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ASSESSMENT OF THE IMPACT OF SELECTED AGRICULTURE FACTORS ON MAIZE NUTRITIONAL STATUS IN CRITICAL GROWTH STAGES USING THE PLANT ANALYSIS METHOD. PART I. 5-6 LEAF STAGE (BBCH 15/16)

Summary

The study presents the results of a 3-year field study, whose aim was to assess the effect of sowing and NP fertilizer application method on dry matter (yield) accumulation at the BBCH 15/16 stage of two different types (traditional and stay-green) of maize varieties. It was found that the nutritional status of maize in the stands rich in nutrients may only incidentally (depending on years) show a reaction to variety selection and row application of NP fertilizers, improving the values of nitrogen nutrition indices. Physiological indices of the plants' status at the BBCH 15/16 stage showed a significant, albeit variable over the years, response to variety selection and the row application of NP fertilizers. The negative effect of the sowing method was revealed incidentally.
Keywords: *maize, dry matter yield, cultivation, fertilization, nutritional status*

OCENA WPŁYWU WYBRANYCH CZYNNIKÓW AGROTECHNICZNYCH NA STAN ODŻYWIENIA KUKURYDZY W KRYTYCZNYCH FAZACH WZROSTU METODĄ ANALIZY ROŚLINNEJ. CZĘŚĆ I. FAZA 5-6 LIŚCI (BBCH 15/16)

Streszczenie

W pracy przedstawiono wyniki 3-letnich badań polowych, których celem była ocena wpływu sposobu siewu i aplikacji nawozu NP na gromadzenie suchej masy (plon) w fazie BBCH 15/16 przez dwa różne typy (tradycyjna i stay-green) odmian kukurydzy. Stwierdzono, że stan odżywienia kukurydzy w stanowiskach zasobnych w składniki pokarmowe tylko incydentalnie (od lat) może wykazać reakcję na dobór odmiany, jak i rzędowe stosowanie nawozów typu NP poprawiając wartość wskaźników odżywienia azotem. Wskaźniki fizjologiczne stanu roślin w stadium BBCH 15/16 wykazują istotną, aczkolwiek zmienną w latach, reakcję na dobór odmiany i rzędowe stosowanie nawozów NP. Ujemne działanie sposobu siewu ujawnia się incydentalnie.
Słowa kluczowe: *kukurydza, plon suchej masy, uprawa, nawożenie, stan odżywienia*

1. Introduction

Plant growth is an irreversible accumulation of dry matter that is closely related to plant development. According to Potarzycki [1], growth analysis based on the dynamics of dry matter accumulation is a useful method of determining the most sensitive stages of maize response to external (stress) factors, including the content of available nitrogen and other nutrients. Maize is very sensitive to nutrient deficiency, especially in the early stages of its growth [2, 3, 4]. Determining the optimal level of nitrogen fertilization, which guarantees the utilization of maize production potential, is one of the most important agriculture issues in growing this plant. Malnutrition of maize plants with nitrogen in the early growing season impairs the formation processes of leaves, ears and ear structure elements [5]. These effects of nitrogen deficiency become apparent very early, already in the 8-leaf stage. According to Subedi and Ma [6], plant nitrogen malnutrition before this phase leads to an irreversible reduction in the number of ears and set kernels even up to about 30%. Therefore, the aim of the conducted field research was to assess the impact of soil preparation method for maize sowing, maize hybrid type and NP fertilization application on: (i) dry matter yield in the BBCH 15/16 stage, (ii) nutrient content and (iii) determination of maize plant nutrition indices.

2. Material 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 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 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 $N \cdot ha^{-1}$, 30.8 kg $P \cdot ha^{-1}$ and 107.9 kg $K \cdot ha^{-1}$) 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 .

2.2. Weather and soil conditions

Characteristics of weather conditions during the research period were based on data from the meteorological station belonging to the Agronomy Department of the Poznań University of Life Sciences, located at the Experimental and Educational unit in Swadzim (52° 26′ N; 16° 45′ E). It should be noted that the sum of atmospheric precipitation in the period from sowing to the BBCH 15/16 stage was very diverse (Tab. 1). The significantly highest sum was recorded in 2013, while the precipitation in 2012 was lower by almost 50%. At the same time, soil temperature at a depth of 10 cm was the lowest in 2012, while the highest in 2014 (Tab. 1). According to the international FAO classification, the soil of the experimental field was classified as *Albic Luvisols*, while according to the American classification, it belonged to the order *Alfisols*. In terms of horizon, it was defined as loamy sand underlined by loam according to the international classification. It was included in the 4th complex of agricultural usefulness (very good rye) and valuation class III b. Winter wheat was the forecrop for maize in each year of the field research.

2.3. Plant material

2.3.1. Mass yield determination in the initial maize vegetation period

- **Plant dry matter (dm) yield in the 5-6 leaf stage (BBCH 15/16)**

Knowing the dry weight of a single plant and the quantitative status of plants after emergence, dry matter yield of plants in the discussed maize development stage was determined. 10 plants for each plot were collected for analysis.

