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DRY MATTER ACCUMULATION IN THE INITIAL VEGETATION PERIOD AS THE RESPONSE OF TWO CULTIVAR TYPES (*Zea mays* L.) TO SOWING AND FERTILIZATION METHODS

Summary

The study presents the results of field trials, whose aim was to assess the impact of sowing and fertilization method on the dynamics of dry matter accumulation in the initial period of growth by two different maize hybrid types. The method of soil cultivation significantly conditioned the growth dynamics of maize plants in the initial vegetation period. In the direct sowing system, the "stay-green" cultivar, with simultaneous phosphorus fertilizer application, may reduce the effects of direct sowing in the BBCH 15/16 stage, but will not eliminate them.
Keywords*: maize, dry matter, juvenile phase, cultivation, fertilization*

GROMADZENIE SUCHEJ MASY W POCZĄTKOWYM OKRESIE WEGETACJI JAKO REAKCJA DWÓCH TYPÓW ODMIAN KUKURYDZY (*Zea mays* L.) NA SPOSÓB SIEWU I NAWOŻENIA

Streszczenie

W pracy przedstawiono wyniki badań polowych, których celem była ocena wpływu sposobu siewu i nawożenia na dynamikę gromadzenia suchej masy w początkowym okresie wzrostu przez dwa różne typy mieszańcowe kukurydzy. Sposób uprawy roli istotnie kształtował dynamikę wzrostu roślin kukurydzy w początkowym okresie wegetacji. W systemie siewu bezpośredniego odmiana typu „stay-green" z jednoczesną aplikacją nawozu fosforowego może zmniejszyć skutki siewu bezpośredniego w stadium BBCH 15/16, ale ich nie wyeliminują.
Słowa kluczowe: *kukurydza, sucha masa, faza młodociana, uprawa, nawożenie*

1. Introduction

Plant phenological development is defined as the initiation, differentiation, enlargement and loss of plant structures [6]. It is the result of cooperation of the plant genotype (cultivar) and the natural environment [2]. It consists of several developmental stages, each of which lasts for a specific period of time. Germination, vegetative growth, reproductive development, physiological maturity [1] and senescence [17] are the five basic stages in the development of an annual crop. Temperature, water and nitrogen content in soil exert the strongest impact on the dynamics of developmental processes. According to Potarzycki [8], growth analysis, based on the dynamics of dry matter accumulation, is a useful method for determining the most sensitive stages of maize response to stress factors, including those related to the availability of nitrogen and other nutrients. Maize is very sensitive to nutrient deficiency, especially in the early stages of its growth [5, 9]. Nitrogen malnutrition of maize in the early vegetation period disrupts leaf, ear and elements of ear structure formation. These effects of nitrogen deficiency are visible very early, because already in the 8-leaf stage. According to Subedi and Ma [12], plant malnutrition with nitrogen before this phase leads to an irreversible reduction in the number of ears and kernels formed even by approximately 30%. Szulc and Bocianowski [13] reported that maize grain yield significantly depended on the nutritional status of plants and the dynamics of the initial growth in the 5-6 leaf stage, regardless of the type of maize hybrid. The experiment hypothesis assumed that the method of sowing and fertilizing differentiates the dynamics of the initial growth of two types of maize cultivars. Therefore, the aim of the study was to determine the effect of sowing and fertilization method on the dynamics of the initial growth of two types of maize cultivars.

2. Materials and Methods

2.1. Experimental field

The field experiment was carried out at the Department of Agronomy of Poznań 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) (Fig. 1); B - 2nd order factor - two types of varieties: B1 - traditional variety SY Cooky, B2 - stay-green variety 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^{-1}, 30.8 kg P·ha^{-1} and 107.9 kg K·ha^{-1}) was applied on all experimental objects. Fertilization was balanced against phosphorus, which was applied at the whole required dose in the form of ammonium phosphate under the trade name of Polidap NP. 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 Polidap. The assumed planting density in the years of research was 7.95 pcs.·m^{-2}, with a spacing between rows of 70 cm and a sowing depth of 5-6 cm. The size of the plant for harvesting was 14 m^2.

