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Yielding of two types of maize cultivars in relation to selected agrotechnical factors

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Abstract: The study presents the results of field experiments, the aim of which was to assess the yield of maize cultivars with different genetic profiles depending on the method of soil preparation for sowing and the method of NP fertilizer application. The yield and water content in the grain were significantly dependent on changing weather conditions in the growing seasons. Sowing maize into the soil cultivated traditionally (autumn ploughing), stay-green type cultivars and row fertilization positively influenced maize yielding. The stay-green cultivar yielded at a higher level compared to the fast maturing cultivar, the difference being significant in the year characterized by unfavourable distribution (deficit) of precipitation in the growing season. The stay-green cultivar reacted favourably to the localized application of NP fertilizer, the clear result of which was the increase in grain yield. Direct maize sowing significantly reduced the number of production ears per surface area unit and the number of grains on the ear. Selection of the stay-green cultivar and row fertilization with NP fertilizer improved this condition.

Keywords: *Zea mays* L.; climatic condition; sowing method; maize

In recent years, maize has gained in popularity and importance (Fischer and Edmeades 2010). This was mainly determined by its utility characteristics. However, they would be insufficient to generalize the cultivation without the participation of breeding, which provided access to cultivars with adequate early maturation (Adamczyk et al. 2010). Until recently, maize was grown for silage from whole plants, whereas in recent years grain cultivation dominated in the sowing acreage (Neumann et al. 2010). It is important for the development of cultivation of this species to develop such technology that would take advantage of sustainable technical and biological progress (Tollenaar and Lee 2002, Paponov et al. 2005). Many high-yielding and sufficiently early cultivars, well adapted to soil and climatic conditions, were bred in domestic and foreign breeding programs (Adamczyk et al. 2010). Unfortunately, the production potential of this species has not yet been fully utilized. This is due to insufficient resources of knowledge and skills, and often underestimating the importance of punctuality and diligence of particular agrotechnical procedures (Bänziger et al. 2002). Therefore, the basic agronomic aspect is the discovery and development of maize production technology, and in particular the elucidation of the genetic profile of the cultivar type of a cultivar selected for cultivation (Szulc et al. 2012, 2016b, Bocianowski et al. 2019). Therefore, an attempt was made in the present study to assess the response of two types of maize cultivars to a simplified method of soil preparation for sowing and the method of component application in the soil.

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MATERIAL AND METHODS

Experimental field. The field experiment was carried out at the Department of Agronomy of the Poznan University of Life Sciences in the years 2012–2014. It was carried out for three years in the same scheme in a split-split-plot design with three factors in 4 field replicates. The study involved the following factors: A – 1st order factor – two methods of maize sowing: A1 – sowing to the soil (traditional cultivation); A2 – direct sowing to the stubble after winter wheat (straw harvested); B – 2nd order factor – two types of cultivars: B1 – fast maturing cv. SY Cooky; B2 – stay-green cv. Drim; C – 3rd order factor – 2 methods of supplying NP fertilizer: C1 – broadcast on the entire surface before seed sowing; C2 – in rows simultaneously with seed sowing. The same level of mineral fertilization (100 kg N/ha, 30.8 kg P/ha and 107.9 kg K/ha) was applied on all experimental objects. Fertilization was balanced against phosphorus, which was applied at the whole required dose in form of ammonium phosphate. It is best to use two-component fertilizers containing nitrogen and phosphorus for starter fertilization. Transformations of phosphorus compounds in the soil depend on the presence of accompanying salts, of which nitrogen compounds have the greatest influence. N and K fertilization was performed before maize sowing using urea and potassium salt (60%). The N dose was reduced by the amount of nitrogen present in the ammonium phosphate. The assumed planting density in the years of research was 7.95 pcs/m^2, with a spacing between rows of 70 cm and sowing depth of 5–6 cm. The size of the plant for harvesting was 14 m^2. Exact methodology used to calculate the components of maize grain yield structure was included in the author's earlier work (Szulc et al. 2017). Soil nutrient content and its pH before establishing the field experiment in growing seasons is listed in Table 1. Soil samples were collected 2 weeks before field preparation for maize sowing. Noteworthy is the very low soil fertility in phosphorus and magnesium in the spring of 2013. Most likely, this was caused by the very high sum of precipitation in the previous year (473.6 mm), which could result in a higher uptake of these components from the soil with the generative crop of the forecrop plant.