2.3.2. Determination of N, P, K, Mg contents in plants dm at the 5-6 leaf stage (BBCH 15/16)

The analysis of mineral contents in dry matter of plants was performed in the laboratory of the Agronomy Department of the Poznań University of Life Sciences, according to the methods described by Gawęcki [7]. In addition, potassium was determined using a "Flapho 40" flame spectrophotometer, and phosphorus and magnesium using a "Specol 11" colorimeter.

2.3.3. Determination of maize plant nutrition indices at the 5-6 leaf stage (BBCH 15/16)

Nutrition index (NI) of plants with macronutrients was determined as the quotient of the current (actual) and critical content of individual nutrients [8]:

$$NI = \frac{\text{current (actual) component value in [\%]}}{\text{critical component content in [\%]}}$$

The current component contents in dry matter of individual maize organs was determined in a laboratory by chemical analysis of plant material. The critical content of N, P, K and Mg was taken from the work of Szulc et al. [8]. The optimal value of the nutritional index is 1. The NI value lower than 1 indicates malnutrition with a given macronutrient, while higher than 1 indicates excessive uptake of the macronutrient by plants [9].

2.3.4. Accumulation of macronutrients from dm at the 5-6 leaf stage (BBCH 15/16)

The uptake (accumulation) of individual macronutrients with dry matter yield in the 5-6 leaf stage (BBCH 15/16) was calculated based on the following formula:

Uptake = (dry matter yield × component content)/100

where: uptake – kg ha^{-1}, dry matter yield – kg ha^{-1}, component content in %.

2.3.5. Statistical analysis

One-year results were subjected to a univariate analysis of variance, followed by a synthesis for multiple experiments. The significance of the differences was estimated at the level of $\alpha = 0.05$ using the Student's t-test. A polynomial curvilinear regression was determined for the means from the individual years. The interaction between grain yield and its structure elements was determined using simple correlation analysis and analysis of path coefficients based on the equation from the study of Douglas et al. [10] using Excel 1997 spreadsheet.

3. Results

3.1. Maize dry matter yield in the 5-6 leaf stage (BBCH 15/16)

Synthetically, dry matter yield of maize plants at the 5-6 leaf stage (BBCH 15/16) was significantly influenced by the sowing method, variety and NP fertilizer sowing method in the period of 3 research years (Tab 2). A significantly higher dry matter yield in the discussed development stage was characteristic of maize sown in cultivated soil compared to maize sown directly into stubble (Tab. 2).

Table 1. Course of meteorological conditions in the period from sowing to the 5-6 leaf stage (BBCH 15/16)
Tab. 1. Przebieg warunków meteorologicznych w okresie od siewu do fazy 5-6 liści (BBCH 15/16)

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

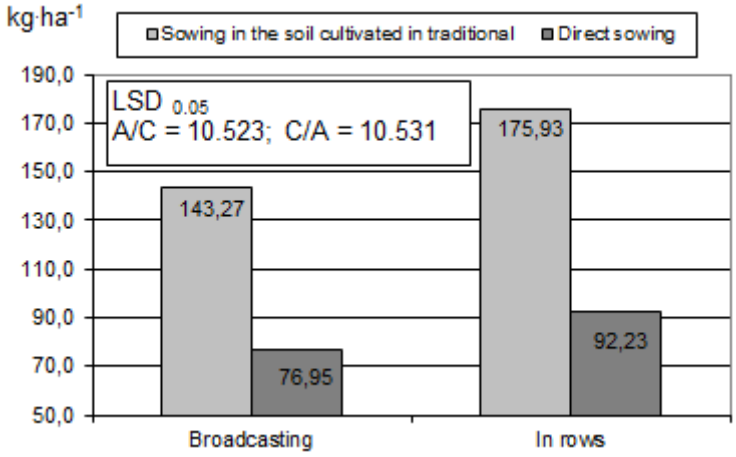
Source: own study / Źródło: opracowanie własne

Table 2. Maize dry matter yield in the 5-6 leaf stage (BBCH 15/16) - (kg·ha^{-1})
Tab. 2. Plon suchej masy kukurydzy w fazie 5-6 liści (BBCH 15/16) - (kg·ha^{-1})

Experimental factors		Years			Average
		2012	2013	2014	
Maize sowing methods **A**	sowing in traditionally cultivated soil	77.17	176.23	225.40	159.60
	direct sowing	76.23	63.90	113.64	84.59
LSD $_{0.05}$		**n.s.**	**23.674**	**18.524**	**7.475**
Varieties **(B)**	SY Cooky	80.03	114.05	155.92	116.67
	Drim „stay-green"	73.37	126.08	183.12	127.53
LSD $_{0.05}$		**n.s.**	**7.239**	**25.396**	**9.447**
NP fertilizer sowing methods **(C)**	broadcasting	70.79	96.20	163.35	110.11
	in rows	82.61	143.94	175.69	134.08
LSD $_{0.05}$		**7.699**	**12.555**	**10.926**	**7.441**
Average		76.70	120.07	169.52	122.10

n.s. – non-significant difference

Source: own study / Źródło: opracowanie własne



Source: own study / Źródło: opracowanie własne

Fig. 1. Dry matter yield of maize in the 5-6 leaf stage (BBCH 15/16) depending on the interaction of the sowing method and the method of NP fertilizer application (2012-2014)
Rys. 1. Plon suchej masy kukurydzy fazie 5-6 liści (BBCH 15/16) w zależności od współdziałania sposobu siewu ze sposobem wysiewu nawozu NP (2012-2014)

