Original Research

Phosphorus Utilization from Fertilizer and Accumulation of Mineral Components in the Initial Stage of Maize Development

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Abstract

On the basis of a 4-year study, the effect of maize fertilization method on the content of mineral components and the utilization of phosphorus from fertilizer were evaluated. Two methods of fertilization were used: by broadcasting and by fertilization in rows. The effect on the content of mineral components was studied by increasing the fertilization doses from 17.4 kg P ha^{-1} to 56.7 kg P ha^{-1} and by the application of superphosphate and ammonium phosphate. It was found that fertilization in rows combined with seed sowing increases the content of phosphorus and nitrogen and raises the percentage of phosphorus utilization from fertilizer in comparison with the fertilization by broadcasting in the initial stage of development. Ammonium phosphate exerted a better influence on the uptake of phosphorus and nitrogen by plants and on the percentage of phosphorus uptake in comparison with superphosphate.

Keywords: fertilization in rows, broadcast fertilization, utilization of phosphorus from fertilizer, content of mineral components

Introduction

One of the negative results of traditional agriculture causing the degradation of the natural environment is the permeation of bioelements introduced into the soil with mineral fertilization beyond the agrosystem. Next to the violance of soil microbiological balance, this phenomenon contributes to the eutrophication of ground waters and surface waters [1, 3, 14, 17, 18, 19]. The modern system of agriculture, called "integrated agriculture," according to Kuś and Fotyma [10], aims at the assurance of a stable efficiency in a safe way for the natural environment.

Fertilization is one of the important elements of plant growing technology which has to be considered when integrated agriculture is being introduced. This agrotechnical factor requires particular attention in the case of plants, which need intensive fertilization. Maize belongs to such plants. Doses of mineral fertilizers must be determined for definite crops by taking into consideration the actual nutritive components available in the soil without any excessive "fertilization for the future." It is also important to use such fertilization methods which not only exert a beneficial effect on plant nutrition but also increase the utilization of fertilizer by plants. Such a fertilization method is the localized fertilization permitting to place the fertilizer in the root zone of young plants. As reported by Peterson et al. [15], it permits us to limit the size of phosphorus dose, because the fertilizer is better utilized in the year of application, and to decrease phosphorus retardation rate, particularly in soil with a low content of this element. In this connection, studies were undertaken which refer to the effect of the fertilization method with phosphates and phosphorus-and-nitrogen fertilizers on uptake of mineral components by maize and

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the degree of phosphorus utilization from fertilizer depending on fertilizer type and its dosage.

Materials and Methods

Studies were carried out in the Experimental and Didactic Farm in Swadzim near Poznań in the years 2000-2003. Field experiments were established as 3-factor ones in a random split-plot design in 4 replications. The 1st-order factor included four phosphorus doses: 17.4 kg P ha^{-1} (40 kg P_2O_5 ha^{-1}), 30.5 kg P ha^{-1} (70 kg P_2O_5 ha^{-1}), 43.6 kg P ha^{-1} (100 kg P_2O_5 ha^{-1}), 56.7 kg P ha^{-1} (130 kg P_2O_5 ha^{-1}); 2nd-order factor included two types of fertilizer: superphosphate (46% P_2O_5) and ammonium phosphate (18% N and 46% P_2O_5); 3rd-order factor included two methods of fertilization: by broadcasting on the whole surface before seed sowing and by fertilization in rows together with seed sowing. Additionally, a control plot was established fertilized with 120 kg N ha^{-1} (ammonium nitrate 34% N), 0 kg P ha^{-1} and 107.9 kg K ha^{-1} (130 kg K_2O ha^{-1} — 60% potash salt).

Maize was sown using a point sowing machine equipped with a fertilizer distributor for applying in rows. Fertilizer coulters in relation to seed coulters were arranged in such a way that the fertilizer was placed in the soil 5 cm beside and 5 cm below the seeds. Phosphorus fertilization was done according to the scheme of the experiment as foreseen for factors of 1st-order and 2nd-order, while N and K fertilization was done before maize sowing in the doses of 120 kg N ha^{-1} (ammonium nitrate 34%) and 107.9 kg K ha^{-1} (130 kg K_2O ha^{-1} — 60% potash salt). On the plots where ammonium phosphate was used, the nitrogen dose (before sowing) was decreased by the amount of nitrogen contained in this fertilizer. Hybrid Mona (FAO 250) was the experimental plant.

In the developmental phases of 2-3 leaves, 4-5 leaves, 6-7 leaves and 8-9 leaves, from each plot, 15 plants were sampled. Analyses of the content of mineral components were carried out on combined samples from fertilizer combinations in the Chemical and Agricultural Station in Poznań. For the determination of phosphorus amounts utilized from the fertilizer, the method of differences was applied by comparing the phosphorus amount taken up by plants in the fertilized plots with the amount of phosphorus in the plants from the not fertilized control plot.

