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STARTER FERTILIZATION OF MAIZE AS A METHOD TO IMPROVE THE EFFICIENCY OF NUTRIENT APPLICATION

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Key words: *Zea mays* L., nitrogen, phosphorus, method fertilization.

Abstract

Phosphorus (P) in most regions worldwide is the most important nutrient, second only to nitrogen (N), with the potential to limit agricultural production. It is an essential nutrient for plant growth and development, while the cycle of this nutrient in nature is also essential for humans and animals. In plants it is a component of organic compounds, which accumulate large amounts of energy used in numerous processes taking place in cells. Plants adequately nourished with phosphorus contain more vitamins and carotene, and less oxalic acid, which excess results in deterioration of quality of produced food and feed. At appropriate phosphorus nutrition plants achieve greater efficiency of photosynthesis and are characterized by improved water relations, as a consequence they produce higher grain yields and dry matter yields of the aboveground parts. This study presents original results of five field trails concerning different application methods for nutrients (N and P) in maize culture. Presented data come from controlled field trials, which were conducted at the Department of Agronomy, the Poznań University of Life Sciences.

NAWOŻENIE STARTOWE KUKURYDZY JAKO METODA POPRAWY EFEKTYWNOŚCI APLIKACJI SKŁADNIKA

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Abstrakt

Fosfor (P) w większości regionów świata jest najważniejszym pierwiastkiem odżywczym po azocie (N) ograniczającym produkcję rolniczą. Jest niezbędnym składnikiem do wzrostu i rozwoju roślin, a w przyrodniczym obiegu tego składnika jest również konieczny dla człowieka oraz zwierząt. Fosfor spełnia ważne funkcje w procesach życiowych rośliny, takich jak fotosynteza i oddychanie. W roślinie wchodzi w skład związków organicznych, które akumulują dużo energii wykorzystywanej w licznych procesach zachodzących w komórce. Rośliny właściwie odżywione fosforem zawierają więcej witamin i karotenu, a mniej kwasu szczawiowego, którego nadmiar pogarsza jakość wyprodukowanej paszy oraz żywności. Prawidłowe żywienie fosforem powoduje, że rośliny osiągają wyższą wydajność procesu fotosyntezy oraz oszczędniej gospodarują wodą, co w konsekwencji daje zwyżkę plonu ziarna oraz plonu suchej masy części nadziemnej. W opracowaniu omówiono wyniki pięciu badań polowych dotyczących różnych metod aplikacji składników pokarmowych (N i P) w uprawie kukurydzy. Badania te zrealizowano w Katedrze Agronomii Uniwersytetu Przyrodniczego w Poznaniu.

Introduction

Maize (*Zea mays* L.) due to its origin is a thermophyte plants (SOWIŃSKI 2000). For adequate growth and rapid development it needs more heat in the vegetation period than other cereals. The effect of temperature is manifested e.g. in the dynamics of dry matter accumulation and initial growth rate (KRUCZEK and SZULC 2006). Low soil and air temperatures at sowing and in the initial phases of growth in maize are primary causes reducing its yielding. Additionally, in the spring cold spells occurring at various development stages of maize retard its growth. In Poland, where maize is sown in the third decade of April and in the first days of May we frequently have to deal with adverse temperature conditions. Maintenance of advantageous nutrition conditions facilitating acceleration of growth rate, particularly in the initial phases of its development, has a positive effect on yielding (SZULC 2013).

Slow initial growth caused by too low temperatures during the vegetation period of maize, as it was shown in recent studies, is a result of reduced uptake of water and nutrients, particularly phosphorus (MOZAFAR et al. 1993). Moreover, in that time the underdeveloped radicle system may supply plants with minerals only at their adequately high concentration in the soil medium. In turn, an adequate concentration of phosphorus in the soil medium is required for a rapid development of the root system in maize and it facilitates alleviation of effects of nutritional stress (YANAI et al. 1996). The concentration of phosphates in comparison to other anions is very low, as the share of the phosphate ion in the total anions in the soil medium is maximum several percent (MOLLIER and PELLERIN 1999).

These problems may be overcome applying various cultivation measures, fertilizer types, particularly mixed fertilizers, as well as their application site (SZULC et al. 2016a, SZULC et al. 2016b) One of the methods to enhance availability of phosphorus in the immediate vicinity of roots is broadcasting large doses of phosphorus fertilizers. In order to ensure uptake of this nutrient by plants under adverse conditions these doses have to considerably exceed nutrient requirements of maize. Such an approach is neither economically viable nor acceptable from the point of view of environmental protection (SHARPLEY et al. 2001, LADHA et al. 2005, SZULC 2010, SZULC et al. 2015). Excessive phosphorus contents in the soil lead to losses of the nutrient due to surface runoff, increasing eutrophication. Agriculture is not a closed system and some of the accumulated phosphorus is released to the environment. Standard broadcasting fertilization does not always ensure adequate plant nutrition, since depending on soil properties some of the nutrient introduced to the soil in the form of fertilizer will be retrograded, particularly in soils with considerable potential for immobilization, or it will be deposited in sites outside the reach of roots of crops (EL-HAMDI and WOODARD 1995).

A much better method to enhance phosphorus availability is to place fertilizer in the immediate vicinity of seeds. Such a method of fertilizer application is referred to as row, starter or topical. It consists in the placement of fertilizer 5 cm deeper and 5 cm away from seeds (MURPHY 1984, MASCAGNI and BOQUET 1996, RHOADS and WRIGHT 1998). It causes better supply of young plants with nutrients, it accelerates their vegetation, while additionally it affects grain yield. Starter fertilization also makes it possible to reduce the dose of phosphorus thanks to its better utilization in the year of application and it reduces the rate of its retrogradation in soils with low resources of this nutrient. Moreover, such a method of phosphorus application results in the deposition of this nutrient in a deeper, moister soil layer, ensuring its improved uptake. This is particularly important in the case of nutrients of limited mobility, such as phosphorus (KRUCZEK and SZULC 2006).

