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INFLUENCE OF FORMULATION OF PHOSPHORUS FERTILIZER ON NITROGEN UPTAKE AND ITS EFFICIENCY UNDER MAIZE GRAIN CROPPING

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Abstract. The aim of the paper was to evaluate the efficiency of nitrogen from ammonium saltpeter as related to the formulation of phosphorus fertilizer under maize grain cropping. Maize was grown in monoculture throughout the consecutive years 2003--2007. A two factorial field experiment was established at a farm located in Nowa Wieś Królewska (52°26' N; 17°57' E) on a slightly acidic soil, moderately rich in phosphorus. Experimental factors were as follows: (i) chemical formulation of the fertilizer, (partially acidulated phosphate rock – PAPR, simple superphosphate – SSP and triple superphosphate – TSP), (ii) nitrogen rate: 80 and 140 kg $N \cdot ha^{-1}$; a phosphorus unfertilized treatment was also considered. The type of phosphorus fertilizer did not differentiate nitrogen uptake, but the lack of phosphorus at the applied rate has induced a decrease in nitrogen accumulation in the aboveground biomass, on average by 8%. Phosphorus fertilization at the rate 26.4 kg $P \cdot ha^{-1}$ was the main determinant of nitrogen uptake by the kernels. Nitrogen recovery (R) from the fertilizers as well as its agronomical (AE) and physiological (PE) efficiency were significantly lower in treatments where phosphorus was not applied. Furthermore, it was found a positive effect of sulphur from simple superphosphate on the AE after the application of 80 kg $N \cdot ha^{-1}$. The R values did not depend on the chemical formulation of phosphorus in the fertilizer and amounted on average to 74 and 59% for the rates 80 and 140 kg $N \cdot ha^{-1}$, respectively, whereas for the treatment without P, these values varied within the range 46-54%.

Key words: efficiency of nitrogen, maize, partially acidulated phosphate rock, superphosphate

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INTRODUCTION

The structure of mineral fertilizer application in Poland, based mostly on nitrogen fertilization, is a cause of the insufficient utilization of yield-forming potential of modern maize cultivars [Grzebisz 2008b].

Maize is a species which is particularly sensitive to phosphorus deficiencies, and soil abundance in this component is considered as the main factor determining the size of maize production [Grzebisz et al. 2003, Ibrikci et al. 2005]. Due to biochemical functions of phosphours in the plant, the most important of which is the activation of enzymes participating in generating and transformation of energy as well as the synthesis of carbohydrates, proteins and fats, this component controls nitrogen metabolism [Reetz 1986, Grzebisz 2008a].

The issue of the yield-forming role of nitrogen and phosphorus in maize cultivation has already been taken up in many studies conducted both under conditions of moderate climate [Kruczek 2000, Kruczek and Szulc 2005] and in tropics [Kogbe and Adediran 2003, Ibrahim and Hala 2007]. However, the combined effect of nitrogen and phosphorus fertilization on nitrogen management in maize is poorly identified. In this context, the hypothesis about the effect of the chemical formulations of phosphorus fertilizers on the state of maize nutrition with nitrogen requires verification. The chemical form of phosphorus in the fertilizer determines the rate of action of this component which, in turn, can affect the dynamics of nitrogen uptake by plants [Marschner 1995].

The aim of this study was to evaluate the effect of phosphorus fertilizer formulation on the uptake and effectiveness of nitrogen in maize grain cropping.

MATERIAL AND METHODS

The study was carried out over the years 2003-2007 on a farm located in Nowa Wieś Królewska (52°26’ N; 17°57’ E). The experiment was established on a typical brown soil formed from boulder clay, of quality class IIIb, with slightly acid reaction, characterized by moderate abundance in available phosphorus, potassium and magnesium and the carbon content in organic compounds amounting to 19.0 $g \cdot kg^{-1}$ soil. Detailed data concerning the chemical properties of soil applied in the experiment was presented in Table 1. Moisture conditions during the plant growth are contained in Table 2.

