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Effect of Soil Practice on Photosynthesis, Yield and Quality of Soyabean (*Glycine max* (L.) Merr.) †

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Abstract: The environmental factor determining the increase in soybean crops during the current climate changes is its adaptation to drought periods; therefore, in addition to conventional tillage (CT), no-till cultivation systems (RT, NT) are practiced in the cultivation of this species. A field experiment was conducted in 2017–2019 in Boguchwała, Poland. The test plant was soybean cv. Merlin. The experimental factors were three tillage systems (conventional—CT, reduced—RT, no-tillage—NT). The use of CT and RT influenced the increase of LAI and SPAD and stimulated the course of the photosynthesis process, which resulted in an increase in the values of F_v/F_0 and PI parameters compared to NT. Soybean with CT yielded significantly higher than with NT, and seeds contained more protein. Fat and P content was significantly higher in NT and K in seeds from RT. Under extremely dry and dry conditions (June–September), in 2017 the seed yield in NT was similar to CT and significantly higher than in RT.

Keywords: soil tillage; LAI; SPAD; chlorophyll fluorescence; yield; chemical composition

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1. Introduction

In Poland, as in other European countries, the growing interest in the cultivation of soybean is mainly due to the high demand for vegetable protein as a source of high-protein, skimmed and roasted soybean meal in animal nutrition [1,2]. Climatic conditions, and above all temperature and rainfall, are the factors limiting soybean yields [3–5]. The benefits of using no-till systems (RT, NT) can be observed in warm years with lower rainfall, which is due to greater accumulation of water in the soil due to less evaporation and changes in water permeability in the soil [1,6]. Conventional tillage (CT), in comparison to reduced tillage practices (RT, NT), results in a higher yield of soybeans and protein content, and the mineral composition of seeds, especially when the weather conditions for mineralization of crop residues in RT and NT are unfavorable [5,7]. According to some authors [5,8,9], tillage systems do not significantly differentiate the yield and quality characteristics, including the mineral composition of soybeans. The aim of the study was to assess the effect of three tillage systems (conventional—CT, reduced—RT, no-tillage—NT) on the productivity and quality of seeds and the parameters of soybean chlorophyll fluorescence under various hydrothermal conditions.

2. Materials and Methods

The field experiment was conducted in the years 2017–2019. It was located on Advisory Center in Boguchwała (49°59′ N, 21°56′ E), Podkarpackie province, Poland. The experiment was carried out in 3 replications in a randomized block design (8 × 100 m), divided into 3 split-plots.

The studied factor were tillage systems: conventional (CT)—shallow plowing (10–12 cm deep), harrowing, plowing (25–30 cm deep); reduced tillage (RT)—disking (13–15 cm deep);

direct seeding—no tillage (NT); herbicide treatment with glyphosate was performed in the dose 4.0 dm^3 ha^{-1}. In the CT and RT plots in the spring, a combined tillage unit (cultivator and string roller) was used before sowing, and in the NT plot the soybean was sown directly into the stubble with a seeder with double-disc coulters. The breeder of soybean cv. Merlin was the Saatbau Poland Sp. z o. o, Środa Śląska, Poland. The experiment was established on sandy loam soil, Fluvic Cambisols (CMfv) according to the WRB FAO (2015) [10]. The soil had a neutral reaction from 7.10 to 7.18 mol/L KCl. C org content was moderate (from 0.99 to 1.05%). The amount of N min varied from 54.1 to 64.5 kg ha^{-1}. The content of available P, K, and Mg was very high or high and micronutrients was medium (Table 1).

Table 1. Content of available nutrients (depth of 0–60 cm).

Years	P	K	Mg	Fe	Zn	Mn	Cu
	[mg kg^{-1}]						
2017	203.0	274.1	26.2	2277.0	13.8	398.0	6.1
2018	130.2	181.0	51.2	2514.0	13.9	252.1	6.3
2019	74.0	251.2	55.7	2219.0	12.7	262.8	6.8

The spring–summer vegetation period in 2017 and 2018 can be classified as very dry (K = 0.6) and dry (K = 0.9), and in 2019, thermal and rainfall conditions as optimal (K = 1.3) (Table 2).