The first studies in Poland concerning the effect of row (starter) application of phosphorus and mixed fertilizers on the course of vegetation and yielding of maize were conducted at the Poznan University of Life Sciences (formerly the Agricultural University) in the 1970's (DUBAS and DUHR 1983). These studies confirmed the assumption that when soil temperature at a depth of 5 cm (sowing depth) at sowing up to the development of 3–4 leaves did not exceed 5.5°C starter fertilization not only increased phosphorus uptake by plants, but also significantly affected grain yield in relation to conventional broadcasting (DUBAS and DUHR 1983). Thus considering frequent long-term spring cold spells in Poland during sowing and the initial period of maize growth it may be assumed that fertilization performed jointly with sowing as starter fertilization will be particularly efficient. It seemed that advisability of starter fertilization in Poland should thus be confirmed by research results. This was also connected with the dramatic change in the selected maize cultivars, in which breeding progress altered their environmental requirements, especially temperature conditions. Moreover, changes were also introduced to offered phosphorus and mixed fertilizers, exhibiting improved availability. For this reason at the Department of Agronomy (formerly the Department of Soil and Plant Cultivation) studies were initiated on the advisability of such a method of fertilizer application in maize growing. This study presents results of five field trials on such a fertilization method. In view of the extensive scope of the research problem only three traits were focused on: (i) the dynamics of initial growth, (ii) grain yield, and (iii) grain moisture content. Moreover, the paper presents and discusses factors determining effectiveness of various maize fertilization methods as well as mechanisms of nutrient uptake by plants.

Thermal and humidity condition in the years of conducting field tests in which the described research tasks were carried out

Air temperature (Table 1) in April and early May, during sowing and emergence of plants, except for 2000 and 2007, was unfavorable for maize as it was less than 10°C. In the later growing seasons, in the maize-critical flowering and flushing (the second half of June and early July), the weather conditions were favorable for most years. Only in the years 2000 and 2001 were they below the requirements of maize. In August and September, thermal conditions, in spite of their differentiation in particular years, generally favored the formation of grains and its maturation. The humidity conditions (Table 2) in

the experimental years were more varied than the air temperature. They express not only differences in the sum of precipitation in the vegetation

Table 1

Average month air temperatures [°C] in growing seasons

Years	Months							
	IV	V	VI	VII	VIII	IX	X	Average for IV–X
2000	12.1	15.7	17.5	16.3	18.5	12.9	12.1	15.0
2001	8.3	15.2	15.3	19.9	19.3	12.2	12.3	14.6
2002	8.9	16.8	18.1	20.6	21.4	14.1	7.3	15.3
2003	8.6	15.7	19.2	19.8	20.0	15.1	5.7	14.8
2004	9.7	12.9	16.1	18.2	20.1	14.2	10.4	14.5
2005	9.4	13.3	16.5	19.9	17.3	16.0	10.5	14.7
2006	8.8	13.8	18.7	24.4	17.7	17.2	11.3	15.9
2007	10.8	15.2	19.3	18.9	19.2	13.7	8.5	15.1

Table 2

Month rainfalls [mm] in growing seasons

Years	Months							
	IV	V	VI	VII	VIII	IX	X	Sum for IV–X
2000	15.7	47.4	29.9	73.0	95.6	38.8	11.8	312.2
2001	33.1	10.4	67.8	65.8	44.6	119.3	31.9	372.9
2002	34.2	45.7	38.1	29.6	56.1	15.8	89.3	308.8
2003	16.2	24.0	40.4	97.7	5.8	15.9	31.6	231.6
2004	19.4	49.8	51.3	49.4	53.6	32.3	45.2	301.0
2005	14.5	74.3	19.1	97.4	60.7	34.4	5.0	305.4
2006	43.6	57.4	26.9	23.1	100.7	22.0	22.1	295.8
2007	9.3	77.0	59.6	87.0	48.1	33.4	18.5	332.9

periods, but especially their distribution in particular months. The monthly precipitation totals ranged from 231.6 mm in 2003 to 372.9 mm in 2001. Their distribution was very different at this time and was characterized by violent precipitation or cumulative short-term and unsuitable water retention in soil or longer periods without precipitation causing periodic water shortages in the soil.

Factors determining effectiveness of different nutrient application methods

Mechanism of phosphorus uptake

Soil provides water and nutrients and they are absorbed by roots (GRZEBISZ 1988). Nutrient uptake, including phosphorus, through roots is dependent on appropriate plant turgor. Plants adequately supplied with water absorb greater amounts of this nutrient transferring it to zones of intensive growth. Ions from the soil medium are absorbed thanks to three basic mechanisms: by root contact with the ion, through movement of ions with water and through diffusion (GRZEBISZ and GAŁA 1999).

The first of the three processes, in which the nutrient penetrates to plant roots consists in the direct contact of soil with the roots. It is responsible to a slight extent for the amount of nutrients, which may reach root surface. In this way approx. 6% nutrient requirements of plants may be met (GRZEBISZ 1990). In the immediate area of the roots soil phosphorus resources are quickly depleted, causing a decrease in the concentration of this nutrient.