Weather conditions. Thermal conditions during maize growth during the experimental years were similar to each other and amounted on average to 15.4°C in 2012, 15.6°C in 2013 and 16.1°C in the warmest year of 2014. Definitely greater differences between years occurred in the amount of precipitation. The highest sum of rainfall was recorded in 2012, 473.6 mm, which was 76.2 mm higher than the precipitation in 2013 and 121.8 mm higher than the amount of rainfall in 2014.

Statistical analysis. The statistical analyses such as analysis of variance (ANOVA), Tukey's *HSD* (honestly significant difference) test for comparisons of pairs of means were performed in the research years separately and over the years according to the model of data obtained from the experiment designed as a split-split-plot (Szulc et al. 2016a). All calculations were carried out using the Statistica 13 software package (2017). Statistical significance was defined at P-value < 0.01 or P-value < 0.05 depending on the source of variation.

RESULTS

Grain yield and yield components of maize. Statistical analysis (Table 2) shows an interaction between maize sowing methods (A) and study years (Y) and its significant influence on the grain yield and the number of productive ears. However, in terms of the effect on the number of kernels per ear and thousand kernels weight (TKW), there was no interaction between study years and methods of maize sowing. Tukey's test (Table 3) showed that significant differences between mean grain yields using different sowing methods were obtained in 2013 only. The lower mean value (10.47 t/ha) was obtained for direct sowing (A2), and the second, significantly higher value (13.23 t/ha) for sowing in traditionally cultivated soil (A1). Also, in 2013 and 2014 only, the means of the number of productive ears differed significantly in favour of maize sowing method A1 (Table 3). Table 2 also shows a significant interaction effect between cultivars (B) and years (Y) on the grain yield and the number of kernels per ear. In a specific analysis (Table 3) it was found that the mean yield of grain of both cultivars was higher in

Table 1. The content of nutrients (mg/kg DM soil) and soil pH (1 mol/dm^3 KCl)

Specification		2012	2013	2014
NH_4NO_3	0–60 cm	18.4	15.9	19.9
P	0–25 cm	11.20	3.80	12.70
K		9.50	11.10	26.10
Mg		2.80	2.30	3.60
pH		4.90	4.80	4.70

DM – dry matter

Table 2. Results of the four-stratum (YABC) ANOVA

Source of variability	Degrees of freedom	Mean squares				
		grain yield	TKW	number of productive ears	number of kernels in ear	grain moisture
Blocks	3	3.14^{**}	181.30	0.191	1444.47	0.49
Years (Y)	2	24.93^{**}	4091.85^{**}	2.163^{*}	$37\,747.14^{**}$	113.39^{**}
Error1	6	2.24	342.03	0.212	1411.44	0.58
A	1	38.62^{**}	1372.59	7.239^{**}	9146.88^{*}	10.87^{**}
Y × A	2	13.58^{**}	210.81	1.863^{**}	1555.85	2.07
Error 2	9	1.10	463.91	0.101	1 464.90	0.72
B	1	10.23^{**}	$60\,260.28^{**}$	1.704^{**}	$93\,127.91^{**}$	2.01^{*}
Y × B	2	3.32^{*}	421.49	0.110	3124.00^{*}	8.85^{**}
A × B	1	0.51	2428.08^{**}	1.044^{**}	6323.05^{**}	0.09
Y × A × B	2	3.34^{*}	269.81	0.227	1601.14	0.10
Error 3	18	0.64	217.62	0.080	580.87	0.44
C	1	15.39^{**}	201.26	1.729^{**}	3711.23^{*}	0.01
Y × C	2	0.04	40.48	0.049	1276.53	0.79
A × C	1	1.07	93.22	0.257	511.76	0.08
B × C	1	2.93^{*}	19.80	0.056	321.97	0.02
Y × A × C	2	0.52	31.09	0.074	131.66	0.20
Y × B × C	2	0.33	223.32	0.080	834.24	2.02^{**}
A × B × C	1	0.92	218.41	0.011	2581.82	0.83
Y × A × B × C	2	0.41	157.86	0.005	1750.33	1.26^{*}
Error 4	36	0.67	334.16	0.105	883.49	0.34

