

Effect of soil cultivation system on the efficiency of the photosynthetic apparatus in maize leaves (*Zea mays* L.)

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Abstract. The cultivation of maize in no-tillage farming systems has become increasingly important in recent years, due to the observed climate changes and the increasing droughts. Such a cultivation system has a positive effect on the physicochemical and biological properties of the soil, but above all allows for greater retention of water available to plants. The aim of the research was to assess the effect of the method of soil preparation for sowing maize grown in monoculture (plough, reduced, direct seeding) on the efficiency of photosystem II (PSII) in leaves and the yield of maize (*Zea mays* L.). The field experiment was carried out in 2017–2019 at the Agricultural Experimental Station IUNG-PIB in Grabów (Mazowieckie Voivodeship), using the split-block method. On three treatments, maize was grown in monoculture, and in a control treatment, in rotation. Three methods of preparing the soil for sowing in monoculture were used: full plough tillage, reduced tillage and direct seeding. The research showed, that the applied tillage system had a significant impact on the parameters of chlorophyll fluorescence and the yielding of maize, while the weather conditions, especially rainfall, were also of great importance. In conditions of water deficiency in the soil, maize cultivated in the reduced tillage and in direct seeding yielded better than in the crop rotation with full plough tillage. Also chlorophyll fluorescence indices (Fv/Fm and PI) in plants cultivated without the use of plough tillage showed higher values than in plants cultivated in rotation, which proves more effective functioning of photosystem II in the conditions of no-tillage cultivation with limited rainfall and greater efficiency of the photosynthetic apparatus under these conditions, which was reflected in the yielding of maize.

Keywords: maize, chlorophyll fluorescence, direct seeding, reduced tillage, monoculture, climate changes

INTRODUCTION

Maize is one of the most important cultivated species in the world. In 2018, its cultivation area in the world was

almost 194 million ha and was third after wheat and rice, while in terms of grain production, at the level of 1,147 million tons, it was the undisputed leader (Faostat, 2020). In Poland, the acreage of maize sown is growing and in 2018 it amounted to 1,247 thousand ha. The economic importance of this species is also increasing. Maize, despite the fact that it is a plant that carries out C4 photosynthesis, and thus copes well in conditions of high temperatures and intensity of solar radiation, has a high demand for water due to the production of large amounts of biomass (Ostrowski et al., 2008). In Poland, this is a big problem, because of scarce water resources. It is estimated that annually there is approximately 3 times less water per inhabitant of Poland than the European average (Suchożebrski, 2018). In the era of climate change, which in Poland brings more and more frequent droughts and dry periods (Kozyra et al., 2010), there is growing interest in simplified farming systems, which ensure better moisture conditions in the soil, and additionally protect the soil and maintain its valuable biodiversity (Holland, 2004; Weber, Kieloch, 2014). According to Niedźwiecki et al. (2006) tillage without ploughing reduces evaporation, improves infiltration and increases soil stability. Moreover, simplified systems are less labour and energy-consuming, which translates into the economics of production, and they favourably shape the physicochemical properties and biological activity of the soil (Berner et al., 2008; Białczyk, Cudzik, 2008; Fonteyne et al., 2019; Tomkowiak et al., 2017; Vogeler et al., 2009). Cultivation without ploughing is commonly used in the United States of America and in most large-scale farms with specialized machinery in Western Europe (Kapusta et al., 1996).

Chlorophyll, or more specifically chlorophylls a and b, are pigments found in chloroplasts, in photosystems I and II, which together with proteins form protein-chlorophyll complexes included in antenna complexes that receive solar energy in the form of radiation. Fluorescence is one form of dissipation of energy obtained during the absorption of photosynthetically active radiation by chlorophyll a. It is energy that was not used in photosynthesis. Although

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it constitutes only about 3–5% of the absorbed energy, its measurements are a good tool for assessing the state of the photosynthetic apparatus of a given plant, and thus for assessing the reaction of a given species to environmental factors that are stressors (Kalaji, Łoboda, 2010). The photosynthesis process is one of the processes most sensitive to stress factors, precisely because of the susceptibility to damage of the PSI and PSII photosystems (Murkowski, 2004). Thanks to the use of chlorophyll fluorescence, it is possible to register changes taking place in the PSII at a very early stage, before any other symptoms of the stress reaction appear (Michalczyk et al., 2008). Thanks to these measurement methods, it is also possible to assess the ability of plants to regulate life processes under stress (Murkowski, 2002).