Source: own study / Źródło: opracowanie własne

Fig. 1. Maize sown directly into stubble in 2014. Visible post-harvest residue

Rys. 1. Kukurydza zasiana bezpośrednio w mulcz w 2014 roku. Widoczne resztki pożniwne

2.2. Dry matter determination of a single plant

Ten plants were collected from each plot for analysis. Samples were collected with a spade, subsequently, the root was separated from the aerial part of the plant. After drying, the dry matter of one plant was determined. The dry matter content in maize plants was determined by the drying method. The plants were dried at 105°C for 36 hours.

2.3. Weather conditions

Meteorological conditions from maize sowing until plants reach the BBCH 15/16 stage are listed in Table 1. It should be noted that two years, i.e. 2013 and 2014, were favorable for the initial growth of maize. In turn, the first year of research (2012) was a dry and cool year. The highest average air and soil temperature was recorded in 2014, while their lowest value was recorded in the first year of the study. At the same time, the first year of research (2012) was the driest (43.9 mm of rainfall). In 2013 and 2014, the sum of atmospheric precipitation in the period from sowing to the BBCH 15/16 stage was over 80 mm.

2.4. Statistical analysis

The statistical analyses, such as analysis of variance (ANOVA), Tukey's HSD test for comparisons of pairs of means, were performed through the research years according to the model of data obtained from the experiments designed as a split-split-plot in each year (see paragraph 2.1). All calculations were carried out using the STATISTICA 13 software package. Statistical significance was defined at *p-value* < 0.01 or *p-value* < 0.05 depending on the source of variation (e.g. [14]).

3. Results

Statistical analysis (Table 2) shows an interaction between maize sowing methods (A) and study years (Y), and its extremely significant influence on dry matter in the aboveground parts of a single plant (g) and weaker influence on dry matter content (%). Tukey's test (Table 4) showed that significant differences between mean dry matter contents using different sowing methods were obtained in 2013 only. The lower mean value (12.03%) was obtained for direct sowing, and the second, significantly higher value (13.67%) for sowing in traditionally cultivated soil. Also, in 2013 and 2014 only, the means of dry matter in the aboveground parts of a single plant differed significantly in favour of maize sown in traditionally cultivated soil (2.21 g in 2013, 2.82 g in 2014). Tables 2 and 4 also show a significant effect of the interaction between varieties (B) and years (Y) on both traits. In a specific analysis it was found that the means of the dry matter in the aboveground parts of a single plant of both varieties were much higher in 2014 than in the remaining years (2.32 g for the SG variety, 2.03 g for the traditional variety). In turn, by far the highest means of the dry matter contents of both varieties were obtained in 2013, compared with the remaining years. However, only in the case of dry matter in the aboveground parts of a single plant, there were significant interaction effects between factors A and B and the years. This means that climatic conditions, represented by the years of research, had different effects on combinations of the tested varieties and methods of sowing. There was no interaction of factors A and B with each other or with years in terms of the dry matter content (Table 2, Fig. 2).

Table 1. Meteorological conditions in the period from sowing to the 5-6 leaf stage (BBCH 15/16) in the years 2012-2014

Tab. 1. Warunki meteorologiczne w okresie od siewu do fazy 5-6 liścia (BBCH 15/16) w latach 2012-2014

Specification	Years		
	2012	**2013**	**2014**
Total rainfall from sowing to the 5-6 leaf stage [mm]	43.9	86.8	81.5
Average air temperature from sowing to the 5-6 leaf stage [°C]	12.6	13.2	14.6
Average soil temperature at a depth of 10 cm from sowing to the 5-6 leaf stage [°C]	11.8	12.2	12.8