$^{**}P < 0.01$; $^{*}P < 0.05$; TKW – thousand kernels weight

2013 than in the remaining years. By far the highest mean number of kernels per ear was obtained for cultivar B1 in 2013. However, regarding the grain yield only, there were significant interaction effects between the A and B factors and the years. This means that climatic conditions, represented by years

Table 3. Mean values for combinations Y × A and Y × B

	Year (Y)	Grain yield (t/ha)	TKW (g)	Number of productive ears (pcs./m^2)	Number of kernels in ear (pcs.)	Grain moisture (%)
Method of maize sowing (A)						
A1	2012	11.45^{b}	301.20^{a}	7.97^{a}	541.89^{a}	23.54^{a}
A2		10.75^{b}	297.03^{a}	7.97^{a}	531.33^{a}	23.63^{a}
A1	2013	13.23^{a}	312.89^{a}	7.91^{a}	615.77^{a}	26.06^{a}
A2		10.47^{b}	299.43^{a}	7.18^{b}	580.18^{a}	27.06^{a}
A1	2014	10.26^{b}	323.77^{a}	7.96^{a}	546.76^{a}	26.61^{a}
A2		9.91^{b}	318.73^{a}	7.04^{b}	534.35^{a}	27.54^{a}
Cultivar (B)						
B1	2012	11.05^{b}	272.08^{a}	7.88^{a}	556.72^{b}	22.90^{d}
B2		11.15^{b}	326.14^{a}	8.06^{a}	516.50^{c}	24.28^{c}
B1	2013	11.60^{ab}	285.29^{a}	7.35^{a}	637.14^{a}	26.45^{b}
B2		12.10^{a}	327.03^{a}	7.74^{a}	558.81^{b}	26.67^{ab}
B1	2014	9.41^{c}	293.98^{a}	7.39^{a}	574.72^{b}	27.44^{a}
B2		10.77^{b}	348.51^{a}	7.61^{a}	506.39^{c}	26.71^{ab}

a, b, c, d – homogeneous groups ($\alpha = 0.01$ or $\alpha = 0.05$); TKW – thousand kernels weight

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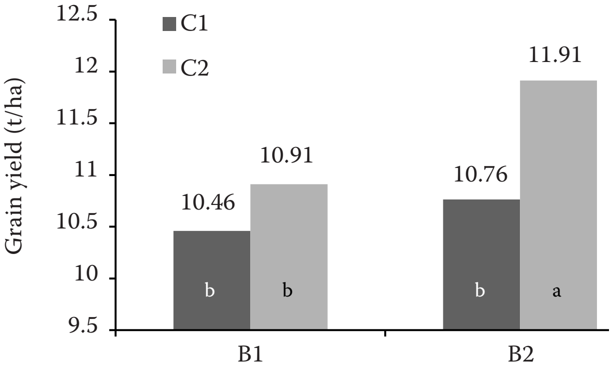

Figure 1. Mean values of the grain yield for combinations of two types of cultivars (B) and two methods of sowing NP fertilizer (C). a, b – homogeneous groups (α = 0.05)