Table 1. Agrochemical properties of topsoil (depth 0-30 cm)
Tabela 1. Właściwości agrochemiczne warstwy ornej (warstwa 0-30 cm)

Specification – Wyszczególnienie	Values – Wartości
Soil reaction – Odczyn, 1M KCl	5.80
Organic carbon*** – C organiczny, $g \cdot kg^{-1}$ gl.	19.00
Available phosphorus* – Fosfor przyswajalny, mg $P \cdot kg^{-1}$	57.20
Available potassium* – Potas przyswajalny, mg $K \cdot kg^{-1}$	116.20
Available magnesium** – Magnez przyswajalny, mg $Mg \cdot kg^{-1}$	50.00
Available zinc**** – Cynk przyswajalny, $mg \cdot kg^{-1}$	6.00

* Egner-Riehm‘s method – metoda Egnera-Riehma
** Schachtschabel‘s method – metoda Schachtschabela
*** Tiurin’s method – metoda Tiurina
**** extract in 1 M HCl – ektrahowany 1 M HCl

Table 2. Rainfalls for years 2003-2007
Tabela 2. Opady w latach 2003-2007

Year Rok	Total rainfall in growth season Suma opadów w sezonie wegetacyjnym, mm (the long-term mean – wielolecie = 333)	Deviation from the long-term mean Odchylenie w stosunku do wielolecia, %	Deviation from the long-term mean Odchylenie w stosunku do wielolecia, %		
			June czerwiec	July lipiec	August sierpień
2003	199	-40	-58	+8	-75
2004	273	-18	-24	-53	+15
2005	311	-7	-55	-1	-2
2006	422	+27	-33	-80	+227
2007	444	+33	+45	+96	+21

Maize hybrid Eurostar was cultivated in monoculture, with balanced phosphorus and potassium rates at levels of 26.4 kg $P \cdot ha^{-1}$ and 99.6 kg $K \cdot ha^{-1}$, respectively. The two-factorial experiment was conducted in the four block design. The following factors were investigated:

– chemical formulation of phosphorus in the fertilizer:
  PAPR (Lubofos PK containing partially acidulated phosphate rock; 14% P_2O_5 and 24% K_2O + KCl),
  SSP (simple granulated superphosphate; 20% P_2O_5 and 12% S + KCl),
  TSP (triple superphosphate; 46% P_2O_5 + KCl),
  control without P;
– nitrogen rate: 80 and 140 kg $N \cdot ha^{-1}$.

All the fertilizers were applied about 2 weeks before maize sowing, which was carried out on 24-26 April, depending on the research year. Nitrogen was introduced into soil in the form of ammonium saltpetre. Irrespective of the fertilization variant, all the rate of the fertilizer was applied preplant. A treatment unfertilized with nitrogen and phosphorus, referred to as the absolute control in the study, was also evaluated. Nitrogen in the plant material was determined with the Kjeldahl distillation method. Chlorophyll index (SPAD) at the stage of maize flowering was determined with the N-tester by Hydro. Nitrogen yield index characterizing the proportion of nitrogen taken up by the grains in the total uptake of this component by maize was also evaluated. Plant harvesting was carried out from an area of 24 m^2.

The following parameters of the efficiency of nitrogen fertilization were analysed in the study:

– agronomical efficiency: $AE = (Pn-Pk)/D$ [$kg \cdot kg^{-1}$],
– physiological efficiency: $PE = (Pn-Pk)/(Nn-Nk)$ [$kg \cdot kg^{-1}$],
– nitrogen recovery: $R = (Nn-Nk)/D$ [%],

where:
Pn – yield of fertilized plants, kg,
Pk – yield of control plants (unfertilized), kg,
Nn – nitrogen uptake with yield of fertilized plants, kg,
Nk – nitrogen uptake with yield of control plants (unfertilized), kg,
D – nitrogen rate, kg.

The results were subjected to the analysis of variance, and the differences were evaluated with Tukey's test.

RESULTS AND DISCUSSION

In the present research, the role of phosphorus in affecting nitrogen management in maize was compared both with the application of this component at a rate of 26.4 kg P·ha^{-1} and with the type of the phosphorus fertilizer.

Phosphorus affects the plant metabolism throughout the growing season, whereas the special importance of that component becomes apparent in the beginning of growth and at the stage after flowering when grains are formed [Marschner 1995]. Phosphorus fertilization, affecting the development of the root system at the initial developmental stages of the plant, determines a potential possibility of water and mineral component uptake, including nitrogen [Grzebisz et al. 2003]. Therefore, it can be stated that releasing this component from fertilizers in the period before flowering may constitute one of the factors determining maize nutrition with nitrogen, which in turn affects the photosynthetic activity of leaves that determines yield-forming results obtained [Montemurro et al. 2006]. When characterizing nitrogen management in maize on the basis of nitrogen content in the leaf below the cob and the chlorophyll index (SPAD) at the flowering stage, it has been found that the level of fertilization with ammonium saltpetre was the main determinant of the state of plant nutrition with nitrogen (Tables 3 and 4). This means that in the period before flowering, the plant supply in phosphorus did not limit nitrogen accumulation in the plants. A positive effect of sulphur from simple superphosphate was observed for both tested factors, which may be explained by the role of this component in controlling the synthesis of chlorophyll and current assimilation of carbon dioxide [Scherer 2001]. However, the importance of sulphur became apparent only in treatments with a lower rate of ammonium saltpetre (80 kg N·ha^{-1}), and this confirms the effect of secondary components on nitrogen metabolism, under conditions of the moderate use of nitrogen fertilizers. Increasing the value of the chlorophyll index (SPAD) in plants of spring barley caused by fertilization with simple superphosphate was observed in an earlier study by Potarzycki [2003].

