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Effect of fertilization method on the uptake and accumulation of mineral components in the initial period of maize development**

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A b s t r a c t. On the basis of a 4–year study, the effect of fertilization methods on the uptake and accumulation of mineral components by maize was evaluated. Two methods were used: by broadcasting over the whole surface and by band fertilization. The applied fertilizer level was gradually increased from 17.4 to 56.7 kg P ha^{-1} with the use of superphosphate and ammonium phosphate. It was found that the uptake and accumulation of mineral components depended on all the studied factors and their effect was increasing with the advancing vegetation. Band fertilization and the use of ammonium phosphate kept increasing the accumulation of all mineral components from 4-5 to 8-9-leaf-stage, in comparison with broadcast fertilization and superphosphate application, respectively. No distinct effect of phosphorus fertilization level on the uptake and accumulation of mineral components was visible before the stage of 8-9 leaves. Regressions were calculated for the relationship between the mineral components accumulation and the lapse of time from emergence to 8-9-leaf-stage and for the relationship between the uptake of mineral components and the accumulation of dry matter.

K e y w o r d s: maize, fertilization, uptake, mineral components

INTRODUCTION

Slow initial growth of maize caused by low temperatures prevailing in that period is the result of decreased uptake of nutritive components, particularly of nitrogen and phosphorus (Mackay and Barber, 1984; Mozafar *et al*., 1993). Quick growth of maize root system permitting to limit the effects of nutritional stress is possible with an adequate nitrogen and phosphorus concentration in the soil solution (Alexandrova and Donov, 2003; Mollier and Pellerin, 1999; Rhoads and Wright, 1998; Scroeder *et al*., 1996). One of the ways of increasing phosphorus availability is the broadcasting of high doses of phosphoric fertilizer. In order to facilitate the uptake of this component by plants under unfavourable conditions, the doses must significantly exceed the nutritive requirements of maize. Such a procedure is not acceptable from the economic and ecological points of view. A significantly better method of increasing the availability of phosphorus is band fertilization, where the fertilizer is located in the direct vicinity of roots (El-Hamdi and Woodard, 1995; Mascagni and Boquet, 1996; Sleight *et al*., 1984; Tlustos *et al*., 1997). Localized fertilization for maize is a routine procedure in some countries, particularly in the USA (Arnon, 1975; Teare and Wright, 1990). Under Polish conditions, this problem is practically not fully recognized. So far, studies on the comparison of broadcast fertilization and band fertilization together with sowing (starting fertilization) were only fragmentary (Dubas and Duhr, 1983), or methodological assumptions limited the possibility of direct transfer of results to productive application (Koter *et al*., 1978). The aim of the present study was the determination of the effect of two methods of starting fertilization (by broadcasting and band fertilization) using phosphoric and phosphor-and-nitrogen fertilizers on the uptake and accumulation of mineral components by maize in the initial stage of development depending on phosphorus dose.

MATERIALS AND METHODS

The studies were carried out at the Experimental and Didactic Department in Swadzim near Poznań, in the years

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2000-2003. Field experiments were established in a 3-factor random split-plot design in 4 replications; each year on a different plot. The first factor included four doses of phosphorus: 17.4 (40 kg P_2O_5 ha^{-1}), 30.5 (70 kg P_2O_5 ha^{-1}), 43.6 (100 kg P_2O_5 ha^{-1}), and 56.7 kg P ha^{-1} (130 kg P_2O_5 ha^{-1}). The second factor included two kinds of fertilizer: superphosphate (46% P_2O_5) and ammonium phosphate (18% N and 46% P_2O_5). The third factor consisted of two fertilization methods: by broadcasting over the whole surface before seed sowing and by band fertilization (starter fertilization together with seed sowing).