Table 2. Sielianinov's hydrothermal index (k) in the growing season.

Year	Month						Mean
	April	May	June	July	August	September	
2017	1.25 *rd*	1.00 *d*	0.38 *ed*	0.61 *vd*	0.23 *ed*	0.37 *ed*	0.65 *vd*
2018	0.21 *ed*	1.30 *rd*	0.95 *d*	1.87 *rh*	0.65 *vd*	0.36 *ed*	0.89 *d*
2019	1.74 *rh*	2.60 *vh*	0.98 *d*	0.68 *vd*	0.85 *d*	0.92 *d*	1.30 *rd*
long term	1.76 *rh*	1.85 *rh*	1.60 *o*	1.58 *o*	1.25 *rd*	1.00 *d*	1.51 *o*

Sielianinov's index (k = (p × 10)/Σt) value [11]: *ed*—extremely dry, *vd*—very dry, *d*—dry, *rd*—rather dry, *o*—optimal, *rh*—rather humid, *h*—humid, *vh*—very humid, *eh*—extremely humid; p—precipitation (mm); t—temperature (°C).

Leaf area index (LAI) measurement was performed using a LAI 2000 apparatus (LI-COR, Lincoln, NE, USA). Measurements of SPAD were made with the apparatus SPAD-502 P Konica Minolta (Tokyo, Japan). Chlorophyll fluorescence was measured using a portable chlorophyll fluorescence meter (Pocket PEA, Norfolk, UK). The protein and fat content was determined by near infrared spectroscopy (NIRS) using an MPA FT NIR spectrometer (Bruker, Billerica, MA, USA). Protein yield and fat was calculated from the product of the seed yield and the percentage of a given seed component. Seed yield from the plots per 1 ha was calculated, taking into consideration 15% humidity. The content of Ca, K, Mg, Zn, Mn, Cu, and Fe in the mineralisates was determined with atomic absorption spectroscopy (FAAS), using a Hitachi Z-2000 apparatus (Tokyo, Japan), whereas P was determined with colorimetry, using a UV-VIS Shimadzu spectro-photometer (Kyoto, Japan), with the vanadium-molybdenum method.

The results were subjected to an analysis of variance, and significant differences were analyzed with the Tukey's (LSD—least significant difference) test (p = 0.05) using Statistica 13.3 programme (StatSoft, Tulsa, OK, USA).

3. Results and Discussion

The use of CT and RT had a stimulating effect on the course of the photosynthesis process, which was manifested by an increase in the values of F_v/F_0 and PI parameters compared to NT (Table 3). The tillage systems did not significantly differentiate the F_v/F_m

index values. Significantly lower values of the parameters of fluorescence F_v/F_0 and PI in the full flowering phase of soybean (BBCH 65) [12] in NT indicate that in this period more stress occurred in soybean plants than in RT and CT. Research conducted by Hussain et al. [13] showed that the value of the chlorophyll fluorescence parameter (F_v/F_m) was at a similar level under and without shading conditions. Khalid et al. [14] showed a decrease in the value of the Fv/Fm parameter as a result of shading compared to the control, on soybean plants treated with different levels of shading.

Table 3. Soil plant analysis development (SPAD), leaf area index (LAI), and chlorophyll fluorescence.

Specification	SPAD	LAI	F_v/F_m	F_v/F_0	PI
			Tillage (T)		
CT	47.3 ^{a}	5.62 ^{a}	0.764 ^{a}	3.44 ^{a}	5.54 ^{a}
RT	44.1 ^{b}	4.89 ^{b}	0.762 ^{a}	3.37 ^{a}	5.28 ^{a}
NT	42.2 ^{b}	5.08 ^{b}	0.731 ^{a}	3.03 ^{b}	4.22 ^{b}
			Year (Y)		
2017	40.3 ^{b}	4.99 ^{b}	0.766 ^{a}	2.42 ^{b}	4.49 ^{b}
2018	42.9 ^{b}	5.19 ^{ab}	0.701 ^{a}	3.63 ^{a}	5.11 ^{b}
2019	50.3 ^{a}	5.41 ^{a}	0.791 ^{a}	3.79 ^{a}	5.44 ^{a}
			ANOVA		
T	***	**	ns	*	*
Y	*	*	ns	*	*
C × Y	***	ns	ns	**	**

*** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$, ns—non-significant, according to the Tukey's honestly significant difference (LSD) test. Mean values with different letters in columns are statistically different. F_v/F_m—maximal quantum yield of PS II photochemistry, F_v/F_0—maximum quantum yield of primary photochemistry, PI—Performance index of PS II, CT—conventional tillage; RT—reduced tillage; NT—no tillage.

The values of the SPAD and LAI were significantly higher in CT compared to RT and NT. The increase in the SPAD index in CT to RT and NT was by 6.1 and 10.8%, respectively, and the LAI index by 13.0 and 9.6%. There were no significant differences in SPAD and LAI measurements between RT and NT.

According to Houx et al. [1] in CT, compared to RT and NT, there is a lower soil compaction, which may result in higher nutrient uptake and thus better nutrition of soybean plants. Adamič and Leskovšek [8] obtained higher protein and fat content in soybeans in the CT and RT system compared to NT. Gawęda et al. [2] showed a decrease in protein content and an increase in seed fat in CT as compared to NT in the case of soybean cultivation in monoculture. The use of CT and RT in comparison to NT resulted in an increase in protein content by 4.4 and 5.5% (Table 4). The lowest protein content (32.6%) was found at NT, where, in contrast to this component, a significantly higher fat content (24.4%) was observed in comparison to CT and RT. Monsefi et al. [7] found a significant decrease in the yield of soybean (to 26.0%) in NT compared to CT, and according to Adamič and Leskovšek [8], the average yield of soybeans was 4.34 t ha^{-1} and was similar in the CT and RT systems. The highest yield was obtained in CT in comparison to RT (by 9.5%) and NT (by 11.2%).

According to Thiagalingam et al. [6], higher yields of soybean seeds in the NT system can be observed especially in warmer growing seasons with lower rainfall. The highest seed yield (3.86 t ha^{-1}) was obtained in CT in 2019, in which favorable thermal and precipitation conditions (K = 1.3) prevailed during the period of pod formation and seed maturation. Soybeans from the RT system contained more K in comparison to the CT and NT systems. The changes in K content between RT and CT and NT ranged from 3.2 to 3.4 g kg^{-1} (Table 5).

Table 4. Chemical seed composition and yield.

Specification	Protein Content (% DM)	Protein Yield (kg ha^{-1})	Fat Content (% DM)	Fat Yield (kg ha^{-1})	Seed Yield (t ha^{-1})
			Tillage (T)		
CT	34.1 ^{a}	1179.0 ^{a}	22.8 ^{b}	794.0 ^{a}	3.47 ^{a}
RT	34.5 ^{a}	1080.9 ^{ab}	22.4 ^{b}	705.6 ^{a}	3.14 ^{b}
NT	32.6 ^{b}	998.8 ^{b}	24.4 ^{a}	755.3 ^{a}	3.08 ^{b}
			Year (Y)		
2017	35.7 ^{a}	1036.8 ^{a}	22.1 ^{c}	640.5 ^{b}	2.90 ^{c}
2018	33.9 ^{b}	1075.0 ^{a}	23.4 ^{b}	739.3 ^{ab}	3.17 ^{b}
2019	31.6 ^{c}	1146.8 ^{a}	24.2 ^{a}	875.1 ^{a}	3.62 ^{a}
			ANOVA		
T	**	**	**	ns	***
Y	***	ns	*	**	***
C × Y	ns	ns	**	ns	**

*** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$, ns—non-significant, according to the Tukey's honestly significant difference (LSD) test. Mean values with different letters in columns are statistically different. CT—conventional tillage; RT—reduced tillage; NT—no tillage; DM—dry matter.

Table 5. Macroelement and microelement content.