The difference between maize sowing methods was 75.01 kg·ha^{-1}. Considering the influence of the variety, it was shown that the "stay-green" Drim hybrid was characterized by a significantly higher dynamics of the initial growth, expressed as dry matter accumulation at the 5-6 leaf stage (BBCH 15/16) compared to the traditional SY Cooky hybrid (Tab. 2). In synthetic terms, maize was characterized by a significantly higher dry matter yield in the juvenile phase during the period of 3 research years, as a result of row fertilization compared to broadcast fertilization. This difference was 23.97 kg ha^{-1} (Tab. 2). Dry matter yield of maize in the 5-6 leaf stage (BBCH 15/16) was significantly influenced by the interaction of the sowing method with maize hybrid type (Fig. 1). Row application of NP fertilizer, irrespective of the method of sowing maize, resulted in a higher dry matter yield in the 5-6 leaf stage compared to the broadcast sowing (Fig. 1). Regardless of the sowing method of nitrogen-phosphorus fertilizer, maize sown into cultivated soil showed a significantly higher dynamics of initial growth compared to direct sowing into stubble, expressed by dry matter accumulation (Fig. 1).

3.2. Changes in plant chemical composition at the 5-6 leaf stage (BBCH 15/16)

3.2.1 The content of N, P, K, Mg in plants' dm

The average content of nitrogen and phosphorus in plants' dry matter in the 5-6 leaf stage (BBCH 15/16) in the three study years was significantly influenced only by the sowing method of NP fertilizer. (Tab 3). Maize fertilized in rows had a significantly higher content of the above-mentioned nutrients compared to the broadcast application. The difference between the tested fertilization methods was: 4.02 g·kg^{-1} and 0.94 g·kg^{-1}, respectively (Tab. 3).

3.2.2. Indices of plant nutrition with nitrogen, phosphorus, potassium and magnesium

The average nitrogen (N-NI) and phosphorus (P-NI) plant nutrition index at the 5-6 leaf stage (BBCH 15/16) during the three study years was significantly shaped only by the sowing method of NP fertilizer. (Tab 4). Significantly higher values of these nutritional indices were recorded for row fertilization compared to the broadcast application (Tab. 4).

Table 3. Nutrient contents ($g \cdot kg^{-1}$) (2012-2014)
Tab. 3. Zawartość składników pokarmowych ($g \cdot kg^{-1}$) (2012-2014)

Experimental factors		N	P	K	Mg
Maize sowing methods of **(A)**	sowing in traditionally cultivated soil	39.95	4.24	38.66	1.68
	direct sowing	38.84	4.66	39.91	1.85
LSD $_{0.05}$		**n.s.**	**n.s.**	**n.s.**	**n.s.**
Varieties **(B)**	SY Cooky	38.89	4.26	39.28	1.77
	Drim „stay-green"	39.89	4.64	39.29	1.76
LSD $_{0.05}$		**n.s.**	**n.s.**	**n.s.**	**n.s.**
NP fertilizer sowing methods **(C)**	broadcasting	37.38	3.98	39.21	1.81
	in rows	41.40	4.92	39.36	1.73
LSD $_{0.05}$		**2.819**	**0.654**	**n.s.**	**n.s.**
Average		39.39	4.45	39.28	1.76

n.s. – non-significant difference

Source: own study / Źródło: opracowanie własne

Table 4. Plant nutrition index values
Tab. 4. Wartości wskaźników odżywienia roślin

Experimental factors		N-NI	P-NI	K-NI	Mg-NI
Maize sowing methods **(A)**	sowing in traditionally cultivated soil	0.87	1.07	0.90	0.65
	direct sowing	0.85	1.18	0.92	0.68
LSD $_{0.05}$		**n.s.**	**n.s.**	**n.s.**	**n.s.**
Varieties **(B)**	SY Cooky	0.88	1.12	0.93	0.67
	Drim „stay-green"	0.83	1.14	0.89	0.66
LSD $_{0.05}$		**n.s.**	**n.s.**	**n.s.**	**n.s.**
NP fertilizer sowing methods **(C)**	broadcasting	0.81	1.01	0.91	0.68
	in rows	0.90	1.25	0.92	0.66
LSD $_{0.05}$		**0.060**	**0.165**	**n.s.**	**n.s.**
Average		0.85	1.13	0.91	0.66

n.s. – non-significant difference

Source: own study / Źródło: opracowanie własne

3.2.3. Nitrogen accumulation in dry matter of plants

Accumulation of nitrogen with maize dry matter in the 5-6 leaf stage (BBCH 15/16) significantly depended on all three experimental factors, i.e. sowing method, variety and the method of NP fertilizer application (Tab. 5). Significantly higher values of this trait were demonstrated for sowing in cultivated soil, the "stay-green" variety Drim and row application of NP fertilizer compared to maize sown directly into stubble, the traditional variety SY Cooky and NP fertilizer broadcast application. (Tab 5). In the present study, nitrogen accumulation with dry matter yield in the 5-6 leaf stage (BBCH 15/16) was also significantly influenced by the interaction of maize sowing method and the method of NP fertilizer application (Fig. 2). Regardless of the method of sowing maize, row fertilization was more effective than broadcast fertilization. Nevertheless, a greater effect of this method of sowing fertilizer was obtained when maize was sown into cultivated soil (difference of 2.08 kg ha^{-1}) compared to sowing maize directly into stubble (difference of 0.86 kg ha^{-1}) (Fig. 2).