Single maize seed-drill equipped with a fertilizer sower for band fertilization was used. Fertilizer coulters were set in relation to seed coulters in such a way that the fertilizer was placed in the soil 5 cm aside and 5 cm below the seeds. Phosphorus fertilization was done according to the experimental scheme within the studied factors, while N and K fertilization was carried out before maize sowing in the doses of 120 kg N ha^{-1} (ammonium nitrate 34% N) and 107.9 kg K ha^{-1} (130 kg K_2O ha^{-1}) – 60% potash salt. Nitrogen dose before sowing on the plots where ammonium phosphate was used was decreased by the amount of nitrogen introduced with this fertilizer. The size of plots for sowing was 42 m^2 (length 15 m, width 2.8 m – 4 rows). Plot area for observation and measurements was 21 m^2 (length 15 m, width 1.4 m – 2 middle rows). Mona hybrid (FAO 250) was the experimental plant.

In the developmental stages of 2-3 leaves, 4-5 leaves, 6-7 leaves and 8-9 leaves, 15 plants were sampled from each plot. Analyses of mineral components content were made (on cumulative samples from fertilizer combinations) in the laboratory of Agricultural and Chemical Station in Poznań. Nitrogen was determined by Kjeldahl's method, phosphorus and magnesium were identified by the colorimetric method, while potassium and calcium by the flame photometry method. The accumulation of mineral components by maize was calculated as the product of plant dry mass yield and the percentage content of the component. Results were statistically analysed using univariant analysis of variance as well as regression and correlation calculus. Hypotheses were tested at the level of $\alpha = 0.05$.

Thermal conditions in the years of the experiment were favourable for the initial growth and development of maize (Table 1). In all the experimental years, in comparison with the mean of many years, there occurred water deficiencies in the soil. Periods of drought occurred in April and June of 2000, in May of 2001, and from May till June in 2003.

The experiments were carried out on grey-brown podzolic soil, medium sand type, lying shallowly on sandy loam and belonging to the good rye complex. Phosphorus and potassium content in the soil was determined by the Egner-Riehm method. Magnesium content was determined by the Schachtschabel method and nitrogen was identified by the distillation method. Soil abundance in nutritive components and soil acidity are shown in Table 1.

RESULTS AND DISCUSSION

The effect of the studied factors on the uptake and accumulation of mineral components by maize in the 2-3-leaf-stage was not high (Tables 2 and 3). Phosphorus fertilization levels exerted an effect only on the uptake and accumulation of sodium. The highest values of these levels were found after the application of 17.4 kg P ha^{-1}, while the lowest ones were found after the application of 56.7 kg P ha^{-1}. The use of ammonium phosphate increased nitrogen and potassium uptake, and nitrogen, potassium and magnesium accumulation in comparison with superphosphate. Band fertilization had a positive effect only on the uptake and accumulation of magnesium in comparison with broadcast fertilization. The absence of a differentiated phosphorus uptake by maize under the influence of the studied factors including, among others, phosphorus doses and P and NP fertilizer forms, probably resulted from the insufficient amount of these components in the seed. As reported by Arnon (1975) and Rintelen (1971), the phosphorus contained in seeds satisfies the plant requirements for about two weeks from the sowing date. In our own studies, the mean time (for 4 years) from the sowing date to the development of 2-3 maize leaves was 11 days.

With the progress of vegetation, the effect of the studied factors on the uptake and accumulation of mineral

T a b l e 1. Weather and soil conditions at 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 100 g^{-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	-	-	-	-	-	-

Table 2. Real uptake of mineral components by maize in dependence on studied factors