Table 3. Nitrogen content of the leaf below the cob at the flowering stage, % N, D.M.
Tabela 3. Zawartość azotu w liściu podkolbowym w fazie kwitnienia, % N w s.m.

Nitrogen fertilization Nawożenie azotem (A)	Type of phosphorus fertilizer – Rodzaj nawozu fosforowego (B)				Mean Średnia
	PAPR	SSP	TSP	without P – bez P	
80 kg N·ha^{-1}	2.47	2.71	2.64	2.59	2.60
140 kg N·ha^{-1}	2.77	2.84	2.77	2.86	2.81
Średnia – Mean	2.62	2.78	2.71	2.73	–
NIR – LSD (A)	0.11**				
NIR – LSD (B)	ns – ni				
Control – Kontrola absolutna	2.10				

** $\alpha < 0.01$ – $\alpha < 0,01$
ns – ni – non-significant difference – różnica nieistotna

Table 4. Chlorophyll index (SPAD) of the leaf below the cob at flowering stage
Tabela 4. Indeks chlorofilowy (SPAD) w liściu podkolbowym w fazie kwitnienia

Nitrogen fertilization Nawożenie azotem (A)	Type of phosphorus fertilizer – Rodzaj nawozu fosforowego (B)				Mean Średnia
	PAPR	SSP	TSP	without P – bez P	
80 kg N·ha^{-1}	689	717	714	708	707
140 kg N·ha^{-1}	774	763	751	734	756
Średnia – Mean	732	740	733	721	–
NIR – LSD (A)	21**				
NIR – LSD (B)	ns – ni				
Control – Kontrola absolutna	627				

** $\alpha < 0.01$ – $\alpha < 0,01$
ns – ni – non-significant difference – różnica nieistotna

The second critical stage in which maize shows a particularly high phosphorus requirement falls in the period after flowering (grain filling). From the research conducted it follows that at the full maturity stage the effect of phosphorus fertilization on nitrogen content in maize organs was shown only in relation to cob cover leaves, and significantly less nitrogen was noted in the treatment with simple superphosphate, whereas the most in the control unfertilized with phosphorus (Table 5). Nitrogen content in leaves and stalks, in turn, depended on the second experimental factor, that is on a rate of ammonium saltpetre, and was significantly higher after increasing the nitrogen rate from 80 to 140 kg N·ha^{-1}. Nitrogen accumulation in grains was at a relatively constant level. From a study by Eltelib et al. [2006] it follows that unlike nitrogen, growing phosphorus rates did not differentiate protein content in fodder maize.

The total nitrogen uptake by maize was affected by both tested experimental factors, that is nitrogen and phosphorus fertilization (Table 6). Plants fertilized with a higher rate of ammonium saltpetre accumulated on average by 10% more nitrogen. While the chemical formulation of phosphorus did not differentiate the total nitrogen uptake, the lack of phosphorus in the fertilizer rate resulted in a decrease in nitrogen accumulation in the above biomass on average by 8% (irrespective of the rate of ammonium saltpetre). Of the analysed maize organs, phosphorus fertilization at a rate of 26.4 kg P·ha^{-1} determined nitrogen uptake only by grains. However, values of the nitrogen yield index, characterizing the accumulation of this component in grains in relation to the total uptake, in both controls (without P and absolute) did not differ significantly from the other treatments (Table 7). Indirectly it indicates that in conditions of a lower phosphorus availability the plants transferred nitrogen from vegetative organs more intensively. Lower values of the indexes in treatments with a higher nitrogen rate (140 kg N·ha^{-1}) confirm the above thesis. Tsai et al. [1991] report that besides nitrogen availability, also varietal differences determine nitrogen uptake and redistribution in maize. Furthermore, a positive role of sulphur contained in simple superphosphate in affecting nitrogen yield index should be noted. Consequently, after the application of a phosphorus-sulphure fertilizer, as which simple superphosphate should be categorized [Potarzycki and Gaj 2000], the plants accumulated more nitrogen in grain, which can be directly related to protein content, i.e. yield quality. Thus, the results obtained confirm the importance of sulphur as a component responsible for protein accumulation in reserve organs [Scherer 2001].