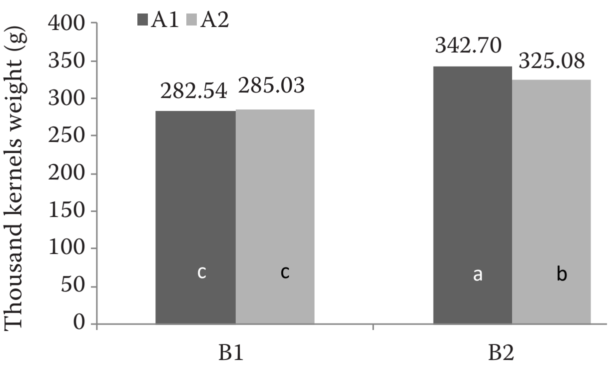

Figure 2. Mean values of thousand kernels weight for combinations of two methods of maize sowing (A) and two types of cultivars (B). a, b, c – homogeneous groups (α = 0.01)

of research, had different effects on combinations of the tested cultivars and methods of sowing. An interesting result was obtained for the interaction of cultivars (B) and NP application methods (C) (Table 2). A significant interaction was shown between these factors for grain yield only, regardless of the year. The cultivars did not respond equally to the change in NP application methods (C). The highest significant mean value for grain yield was obtained for the stay-green cultivars (B1) when applying NP fertilizer in rows (Figure 1). In addition, in the analysis of yield components (Table 3), it was shown that cultivars (B) did not respond equally to the change in maize sowing methods (A), regardless of the year of research. Cultivar B1 had a significantly higher mean TKW compared with cultivar B2, and the use of sowing method A1 significantly increased the TKW of cultivar B1 (Figure 2). In Figure 3a, it was observed that traditional cultivation (A2) significantly increases the mean number of productive ears of both cultivars. It was also shown (Figure 3b) that the stay-green cultivar (B1) obtained a significantly higher mean number of kernels per ear than cultivar B2. It may also be noted that the use of the direct sowing method (A1) significantly increased the number of kernels per ear of the B1 cultivar.

Grain moisture. In the analysis of this trait (Table 2) attention should be paid to some highly significant interactions. The first (Y × B) indicates the interaction between years of research and cultivars, regardless of the NP fertilization method. Tukey's test (Table 3) showed no significant differences between means of grain moisture for the two cultivars in 2013 and 2014; by contrast, the difference in 2012 was significant. The second interaction, of the Y × B × C type, indicates that the reaction of cultivars to the applied NP fertilization was non-uniform in particular years. However, the applied NP fertilization methods do not significantly differentiate the means for the Y × B combination (Figure 4).