In order to provide adequate plant phosphorus nutrition it needs to be supplied from more distant soil zones. From these zones ions may penetrate towards the roots flowing with water or as a result of diffusion. The amount of nutrients reaching the roots in this way is dependent on the water flow rate and on its uptake by plants, as well as the concentration of a given nutrient in the soil medium. However, irrespective of soil fertility, mass flow does not always satisfy nutrient requirements of plants in relation to phosphorus. As it was reported by CAMPBELL et al. (1989) the limited importance of water flow may be explained by the low concentration of phosphorus in the soil medium. As a result of water flow plants may absorb as little as 1–10% required amounts of phosphorus. Mechanisms of ion transport in the soil towards the physiologically active root surface in the case of phosphorus a decisive role is played by the process of diffusion. Diffusion consists in the flow of ions in accordance with the gradient of concentration caused by the presence of plant roots. Plants, by absorbing the ion, cause its movement towards the roots, i.e. absorb it according to the gradient of concentration. This process occurs in the direction towards plant roots, when ion concentrations in this zone are reduced or in the opposite direction when concentrations of ions in the root zone are greater than in the soil medium. The rate of ion movement is dependent on the values of ion diffusion coefficients and on soil moisture content. Movement of ions, irrespective of the mechanism of this process, always takes place in water. The dependence of diffusion rate on soil moisture content may be explained by the increase in the share of pores filled with air with the decrease in soil moisture content. The moister the soil is, the faster (shorter) the path of phosphorus to plant roots. As it was reported by BHADORIA et al. (1991), at soil saturation with water the rate of ion diffusion towards the roots is dependent on the difference in concentrations on the root surface and in the soil. Considering weak solubility of phosphorus and its low concentration in the soil solution the amount of the active nutrient in the soil is determined by soil moisture content. Phosphorus in the soil solution is supplemented from the soil solid phase, on condition a sufficient amount of water is present. In soils of low water holding capacity or during drought the concentration of phosphorus in the soil medium should be greater for plants to be able to absorb the amount of this nutrient required for their development. In practice this means that greater doses of fertilizers have to be applied. As it was reported by ŁABĘTOWICZ and RUTKOWSKA (2001) concentration of phosphates in the soil medium is crucial for the uptake of this macronutrient by crops.

The effect of temperature on phosphorus uptake

Studies conducted by many authors indicate that changing soil temperature has a tremendous effect on many mechanisms involved in nutrient uptake by plants (MURPHY 1984). A decrease in soil temperature (below 10–12°C) reduces the rate of organic matter mineralization, solubility of inorganic forms of phosphorus, permeability of cytoplasmic membranes, while it also limits root activity (KRUCZEK 2005e). A decrease in soil temperature leads to a reduced uptake of several essential ions, particularly phosphorus. A low soil temperature increases viscosity of the soil solution and reduces the rate of diffusion, thus decreasing the amount of absorbable phosphorus, which reaches root surface. An increase in temperature by 1°C causes an increase in phosphorus contents in the soil solution by 1–2%. One of the functions of roots is connected with nutrient uptake from the substrate. Maize plants due to their abundant growth have a very well developed root system, which supplies them with adequate amounts of water and nutrients. As it was reported by SOWIŃSKI and MALISZEWSKI (1989), root pressure responsible for shoot supply with minerals is reduced at a low temperature. In turn, phosphorus is the only ion, which uptake is dependent particularly on root activity.

Experiments conducted by MACKAY and BARBER (1984) at a soil temperature of 25°C the total yield of maize (roots and shoots) was by 4–6.5-fold greater than at 18°C, root growth was by 2.6 to 5.1 times greater, while phosphorus uptake was by 2- to 4-fold greater. An increase in air temperature to 25°C at soil temperature of 18°C caused a 2.7-fold greater growth of roots and 2.2-fold greater phosphorus uptake. CHING and BARBER (1979) showed that growth rate of maize roots at 15°C was by 50% lower than at 29°C. DIBB et al. (1989) also stated that an increase in soil temperature from 5°C to 27°C caused an increase in growth of aboveground parts in maize by approx. 400%, while uptake of phosphorus by 275%. MOZAFAR et al. (1993) investigated the effect of day length and soil temperature in the root zone on growth and contents of nutrients as well as their distribution in maize. A 3-fold increase in day length from 6 to 18 h had no effect on growth of aboveground parts of plants and roots if soil temperature in the root zone was 9°C, but it increased each of the parameters 8-fold if the temperature of the root zone was 21°C. Interacting day length and the temperature of the root zone showed a completely different effect on contents of nutrients in both roots and aboveground parts of plants. An extension of day length at a given temperature of the root zone reduced nutrient concentrations, while an increase in soil temperature in the root zone in a given lighting period increased contents of most elements both in roots and the aboveground parts. A lack of response in maize to an extended day length, manifested in plant growth on condition that roots are subjected to low soil temperatures, indicates a dominant role of temperature in the root zone over the role of day length at early development phases of maize.

Response of cultivars to starter fertilization

An important factor determining the effectiveness of topical fertilization is connected with an appropriate selection of cultivars. It results from studies conducted by MASCAGNI and BOQUET (1996) and TEARE and WRIGHT (1990) that not all cultivars respond positively to starter fertilization in terms of the volume of grain yield. There are cultivars responding to starter fertilization consistently with an increased grain yield, cultivars consistently responding negatively and hybrids indifferent to this method of fertilizer application. Cultivars, which are highly sensitive to temperature, are more prone to respond to starter application of phosphorus when the temperature is below normal (RHOADS and WRIGHT 1998). Moreover, those authors ascribed the response of cultivars to fertilizer application methods (broadcasting, row application) on weather conditions in the years of the study. They reached a similar conclusion as the previously cited authors, stating that certain cultivars respond with increased grain yields irrespective of weather conditions over the years, while the response of the other cultivars varies over the years. Cultivars with a high growth rate of roots and high uptake rates of N and P exhibit a lesser response to the starter fertilizer. As it was reported by RHOADS and WRIGHT (1998), a positive constant response of maize to topical fertilization is observed in the case of low soil temperatures, which limit growth rate of roots. Thus it results from conducted analyses that the hybrids with a low root growth rate and a low nutrient uptake rate react positively to starter fertilization.