Table 5. Nitrogen accumulation in dry matter in the 5-6 leaf stage (BBCH 15/16)
Tab. 5. Pobranie azotu z suchą masą roślin kukurydzy w fazie 5-6 liści (BBCH 15/16)

Experimental factors		Years			Average
		2012	2013	2014	
		$kg \cdot ha^{-1}$	$kg \cdot ha^{-1}$	$kg \cdot ha^{-1}$	$kg \cdot ha^{-1}$
Maize sowing methods **(A)**	sowing in traditionally cultivated soil	3.32	7.70	8.00	6.31
	direct sowing	3.19	2.30	4.44	3.31
LSD $_{0.05}$		**n.s.**	**0.911**	**0.628**	**0.277**
Varieties **(B)**	SY Cooky	3.32	4.71	5.62	4.55
	Drim „stay-green"	3.10	5.29	6.82	5.07
LSD $_{0.05}$		**n.s.**	**n.s.**	**0.923**	**0.360**
NP fertilizer sowing methods **(C)**	broadcasting	2.85	3.49	5.88	4.07
	in rows	3.57	6.51	6.56	5.55
LSD $_{0.05}$		**0.318**	**0.488**	**n.s.**	**0.283**
Average		3.21	5.00	6.22	4.81

n.s. – non-significant difference

Source: own study / Źródło: opracowanie własne

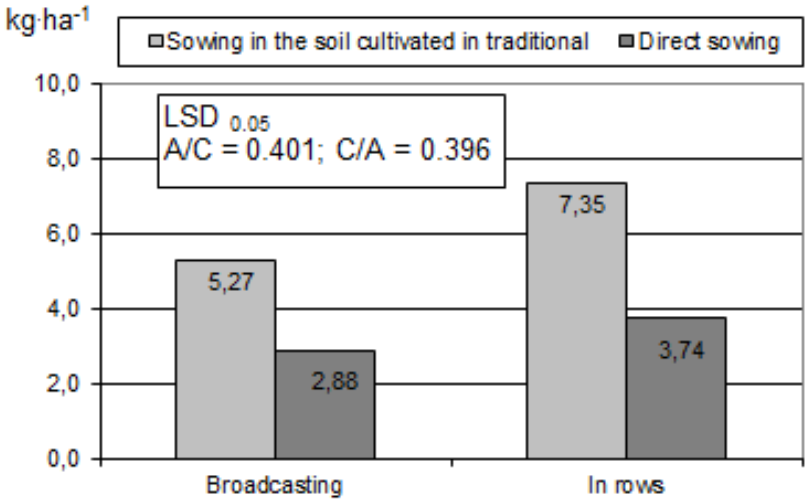


Fig. 2. Nitrogen accumulation in dry matter yield of plants in the 5-6 leaf stage (BBCH 15/16) depending on the interaction of the sowing method with the method of NP fertilizer application (2012-2014)
Rys. 2. Pobranie azotu z suchą masą roślin w fazie 5-6 liści (BBCH 15/16) w zależności od współdziałania sposobu siewu ze sposobem wysiewu nawozu NP (2012-2014)

3.2.4. Phosphorus accumulation in maize dry matter yield

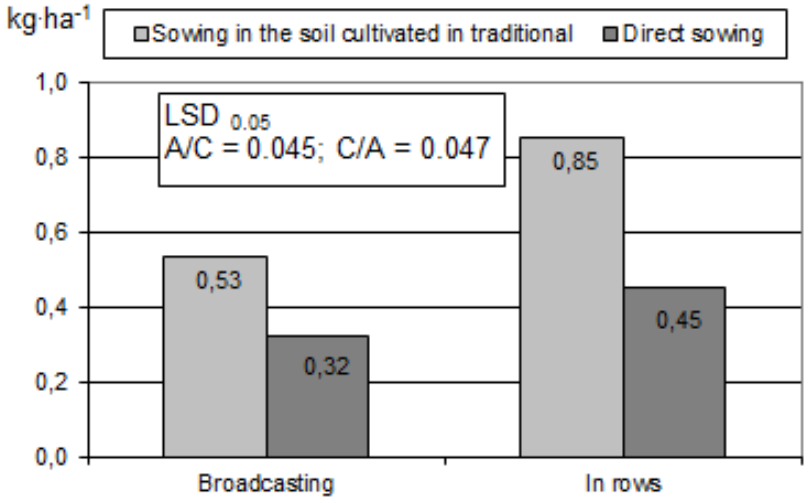
Accumulation of phosphorus with maize dry matter in the 5-6 leaf stage (BBCH 15/16) significantly depended on all three experimental factors, i.e. sowing method, variety and the method of sowing NP fertilizer (Tab. 6). Significantly higher values of this trait were demonstrated for sowing in cultivated soil, the "stay-green" variety Drim and row application of NP fertilizer compared to maize sown directly into stubble, the traditional variety SY Cooky and NP fertilizer broadcast application (Tab. 6). In the present study, phosphorus accumulation with dry matter yield in the 5-6 leaf stage (BBCH 15/16) was also significantly influenced by the interaction of maize sowing method with the method of NP fertilizer application (Fig. 3). Regardless of the method of sowing maize, row fertilization was more effective than broadcast fertilization. Nevertheless, a greater effect of this method of fertilizer application was obtained when maize was sown into cultivated soil (difference of 0.32 kg ha^{-1}) compared to sowing maize directly into stubble (difference of 0.13 kg ha^{-1}) (Fig. 3).