The aim of the research was to assess how tillage and sowing methods affect the efficiency of the photosynthesis process and the yield of maize (*Zea mays* L.) grown in monoculture (plough, reduced, direct sowing) on vs. that grown in crop rotation.

METHODS

The field experiment was carried out in 2017–2019 at the Agricultural Experimental Station IUNG-PIB in Grabów (Mazowieckie Voivodeship), on lessive soil made of light clay classified as a very good rye complex. The experiment was performed using the split-block method. Maize grown in monoculture and in rotation was from varieties characterized by FAO 240-250. Under monoculture, three methods of seedbed preparation were used: full plough tillage, reduced tillage (no-plough tillage) and zero tillage (direct sowing). In the treatment with full and reduced tillage, after harvesting the cobs, corn straw was chopped and ploughed under in the autumn while in the treatment without mechanical cultivation, the straw remained on the field surface after chopping. On the control treatment, maize was grown in rotation with barley and wheat, with full ploughing and additional fertilization with manure at the dose of 25 t ha⁻¹.

Corn was sown in the first ten days of May, using a single-seed drill (pneumatic). In the case of plough cultivation, a passive tilling set and a cultivator were used, while in the case of reduced tillage, only a grubber was deployed. Plant spacing during sowing was 70×16 cm.

In the experiment, mineral fertilization was applied: N – 140 t ha⁻¹ in two doses (50% before sowing and 50% in the 6-leaves stage) as ammonium saltpeter and pre-sowing P – 80 kg P₂O₅ ha⁻¹, as triple superphosphate and K – 125 kg K₂O ha⁻¹, as potassium salt. Before emergence, the herbicide Maister Power 42.5 OD was sprayed at a dose of 1.5 l ha⁻¹. Additionally, Agrosar 360 SL was applied before sowing at a dose of 5 t ha⁻¹ under reduced tillage and direct sowing. The plants were harvested at the full grain maturity stage.

In the experiment, measurements of chlorophyll fluorescence were performed with the Pocket PEA fluorimeter by Hansatech (England). Measurements were performed in 10 replications on each treatment, one measurement on one plant, on the second fully developed leaf from the top, in the central part of the leaf blade, after 20 min of adaptation to darkness. Measurements were made in five maize development stages: BBCH 19 (nine leaves stage), BBCH 31 (1 node visible stage), BBCH 63 (early flowering stage), BBCH 67 (full flowering stage), BBCH 71 (first kernels stage). Two parameters of chlorophyll fluorescence were assessed: Fv/Fm – determining the maximum quantum efficiency of PSII, and PI (Performance Index) – an indicator of the functioning (vitality) of photosystem II concerning its overall viability. The measurement of chlorophyll fluorescence was used to determine the efficiency of the photosynthetic apparatus under the conditions of the experiment. The relative grain yield of maize cultivated in monoculture was determined as compared to that in rotation depending on the method of seedbed preparation.

The results were statistically analysed using the analysis of variance and the Tukey's Test ($\alpha = 0.05$) in the Statgraphics Centurion XVI program.

Weather conditions varied during the study period, with dry periods being observed in each year (Table 1).

Table 1. Meteorological conditions during the growing season of maize (2017–2019).