Development stages	Studied factors	Nutrients (mg per plant)					
		P	N	K	Mg	Na	Ca
2-3 leaves	17.4 kg P ha^{-1}	0.468	3.962	2.893	0.251	0.018	0.551
	30.5 kg P ha^{-1}	0.464	3.845	2.809	0.242	0.017	0.505
	43.6 kg P ha^{-1}	0.487	3.985	2.717	0.255	0.017	0.542
	56.7 kg P ha^{-1}	0.474	3.904	2.909	0.239	0.016	0.549
	$LSD_{0.05}$	n.s.	n.s.	n.s.	n.s.	0.0012	n.s.
	superphosphate	0.472	3.846	2.772	0.244	0.017	0.532
	ammonium phosphate	0.476	4.002	2.892	0.250	0.017	0.541
	$LSD_{0.05}$	n.s.	0.1093	0.0785	n.s.	n.s.	n.s.
	broadcast fertilization	0.469	3.878	2.824	0.242	0.017	0.533
	band fertilization	0.478	3.970	2.840	0.251	0.017	0.540
	$LSD_{0.05}$	n.s.	n.s.	n.s.	0.0068	n.s.	n.s.
4-5 leaves	17.4 kg P ha^{-1}	1.186	12.811	10.982	0.727	0.058	2.034
	30.5 kg P ha^{-1}	1.272	12.953	10.814	0.690	0.062	1.941
	43.6 kg P ha^{-1}	1.457	13.849	10.351	0.726	0.065	1.968
	56.7 kg P ha^{-1}	1.620	14.493	11.474	0.750	0.066	2.068
	$LSD_{0.05}$	0.0945	0.9895	n.s.	n.s.	0.0045	n.s.
	superphosphate	1.282	12.468	10.676	0.703	0.062	1.976
	ammonium phosphate	1.486	14.585	11.134	0.744	0.064	2.029
	$LSD_{0.05}$	0.0587	1.4959	0.3745	0.0280	n.s.	n.s.
	broadcast fertilization	1.094	12.339	10.335	0.694	0.061	1.952
	band fertilization	1.674	14.714	11.475	0.753	0.064	2.053
	$LSD_{0.05}$	0.4650	2.3340	1.0727	0.0229	0.0019	0.0705
6-7 leaves	17.4 kg P ha^{-1}	5.364	50.988	49.537	2.581	0.375	6.810
	30.5 kg P ha^{-1}	5.986	51.126	46.689	2.649	0.351	6.522
	43.6 kg P ha^{-1}	6.486	54.147	48.585	2.923	0.358	6.840
	56.7 kg P ha^{-1}	6.594	54.471	51.649	2.758	0.427	6.993
	$LSD_{0.05}$	0.6835	2.6031	n.s.	n.s.	0.0392	n.s.
	superphosphate	4.880	44.444	46.545	2.376	0.364	6.386
	ammonium phosphate	7.335	60.922	51.685	3.079	0.391	7.197
	$LSD_{0.05}$	0.3885	2.8985	2.5040	0.1539	0.0211	0.3198
	broadcast fertilization	3.660	40.022	42.625	2.139	0.314	5.788
	band fertilization	8.554	65.344	55.605	3.317	0.442	7.795
	$LSD_{0.05}$	0.4018	2.915	2.6126	0.1582	0.0220	0.3161
8-9 leaves	17.4 kg P ha^{-1}	13.324	132.237	107.719	6.566	0.504	15.887
	30.5 kg P ha^{-1}	15.649	141.628	116.544	7.958	0.589	17.783
	43.6 kg P ha^{-1}	17.832	148.243	136.110	9.087	0.725	19.960
	56.7 kg P ha^{-1}	20.103	171.414	158.940	9.826	0.764	22.221
	$LSD_{0.05}$	2.4678	20.9383	18.5109	1.2576	0.0858	2.6966
	superphosphate	13.070	128.188	122.400	6.995	0.580	17.377
	ammonium phosphate	20.384	168.573	137.256	9.723	0.710	20.548
	$LSD_{0.05}$	1.4512	12.4529	11.3519	0.8019	0.0555	1.5981
	broadcast fertilization	10.572	109.310	109.059	6.096	0.505	14.882
	band fertilization	22.882	187.452	150.597	10.622	0.786	23.044
	$LSD_{0.05}$	1.3995	11.4399	9.6154	0.6966	0.0504	1.4375

n.s. – no significant differences.