Table 6. Phosphorus accumulation in dry matter in the 5-6 leaf stage (BBCH 15/16)
Tab. 6. Pobranie fosforu z suchą masą roślin kukurydzy w fazie 5-6 liści (BBCH 15/16)

Experimental Factors		Years			Average
		2012	2013	2014	
		kg·ha^{-1}	kg·ha^{-1}	kg·ha^{-1}	kg·ha^{-1}
Maize sowing methods **(A)**	sowing in traditionally cultivated soil	0.31	0.86	0.92	0.69
	direct sowing	0.36	0.35	0.45	0.38
LSD $_{0.05}$		**0.039**	**0.126**	**0.067**	**0.035**
Varieties **(B)**	SY Cooky	0.34	0.52	0.61	0.49
	Drim „stay-green"	0.32	0.68	0.76	0.59
LSD $_{0.05}$		**n.s.**	**0.092**	**0.103**	**0.040**
NP fertilizer sowing methods **(C)**	broadcasting	0.29	0.37	0.62	0.43
	in rows	0.37	0.83	0.75	0.65
LSD $_{0.05}$		**0.033**	**0.06**	**0.076**	**0.032**
Average		0.33	0.60	0.69	0.54

n.s. – non-significant difference

Source: own study / Źródło: opracowanie własne



Source: own study / Źródło: opracowanie własne

Fig. 3. Phosphorus accumulation in dry matter yield of plants in the 5-6 leaf stage (BBCH 15/16) depending on the interaction of the sowing method and the method of NP fertilizer application (2012-2014)
Rys. 3. Pobranie fosforu z suchą masą roślin w fazie 5-6 liści (BBCH 15/16) w zależności od współdziałania sposobu siewu ze sposobem wysiewu nawozu NP (2012-2014)

3.2.5. Phosphorus accumulation in maize dry matter yield

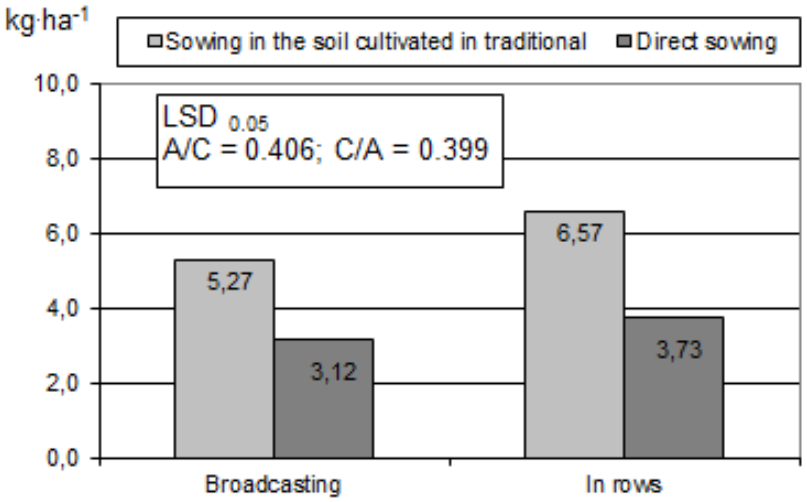
Accumulation of potassium with maize dry matter in the 5-6 leaf stage (BBCH 15/16) significantly depended on all three experimental factors, i.e. sowing method, variety and the method of sowing NP fertilizer (Tab. 7). Significantly higher values of this trait were demonstrated for sowing in cultivated soil, the "stay-green" variety Drim and row application of NP fertilizer compared to maize sown directly into stubble, the traditional variety SY Cooky and NP fertilizer broadcast application (Tab. 7). In the present study, potassium accumulation with dry matter yield in the 5-6 leaf stage (BBCH 15/16) was also significantly influenced by the interaction of maize sowing method and the method of NP fertilizer application (Fig. 4). Regardless of the method of sowing maize, row fertilization was more effective than broadcast fertilization. Nevertheless, a greater effect of this method of fertilizer application was obtained when maize was sown into cultivated soil (difference of 1.30 kg ha^{-1}) compared to sowing maize directly into stubble (difference of 0.61 kg ha^{-1}) (Fig. 4).