Year	Total precipitation [mm]						
	IV	V	VI	VII	VIII	IX	IV–IX
2017	69.1	34.4	32.6	86.3	55.3	102.7	380.4
2018	25.3	97.4	44.6	118.5	70.6	44.5	400.9
2019	37.5	51.5	51.2	20.2	69.8	56.1	308.5
Long-term average	39	57	71	84	75	50	376
Year	Average air temperature [°C]						
	IV	V	VI	VII	VIII	IX	IV–IX
2017	7.5	13.9	18.1	18.6	19.6	13.9	15.3
2018	13.3	17.0	18.4	20.4	20.2	15.4	17.4
2019	9.8	13.1	21.7	18.7	20.2	14.4	16.3
Long-term average	7.7	13.4	16.7	18.3	17.3	13.2	16.3

In 2017, a shortage of rainfall was recorded in May (60% of the multi-year norm) and June (46%), which, combined with high air temperatures, contributed to unfavourable conditions for plant growth and development. In 2018, the air temperature for most of the growing season was higher than the multi-year average, while better moisture conditions occurred, except for June, when rainfall was much lower than in the multi-year period (63%). On the other hand, 2019 was the most extreme year in terms of water shortage in soil, due to the droughts in June (72%) and July (24%). Weather conditions had a significant impact on the yield of plants and the photochemical efficiency of photosystem II in maize leaves.

RESULTS AND DISCUSSION

The maize cultivation system significantly influenced the parameters of chlorophyll fluorescence. Maize grown in monoculture that involved reduced tillage and direct sowing showed a generally higher maximum efficiency of photosystem II (Fv/Fm) and a higher PSII functioning index (PI) compared to maize grown in rotation, but it was dependent on the plant developmental stage and the weather conditions prevailing in a given year. In the first year of the study (2017), significantly higher values of the Fv/Fm ratio were recorded in the BBCH 19 phase and in the mean value of all measurements, while in the remaining development phases only such a tendency was shown (Table 2). In turn, the highest values of the PI index were found in maize grown in monoculture in direct sowing, with significant differences noted in the earlier development stages of BBCH 19 and 31 and when averaged across all measurements (Table 3). In the second year of the study (2018), the mean value of chlorophyll fluorescence indices in maize cultivated under reduced tillage and under direct sowing was significantly higher than in maize cultivated in rotation. Considering the individual development stages, significant differences were noted in the BBCH 31 phase and the tendency was maintained in the remaining phases (Table 4, 5). In the last year of the research (2019), the cultivation system also significantly influenced the value of the Fv/Fm and PI indices. Higher values of the index describing the maximum photochemical efficiency of PSII were demonstrated for directly seeded maize vs. that grown under ploughing system, with significant diffe-

Table 2. Maximum photochemical efficiency of PSII (Fv/Fm index) in 2017.

Cultivation system	Developmental phase on the BBCH scale					
	19	31	63	67	71	average
Crop rotation	0.73	0.73	0.77	0.74	0.71	0.74
Ploughing	0.75	0.74	0.78	0.75	0.71	0.75
Reduced tillage	0.76	0.74	0.76	0.75	0.72	0.75
Direct seeding	0.75	0.77	0.77	0.75	0.74	0.76
HSD $\alpha=0.05$	0.016	ns.	ns.	ns.	ns.	0.016

ns. – nonsignificant

Table 3. PSII performance index (PI index) in 2017.

Cultivation system	Developmental phase on the BBCH scale					
	19	31	63	67	71	average
Crop rotation	2.09	3.46	4.61	3.98	2.34	3.30
Ploughing	3.36	2.93	5.76	3.91	2.56	3.70
Reduced tillage	3.51	2.86	5.13	4.73	2.52	3.75
Direct seeding	3.62	4.41	5.35	4.83	3.10	4.26
HSD $\alpha=0.05$	1.155	1.503	ns.	ns.	ns.	0.845

ns. – nonsignificant

Table 4. Maximum photochemical efficiency of PSII (Fv/Fm index) in 2018.