Temperature conditions in the years of studies were favourable for the growth and development of maize (Table 1). In all experimental years, in comparison with the mean value of many years, water deficiencies in the soil have occurred. Periods of drought occurred in April and June of 2000, in May of 2001 and from May to June of 2003.

Experiments were carried out on grey-brown podzolic soils, medium sands, lying shallowly on sandy loam belonging to a good rye complex. The abundance in soil of nutrition elements and soil acidity are shown in Table 1.

The results of experiments were statistically evaluated using univariate analysis of variance and hypotheses were tested at the level of α= 0.05.

Results and Discussion

In the phase of 2-3 leaves, the size of phosphorus dose, the type of fertilizer and the method of fertilization did not affect significantly the content of phosphorus, nitrogen, potassium, magnesium, calcium and sodium in the dry mass of overground parts of maize (Table 2). The effect of the studied factors on the content of some mineral components appeared in the phase of 4-5 leaves.

An increase of phosphorus fertilization level from 17.4 to 56.7 kg P ha^{-1} gradually increased the phosphorus content in plants in the phase of 4-5 leaves and 6-7 leaves (Table 2). In the phase of 8-9 leaves, P content increased only in the range of doses from 17.4 to 43.6 kg P ha^{-1}. However, it must be noted that the dry mass of the sample with the highest phosphorus dose of 56.7 kg P ha^{-1} was significantly higher than the dry mass of the sample with the dose of 43.6 kg P ha^{-1}. This result agrees with the results of El-Hamdi and Woodard [7] and Lu and Miller [11], where the increase of phosphorus dose increased the percentage of this component content. On the other hand, Fotyma and Naglik [8], in their evaluation of the fertilization value of phosphorus and potassium reserves in the soil, found only a slight and not proven effect of phosphorus fertilization on the content of this element in the vegetative plant parts, among others in

Table 1. Weather and soil conditions in Swadzim.

Years	Temperature				Rainfall				Soil conditions					
	April	May	June	mean	April	May	June	total	N-NH_4	N-NO_3	P	K	Mg	pH in KCl
	°C				mm				mg $100g^{-1}$ dry mass of soil					
2000	12.1	15.7	17.5	15.1	15.7	47.4	29.9	93.0	0.15	0.46	7.7	16.0	4.6	6.10
2001	8.3	15.2	15.3	12.9	33.1	10.4	67.8	111.3	0.12	0.32	12.9	13.5	3.6	6.80
2002	8.9	16.8	18.1	14.6	34.2	45.7	38.1	118.0	0.10	0.30	10.8	12.3	4.8	6.97
2003	8.6	15.7	19.2	14.5	16.2	24.0	40.4	80.6	0.09	0.50	6.4	5.2	5.6	6.40
1958-2003	7.8	13.3	16.5	12.5	33.2	51.4	58.7	143.3	-	-	-	-	-	-

maize. Pot experiments of Uziak and Szymańska [20] showed that increased content of phosphorus in the environment caused an increase of the proportional content of this component. According to those authoresses, a higher content of phosphorus in the biomass did not exert any influence on the proportional content of nitrogen, potassium, cal-

Table 2. Content of nutrients in the overground part of plants (2000-2003).