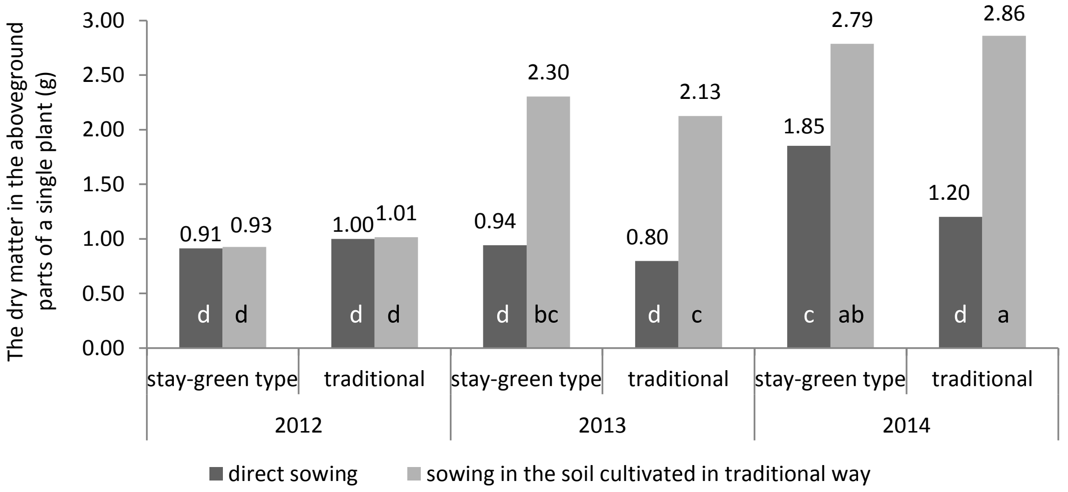
Source: own study / Źródło: opracowanie własne

Table 2. Results of the four-stratum (YABC) ANOVA
Tab. 2. Wyniki czterowarstwowej analizy wariancji (YABC)

Source of variation	df	Mean squares	
		The dry matter in the aboveground parts of a single part (g)	The dry matter content (%)
Blocks	3	0.092	0.529
Years (Y)	2	11.743**	29.987**
Error 1	6	0.042	0.183
Methods of sowing maize (A)	1	18.808**	3.781
Y×A	2	4.551**	10.714*
Error 2	9	0.036	1.623
Varieties (B)	1	0.350*	0.389
Y×B	2	0.291*	2.127*
A×B	1	0.318*	0.086
Y×A×B	2	0.366**	0.317
Error 3	18	0.060	0.563
Methods of sowing NP fertilizer (C)	1	2.460**	3.378*
Y×C	2	0.635**	2.450*
A×C	1	0.286*	1.117
B×C	1	0.007	0.037
Y×A×C	2	0.289*	1.361
Y×B×C	2	0.003	0.810
A×B×C	1	0.005	1.300
Y×A×B×C	2	0.288*	2.705*
Error 4	36	0.060	0.578

** – significant at *p-value* < 0.01, * – significant at *p-value* < 0.05

Source: own study / Źródło: opracowanie własne



a, b, c, d - homogeneous groups (α = 0.01)

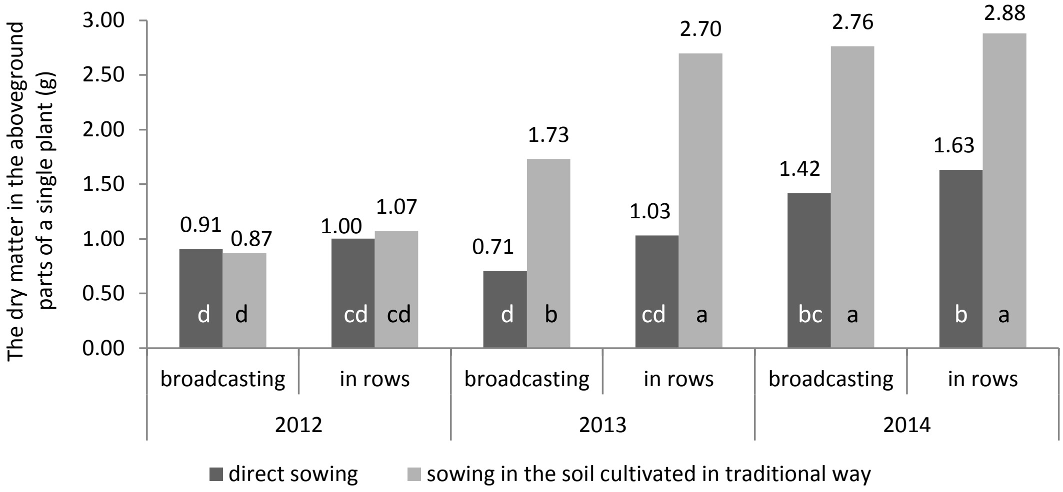
Source: own study / Źródło: opracowanie własne