T a b l e 3. Accumulation of mineral components by maize in dependence on studied factors

Development stages	Studied factors	Nutrients (g ha^{-1})					
		P	N	K	Mg	Na	Ca
2-3 leaves	17.4 kg P ha^{-1}	38.01	320.81	235.50	20.35	1.49	44.41
	30.5 kg P ha^{-1}	37.81	313.60	229.67	19.75	1.37	44.04
	43.6 kg P ha^{-1}	39.79	324.61	221.51	20.80	1.39	44.07
	56.7 kg P ha^{-1}	38.61	317.14	237.30	19.39	1.28	44.48
	$LSD_{0.05}$	n.s.	n.s.	n.s.	n.s.	0.094	n.s.
	superphosphate	38.34	312.17	225.68	19.79	1.37	43.07
	ammonium phosphate	38.77	325.91	236.31	20.36	1.40	43.93
	$LSD_{0.05}$	n.s.	8.645	6.432	0.542	n.s.	n.s.
	broadcast fertilization	38.29	316.05	230.91	19.73	1.38	43.34
	band fertilization	38.83	322.04	231.08	20.41	1.39	43.66
	$LSD_{0.05}$	n.s.	n.s.	n.s.	0.560	n.s.	n.s.
4-5 leaves	17.4 kg P ha^{-1}	97.07	1045.23	899.11	59.09	4.68	163.98
	30.5 kg P ha^{-1}	104.31	1057.04	887.80	56.12	5.10	156.84
	43.6 kg P ha^{-1}	119.78	1132.79	849.35	59.35	5.35	159.45
	56.7 kg P ha^{-1}	132.01	1177.24	937.38	60.87	5.32	166.41
	$LSD_{0.05}$	7.603	80.434	n.s.	n.s.	0.371	n.s.
	superphosphate	104.81	1014.66	873.55	57.05	5.03	159.29
	ammonium phosphate	121.78	1191.49	913.27	60.66	5.19	164.05
	$LSD_{0.05}$	9.006	131.615	30.125	2.226	n.s.	n.s.
	broadcast fertilization	89.59	1007.43	848.22	56.51	5.00	157.93
	band fertilization	137.00	1198.72	938.60	61.20	5.23	165.41
	$LSD_{0.05}$	39.980	33.656	25.210	1.785	0.146	5.466
6-7 leaves	17.4 kg P ha^{-1}	442.27	4193.63	4078.52	211.31	30.94	555.77
	30.5 kg P ha^{-1}	495.78	4216.97	3867.12	217.32	29.19	534.03
	43.6 kg P ha^{-1}	536.62	4442.95	4019.78	241.23	29.67	561.54
	56.7 kg P ha^{-1}	539.48	4469.08	4245.84	225.54	35.25	569.58
	$LSD_{0.05}$	56.197	260.750	n.s.	n.s.	3.197	n.s.
	superphosphate	401.27	3641.16	3832.89	194.06	30.11	520.46
	ammonium phosphate	605.81	5020.15	4272.74	253.64	32.42	590.00
	$LSD_{0.05}$	33.665	249.740	216.87	13.264	1.840	27.108
	broadcast fertilization	301.55	3285.72	3518.17	175.11	25.94	472.97
	band fertilization	705.53	5375.59	4587.46	272.59	36.58	637.49
	$LSD_{0.05}$	34.202	246.699	220.658	13.397	1.849	26.428
8-9 leaves	17.4 kg P ha^{-1}	1034.85	10282.18	9111.82	510.13	39.12	1306.32
	30.5 kg P ha^{-1}	1299.24	10506.40	9843.21	630.04	49.03	1408.52
	43.6 kg P ha^{-1}	1323.56	12173.97	10099.93	693.58	53.64	1459.12
	56.7 kg P ha^{-1}	1557.54	13292.64	11302.12	756.00	59.22	1714.19
	$LSD_{0.05}$	192.855	1620.778	1435.437	98.819	6.658	210.052
	superphosphate	1015.49	9973.23	9511.21	541.47	45.15	1347.26
	ammonium phosphate	1592.11	13154.37	10667.33	753.41	55.36	1596.81
	$LSD_{0.05}$	106.930	928.566	851.632	58.781	4.170	119.701
	broadcast fertilization	824.24	8529.79	8506.43	473.13	39.35	1157.27
	band fertilization	1783.36	14597.81	11672.11	821.74	61.15	1786.81
	$LSD_{0.05}$	111.519	909.326	768.37	55.633	4.003	115.136

n.s. – no significant differences.