Cultivation system	Developmental phase on the BBCH scale					
	19	31	63	67	71	average
Crop rotation	0.72	0.72	0.79	0.73	0.73	0.74
Ploughing	0.74	0.74	0.79	0.74	0.74	0.75
Reduced tillage	0.74	0.77	0.80	0.75	0.74	0.76
Direct seeding	0.75	0.78	0.80	0.76	0.75	0.77
HSD $\alpha=0.05$	ns.	0.026	ns.	ns.	ns.	0.015

ns. – nonsignificant

Table 5. PSII performance index (PI index) in 2018.

Cultivation system	Developmental phase on the BBCH scale					
	19	31	63	67	71	average
Crop rotation	1.70	2.20	5.92	3.52	3.52	3.38
Ploughing	2.44	3.49	6.13	3.55	4.29	3.98
Reduced tillage	2.76	4.47	6.85	3.92	4.45	4.49
Direct seeding	3.01	5.07	7.11	4.52	4.98	4.94
HSD $\alpha=0.05$	ns.	1.085	ns.	ns.	ns.	0.686

ns. – nonsignificant

rences noted in the BBCH 19, 31 and 71 phases. In the BBCH 63 phase, significantly higher values of this index were recorded in continuously grown maize under reduced tillage and direct sowing compared to that grown under crop rotation. Taking into account the average values, a higher maximum PSII photochemical efficiency and PSII perfor-

Table 6. Maximum photochemical efficiency of PSII (Fv/Fm index) in 2019.

Cultivation system	Developmental phase on the BBCH scale					
	19	31	63	67	71	average
Crop rotation	0.72	0.74	0.75	0.73	0.74	0.73
Ploughing	0.69	0.73	0.77	0.75	0.73	0.73
Reduced tillage	0.72	0.78	0.78	0.77	0.77	0.76
Direct seeding	0.75	0.77	0.78	0.76	0.77	0.77
HSD $\alpha=0.05$	0.057	0.037	0.028	ns.	0.042	0.021

ns. – nonsignificant

Table 7. PSII performance index (PI index) in 2019.

Cultivation system	Developmental phase on the BBCH scale					
	19	31	63	67	71	average
Crop rotation	3.07	3.37	2.44	2.16	2.90	2.79
Ploughing	2.99	3.33	2.75	3.23	3.83	3.22
Reduced tillage	2.99	3.33	2.75	3.23	3.83	3.22
Direct seeding	4.35	4.76	4.20	5.50	5.89	4.94
HSD $\alpha=0.05$	ns.	ns.	1.438	1.517	2.113	0.872

ns. – nonsignificant

mance index was demonstrated in maize cultivated in the reduced tillage and in direct sowing, and significantly lower in the plough system in crop rotation (Table 6, 7).

The weather conditions in the experimental years were not favourable for the growth and development of maize, due to the lack of rainfall. Maize is the C4 photosynthesis type species, therefore it tolerates high air temperatures well, while significant increases in biomass mean that it has a high demand for water both during the growing period, as well as during the formation of generative organs, and also

during the formation and pouring of grain. According to Ostrowski et al. (2008) maize water needs are at the level of 450–480 mm in the spring and summer, which means that in all the years of the study there were significant shortages of moisture (precipitation ≤ 400 mm), especially in 2019 (308 mm). No-plough cultivation systems retain water better due to the preserved capillary infiltration, which is reflected in the functioning of PSII in drought conditions. Higher values of Fv/Fm and PI indexes in maize cultivated in the reduced tillage and in direct sowing indicate lower impact of drought stress on the physiological state and health of plants than in the plough system. Under optimal moisture conditions, most plants in the stage of full development show the maximum value of the Fv/Fm parameter at the level of 0.83, while its reduction indicates the plant's response to the stress factor (Björkman, Demmig, 1987; Murkowski, 2002). In the conducted studies, the value of the Fv/Fm parameter was in the range of 0.69–0.80, which indicates a reduction in the efficiency of PSII and disruptions in physiological processes as well as the possibility of stress-induced damage within photosystem II, e.g. caused by interference with the transport of electrons in the photosynthetic chain (Tuba et al., 2010). The vitality index (PI) describes the amount of effective energy that is converted by Photosystem II. It also expresses the plant's ability to withstand stressful conditions (Kalaji, Łoboda, 2010). Higher values of this index in maize under the conditions of no-plough cultivation and direct sowing testify to better vitality and more efficient functioning of photosystem II compared to plough cultivation, in which the effects of drought were more severe.