Table 5. Nitrogen content in maize organs at full maturity stage, % N, D.M.
Tabela 5. Zawartość azotu w organach kukurydzy w fazie dojrzałości pełnej, % N w s.m.

Nitrogen fertilization Nawożenie azotem (A)	Type of phosphorus fertilizer – Rodzaj nawozu fosforowego (B)				Mean Średnia
	PAPR	SSP	TSP	without P – bez P	
Stems – Łodygi					
80 kg N·ha^{-1}	0.51	0.48	0.48	0.49	0.49
140 kg N·ha^{-1}	0.56	0.52	0.55	0.53	0.54
Mean – Średnia	0.53	0.50	0.52	0.51	–
LSD – NIR (A)	0.04*				
LSD – NIR (B)	ns – ni				
Control – Kontrola absolutna	0.57				
Leaves – Liście					
80 kg N·ha^{-1}	0.98	0.85	1.01	0.99	0.96
140 kg N·ha^{-1}	1.09	1.07	1.09	1.10	1.09
Mean – Średnia	1.03	0.96	1.05	1.05	–
LSD – NIR (A)	0.08**				
LSD – NIR (B)	ns – ni				
Control – Kontrola absolutna	0.90				
Grain – Ziarno					
80 kg N·ha^{-1}	1.73	1.77	1.76	1.77	1.76
140 kg N·ha^{-1}	1.74	1.74	1.72	1.80	1.75
Mean – Średnia	1.73	1.76	1.74	1.78	–
LSD – NIR (A)	ns – ni				
LSD – NIR (B)	ns – ni				
Control – Kontrola absolutna	1.61				
Cob cover leaves – Liście okrywowe kolby					
80 kg N·ha^{-1}	0.55	0.45	0.58	0.61	0.55
140 kg N·ha^{-1}	0.67	0.50	0.54	0.65	0.59
Mean – Średnia	0.61	0.48	0.56	0.63	–
LSD – NIR (A)	ns – ni				
LSD – NIR (B)	0.10*				
Control – Kontrola absolutna	0.57				

* $\alpha < 0.05$ – $\alpha < 0,05$
** $\alpha < 0.01$ – $\alpha < 0,01$
ns – ni – non-significant difference – różnica nieistotna

Table 6. Nitrogen uptake by maize at full maturity stage, kg N·ha^{-1}
Tabela 6. Pobranie azotu przez kukurydzę w fazie dojrzałości pełnej, kg N·ha^{-1}

Nitrogen fertilization Nawożenie azotem (A)	Type of phosphorus fertilizer – Rodzaj nawozu fosforowego (B)				Mean Średnia
	PAPR	SSP	TSP	without P – bez P	
Stems – Łodygi					
80 kg N·ha^{-1}	25.2	22.9	23.6	22.9	23.7
140 kg N·ha^{-1}	30.5	27.9	29.2	26.2	28.5
Mean – Średnia	27.9	25.4	26.4	24.6	–
LSD – NIR (A)	2.5**				
LSD – NIR (B)	ns – ni				
Control – Kontrola absolutna	22.2				
Leaves – Liście					
80 kg N·ha^{-1}	30.3	23.2	26.4	25.0	26.2
140 kg N·ha^{-1}	33.8	30.9	30.7	29.4	31.2
Mean – Średnia	32.1	27.1	28.6	27.2	–
LSD – NIR (A)	3.6**				
LSD – NIR (B)	ns – ni				
Control – Kontrola absolutna	18.6				
Grain – Ziarno					
80 kg N·ha^{-1}	164.3	174.2	168.1	155.5	165.5
140 kg N·ha^{-1}	181.2	182.7	179.2	167.6	177.7
Mean – Średnia	172.8	178.5	173.7	161.6	–
LSD – NIR (A)	6.2**				
LSD – NIR (B)	8.7**				
Control – Kontrola absolutna	120.5				
Cob cover leaves – Liście okrywowe kolby					
80 kg N·ha^{-1}	4.9	3.8	4.5	4.6	4.5
140 kg N·ha^{-1}	6.7	4.7	5.0	5.7	5.5
Mean – Średnia	5.8	4.2	4.7	5.2	–
LSD – NIR (A)	0.8*				
LSD – NIR (B)	ns – ni				
Control – Kontrola absolutna	2.6				
Total – Razem					
80 kg N·ha^{-1}	224.8	224.2	222.8	208	220
140 kg N·ha^{-1}	252.2	246.2	244.2	229	243
Mean – Średnia	238.5	235.2	233.5	218.5	–
LSD – NIR (A)	6.1**				
LSD – NIR (B)	8.6**				
Control – Kontrola absolutna	163.9				