Table 7. Potassium accumulation in dry matter in the 5-6 leaf stage (BBCH 15/16)
Tab. 7. Pobranie potasu z suchą masą roślin kukurydzy w fazie 5-6 liści (BBCH 15/16)

Experimental Factors		Years			Average
		2012	2013	2014	
		kg·ha^{-1}	kg·ha^{-1}	kg·ha^{-1}	kg·ha^{-1}
Maize sowing methods **(A)**	sowing in traditionally cultivated soil	3.57	5.79	8.41	5.92
	direct sowing	3.39	2.19	4.70	3.42
LSD $_{0.05}$		**n.s.**	**0.868**	**0.646**	**0.278**
Varieties **(B)**	SY Cooky	3.65	3.77	5.98	4.47
	Drim „stay-green"	3.31	4.20	7.12	4.88
LSD $_{0.05}$		**0.336**	**n.s.**	**0.967**	**0.349**
NP fertilizer sowing methods **(C)**	broadcasting	3.38	2.95	6.26	4.20
	in rows	3.58	5.03	6.84	5.15
LSD $_{0.05}$		**n.s.**	**0.426**	**n.s.**	**0.287**
Average		3.48	3.99	6.55	4.67

n.s. – non-significant difference

Source: own study / Źródło: opracowanie własne



Source: own study / Źródło: opracowanie własne

Fig. 4. Potassium accumulation in dry matter yield of plants in the 5-6 leaf stage (BBCH 15/16) depending on the interaction of the sowing method with the method of sowing NP fertilizer. (2012-2014)
Rys. 4. Pobranie potasu z suchą masą roślin w fazie 5-6 liści (BBCH 15/16) w zależności od współdziałania sposobu siewu ze sposobem wysiewu nawozu NP. (2012-2014)

3.2.5. Magnesium accumulation in maize dry matter yield

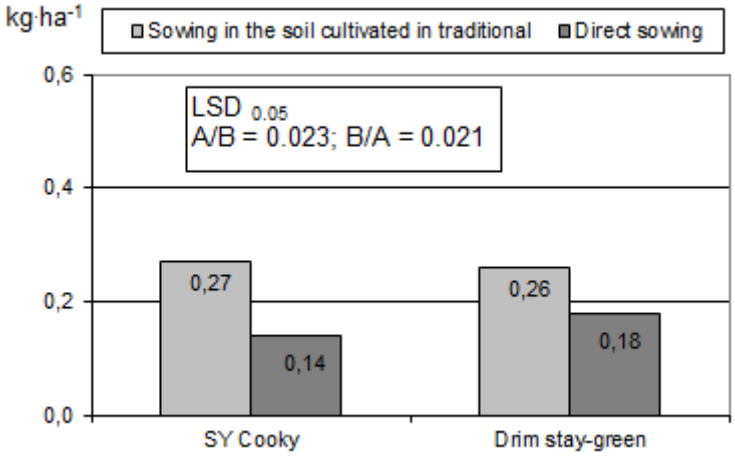
Accumulation of magnesium with maize dry matter in the 5-6 leaf stage (BBCH 15/16) significantly depended on all three experimental factors, i.e. sowing method, variety and the method of sowing NP fertilizer (Tab. 8). Significantly higher values of this trait were demonstrated for sowing in cultivated soil, the "stay-green" variety Drim and row application of NP fertilizer compared to maize sown directly into stubble, the traditional variety SY Cooky and NP fertilizer broadcast application (Tab. 8). Magnesium accumulation in dry matter of plants also depended on the interaction of the maize sowing method and variety (Fig. 5). The value of the tested trait, regardless of hybrid type, was statistically at the same level for sowing in cultivated soil. On the other hand, a higher value of magnesium accumulation was demonstrated for the "stay-green" Drim hybrid when maize was sown directly into stubble compared to the classic variety SY Cooky. The difference between the tested varieties was 0.04 kg·ha^{-1} (Fig. 5). In the current study, magnesium accumulation with dry matter yield in the 5-6 leaf stage (BBCH 15/16) was also significantly influenced by the interaction of maize sowing method with the method of NP fertilizer application (Fig. 6). Regardless of the method of sowing maize, row fertilization was more effective than broadcast fertilization. Nevertheless, a greater effect of this method of fertilizer application was obtained when maize was sown into cultivated soil compared to sowing maize directly into stubble (Fig. 6).