components by maize increased (Tables 2 and 3). In the stages of 4-5 and 6-7 leaves, the increase of phosphorus fertilization level increased also the uptake and accumulation of nitrogen and phosphorus and it changed these values with respect to sodium. On the other hand, in the 8-9-leaf-stage, the uptake and accumulation of all analysed mineral components increased gradually with the increase of phosphorus dose from 17.4 to 56.7 kg P ha^{-1}. Similar results regarding phosphorus were obtained by El-Hamdi and Woodard (1995), who found an increase in the uptake of this component by maize with the increase of phosphorus dose.

The application of ammonium phosphate significantly increased, in comparison with superphosphate, the uptake and accumulation of P, N, K and Mg in the 4-5-leaf-stage and, additionally, it increased the uptake and accumulation of calcium and sodium in the stages of 6-7 and 8-9 leaves. The result obtained in the case of phosphorus was explained by Moskal (1972) who argued that the uptake and utilization of phosphorus by plants depends on the uptake of inorganic nitrogen compounds as a result of mutual physiological relations in plant metabolism.

Band fertilization significantly increased the uptake and accumulation of all mineral components, in relation to broadcast fertilization, both in the stages of 4-5, 6-7 and 8-9 leaves. A higher uptake of phosphorus by maize as a result of band fertilization was also found on the 28th day from the sowing date by El-Hamdi and Woodard (1995), and Rhoads and Wright (1998) reported the same observation on the 41st day from the sowing date.

With the progress of vegetation, there was also an increase in the influencing intensity of the studied factors on the uptake and accumulation of mineral components (Tables 2 and 3). For example, in the 4-5-leaf-stage, the increase of phosphorus dose from 17.4 to 56.7 kg P ha^{-1} increased also the P uptake by 36.6% and the N uptake by 13.1%, while the accumulation of these elements increased by 36 and 12.6%, respectively. On the other hand, in the stage of 8-9 leaves, both the uptake and accumulation were increased by about 50.9 and 29.6%, respectively. In the case of the application of ammonium phosphate, in comparison with superphosphate, in the 4-5-leaf-stage the P and N uptake increased by 15.9 and 17%, respectively, while P and N accumulation increased by 16.2 and 17.4%, respectively. In the 8-9-leaf-stage, the uptake and accumulation of P and N increased by 56 and 31.5% and by 56.8 and 31.9%, respectively. Band fertilization, in comparison with broadcasting fertilization, increased the P and N uptake by 53 and 19.2%, respectively, while the P and N accumulation increased by 52.9 and 19%, respectively. In the 8-9-leaf-stage, P uptake increased by 116.4% and N uptake by 71.5% while P and N accumulation increased by 116.4 and 71.1%, respectively.

Accumulation of dry mass, and thereby the occurrence of mineral components, is more associated with plant growth than with its development. In a definite development stage, depending on time lapse and different amounts of dry mass in the years, plants can accumulate different amounts of components. On this basis, we can conclude that it is more practical to determine the effect of the studied factors on the amount of accumulated mineral components for a definite amount of dry mass rather than to calculate it in reference to the developmental stage of maize, because it allows to minimize the impairing effect on the environment. Hence, in the calculus of regression presented below, the time lapse counted in days from full emergence to the occurrence of the definite developmental phase was accepted as independent variable. The occurrence variability of the particular developmental stages, differentiated under the influence of soil and climatic conditions, is presented in Table 4.

Relationships between the yield of dry mass or the accumulation of mineral components and the time lapse were described by an exponential model in the form:

$$y = ax^b,$$

where: y – yield of dry mass (kg ha^{-1}) or accumulation of mineral components (g ha^{-1}); x – number of days from emergence; a, b – regression coefficients.