Fig. 2. Mean values of the dry matter in the aboveground parts of a single plant for the combinations of three years, two methods of sowing maize and two types of varieties
Rys. 2. Średnie suchej masy części nadziemnych pojedynczej rośliny w odniesieniu do kombinacji trzech lat, dwóch sposobów siewu kukurydzy i dwóch typów odmian

Tables 2 and 4 also indicate that NP fertilizer application methods (C) interact with years of research for both considered traits. For both NP application methods, significantly the highest mean dry matter in the aboveground parts of a single plant was obtained in 2014. In turn, significantly the highest mean dry matter content was obtained using broadcasting as the NP application method in 2013 (13.35%).

It was also found that the years of research diversified the impact of interactions between maize sowing methods (A) and NP application methods (C), but only in case of dry matter in the aboveground parts of a single plant (Table 2).The highest means of dry matter in the aboveground parts of a single plant (g) were obtained using the traditional maize sowing method and both NP fertilizer application methods in 2014 and only the in-row NP application method in 2013 (Fig. 3).

It is also noteworthy (Table 2) that the varieties did not respond equally to the changes in climatic conditions in the study years in combination with the two maize sowing methods and the two methods of applying NP fertilizer. The effect of the interaction of these factors and the years mentioned above, both for dry matter in the aboveground parts of a single plant (g) and for dry matter content (%), is significant ($p < 0.05$).



a, b, c, d - homogeneous groups (α = 0.01) *Source: own study / Źródło: opracowanie własne*

Fig. 3. Mean values of the dry matter in the aboveground parts of a single plant for the combinations of three years, two methods of sowing maize and two methods of sowing NP fertilizer
Rys. 3. Średnie suchej masy części nadziemnych pojedynczej rośliny dla kombinacji trzech lat, dwóch sposobów siewu kukurydzy i dwóch metod wysiewu nawozu NP

Table 3. Mean values of the traits for the years and other factors
Tab. 3. Średnie obu cech dla lat i innych czynników

Factors	The levels of the factors	The dry matter in the aboveground parts of a single part (g)	The dry matter content (%)
Y	2012	0.96^{c}	11.63^{b}
	2013	1.54^{b}	12.85^{a}
	2014	2.17^{a}	10.94^{c}
A	direct sowing	1.12^{b}	11.61^{a}
	sowing in the soil cultivated in traditional way	2.00^{a}	12.01^{a}
B	stay-green type	1.62^{a}	11.87^{a}
	traditional	1.50^{b}	11.74^{a}
C	broadcasting	1.40^{b}	11.99^{a}
	in rows	1.72^{a}	11.62^{b}

a, b, c – homogeneous groups (α = 0.01 or α = 0.05) *Source: own study / Źródło: opracowanie własne*

Table 4. Mean values for the combinations Y×A, Y×B and Y×C
Tab. 4. Średnie obu cech dla kombinacji Y×A, Y×B i Y×C

Years (Y)	Methods of sowing maize (A)	The dry matter in the aboveground parts of a single part (g)	The dry matter content (%)
2012	direct sowing	0.96^{d}	11.52^{b}
	sowing in the soil cultivated in traditional way	0.97^{d}	11.74^{b}
2013	direct sowing	0.87^{d}	12.03^{b}
	sowing in the soil cultivated in traditional way	2.21^{b}	13.67^{a}
2014	direct sowing	1.53^{c}	11.27^{b}
	sowing in the soil cultivated in traditional way	2.82^{a}	10.61^{b}
Years (Y)	Varieties (B)	The dry matter in the aboveground parts of a single part (g)	The dry matter content (%)
2012	stay-green type	0.92^{d}	11.68^{b}
	traditional	1.01^{d}	11.59^{bc}
2013	stay-green type	1.62^{c}	13.18^{a}
	traditional	1.46^{c}	12.52^{a}
2014	stay-green type	2.32^{a}	10.75^{c}
	traditional	2.03^{b}	11.12^{bc}
Years (Y)	Methods of sowing NP fertilizer (C)	The dry matter in the aboveground parts of a single part (g)	The dry matter content (%)
2012	broadcasting	0.89^{d}	11.60^{bcd}
	in rows	1.04^{cd}	11.66^{bc}
2013	broadcasting	1.22^{c}	13.35^{a}
	in rows	1.86^{b}	12.35^{b}
2014	broadcasting	2.09^{ab}	11.03^{cd}
	in rows	2.26^{a}	10.84^{d}

a, b, c, d – homogeneous groups (α = 0.01 or α = 0.05) *Source: own study / Źródło: opracowanie własne*