* $\alpha < 0.05$ – $\alpha < 0,05$
** $\alpha < 0.01$ – $\alpha < 0,01$
ns – ni – non-significant difference – różnica nieistotna

Table 7. Nitrogen yield index, %
Tabela 7. Indeks plonu azotu, %

Nitrogen fertilization Nawożenie azotem (A)	Type of phosphorus fertilizer – Rodzaj nawozu fosforowego (B)				Mean Średnia
	PAPR	SSP	TSP	without P – bez P	
80 kg N·ha^{-1}	73	77	75	74	75
140 kg N·ha^{-1}	71	74	73	73	73
Mean – Średnia	72	76	74	74	–
LSD – NIR (A)	2.0**				
LSD – NIR (B)	2.0*				
Control – Kontrola absolutna	73				

* α < 0.05 – α < 0,05
** α < 0.01 – α < 0,01

Values of the index of nitrogen recovery (R) from fertilizers by maize as well as agronomical efficiency (AE) and physiological efficiency (PE) were significantly less after the application of a higher rate of ammonium saltpetre (Table 8), which corresponds with the results of studies carried out by Ma et al. [1999], Kruczek [2000] and Kogbe and Adediran [2003]. According to Halvorson et al. [2005], nitrogen recovery from fertilizers by maize was inversely proportional to nitrogen availability in soil, varying within the range 30-55% depending on the nitrogen rate. From the data in Table 8, it appears that phosphorus fertilization differentiated all the analysed efficiency indexes, but to the least extent physiological efficiency. Furthermore, a positive effect of sulphur from simple superphosphate on the agronomical efficiency of nitrogen was observed. In a long-term study conducted by Benbi and Biswas [1996] a considerably higher nitrogen recovery from fertilizers by maize was indicated as a result of the presence of potassium and phosphorus in the fertilizer rate. In the present study, in treatments fertilized with phosphorus nitrogen recovery from ammonium saltpetre amounted on average to 74 and 59% for rates 80 and 140 kg N·ha^{-1}, respectively, while in the control (without P) it varied within the range 46-54%. Bearing in mind that at the flowering stage phosphorus did not differentiate nitrogen content in the cob leaf (Table 3), the limiting effect of the lack of phosphorus fertilization on nitrogen uptake in the final period of maize growth and hence, a lower nitrogen recovery from the fertilizer should be pointed out (Table 8). The above statement is significant, due to the fact that nitrogen accumulation in grains lasts until the end of maize growth. Ma et al. [1999] report that nitrogen uptake by plants after flowering may vary within the wide range accounting for 25-50% of all the component pool. From the study by Montemurro et al. [2006] it follows that maize at the grain filling stage took up as much as 59% nitrogen from soil, whereas the accumulation of this component by the plants after flowering was positively correlated with the yield size. The authors report, however, that protein content in grains was determined by the amount of nitrogen taken up at the vegetative stage of maize growth. The studies cited correspond with the present results, according to which the analysed experimental factors did not differentiate nitrogen content in grains (Table 5), but they affected maize grain yield [Potarzycki 2008]. Thus a significant role of phosphorus in affecting the efficiency of nitrogen fertilizers in the final period of maize growth was confirmed, in spite of the lack of plant response to fertilization with this component, related to nutrition with nitrogen at the flowering stage.