Selection of fertilizer for starter fertilization

Optimal choices for starter fertilization include two-component fertilizers containing nitrogen and phosphorus. Changes of phosphorus compounds in the soil are dependent on the presence of accompanying salts, of which the greatest effect is found for nitrogen compounds (MURPHY 1984). Fertilizer pellets after being introduced to the soil dissolve very rapidly. In the vicinity of pellets a saturated phosphate solution is formed in relation to the most readily soluble compounds contained in the fertilizer. The composition and concentration of this solution are not dependent on soil properties, but solely on fertilizer properties. Ions from the concentrated solution diffuse outside fertilizer pellets, while water flows in the opposite direction. With an increase in the distance from the fertilizer pellet phosphates undergo chemical and physico-chemical sorption, causing a decrease in the concentration of phosphorus in the soil solution. A combination of two components, N and P, increases the uptake of phosphorus by maize during initial development phases (KRUCZEK 2005e). However, it needs to be remembered that the rate of phosphorus absorption depends on the form, in which plants absorb nitrogen. At plant nutrition with ammonia nitrogen N-NH_4 H^+ is released from the cells to the soil solution, causing its acidification, which as a rule increases the concentration of phosphorus and the rate of its absorption. At plant nutrition with the nitrate form N-NO_3 ions of HCO_3^- and OH^- are secreted from cells, causing alkalization of the soil solution, at the same time reducing absorption of phosphorus. At phosphorus deficit in the plant environment plants absorb little nitrogen, while the uptake of nitrogen is limited also at an excessive dose of phosphorus. For this reason only an N : P ratio adequate for a given plant ensures appropriate growth and development. It results from pot experiments conducted by SEIDLER and GÓRSKI (1986) that the greatest plant height and total leaf blade area in maize plants were obtained at a nitrogen to phosphorus ratio of 1:0.6. In turn, SEIDLER and GÓRSKI (1984, 1980) in similar experiments showed that the application of phosphorus in the nutrient medium in the amounts close to the nitrogen dose of 1:0.8 provided the best values of analyzed parameters in maize (net assimilation rate NAR, yield of dry matter). These authors explained it by a greater efficiency of photosynthesis, as well as more efficient water management of plants. Doses of phosphorus greater than those of nitrogen at 1:1.6 disturbed physiological processes, resulting in dry matter yield depression.

Results of studies on maize fertilization methods

Experiment 1. The effect of method of fertilization with phosphorus and mixed fertilizer on growth and development as well as yielding in maize

The effect of starter fertilization on the rate of dry matter accumulation by maize in the initial period of development was manifested starting from the phase of 4–5 leaves and it increased with progress in vegetation (Table 3). Dry matter of the aboveground parts of a single plant as a result of row fertilization in comparison to broadcasting was by 10.8% higher at the phase of 4–5 leaves, by 41.8% at the phase of 6–7 leaves and by 60.9% at the phase of 8–9 leaves. A greater dry matter of the aboveground parts of a single plant under the influence of row fertilization was obtained not only irrespective of weather conditions, but also in all the 4 years of the study (Table 3). Those years in the initial development phases of maize were characterized by moisture deficit in the soil, showing that thanks to starter fertilization the action of fertilizer is independent of periodical water deficits in the spring as a consequence of a more advantageous deposition of fertilizer in a deeper soil layer, moister thanks to the upward water movement. Thus these experiments did not confirm a conjecture of a greater effectiveness of starter fertilization at low temperatures found in spring. It resulted from advantageous temperature conditions in all the four years of the study. Row application of a single-component fertilizer (triple superphosphate) and two-component fertilizer (ammonia phosphate) had an advantageous effect on the accumulation of dry matter by maize at initial growth phases. A greater effectiveness was recorded in the case of ammonia phosphate (Figure 1). Row application of both triple

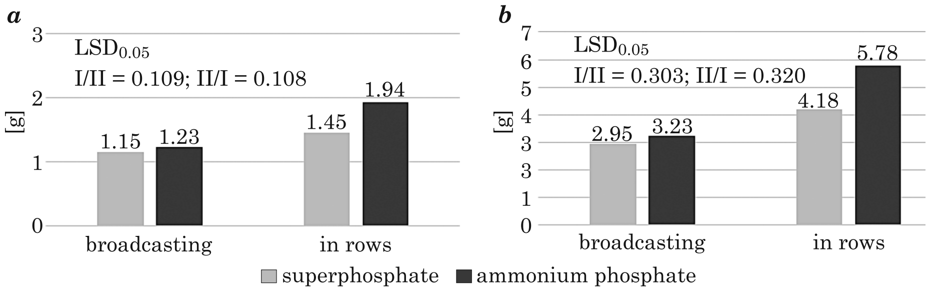

Fig. 1. Dry mass of above-ground part of one plant in phases of 6–7 leaves (a) and 8–9 (*b*) in dependence on kind of fertilizer and method of fertilization (2000–2003) (KRUCZEK and SZULC 2005a)

superphosphate and ammonia phosphate had an advantageous effect on the accumulation of dry matter by maize at initial growth phases. However, a markedly greater effectiveness was recorded in the case of ammonia phosphate. Dry matter of the aboveground parts increased with an increase in phosphorus fertilization ranging from 40 to 130 kg P_2O^{35} ha^{-1} at the phase of 8–9 leaves (Table 3). Row application of fertilizer significantly increased grain yield in maize in relation to row application, and it was irrespective of weather conditions in the years of the study, type of fertilizer and soil phosphorus resources (Table 4). Moisture content in the period of flowering and grain setting by maize were factors determining the effectiveness of row fertilization. Optimal soil moisture content in that period provided the greatest increase in grain yield as a result of row fertilization, irrespective of precipitation total throughout the vegetation period. Starter broadcasting of ammonia phosphate significantly increased grain yield in relation to row application. In the case of triple superphosphate the method of fertilization did not change grain yields (Figure 2).