4. Discussion

The obtained results indicate the significance of weather conditions that varied between the years of the study on the amount of dry matter of a single plant and its content in the 5-6 leaf stage (Table 3). On average, for the years of research, the highest dry matter of a single plant, regardless of the tested factors of the experiment, was obtained in 2014 (2.17 g), while the lowest in 2012 (0.96 g). The lowest value of dry matter content in the discussed maize developmental phase was recorded in 2014 (10.94%), while the highest in 2013 (12.85%). The year 2012, in which maize was characterized by the slowest vigor of initial growth in the period from sowing to the 5-6 leaf stage, was the coolest and at the same time the driest. During this period, 43.9 mm of rainfall was recorded, while the average air temperature was 12.6°C. Soil temperature at a depth of 10 cm was also the lowest – 11.8°C. The result obtained in our study confirms earlier literature reports regarding the thermal requirements of maize [10]. Low soil and air temperature during sowing and in the early stages of maize growth is the main reason limiting its yield [11]. Sowing and fertilization method and cultivar type significantly determined the average dry matter of a single plant during the years of research. A significantly lower dry matter of a single plant and its yield in the 5-6 leaf stage were obtained when sowing maize into no-tillage soil compared to maize sown into tillage soil. The obtained result in the present study confirms earlier literature reports [4]. According to these authors, the method of soil cultivation has a significant impact on the dynamics of plant development, especially in the non-ploughing tillage system. In that study, slight, but significant delays in the development of maize plants were noted when the latter system was applied. They were the result of slower heating up of unplowed soil in the spring and the observed increase in its bulk density and reduction of porosity. Soil temperatures in the spring period confirmed this finding. Similar results regarding the dynamics of emergence depending on the method of soil preparation for maize sowing were also obtained by other researchers [3, 7]. A significantly higher dry matter of a single plant and dry matter yield were recorded for the "stay-green" cultivar Drim compared to the cultivar SY Cooky. This difference was 0.12 g. In the earlier work, Szulc et al. [16] also showed that the "stay-green" cultivar was characterized by a significantly higher vigor of initial growth, expressed by dry matter accumulation, compared to the traditional hybrid. In the present study, row fertilization compared to the broadcast application, resulted in a significantly higher dry matter of a single plant and its yield in the BBCH 15/16 stage (Fig. 4). The obtained result also corresponds to the outcomes included in another work of Szulc et al. [15]. According to the latter authors, fertilization in rows, compared to the broadcast and row fertilization combined with top dressing, had a positive effect on the vigor of the initial maize growth, which was manifested by a higher dry matter of one plant in the BBCH 16/17 stage, higher dry matter yield from a unit area in the BBCH 16/17 stage, higher increase rate of total dry matter of one plant and higher increase rate of total dry matter yield.

Source: own study / Źródło: opracowanie własne

Fig. 4. Effect of maize fertilization method on the dynamics of initial growth. On the left: maize fertilized in rows, on the right: broadcast fertilization

Rys. 4. Wpływ sposobu nawożenia kukurydzy na dynamikę początkowego wzrostu. Z lewej kukurydza nawożona rzędowo, z prawej rzutowo

5. Conclusions

1. Varied weather conditions from the sowing to the BBCH 15/16 stage have a significant impact on dry matter quantity of a single plant and its content. Warm and humid weather increases the dynamics of the initial maize growth.
2. The method of soil cultivation significantly shapes the growth dynamics of maize plants in the initial vegetation period. Direct sowing, resulting in a decrease in dry matter of plants in the BBCH 15/16 stage, significantly affects yield formation processes.
3. The "stay-green" cultivar in the direct sowing system with simultaneous phosphorus fertilizer application may reduce, but not eliminate the effects of direct sowing at the BBCH 15/16 stage.

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