Table 8. Indices of nitrogen fertilization efficiency
Tabela 8. Wskaźniki efektywności nawożenia azotem

Nitrogen fertilization Nawożenie azotem (A)	Type of phosphorus fertilizer – Rodzaj nawozu fosforowego (B)				Mean Średnia
	PAPR	SSP	TSP	without P – bez P	
Agronomical efficiency (AE) – Efektywność agronomiczna (EA), $kg \cdot kg^{-1}$					
80 kg $N \cdot ha^{-1}$	25.4	29.2	25.9	16.7	24.3
140 kg $N \cdot ha^{-1}$	20.6	21.5	21.1	13.6	19.2
Mean – Średnia	23.0	25.4	23.5	15.2	–
LSD – NIR (A)	1.8**				
LSD – NIR (B)	2.6**				
Physiological efficiency (PE) – Efektywność fizjologiczna (EF), $kg \cdot kg^{-1}$					
80 kg $N \cdot ha^{-1}$	34.4	41.6	39.0	36.7	37.9
140 kg $N \cdot ha^{-1}$	34.0	38.8	38.2	30.9	35.5
Mean – Średnia	34.2	40.2	38.6	33.8	–
LSD – NIR (A)	ns – ni				
LSD – NIR (B)	4.3*				
Nitrogen recovery (R) – Wykorzystanie azotu (W), %					
80 kg $N \cdot ha^{-1}$	74	74	72	54	68
140 kg $N \cdot ha^{-1}$	62	58	56	46	55
Mean – Średnia	68	66	64	50	–
LSD – NIR (A)	7**				
LSD – NIR (B)	9**				

* $\alpha < 0.05$ – $\alpha < 0{,}05$
** $\alpha < 0.01$ – $\alpha < 0{,}01$
ns – ni – non-significant difference – różnica nieistotna

CONCLUSIONS

1. State of maize nutrition with nitrogen at the flowering stage, expressed by the nitrogen content in the leaf below the cob and the chlorophyll index (SPAD), were determined by the level of nitrogen fertilization and did not depend on phosphorus fertilization type
2. At the full maturity stage the total nitrogen uptake by maize was not differentiated by the chemical formulation of the phosphorus fertilizer, but the lack of this component in the fertilizer rate resulted in a decrease in nitrogen accumulation in the aboveground biomass on average by 8%.
3. Phosphorus fertilization at a rate of 26.4 kg $P \cdot ha^{-1}$ affected only nitrogen uptake by grains.
4. Application of all the tested phosphorus fertilizers (simple and triple superphosphates and partially acidulated phosphate rock) significantly increased the agronomical efficiency and nitrogen recovery from ammonium saltpetre.
5. Importance of the chemical formulation of the phosphorus fertilizer in affecting nitrogen management in maize resulted from the presence of sulphur in simple superphosphate and was expressed by an increase in agronomical efficiency and the nitrogen yield index.

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WPŁYW FORMY NAWOZU FOSFOROWEGO NA POBRANIE I EFEKTYWNOŚĆ AZOTU W UPRAWIE KUKURYDZY NA ZIARNO

Streszczenie. Celem pracy była ocena efektywności azotu z saletry amonowej w zależności od formy nawozu fosforowego w uprawie kukurydzy przeznaczonej na ziarno. Kukurydzę uprawiano w latach 2003-2007 w monokulturze. Dwuczynnikowe doświadczenie założono w gospodarstwie zlokalizowanym w Nowej Wsi Królewskiej (52°26' N; 17°57' E), na glebie lekko kwaśnej, średnio zasobnej w przyswajalny fosfor. Czynniki doświadczalne: (i) formulacja chemiczna nawozu (częściowo rozłożony fosforyt – PAPR, superfosfat prosty – SSP oraz superfosfat potrójny – TSP), (ii) dawka azotu (80 i 140 kg $N \cdot ha^{-1}$); analizowano także wariant bez nawożenia fosforem. Forma nawozu fosforowego nie różnicowała pobrania azotu, natomiast brak fosforu w dawce nawozowej prowadził do zmniejszenia akumulacji azotu w biomasie nadziemnej średnio o 8%. Nawożenie fosforem w dawce 26,4 kg $P \cdot ha^{-1}$ determinowało pobranie azotu przez ziarniaki. Wykorzystanie azotu z nawozów (W) oraz efektywność agronomiczna (EA) i fizjologiczna (EF) tego składnika były istotnie mniejsze w warunkach braku nawożenia fosforem. Potwierdzono dodatnie działanie siarki z superfosfatu prostego na EA po zastosowaniu 80 kg $N \cdot ha^{-1}$. Wartości W nie zależały od formulacji chemicznej fosforu w nawozie i wynosiły średnio 74 i 59% odpowiednio dla dawek 80 i 140 kg $N \cdot ha^{-1}$, a na kontroli (bez P) wahały się w granicach 46-54%.

Słowa kluczowe: częściowo rozłożony fosforyt, efektywność azotu, kukurydza, superfosfat

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