Table 8. Magnesium accumulation in dry matter in the 5-6 leaf stage (BBCH 15/16)
Tab. 8. Pobranie magnezu z suchą masą roślin kukurydzy w fazie 5-6 liści (BBCH 15/16)

Experimental Factors		Years			Average
		2012	2013	2014	
		kg·ha^{-1}	kg·ha^{-1}	kg·ha^{-1}	kg·ha^{-1}
Maize sowing methods **(A)**	sowing in traditionally cultivated soil	0.12	0.29	0.39	0.27
	direct sowing	0.12	0.11	0.24	0.16
LSD $_{0.05}$		**r.n.**	**0.044**	**0.033**	**0.013**
Varieties **(B)**	SY Cooky	0.13	0.20	0.28	0.20
	Drim „stay-green"	0.11	0.21	0.34	0.22
LSD $_{0.05}$		**0.011**	**r.n.**	**0.045**	**0.016**
NP fertilizer sowing methods **(C)**	broadcasting	0.12	0.16	0.31	0.19
	in rows	0.13	0.25	0.32	0.23
LSD $_{0.05}$		**r.n.**	**0.022**	**r.n.**	**0.013**
Average		0.12	0.21	0.32	0.22

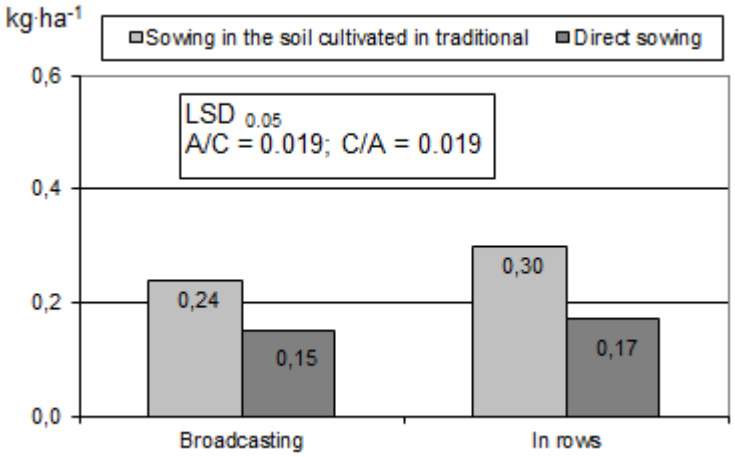
n.s. – non-significant difference

Source: own study / Źródło: opracowanie własne



Source: own study / Źródło: opracowanie własne

Fig. 5. Magnesium accumulation in dry matter yield of plants in the 5-6 leaf stage (BBCH 15/16) depending on the interaction of the sowing method with the variety (2012-2014)
Rys. 5. Pobranie magnezu z suchą masą roślin w fazie 5-6 liści (BBCH 15/16) w zależności od współdziałania sposobu siewu z odmianą (2012-2014)



Source: own study / Źródło: opracowanie własne

Fig. 6. Magnesium accumulation in dry matter yield of plants in the 5-6 leaf stage (BBCH 15/16) depending on the interaction of the sowing method with the method of NP fertilizer application (2012-2014)
Rys. 6. Pobranie magnezu z suchą masą roślin w fazie 5-6 liści (BBCH 15/16) w zależności od współdziałania sposobu ze sposobem wysiewu nawozu NP. (2012-2014)

4. Discussion

The results indicated a significant influence of different weather conditions between the study years on maize dry matter yield in the 5-6 leaf stage. On average, the highest dry matter yield for the study years, regardless of the tested experimental factors, was obtained in 2014 (169.52 kg ha^{-1}), while the lowest in 2012 (76.70 kg ha^{-1}). The year 2012, when 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 one. During this period, 43.9 mm of precipitation was recorded, while the average air temperature was 12.6°C. Soil temperature at a depth of 10 cm was also the lowest and amounted to 11.8°C. The result obtained in the current study confirmed previous literature reports regarding maize thermal requirements [11, 12]. Low soil and air temperature during sowing and initial stages of maize growth is the main reason limiting its yield [13]. The sowing method, type of variety and fertilization method significantly determined the average dry matter yield during the research years. When sowing maize into non-cultivated soil, a significantly lower dry matter yield was obtained in the 5-6 leaf stage compared to maize sown in cultivated soil. The result obtained in this study confirmed previous literature reports [14]. According to the latter authors, tillage method had a significant impact on the dynamics of plant development, especially in no-tillage cultivation. In that study, slight but distinct delays in the development of maize plants were noted with the use of the latter method. They were caused by slower warming of unplowed soil in spring and the observed increase in its bulk density and decrease in porosity. This statement was confirmed by soil temperatures in the spring. Similar results concerning the dynamics of emergence depending on the method of soil preparation for maize sowing were also obtained by other researchers [15, 16]. Significantly higher dry matter yield was recorded for the "stay-green" variety Drim compared

to the variety SY Cooky. This difference was 10.86 kg ha^{-1}. Szulc et al. [17, 18] also showed in the earlier work that the "stay-green" type variety was characterized by a significantly greater vigor of initial growth compared to the traditional hybrid, expressed by dry matter accumulation. In the present study, a significantly higher dry matter yield was obtained in the 5-6 leaf stage as a result of row fertilization compared to the broadcast application. The result obtained here was consistent with the previous report of Szulc et al. [19]. According to the latter authors, row fertilization, compared to the broadcast and row fertilization complemented with top dressing, had a positive effect on the vigor of the initial maize growth, which was manifested by a higher dry matter of 1 plant in the 6-7 leaf stage, a higher dry matter yield per unit area in the 6-7 leaf stage, a higher absolute rate of dry matter increase of 1 plant and a higher absolute increase in dry matter yield (AGR).