Development stages	Research factors	Content of nutrients						Total dry mass of samples
		P	N	K	Mg	Na	Ca	
		g kg^{-1} dry mass						g
2-3 leaves	17.4 kg P ha^{-1}	5.31	43.10	29.69	2.70	0.199	5.79	1.35
	30.5 kg P ha^{-1}	5.41	43.39	30.20	2.66	0.189	5.50	1.32
	43.6 kg P ha^{-1}	5.62	44.02	28.57	2.81	0.176	5.78	1.32
	56.7 kg P ha^{-1}	5.49	43.40	31.23	2.61	0.175	5.81	1.24
	$LSD_{0.05}$	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
	superphosphate	5.51	43.08	29.71	2.69	0.186	5.74	1.31
	ammonium phosphate	5.41	43.87	30.14	2.69	0.183	5.70	1.31
	$LSD_{0.05}$	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
	broadcast	5.43	43.26	29.82	2.65	0.188	5.67	1.32
	in rows	5.49	43.70	30.03	2.74	0.181	5.77	1.30
	$LSD_{0.05}$	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
4-5 leaves	17.4 kg P ha^{-1}	3.59	38.76	32.60	2.21	0.176	6.37	4.91
	30.5 kg P ha^{-1}	3.95	40.30	32.74	2.16	0.194	6.21	4.80
	43.6 kg P ha^{-1}	4.39	41.84	30.84	2.19	0.201	6.16	4.91
	56.7 kg P ha^{-1}	4.61	41.13	31.96	2.13	0.187	6.04	5.24
	$LSD_{0.05}$	0.377	1.874	n.s.	n.s.	n.s.	0.176	n.s.
	superphosphate	4.01	39.04	32.68	2.20	0.195	6.33	4.77
	ammonium phosphate	4.25	41.97	31.39	2.15	0.184	6.06	5.16
	$LSD_{0.05}$	0.168	0.972	0.892	n.s.	n.s.	0.243	0.198
	broadcast	3.49	39.19	31.98	2.19	0.194	6.33	4.71
	in rows	4.78	41.83	32.09	2.16	0.185	6.05	5.22
	$LSD_{0.05}$	0.289	0.982	n.s.	n.s.	n.s.	0.159	0.154
6-7 leaves	17.4 kg P ha^{-1}	3.49	35.51	34.21	1.86	0.248	5.17	21.53
	30.5 kg P ha^{-1}	3.82	35.89	32.93	1.98	0.224	5.15	21.04
	43.6 kg P ha^{-1}	3.99	36.59	31.84	1.95	0.229	5.05	22.30
	56.7 kg P ha^{-1}	4.20	36.82	34.14	1.88	0.259	5.06	22.03
	$LSD_{0.05}$	0.235	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
	superphosphate	3.57	34.59	34.48	1.91	0.252	5.26	19.58
	ammonium phosphate	4.18	37.82	32.08	1.93	0.228	4.95	23.86
	$LSD_{0.05}$	0.173	1.213	1.236	n.s.	n.s.	0.208	1.148
	broadcast	2.97	34.20	34.16	1.87	0.239	5.20	17.97
	in rows	4.77	38.21	32.40	1.97	0.241	5.01	25.48
	$LSD_{0.05}$	0.319	1.271	1.034	n.s.	n.s.	0.179	1.158
8-9 leaves *	17.4 kg P ha^{-1}	3.59	35.94	32.82	1.78	0.140	4.69	54.87
	30.5 kg P ha^{-1}	3.91	36.20	32.42	2.20	0.172	4.73	60.68
	43.6 kg P ha^{-1}	4.15	36.31	31.12	2.12	0.165	4.68	57.98
	56.7 kg P ha^{-1}	4.07	36.84	35.78	2.14	0.166	4.98	68.81
	$LSD_{0.05}$	0.214	n.s.	1.968	n.s.	n.s.	n.s.	8.284
	superphosphate	3.63	35.92	34.35	1.99	0.161	4.90	53.54
	ammonium phosphate	4.23	36.72	31.73	2.13	0.160	4.64	67.63
	$LSD_{0.05}$	0.172	0.547	1.847	0.069	n.s.	0.109	3.570
	broadcast	3.42	35.30	35.08	1.97	0.163	4.81	46.44
	in rows	4.45	37.34	31.00	2.15	0.158	4.72	74.73
	$LSD_{0.05}$	0.120	0.803	1.679	0.053	n.s.	0.076	3.222

n. s. — non significant differences. * — mean only for 2002-2003 cium and magnesium. In my own studies, the levels of phosphorus fertilization had an effect on the content of nitrogen and calcium but only in the phase of 4-5 leaves (Table 2). The content of calcium decreased with the increase of phosphorus doses from 17.4 to 56.7 kg P ha^{-1}, while the content of nitrogen increased in the range of doses from 17.4 to 43.6 kg P ha^{-1}. The statistically confirmed effect of phosphorus fertilization level on the content of potassium in the phase of 8-9 leaves seems to be incidental.

Application of ammonium phosphate increased the content of phosphorus and nitrogen in dry mass in the phases of 4-5, 6-7 and 8-9 leaves, as well as the content of magnesium in the phase of 8-9 leaves when compared with plots fertilized with superphosphate (Table 2). The increase of phosphorus and nitrogen content took place simultaneously with the increase of the dry mass of sample in cases when ammonium phosphate was used, as compared with superphosphate application. On the other hand, in all mentioned developmental phases, the contents of potassium and calcium, depending on the studied forms of the fertilizers, were decreasing. This result is confirmed by Moskal [12] and Murphy [13]. According to them, the uptake and utilization of phosphorus by plants depends on the uptake of inorganic nitrogen compounds as a result of mutual physiological relations in the metabolism of the plant.

In the phases of 4-5, 6-7 and 8-9 leaves, the fertilization in rows method significantly increased the content of phosphorus and nitrogen in the overground plant parts in comparison with broadcast fertilization (Table 2). The increase of these components occurred simultaneously with the increase of the dry mass of sample by 60.9% in result of fertilization in rows, as compared with broadcast fertilization. A reverse dependence was found in cases of potassium and calcium, statistically confirmed for calcium in the phases of 4-5, 6-7 and 8-9 leaves, and for potassium in the phases of 6-7 and 8-9 leaves. A significantly higher content of magnesium in the phase of 8-9 leaves was obtained in plots fertilized in rows in comparison with plots fertilized by broadcasting on the whole surface. In earlier studies, Dubas and Duhr [6] found that as a result of fertilization in rows in relation to broadcast fertilization, the content of phosphorus in maize plants in the phase of 3-4 leaves increased by 1.9 g kg^{-1} of dry mass. Also El-Hamdi and Woodard [7] and Rhoads and Wright [16] showed that maize fertilized in rows took up in the 28th and 41st days from the date of sowing more phosphorus than maize fertilized by broadcasting.