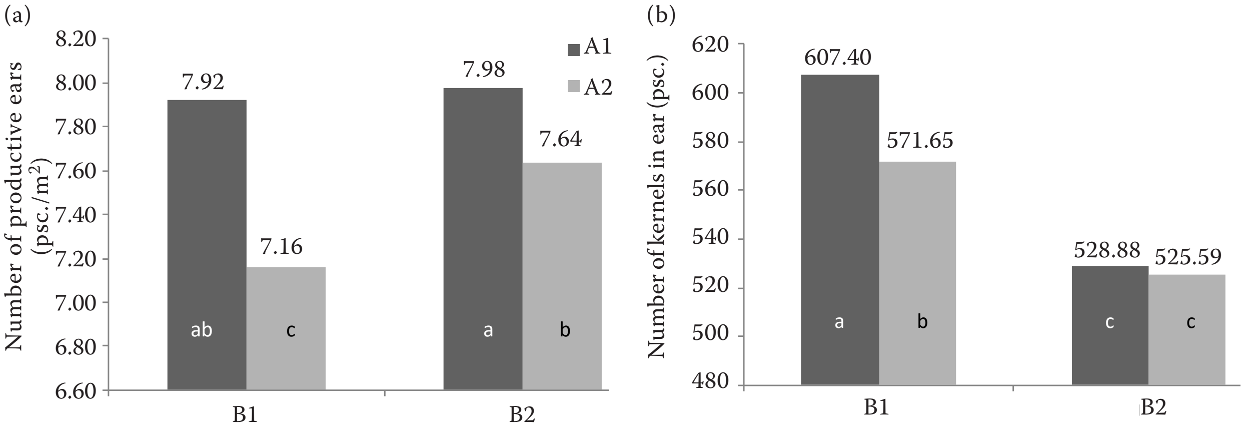

Figure 3. Mean values of (a) the number of productive ears and (b) the number of kernels in ear for combinations of two methods of maize sowing (A) and two types of cultivars (B). a, b, c – homogeneous groups (α = 0.01)

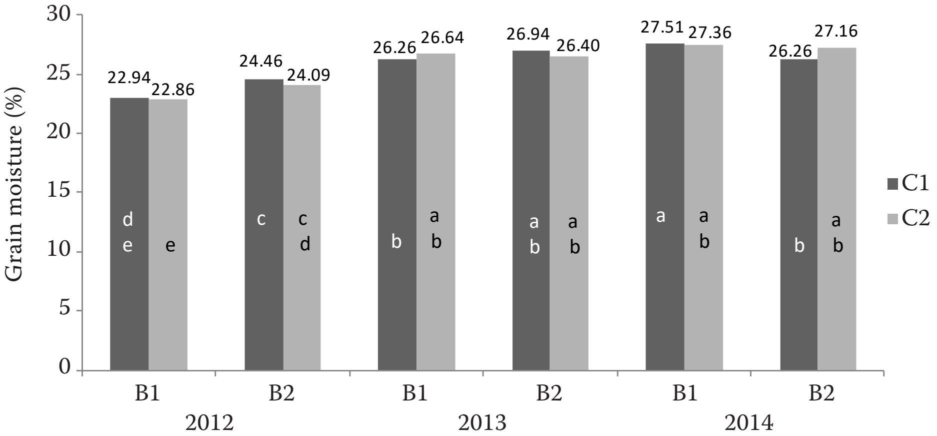

Figure 4. Mean values of the grain moisture for combinations of three years (Y), two types of cultivars (B) and two methods of sowing NP fertilizer (C). a, b, c, d, e – homogeneous groups (α = 0.01)

DISCUSSION

The results indicate a significant influence of weather conditions, varying between experimental years, on the obtained grain yield (Table 4). On average, for years, maize grain yield was the lowest in 2014, which was characterized by the lowest total atmospheric precipitation in the growing season (351.8 mm). In this year, the occurrence of the period of drought was found from June to October, thus the grain yield was significantly lower. Maize had the highest yield in 2013, which was characterized by the optimal atmospheric precipitation distribution in the growing season. Regardless of weather conditions in the years, significantly higher grain yield was obtained for maize sown in the cultivated soil, compared to the direct sowing in stubble. The results of other studies (Torbert et al. 2001) indicated that the cultivation method has a strong impact on the level of maize yield. A view prevails in the literature that the use of simplified cultivation, especially direct sowing (Drury et al. 1999), causes a significant reduction in grain yield, as demonstrated in our own research. An interesting observation is the fact that the biggest difference between the methods of maize sowing in the own research was found in 2013. That year, the difference between the methods of maize sowing was as high as 26.4%, to the disadvantage of direct sowing in the stubble. This was due to the fact that August in that year was characterized by the lowest sum of atmospheric precipitation (32.4 mm), and simultaneously the highest average daily air temperature (20.2°C) (Table 5). The rainfall deficit in that month (grain filling) with simultaneous high air temperature resulted in a reduction in grain number on the cob by 6.1% and thousand grain weight by 4.5% in maize planted directly in the stubble (Table 5). In the remaining years of the experiment, the difference between the components of maize yielding, differentiated by the sowing technique, was much lower. In synthetic terms, it was found that the stay-green cultivar was characterized by significantly higher grain yield compared to the classic cultivar. The author's previous work (Szulc et al. 2016c) assessed the influence of agrotechnical factors on the grain yield of the studied maize