Irrespective of weather conditions, water content in grain depended solely on the method of fertilizer application (Table 5). A significantly lower moisture content was recorded in treatments, in which fertilizer was applied in rows (27.5%), in comparison to treatments with conventional row application (27.9%). This dependence was observed in all the years of the study, while it was confirmed statistically in the years 2000 and 2003.

Table 3

Dry mass of above-ground parts of 1 plant [g] (2000–2003) (KRUCZEK and SZULC 2005a)

Specification		Sampling dates				
		full emergency	2–3 leaves	4–5 leaves	6–7 leaves	8–9 leaves
Average for control		0.05	0.08	0.29	1.04	2.47
P_2O_5 dose [kg ha^{-1}]	40	0.05	0.09	0.32	1.43	3.65
	70	0.05	0.08	0.32	1.40	4.04
	100	0.05	0.08	0.32	1.48	3.86
	130	0.05	0.08	0.35	1.46	4.58
$LSD_{0.05}$		n.s.	n.s.	n.s.	n.s.	0.390
Kind of fertilizer	superphosphate	0.05	0.08	0.31	1.30	3.57
	ammonium phosphate	0.05	0.09	0.34	1.59	4.50
$LSD_{0.05}$		n.s.	0.002	0.013	0.076	0.238
Fertilization method	broadcast	0.05	0.08	0.31	1.19	3.09
	in rows	0.05	0.08	0.34	1.69	4.98
$LSD_{0.05}$		n.s.	n.s.	0.010	0.072	0.215

n.s. – no significant differences

Table 4

Yield of maize grain [dt ha^{-1}] (KRUCZEK and SZULC 2005b)

Specification		Years				Average
		2000	2001	2002	2003	
Average for control		92.5	91.2	59.0	104.6	
P_2O_5 dose [kg ha^{-1}]	40	94.2	94.7	62.4	103.3	88.7
	70	97.6	93.7	60.0	105.4	89.2
	100	84.6	95.6	55.9	107.8	86.0
	130	94.5	94.4	59.0	109.2	89.3
$LSD_{0.05}$		8.46	n.s.	n.s.	1.41	n.s.
Kind of fertilizer	superphosphate	93.0	94.3	58.7	106.0	88.0
	ammonium phosphate	92.5	94.9	60.0	106.8	88.5
$LSD_{0.05}$		n.s.	n.s.	n.s.	n.s.	n.s.
Fertilization method	broadcast	91.5	94.5	58.6	105.7	87.6
	in rows	93.9	94.7	60.1	107.1	89.0
$LSD_{0.05}$		1.76	n.s.	n.s.	1.21	0.95

n.s. – no significant differences

Table 5

Grain moisture [%] (Kruczek and Szulc 2005b)

Fertilization method	Years				Average
	2000	2001	2002	2003	
Broadcast	33.0	27.3	28.5	22.6	27.9
In rows	32.3	27.0	28.1	22.4	27.5
$LSD_{0.05}$	0.49	n.s.	n.s.	0.18	0.19

n.s. – no significant differences

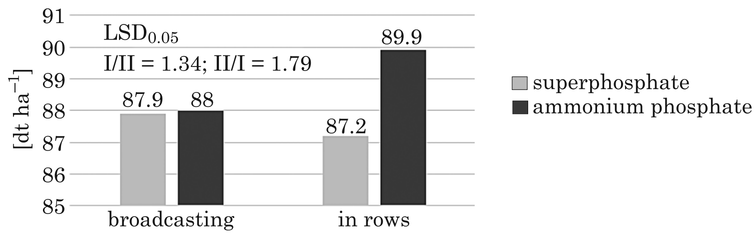

Fig. 2. Effect of fertilization method and kind of fertilizer on grain yield (2000–2003) (Kruczek and Szulc 2005b)

Experiment 2. The effect of method of fertilization with nitrogen and mixed fertilizer on development and yielding of maize

Topical fertilization, applied jointly with grain sowing, had an advantageous effect on the initial growth of maize plants, irrespective of weather conditions. It was manifested in an increased dry matter of a single plant at the phase of 4–5 leaves, in comparison to broadcasting (Table 6). A positive effect of row fertilization on these traits was particularly strong at low doses of nitrogen, while at doses above 95 kg N ha^{-1} this effect was not observed (Figure 3). The greatest positive effect of starter fertilization on increment in dry matter of a single plant in comparison to broadcasting was obtained using a mixed fertilizer, hydrofoska, while it was lower following the application of ammonium nitrate and the lowest after urea application. Starter broadcasting of nitrogen fertilizers or mixed fertilizer gave better effect in grain yield than their broadcasting, irrespective of weather conditions, the level of nitrogen fertilization and the type of fertilizer (Table 7). Starter fertilization significantly increased grain yield in comparison to conventional fertilization (broadcasting) in the years, in which precipitation total in the vegetation period was comparable to the multiannual mean. The type of nitrogen fertilizer (urea and ammonium nitrate) or mixed fertilizer (hydrofoska 21) did not cause changes in grain yield of maize, either at row or broadcasting application, and it was irrespective of the method of their application (Table 7).