In case of fertilization in rows, in the phases of 6-7 and 8-9 leaves, phosphorus content gradually increased together with the increasing level of phosphorus fertilization from 17.4 to 56.7 kg P ha^{-1} (Fig. 1). In broadcast fertilization, the size of phosphorus dose did not change the P content in the plants. In both discussed developmental phases, fertilization in rows increased phosphorus content in plants in all levels of phosphorus fertilization.

In the phases of 4-5, 6-7 and 8-9 leaves, the contents of phosphorus, nitrogen, potassium, magnesium and calcium depended on the cooperation of fertilizer type and the fertilization method (Figs. 2, 3). In all discussed developmental phases, fertilization in rows significantly increased phosphorus content in the case of both studied fertilizer types and the content of nitrogen increased only in the case of ammonium phosphate when compared to broadcast fertilization. Plots receiving fertilization in rows with ammonium phosphate showed a higher content of phosphorus and nitrogen and a lower content of potassium and calcium in comparison with plots receiving fertilization in rows with superphosphate. In the case of broadcast fertilization, the fertilizer type did not determine the content of phosphorus, nitrogen, potassium, magnesium and calcium in plants. The application of ammonium phosphate in fertilization in rows increased the content of magnesium in comparison with broadcast fertilization in the phases of 6-7 and 8-9 leaves. The effect of the interaction of fertilizer type and the method of fertilization on Mg content in the phase of 4-5 leaves departs from the remaining trends.

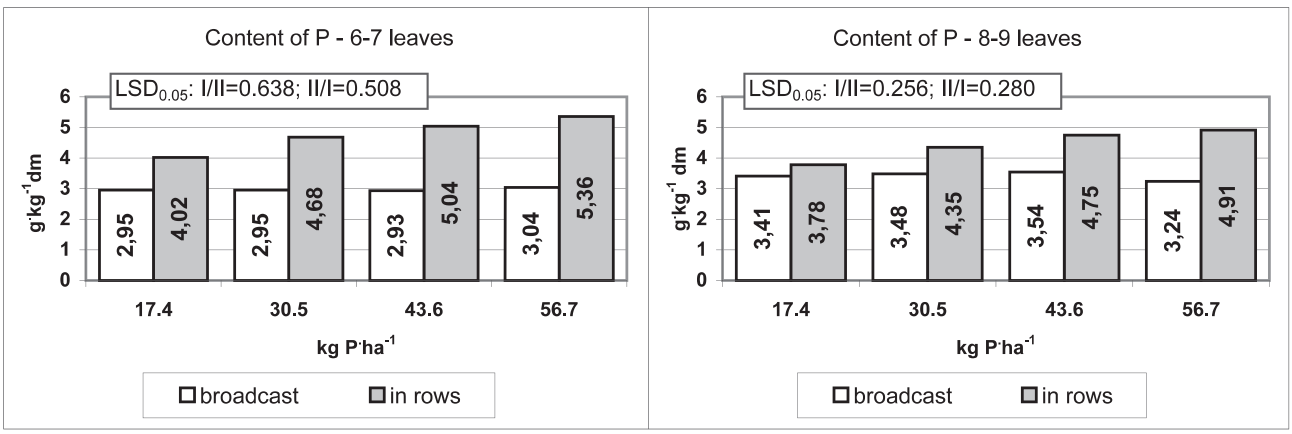

Fig. 1. Content of phosphorus in the dry mass of overground parts of maize depending on phosphorus fertilization level and the method of fertilization.