Table 4. Mean values of the traits for years and other factors

Factor	The level of factor	Grain yield (t/ha)	TKW (g)	Number of productive ears (pcs./m^2)	Number of kernels in ear (pcs.)	Grain moisture (%)
Y	2012	11.10^{ab}	299.11^{b}	7.97^{a}	536.61^{b}	23.59^{b}
	2013	11.85^{a}	306.16^{ab}	7.55^{b}	597.97^{a}	26.56^{a}
	2014	10.09^{b}	321.25^{a}	7.50^{b}	540.55^{b}	27.07^{a}
A	A1	11.65^{a}	312.62^{a}	7.95^{a}	568.14^{a}	25.40^{b}
	A2	10.38^{b}	305.06^{a}	7.40^{b}	548.62^{b}	26.08^{a}
B	B1	10.69^{b}	283.79^{b}	7.54^{b}	589.52^{a}	25.60^{b}
	B2	11.34^{a}	333.89^{a}	7.81^{a}	527.23^{b}	25.89^{a}
C	C1	10.61^{b}	307.39^{a}	7.54^{b}	552.16^{b}	25.73^{a}
	C2	11.41^{a}	310.29^{a}	7.81^{a}	564.60^{a}	25.75^{a}

a, b – homogeneous groups (α = 0.01 or α = 0.05). TKW – thousand kernels weight

Table 5. The average monthly air temperature and the monthly sum of atmospheric precipitation in Swadzim for the growing season

Year	Temperature (°C)							
	IV	V	VI	VII	VIII	IX	X	mean/sum
2012	9.3	16.3	17.0	20.0	19.8	15.0	8.6	15.4
2013	8.9	15.6	18.4	22.0	20.2	13.2	10.8	15.6
2014	11.4	14.6	17.9	23.2	18.8	16.0	11.2	16.1
1957–2013	11.4	14.6	17.9	23.2	18.8	16.0	11.2	16.1
	precipitation (mm)							
2012	17.4	84.4	118.1	136.2	52.7	28.4	36.4	473.6
2013	10.5	95.5	114.9	52.9	32.4	75.9	15.3	397.4
2014	50.3	80.7	44.6	51.5	56.5	39.2	29.0	351.8
1957–2013	31.4	54.1	59.0	76.0	57.8	43.8	37.3	359.4