Table 6

The dry mass of above-ground parts of 1 plant in phase 4–5 leaves [g] (KRUCZEK 2004a)

Specification		Years				Average
		2000	2001	2002	2003	
N dose [kg ha^{-1}]	25	0.48	0.31	1.31	1.61	0.93
	60	0.50	0.33	1.36	1.53	0.93
	95	0.47	0.34	1.23	1.38	0.85
	130	0.48	0.34	1.32	1.36	0.87
$LSD_{0.05}$		n.s.	n.s.	n.s.	n.s.	n.s.
Kind of fertilizer	urea	0.46	0.33	1.31	1.49	0.90
	ammonium nitrate	0.49	0.33	1.28	1.36	0.87
	hydrofoska	0.50	0.32	1.32	1.56	0.92
$LSD_{0.05}$		0.022	n.s.	n.s.	0.110	0.039
Fertilization method	broadcast	0.47	0.32	1.26	1.36	0.85
	in rows	0.50	0.34	1.35	1.58	0.94
$LSD_{0.05}$		0.02	0.01	0.04	0.07	0.02

n.s. – no significant differences

Table 7

Yield of the maize grain [dt ha^{-1}] (KRUCZEK 2005a)

Specification		Years				Average
		2000	2001	2002	2003	
Average for control		82.5	65.7	59.3	67.0	
N dose [kg ha^{-1}]	25	92.4	81.7	61.0	78.5	78.4
	60	101.0	94.5	65.1	90.6	87.8
	95	103.7	102.6	58.8	98.9	91.0
	130	107.4	96.6	64.0	90.0	89.5
$LSD_{0.05}$		5.8	8.9	n.s.	n.s.	5.4
Kind of fertilizer	urea	12.2	93.6	64.2	85.4	86.4
	ammonium nitrate	100.0	93.2	60.6	91.9	86.4
	hydrofoska	101.1	94.7	61.8	91.3	87.2
$LSD_{0.05}$		n.s.	n.s.	n.s.	n.s.	n.s.
Fertilization method	broadcast	100.0	92.9	61.2	89.2	85.9
	in rows	102.2	94.8	63.2	89.8	87.5
$LSD_{0.05}$		1.9	1.4	n.s.	n.s.	1.0

n.s. – no significant differences

The method of fertilizer application did not change water content in grain at the application of nitrogen doses of 25, 60 or 95 kg N ha^{-1}. In turn, row application of 130 kg N ha^{-1} significantly increased moisture content in grain in comparison to broadcasting. Doses of nitrogen did not alter moisture content in grain during harvest if row fertilization was applied together with sowing. In the case of fertilizer broadcasting the moisture content in grain from treatments with the fertilizer dose of 95 kg N ha^{-1} was significantly greater than in treatments with doses of 60 and 130 kg N ha^{-1}, in the case of which water content in grain was comparable (Figure 4).

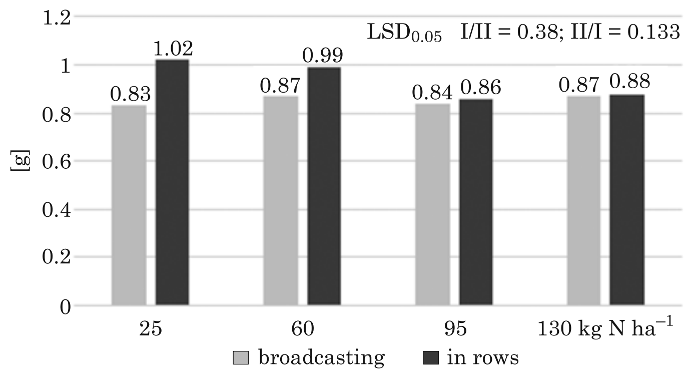

Fig. 3. The dry mass of above-ground parts of one plant (2000–2003) (KRUCZEK 2004a)

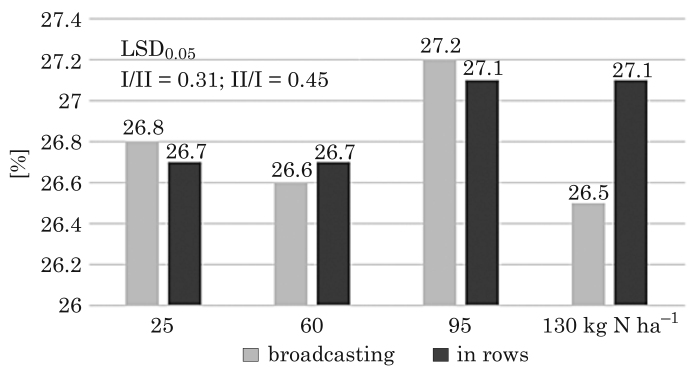

Fig. 4. Effect of nitrogen rate and fertilization method on moisture of grain (2000–2003) (KRUCZEK 2005a)

Experiment 3. Response of maize cultivars to the date and method of fertilization with two-component fertilizer (NP)

In studies concerning the response of hybrid maize cultivars to the method of fertilizer application at different sowing dates it was shown that starter broadcasting of ammonia phosphate significantly increased initial growth rate of maize, which was manifested in the production of dry matter of aboveground

Table 8

The dry mass of above-ground parts of 1 plant in phase 4–5 leaves [g] (KRUCZEK 2004b)

Specification		Years				Average
		2000	2001	2002	2003	
Varieties	Janna	0.82	0.21	1.21	0.84	0.77
	Costella	0.85	0.34	0.99	0.72	0.73
	Marignian	1.09	0.35	1.52	0.99	0.99
$LSD_{0.05}$		0.11	0.03	n.s.	0.20	0.12
Sowing date	12 IV	0.31	0.26	0.58	0.72	0.46
	26 IV	0.75	0.34	1.61	0.96	0.92
	10 V	1.71	0.30	1.53	0.88	1.11
$LSD_{0.05}$		0.09	0.02	0.24	0.10	0.07
Fertilization method	broadcast	0.84	0.27	1.04	0.71	0.72
	in rows	1.01	0.33	1.43	0.99	0.94
$LSD_{0.05}$		0.05	0.01	0.12	0.08	0.05

n.s. – no significant differences

Table 9

Yield of the maize grain [dt ha^{-1}] (KRUCZEK 2005b)

