on the ground + postemergent (control)	126.4	100.0	0.00	Mt.
c_2. Preemergent herbicides on the ground + postemergent + fungicide	129.4	102.4	3.00	***
c_3. Preemergent herbicides on the ground + postemergent + insecticide	129.4	102.4	3.00	***
c_4. Preemergent herbicides on the ground + postemergent + fungicide+insecticide	131.3	103.9	4.94	***

Note: DL 5% = 0.90 cm; DL 1% = 1.19 cm; DL 0.1% = 1.54 cm.

CONCLUSIONS

Soil tillage system influences differently the yield of the soybean crop. Conventional system with plough was the most efficient for Teo TD soybean cultivar with best results in terms of yield and plants size, when chisel was applied, compared to disk.

Teo TD soybean cultivar responds very well to organic-mineral fertilization, thus plants are very resistant to environment factors, obtaining significant yield increases when gulle (345 kg/ha) or green fertilizer is applied.

Plant protection treatments during vegetation (insecticides + fungicides) determined small, but significant size increases.

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