Specification	P	K	Ca	Mg	Fe	Cu	Mn	Zn
	[g kg^{-1} DM]				[mg kg^{-1} DM]			
				Tillage (T)				
CT	6.3 ^{a}	15.0 ^{b}	0.8 ^{a}	2.0 ^{a}	115.4 ^{a}	20.9 ^{a}	21.5 ^{a}	52.1 ^{a}
RT	6.5 ^{b}	18.2 ^{a}	1.0 ^{a}	2.4 ^{a}	114.9 ^{a}	20.1 ^{a}	20.4 ^{a}	50.3 ^{a}
NT	8.1 ^{b}	14.8 ^{b}	0.7 ^{a}	2.1 ^{a}	117.7 ^{a}	19.8 ^{a}	19.6 ^{a}	49.9 ^{a}
				Year (Y)				
2017	6.4 ^{b}	14.6 ^{b}	0.6 ^{a}	1.5 ^{a}	114.3 ^{a}	26.9 ^{a}	24.3 ^{a}	57.9 ^{a}
2018	7.0 ^{b}	16.0 ^{b}	0.8 ^{a}	2.3 ^{a}	117.4 ^{a}	16.4 ^{b}	20.4 ^{b}	52.1 ^{b}
2019	7.5 ^{a}	17.5 ^{a}	1.0 ^{a}	2.6 ^{a}	116.2 ^{a}	17.4 ^{b}	16.8 ^{c}	42.3 ^{c}
				ANOVA				
T	**	**	ns	ns	ns	ns	ns	ns
Y	**	**	ns	ns	ns	**	***	***
C × Y	ns	ns	ns	ns	ns	ns	*	*

*** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$, ns—non-significant, according to the Tukey's honestly significant difference (LSD) test. Mean values with different letters in columns are statistically different. CT—conventional tillage; RT—reduced tillage; NT—no tillage; DM—dry matter.

However, the NT system favored the accumulation of P in seeds in the range from 1.6 to 1.8 g kg^{-1} in comparison with CT and RT. Farmaha et al. [3] reports that in CT, excessive soil drying, especially during the soybean ripening period, may limit the absorption of P and K and reduce the content of these macroelements in seeds. In our own research, the mean content of Ca and Mg was 0.8 and 2.2 g kg^{-1} and was not differentiated by the experimental factor. Similar contents of these elements for soybeans cv. Merlin were obtained by Biel et al. [15] in the ecological and conventional system, and higher ones in Szostak et al. [16], depending on the dose of N fertilization.

In our own experiment, the content of Cu, Mn, and Zn in soybeans increased in the CT > RT > NT systems, and the content of Fe decreased in NT < RT < CT. These relationships have not been statistically proved. Also, Houx et al. [1] obtained a significantly lower (by 7.7%) content in seeds of Fe in CT than in NT, and a higher (by 5.5%) content of Zn in CT than in NT. Moreover, the differences in Cu and Mn content between CT and NT were not significant. In our own research, the mineral composition of soybean seeds was variable in the years of the research. In the very dry 2017 (K = 0.6) and dry 2018 (K = 0.9), significantly more Cu, Mn, and Zn seeds were found by Samarah et al. [4]. Optimal thermal and precipitation conditions in 2019 (K = 1.3) favored the accumulation of P and K in soybean seeds, as also noted by Houx et al. [1].

4. Conclusions

The variability of hydrothermal conditions in the years of research and the tillage systems had a decisive influence on the values of the physiological parameters of soybean plants, as well as the yield and quality of seeds. More favorable hydrothermal conditions in the years of the research resulted in higher seed yield, LAI values, chlorophyll content and chlorophyll fluorescence, and the amount of protein in seeds in the CT system. In the case of large rainfall deficits, a similar seed yield was obtained in the NT and CT systems; moreover, the seeds contained more fat (especially in NT), P, and K. The conducted research showed that in areas exposed to different hydrothermal conditions during the growing season, no-till cultivation systems (RT, NT) can be an alternative to conventional (CT) soybean cultivation.

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