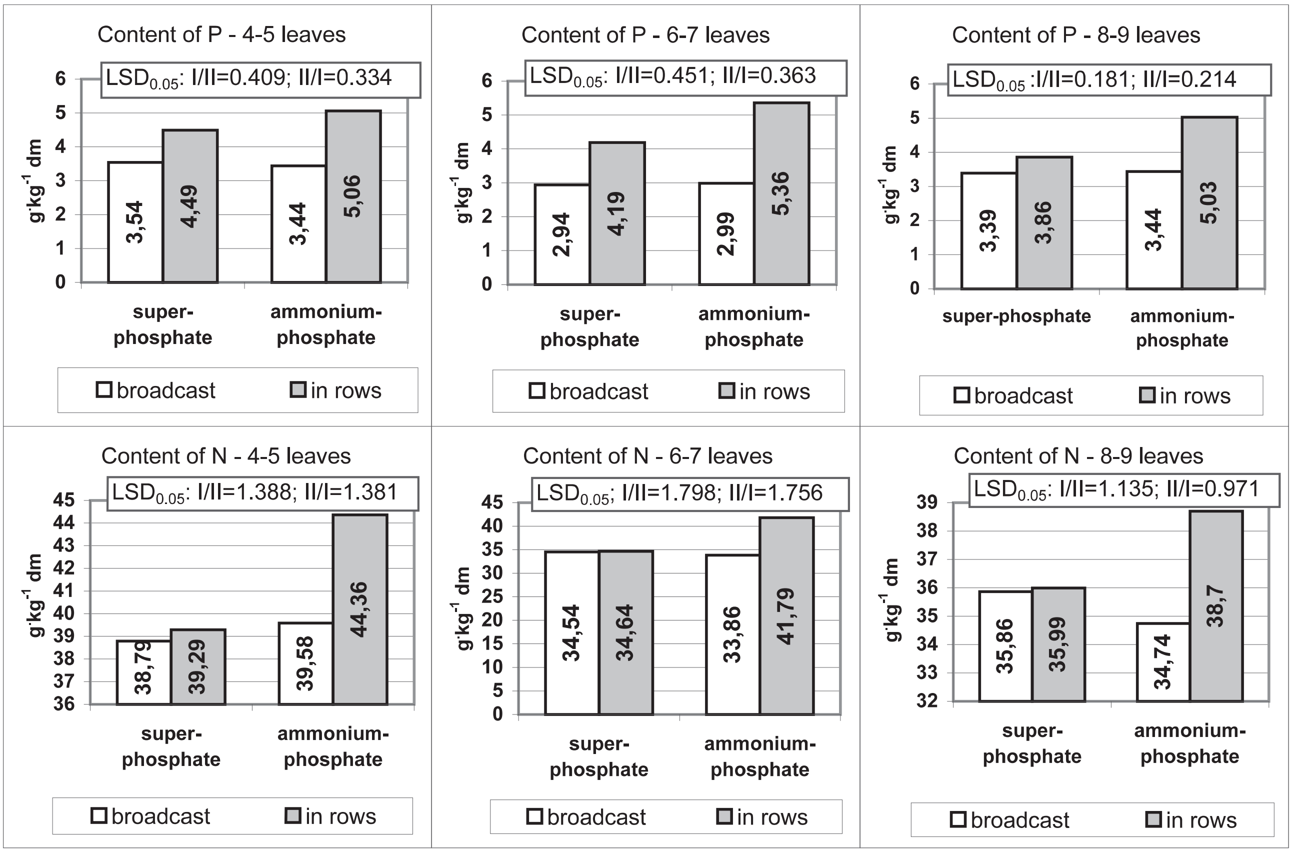

Fig. 2. Phosphorus and nitrogen content in the dry mass of overground parts of maize depending on fertilizer type and method.

Factors studied in the experiment did not affect the percentage of phosphorus uptake from fertilizer and from soil in the phase of 2-3 leaves (Fig. 4). For the fertilization objects, the mean percentage of P taken up from fertilizer oscillated between 9.8% and 13.3%. An essential effect of the studied factors became visible in the successive sampling terms.

An increase of phosphorus fertilization from 17.4 to 56.7 kg P. ha^{-1} caused a gradual increase of the amount of phosphorus taken up from fertilizer in the developmental phases of 4-5, 6-7 and 8-9 leaves (Fig. 4). Also, the use of ammonium phosphate increased the percentage of P taken up from fertilizer in comparison with superphosphate fertilization. The increase ranged between 6.4 point percent in the phase of 4-5 leaves and 13.7 point percent in the phase of 8-9 leaves. The greatest effect on the amount of phosphorus taken up from fertilizer was exerted by the fertilization method. Fertilization in rows, as compared with broadcast fertilization, increased the percentage of phosphorus uptake from fertilizer by 24.7 point percent in the phase of 4-5 leaves, by 39.7 point percent in the phase of 6-7 leaves and by 35.2 point percent in the phase of 8-9 leaves. The better utilization of phosphorus from fertilizer applied in the root zone, according to many authors [2, 4, 5, 9, 12], can be explained by the fact that among the mechanisms of ion transport in the soil in the direction of the physiologically active root surface, in the case of phosphorus, the diffusion process plays a crucial role. The flow of ions takes place in agreement with the concentration gradient modified by the presence of plant root. Hence, fertilization in rows is more effective than the broadcast fertilization in reference to the uptake, particularly in the case of components which have small mobility like phosphorus. The diffusion process takes place quicker in a moist environment than in a dry one. The placement of fertilizer in the zone of young plant roots increases the utilization of phosphorus even in periods of drought, and such conditions were prevailing during three out of the four years of studies.