5. Conclusions

1. Tillage method significantly shapes the dynamics of plant growth in the initial period of the growing season; direct sowing, resulting in a decrease in plant weight at the BBCH 15/16 stage, has a significant impact on yield formation processes (yield index).
2. It was found that the nutritional status of maize in the stands rich in nutrients could only incidentally (depending on years) show a reaction to variety selection and row application of NP-type fertilizers, improving the values of nitrogen nutrition indices.
3. Physiological indices of the plants' status at the BBCH 15/16 stage demonstrated a significant, albeit variable over the years, response to variety selection and the row application of NP fertilizers; the negative effect of the sowing method was revealed incidentally.
4. In the direct sowing system, the "stay-green" variety with a simultaneous application of phosphorus fertilizer may reduce, but will not eliminate the effects of direct sowing in the BBCH 15/61 stage.

5. References

[1] Potarzycki J.: Improving nitrogen use efficiency of maize by Belter fertilizing practices. Review paper. Nawozy i Nawożenie/Fertilizers and Fertilization, 2010, 39, 5-24.

[2] Potarzycki J.: Effect of magnesium or zinc supplementation at the background of nitrogen rate on nitrogen management by maize canopy cultivated in monoculture. Plant Soil Environ., 2011, 57(1), 19-25.

[3] Fageria N.K., Baligar V.C.: Enhancing nitrogen use efficiency in crop plants. Advances in Agronomy, 2005, 88, 97-185.

[4] Gaj R., Szulc P., Siatkowski I., Waligóra H.: Assessment of the effect of the mineral fertilization system on the nutritional status of maize plants and grain yield prediction. Agriculture, 2020, 10, 404, doi:10.3390/agriculture10090404.

[5] Szulc P., Barłóg P., Ambroży-Deręgowska K., Mejza I., Kobus-Cisowska J.: In-soil application of NP mineral fertilizer as a method of improving nitrogen yielding efficiency. Agronomy, 2020, 10, 1488; doi: 10.3390/ agronomy10101488.

[6] Subedi K.D., Ma B.L.: Nitrogen uptake and partitioning in stay-green and leafy maize hybrids. Crop Science, 2005, 4, 740-747.

[7] Gawęcki K.: Ćwiczenia z żywienia zwierząt i paszoznawstwo. Wyd. AR Poznań, 1994, 1-223.

[8] Szulc P., Bocianowski J.: Quantitative relationships between dry matter production and N, P, K and Mg contents, and plant nutrition indices, depending on maize hybrids (*Zea mays* L.). Fres. Envi. Bulletin, 2012, 21(7), 1740-1751.

[9] Machul M., Jadczyszyn T.: Przydatność wskaźnika względnej zawartości chlorofilu do oceny stanu odżywienia kukurydzy azotem. Pam. Puł., 2005, 140, 173-185.

[10] Douglas R., Dewey D.R., Cu K.H.: A correlation and path coefficient analysis of components of crested wheatgrass seed production. Agronomy Journal, 1958, 15, 515-517.

[11] Aitken T.: Evaluation of maturity genotype – climate interaction in maize (*Zea mays* L.). Pflanzenzüchtung, 1977, 78, 216-237.

[12] Sowiński P.: Wrażliwość kukurydzy na chłód. Cz. I. Wzrost, rozwój, fotosynteza. Biuletyn IHiAR, 2000, 214, 3-16.

[13] Sowiński P., Maleszewski S.: Chilling sensitivity in maize seedlings. I. Growth and functioning of shoots and roots. Acta Physiol. Plant., 1989, 11, 165-171.

[14] Dubas A., Drzymała S., Mocek A., Owczarzak W., Szulc P.: Wpływ uproszczeń w uprawie roli w wieloletniej monokulturze kukurydzy (*Zea mays* L.) na właściwości gleby oraz przebieg wegetacji i plonowanie. Wydawnictwo UP Poznań, 2012, ISBN 978-83-7160-662-5, 1-74.

[15] Drury F.C., Tan C., Walecky T.W., Oloya T.O., Hamil A.S., Weaver S.E.: Red clover ans tillage influence on soil temperature, water content and corn emergence. Agronomy Journal, 1999, 91, 101-108.

[16] Menzel L. Dubas A.: Reakcja kukurydzy uprawianej w monokulturze na uproszczenia w uprawie roli. Pam. Puł., 2003, 133, 123-134.

[17] Szulc P., Skrzypczak W., Waligóra H.: Improvement of the effectiveness of maize (*Zea mays* L.) fertilization with nitrogen by the application of magnesium. Part I. Grain yield and its structure. Acta Scientiarum Polonorum, 2008, 7(4), 125-135.

[18] Szulc P., Bocianowski J., Rybus-Zając M.: Accumulation of N, P, K and Mg nutrient elements and nutrient remobilization indices in the biomass of two contrasting maize (*Zea mays* L.) hybrids. Fres. Envi. Bulletin, 2012, 21(8), 2062-2071.

[19] Szulc P., Waligóra H., Michalski T., Rybus-Zając M., Olejarski P.: Efficiency of nitrogen fertilization based on the fertilizer application method and type of maize cultivar (*Zea mays* L.). Plant Soil Environ., 2016, 62 (3), 135-142.