genotypes. It was found that the stay-green type cultivar was characterized by significantly higher grain yield potential compared to the fast maturing cultivar. Regardless of the course of the weather during experimental years, a higher yield of grain was obtained as a result of row fertilization in relation to broadcast fertilization. Higher grain yields obtained under row fertilization were also obtained by Mascagni and Boquet (1996) and Szulc et al. (2016c). Higher grain yield in row fertilization resulted from better nutrition of plants with nitrogen and phosphorus in the juvenile phase. This was confirmed by Barry and Miller (1989), who found that high phosphorus concentration in the dry mass of maize plants before the 6-leaf stage significantly increased grain yield. Maize grain yield in the present study was also significantly affected by the interaction of the cultivar with the NP fertilizer sowing method (Figure 1). Irrespective of the methods of NP fertilization, the stay-green cultivar had higher yields in relation to the fast maturing cultivar, while a significant increase in grain yield was found only for row fertilization (Figure 1). According to Zhang et al. (2012), root system structure is strongly dependent on both the degree of soil compaction and the distribution of fertilizers. The local, elevated dose of fertilizers introduced with the starting fertilization stimulates growth, contributing to the changes in root morphology and structure, affecting the uptake of water and minerals dissolved in it (Alameda and Villar 2012). In the conducted field experiment, it was found during row fertilization that the stay-green cultivar was characterized by significantly higher grain yield compared to the fast maturing cultivar. It is a very interesting observation that the stay-green cultivar reacted very positively to row fertilization. In the conducted field experiment, the surface application of ammonium phosphate (it was not mixed with the soil) on the object with direct sowing contributed to its weaker utilization by plants. It should be assumed that fertilizers used in this manner were much more susceptible to higher nitrogen losses (N + P fertilizer) as a result of ammonia volatilization compared to those mixed with soil. This was also indicated by Stecker et al. (1993), who suggested that the row application of mineral fertilizers in the soil is the best solution in the conditions of zero cultivation. Raun and Barreto (1995) showed in their study that the placement of phosphate and potassium fertilizers near the developing plant roots under zero cultivation conditions could improve their utilization. Similarly, Mascagni and Boquet (1996) demonstrated the benefits of row N and P start fertilization under zero cultivation conditions relative to their surface application, as demonstrated in the current study. In the current study, water content in the grain during threshing was significantly dependent on weather conditions changes in the growing seasons. It should be noted that the highest water content in the grain was found in 2014 (27.07%), which was the most unfavourable for the yielding of maize (drought). In the remaining years of observation, the value of this feature was below 27%. On average, for years, maize grown in direct sowing in stubble and stay-green cultivar had a significantly higher grain water content compared to maize cultivated in the traditional method (autumn ploughing) and fast maturing cultivar (Table 4). Agrotechnical factors such as: (i) method of soil preparation for sowing; (ii) cultivar; (iii) fertilizer application technique can significantly shape maize yielding components, directly affecting the size of the grain yield. Formation of the number of ears starts at the juvenile maize stage. The number of leaves and ears with spikelet primordia is determined during this period. The number of ears that will develop depends on the genotype (cultivar) and the availability of water and nutrients, mainly nitrogen. Nitrogen availability shapes the grain yield from the ears by affecting the number of formed grains and preventing their reduction after fertilization (Bänziger et al. 2002). Considering the role of a maize cultivar type in shaping thousand grain weight, it was found that the value of this trait was significantly greater for the stay-green cultivar (Szulc and Bocianowski 2012). The resulting increase in thousand grain weight was caused by the greater efficiency of the vegetative maize parts (plant longer green) in supplying nitrogen and assimilates to developing grains on the ears (Cazetta et al. 1999). The period of grain filling depended on the factors responsible for durability of leaf greenness and the rate of nitrogen remobilization from the vegetative parts of maize. The stay-green cultivar at the end of the growing season, thanks to the still active green vegetative parts, assimilated longer, often until full grain maturity. In turn, the number of rows on the ears is a genetic trait. However, under conditions of abiotic stress, the number of rows may be reduced (Ritche and Alagarswamy 2003). Plant losses during maize growing season largely affected the number of formed ears. It was found (Szulc and Bocianowski 2012) that at the same seed sowing rate, the stay-green cultivar was characterized by a significantly higher number of the formed production ears established per surface area unit compared to the fast maturing cultivar. In own study, a significant effect on maize grain yield and the formation of its yield components was caused by the reduction of the root system during direct sowing. Selection of the stay-green cultivar and row fertilization with NP fertilizer improved this condition.

In conclusion, the sum of atmospheric precipitation and the average daily temperature of air significantly influenced maize yielding and water content in the grain during harvesting; sowing of maize into the traditionally cultivated soil, the use of the stay-green cultivar and row fertilization had a positive effect on maize yield; the stay-green cultivar yielded at a higher level compared to the fast maturing cultivar, the difference being significant in the year characterized by unfavourable precipitation distribution in the growing season; the stay-green cultivar fertilized in rows with NP fertilizer yielded at a significantly higher level than the fast maturing cultivar; direct maize sowing significantly reduced the number of production ears per surface area unit and the number of grains on the ear. Selection of the stay-green cultivar and row fertilization with NP fertilizer improved this condition, and water stress before flowering of maize grown in direct sowing reduced the number of grains on the ear by increasing the number of unfertilized individual flowers.

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