In the phase of 6-7 leaves, the percentage of phosphorus taken up from fertilizer depended on the cooperation of the dose of phosphorus and fertilizer type and the dose of phosphorus and fertilization method (Fig. 5). In all levels of phosphorus fertilization, the use of ammonium phosphate or the application of fertilization in rows increased the percentage of phosphorus taken up from fertilizer when compared with superphosphate and broadcast fertilization respectively. The increase of phosphorus doses from 17.4 to 56.7 kg P. ha^{-1} applied in the form of ammonium phosphate or fertilization in rows gradually increased the uptake of phosphorus from fertilizer as compared with the use of superphosphate and broadcast fertilization, respectively.

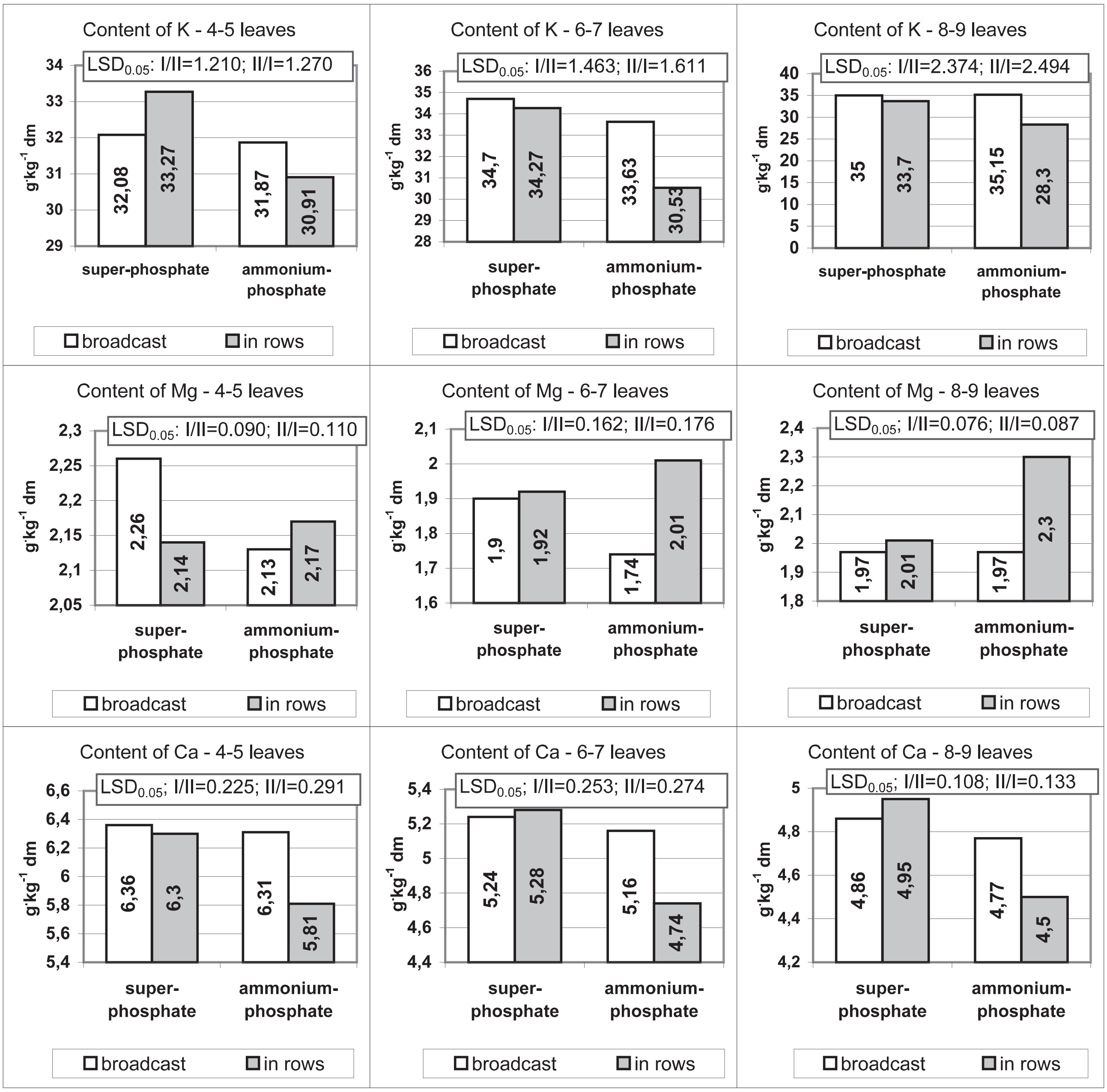

Fig. 3. Content of potassium, magnesium and calcium in the dry mass of overground parts of maize depending on fertilizer type and method.