Maize yield varied between years and depended on the cultivation system and weather conditions, especially rainfall. In the years characterized by high moisture deficiencies (2017 and 2019), the best yields were obtained from directly seeded maize grown under continuous cropping, with the grain yield higher by 32.9% and 36.0%, respectively, than those obtained from rotated maize. In 2019, which was characterized by the greatest water deficit, a much higher yield of maize grain compared to crop rotation was also obtained in the reduced tillage system (by 30.7%). In the more favourable year in terms of soil moisture (2018), the maize cultivated in rotation yielded the best, while the yields obtained in the other cultivation systems

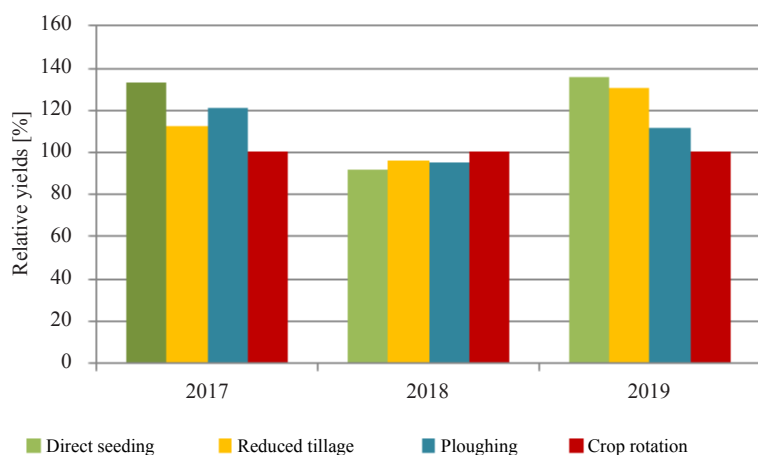


Figure 1. Relative yield of maize grown in monoculture in relation to crop rotation (100%) depending on the method of soil cultivation.

were slightly lower (by 3.7–8.2%). These results are confirmed by the studies of Ismail et al. (1994), who, in a study with a 20-year maize monoculture, showed that in similar to optimal weather conditions, maize cultivated in a plough system yielded better, while in dry years, direct sowing was more favourable. The poorer yielding of maize grown in direct sowing in optimal moisture conditions is generally due to weaker emergence, and thus a smaller plant and cob density per area unit (Księżak et al., 2018b). The significant influence of soil moisture conditions on the grain yield of maize cultivated in monoculture in a plough system and a simplified system with zero tillage (direct sowing) was also demonstrated in the studies of Księżak et al. (2018a). Under favourable weather conditions (2012, 2014), maize grown in the plough system yielded better, while in the extremely dry 2015, a significantly higher grain yield was obtained in simplified systems, in the no-ploughing system it was higher by 220%, and in zero-tillage – by 230% compared to plough tillage.

CONCLUSIONS

1. Under the drought stress the maize cultivation system, in combination with weather conditions, had a significant impact on the efficiency of the maize photosynthetic apparatus, and thus the possibility of carrying out the photosynthesis process. Plants grown in monoculture in direct sowing and in reduced tillage showed a higher maximum efficiency of photosystem II (Fv/Fm) and a higher index of photosystem II functioning (PI) than those grown in rotation, which indicates a better physiological condition and health of plants grown in these systems.

2. The cultivation system differentiated the maize yield, which was largely influenced by the weather. Under the conditions of insufficient moisture in the soil, maize grown in the reduced tillage and in direct sowing yielded better than in rotation with full plough.

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