Specification		Years				Average
		2000	2001	2002	2003	
Varieties	Janna	83.7	76.2	51.9	83.9	73.9
	Costella	108.4	96.4	75.0	99.0	94.7
	Marignian	111.3	96.6	63.5	94.7	91.5
$LSD_{0.05}$		8.0	7.0	n.s.	0.8	5.2
Sowing date	12 IV	100.2	86.0	63.0	97.6	86.7
	26 IV	101.6	90.8	64.1	92.6	87.3
	10 V	101.6	92.3	63.3	87.4	86.2
$LSD_{0.05}$		n.s.	2.8	n.s.	1.2	n.s.
Fertilization method	broadcast	99.7	88.3	63.4	90.2	85.4
	in rows	102.6	91.1	63.6	94.9	88.0
$LSD_{0.05}$		1.6	2.2	n.s.	0.9	0.9

n.s. – no significant differences

parts of 1 plant at the phase of 4-5 leaves by 30.9% greater than in the case of broadcasting (Table 8). Row fertilizer application increased dry matter of 1 plant at this development phase at all sowing dates. Dry matter of aboveground parts of 1 plant at the phase of 4–5 leaves increased with a delay in sowing date from 12 April to 10 May (Table 8). This increase was more marked in treatments with starter fertilization in comparison to treatments with broadcasting fertilization. Irrespective of weather conditions and soil phosphorus resources, starter application of ammonia phosphate contributed to an increase in grain yield of maize in comparison to broadcasting (Table 9). Starter fertilization in maize using two-component fertilizer NP was far more effective than broadcasting not only at the optimal sowing date (26 April), but also at dates accelerated or delayed by 2 weeks (Figure 5). No varied response of maize cultivars to fertilization method was observed. Cultivars Janna, Costella and Marignian differed in their response to sowing date. The most advantageous sowing date for yielding of the earliest cv. Janna was 26 April, while for the latest-yielding cultivar Marignian it was 12 April. The date of sowing had no effect on yielding in medium early cv. Costella. Among the investigated factors moisture content of grain was influenced by cultivar and the date of sowing. As it could have been expected, the lowest moisture content at harvest was recorded in grain of the earliest cv. Janna, followed by the later cv. Costella, while it was greatest for the latest cv. Marignian. Differences in moisture content in grain between all the tested cultivars were statistically significant. On average for the 4 years of the study a delay in sowing date from 12 April to 10 May gradually increased grain water content. In comparison to the optimal sowing date of maize, i.e. 26 April, acceleration of sowing by 2 weeks reduced moisture content in grain by 0.9%, while delay in sowing by 2 weeks increased grain moisture content by 3.8%.

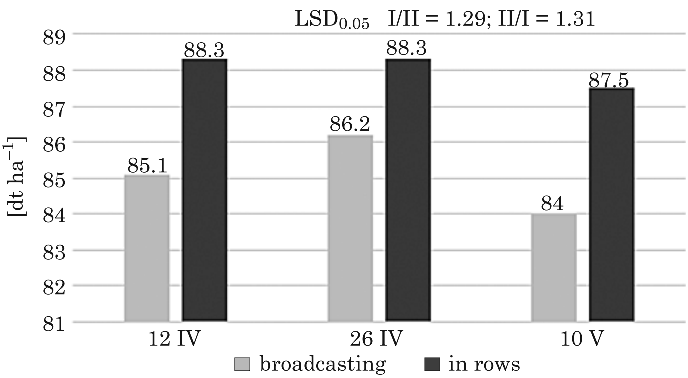

Fig. 5. Effect of sowing date and fertilizing method on the grain yield (2000–2003) (Kruczek 2005b)

Experiment 4. The effect of fertilization method for different types of fertilizers on growth development and yielding of maize

Studies concerning the method of fertilization using different types of fertilizers showed the most advantageous effect on yield of dry matter in the initial period of maize growth for row application of fertilizers. in which

P content was lower than that of N or it slightly exceeded it as in the case of hydrofoska 16 (N:P = 1:0.44). polifoska 8 (N:P = 1:1.31) and ammonia phosphate (N:P = 1:1.11). Row application of amofoska NPK/S. i.e. a fertilizer. in which P content markedly exceeded N content (N:P = 1:1.74). did not stimulate initial growth in maize plants (Table 10). Row application of fertilizers had a positive effect on grain yield in maize in comparison to broadcasting. particularly in the years. in which the distribution of precipitation promoted high yields. In the year characterized by rainfall deficit throughout the vegetation period no such effect was observed (Table 11).