In the phases of 4-5, 6-7 and 8-9 leaves, the amount of phosphorus taken up from fertilizer by maize depended on the interaction between fertilizer type and the method of its application (Fig. 6). Fertilization in rows with superphosphate as well as with ammonium phosphate increased the percentage of P taken up from fertilizer in comparison with broadcast fertilization. Ammonium phosphate applied in fertilization in rows essentially increased the uptake of phosphorus by plants in comparison with the use of superphosphate. With broadcast fertilization, the type of fertilizer had no effect on the uptake of phosphorus from fertilizer, although there was a tendency similar to cases of fertilization in rows.

Conclusion

Phosphorus content in the initial development stage of maize and phosphorus utilization from fertilizer increased with the increasing phosphorus fertilization level. These changes resulted from the beneficial effect of fertilization in rows on phosphorus content and its uptake from fertilizer in cases of all fertilization levels. When broadcast fertilization was used, the values of the mentioned features did not change with the increasing doses of phosphorus.

Fertilization in rows increased phosphorus content in the overground parts of young maize plants and the percentage of phosphorus uptake from fertilizer in compar-

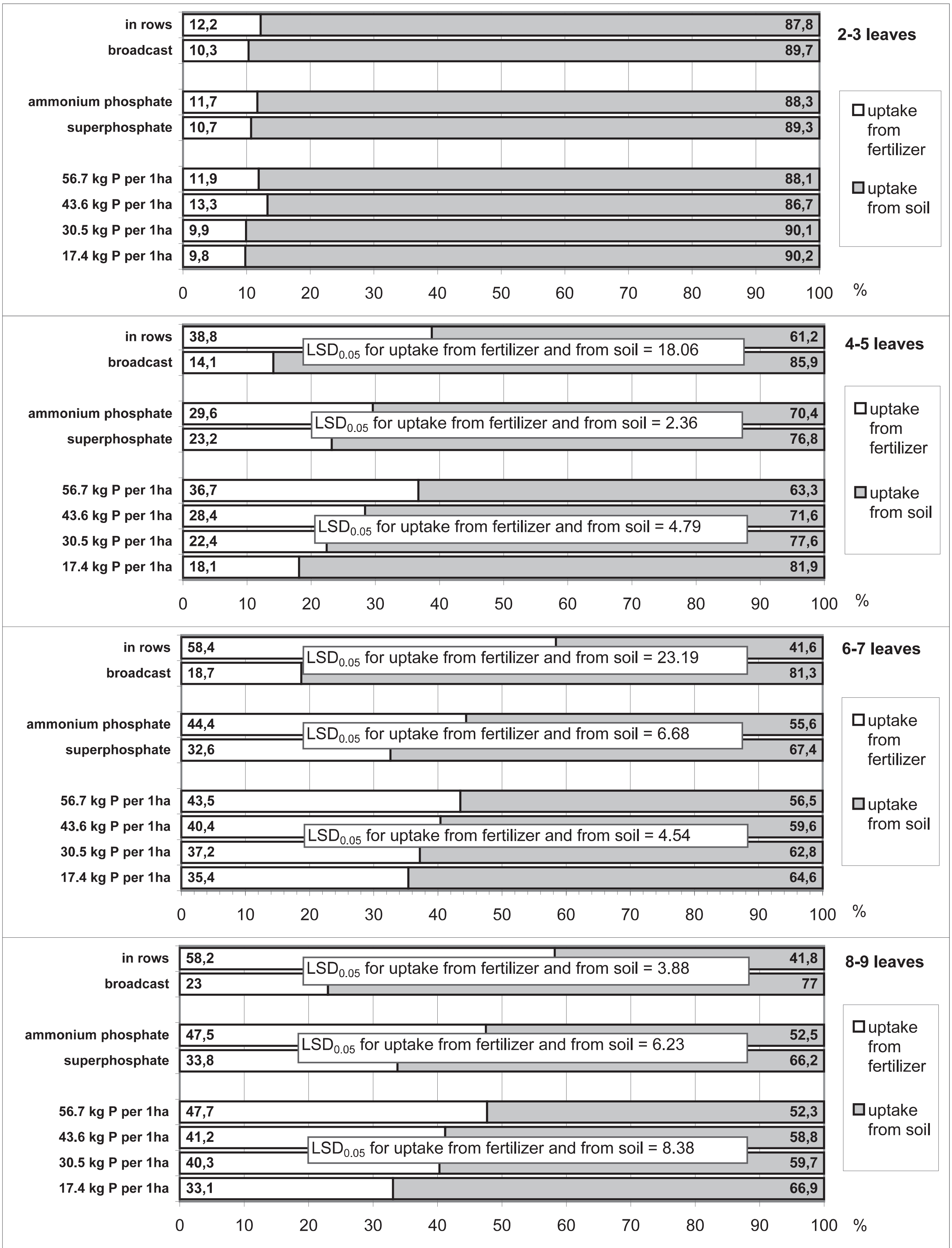

Fig 4. Phosphorus percentage taken up from fertilizer and from soil.

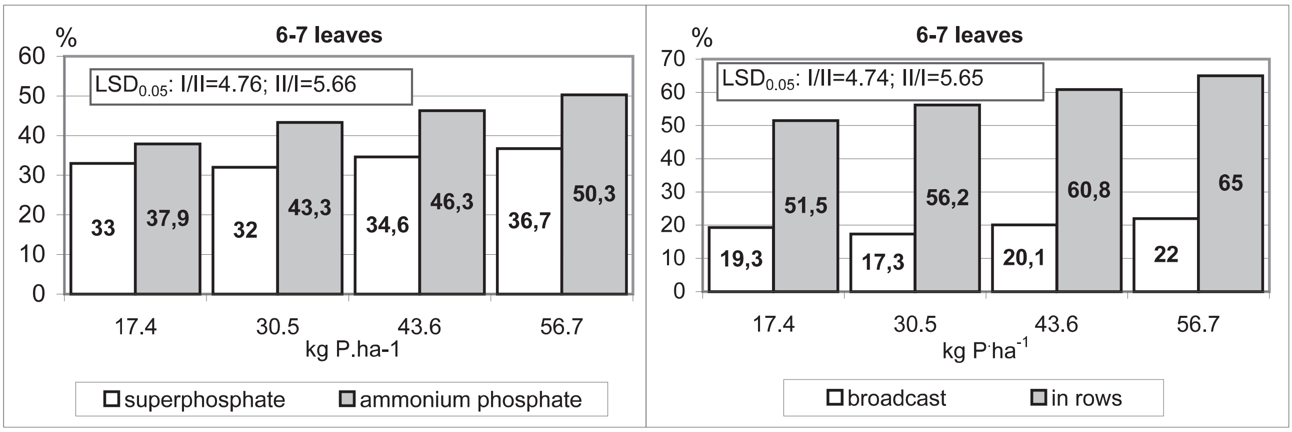

Fig. 5. Percentage of phosphorus taken up from fertilizer depending on phosphorus fertilization level and fertilizer type.

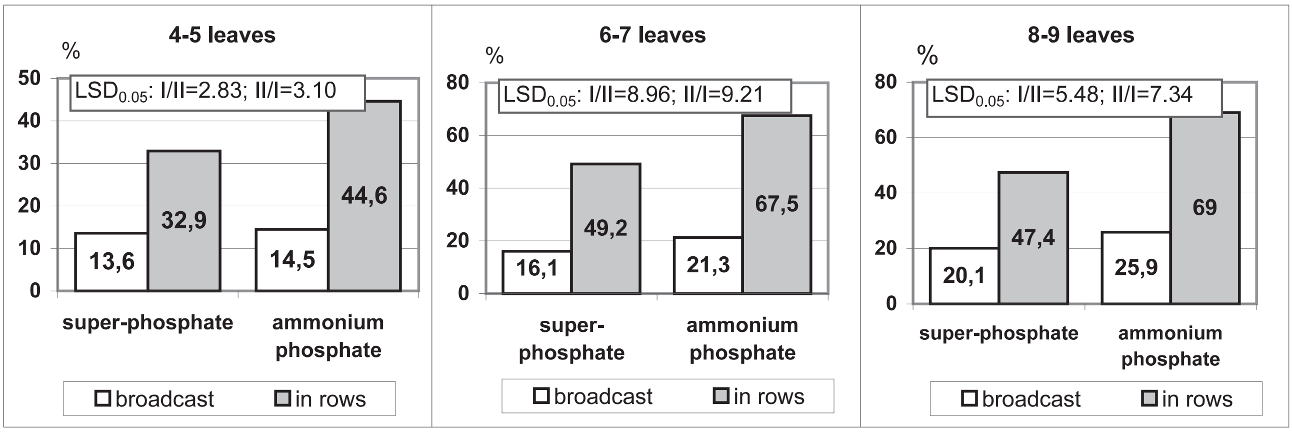

Fig. 6. Percentage of phosphorus taken up from fertilizer depending on fertilizer type and fertilization method.

ison with broadcast fertilization. The differences were significantly higher in cases where ammonium phosphate was used as compared with the use of superphosphate. Fertilization in rows also increased the content of nitrogen and decreased the content of potassium and calcium in young plants. An increase of nitrogen occurred only in cases when ammonium phosphate was used. The application of ammonium phosphate increased the content of phosphorus and nitrogen in young plants and decreased the content of potassium and calcium as compared with superphosphate independent of the fertilization method.

The presented studies indicate that row fertilization of maize with a two-component fertilizer such as ammonium phosphate supplies a still stronger justification for maize cultivation in the system of integrated agriculture. Such methods of fertilization, thanks to the favourable effect on the uptake of phosphorus and nitrogen, and on the utilization degree of phosphorus from the fertilizer, contributes both to the protection of the natural environment and stimulates the early development of maize, particularly when temperature and moisture conditions are unfavourable for this plant.

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