Table 10

The yield of dry mass of above-ground parts of in the phase of 5–6 leaves [kg ha^{-1}] (KRUCZEK 2005c)

Studied factors	Years			Mean
	2001	2002	2003	
Hydrofoska 16; N:P = 1:0.44	32.9	40.0	103.8	58.9
Amofoska N:P = 1:1.74	28.9	36.6	54.1	39.9
Polifoska 8; N:P = 1:1.31	36.1	49.2	108.3	64.5
Ammonium phosphate N:P = 1:1.11	34.0	49.8	113.0	65.6
Superphosphate	33.3	40.2	74.8	49.4
$LSD_{0.05}$	6.62	9.62	28.80	9.49
Broadcast fertilization	31.2	41.8	56.0	43.0
In rows fertilization	34.9	44.6	125.6	68.3
$LSD_{0.05}$	2.1	n.s.	14.4	4.8

n.s. – no significant differences

Table 11

Yield of the maize grain [dt ha^{-1}] (KRUCZEK 2005d)

Studied factors	Years			Mean
	2001	2002	2003	
Hydrofoska 16; N/P = 1:0.44	98.7	66.6	101.6	89.0
Amofoska N:P = 1:1.74	100.6	65.5	102.6	89.6
Polifoska 8; N:P = 1:1.31	102.6	68.0	97.3	89.3
Ammonium phosphate N:P = 1:1.11	98.9	69.9	106.7	91.8
Superphosphate	98.9	65.3	104.0	89.4
$LSD_{0.05}$	n.s.	n.s.	n.s.	n.s.
Broadcast fertilization	97.7	66.8	100.8	88.4
In rows fertilization	102.2	67.4	104.0	91.2
$LSD_{0.05}$	2.6	n.s.	1.0	1.2

n.s. – no significant differences

Experiment 5. Response of medium early maize cultivars to fertilization method

In all the years of the study starter fertilization. in comparison to conventional broadcasting. significantly increased dry matter of aboveground parts of a single plant at the phase of 6–7 leaves (Table 12). On average for years (2004–2007) the greatest vigour of initial growth was found for hybrids Eurostar and Monumental. which differed significantly in terms of the level of this trait from hybrid Veritis. which dry matter of a single plant was the lowest. Hybrids tested in the experiment. when started fertilization was applied. had an increased dry matter in the initial period of plant development in comparison to broadcasting. Starter fertilization had an advantageous effect on grain yield. significantly increasing its level in comparison to broadcasting. on average for years and cultivars (Table 13). This information is of particular importance. since no significant interaction was observed for the method of fertilization with years of the study. A similar response to starter fertilization was found for all tested hybrids. Row application of ammonia phosphate significantly reduced grain moisture content in comparison to broadcasting (Table 14). A significant decrease in water content in grain as a result of starter application of fertilizer. in comparison to broadcasting was reported for hybrids Eurostar. Inagua. Energystar and LG 3226. It also needs to be stressed that the other hybrids responded similarly. although this difference was not confirmed statistically.

Table 12

The dry mass of above-ground parts of 1 plant in phase 6–7 leaves [g] (Kruczek and Skrzypczak 2010)

Hybrids	Method of fertilization		Mean
	broadcast	in rows	
Eurostar	3.23	4.33	3.78
Monumental	3.38	4.16	3.77
PR 39H32	3.11	4.36	3.73
Menuet	3.39	3.88	3.63
System	3.09	4.12	3.61
Delitop	3.40	3.71	3.55
Inagua	2.68	3.73	3.21
LG 3226	2.90	3.38	3.14
Energystar	2.53	3.50	3.01
Veritis	2.54	3.37	2.96
Mean	3.02	3.85	–
$LSD_{0.05}$	for method of fertilization = 0.22		for hybrids = 0.78

Table 13

Yield of the maize grain [dt ha^{-1}] (Kruczek and Skrzypczak 2010)

Hybrids	Method of fertilization		Mean
	broadcast	in rows	
Delitop	95.0	105.2	100.1
PR 39H32	90.0	94.1	92.0
Menuet	88.7	94.5	91.6
Veritis	87.9	92.4	90.2
Monumental	85.2	90.4	87.8
LG 3226	82.7	89.7	86.2
Eurostar	84.1	85.7	84.9
System	78.6	84.3	81.5
Energystar	79.0	83.5	81.2
Inagua	77.4	82.9	80.2
Mean	84.9	90.3	–
$LSD_{0.05}$	for method of fertilization = 1.5		for hybrids = 8.4

Table 14

Moisture content of grain at harvest [%] (Kruczek and Skrzypczak 2010)

Hybrids	Method of fertilization		Mean
	broadcast	in rows	
Monumental	27.7	27.4	27.6
PR 39H32	27.4	26.8	27.1
Eurostar	27.3	26.4	26.9
Menuet	27.0	26.5	26.8
System	26.9	26.4	26.6
Inagua	27.1	26.1	26.6
Veritis	26.3	25.8	26.0
Energystar	26.3	25.0	25.6
Delitop	25.7	25.3	25.5
LG 3226	26.7	24.3	25.5
Mean	26.8	26.0	–
$LSD_{0.05}$	for method of fertilization = 0.3		for hybrids = 1.3

Conclusions

Presented results clearly indicate an advantageous effect of topical fertilization with nitrogen (N) and phosphorus (P) on growth. development and yielding in maize. This effect is particularly evident in the initial period of plant development. in which weather conditions in Poland are frequently stress factors for maize. An adverse course of weather conditions hinders nutrient uptake by maize. mainly phosphorus. which leads to growth inhibition. Research results clearly indicate that this adverse phenomenon may be practically prevented by topical fertilization performed together with sowing. The positive effect of starter fertilization on maize in the initial period of vegetation is also reflected in its yielding. Yields of grain are significantly greater at fertilizer application simultaneous with sowing. than in the case of conventional broadcasting over the entire area of the field. A very important trait determining profitability of maize growing is also connected with grain moisture content at harvest. In all studies conducted at the Department of Agronomy the Poznan University of Life Sciences row application of fertilizers. in comparison to conventional broadcasting reduces water content in grain. Moreover. row fertilizer application makes it possible to reduce fertilization rates and extend the period of maize sowing. especially thanks to their acceleration. which is significant during periodical soil moisture deficits in early spring. Presented results are thus of considerable applicatory importance. which may improve economic results and organisation of maize growing in Poland.

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