Corresponding regressions are presented in Table 5 and the high coefficients of determination certify that the model has been well selected to describe this dependence. On the basis of these coefficients, the yields of dry mass for the particular developmental stages of maize and the uptake of mineral components were calculated (Table 6). As follows from the equations and from Table 6, the accumulation of dry mass, under the influence of the studied factors,

T a b l e 4. Time (in days) since emergence to reach the given stage of maize plant development

Development stage	Number of days from emergence			Standard deviation	Coefficient of variation
	minimal	maximal	mean		
2-3 leaves	4	5	4.25	0.5000	11.76
4-5 leaves	10	11	10.5	0.5774	5.50
6-7 leaves	18	19	18.5	0.5774	3.12
8-9 leaves	31	34	32.5	1.7321	5.33

T a b l e 5. Coefficients of regression equations for the relation between the time of emergence (days) and the yield of dry mass of aboveground plant parts (kg ha^{-1}) or the accumulation of mineral components (g ha^{-1})

Specification	Coefficients*	Studied factors							
		P dose (kg ha^{-1})				Kind of fertilizer		Method of fertilization	
		17.4	30.5	43.6	56.7	superphosphate	ammonium phosphate	broadcast fertilization	band fertilization
Yield of dry mass	a	0.4467	0.4080	0.4143	0.3730	0.4326	0.3848	0.4898	0.3568
	b	1.8351	1.8759	1.8742	1.9403	1.8381	1.9307	1.7634	1.9756
	R^2	0.9297	0.9330	0.9371	0.9523	0.9414	0.9372	0.9427	0.9346
P accumulation	a	2.7276	2.4383	2.6692	2.2942	3.0026	2.1912	3.4252	2.0618
	b	1.6622	1.7460	1.7393	1.8323	1.6283	1.8465	1.5140	1.9057
	R^2	0.8849	0.8888	0.8993	0.9359	0.9068	0.9065	0.8967	0.9064
N accumulation	a	21.924	20.1400	22.251	18.895	22.195	19.597	25.753	17.644
	b	1.7379	1.7837	1.7595	1.8475	1.7177	1.8403	1.6361	1.8959
	R^2	0.9178	0.9275	0.9315	0.9498	0.9363	0.9315	0.94	0.9275
K accumulation	a	12.178	11.849	11.906	10.573	11.901	11.299	13.068	10.439
	b	1.8946	1.9037	1.8932	1.9947	1.8995	1.9463	1.8412	1.9952
	R^2	0.9098	0.9073	0.9097	0.9250	0.9170	0.9118	0.9108	0.9168
Mg accumulation	a	1.6012	1.1888	1.4123	1.1245	1.4816	1.1761	1.6487	1.1041
	b	1.6276	1.7739	1.7115	1.8118	1.6555	1.8055	1.5873	1.8482
	R^2	0.9238	0.9328	0.9187	0.9303	0.9384	0.9217	0.9333	0.9237
Ca accumulation	a	3.3844	2.7806	3.2153	2.7469	3.1987	2.8416	3.6134	2.6032
	b	1.7048	1.7784	1.7303	1.8190	1.7205	1.7976	1.6470	1.8414
	R^2	0.9473	0.9565	0.9468	0.9555	0.9553	0.9505	0.9519	0.9512
Na accumulation	a	0.0929	0.0728	0.0785	0.0570	0.0806	0.0695	0.0970	0.0652
	b	1.7797	1.8964	1.8647	2.0165	1.8457	1.9304	1.7172	1.9431
	R^2	0.8745	0.8965	0.8916	0.8978	0.8943	0.8933	0.9502	0.9383

*a, b – coefficients of regression, R^2 – coefficient of determination.

occurred with different intensity in the particular developmental stages, disregarding the 2-3-leaf-stage where the effect of the studied factors was not high. The increase of phosphorus dose from 17.4 to 56.7 kg P ha^{-1} caused the increase of the yield of plant dry mass by 6.9% after 10.5 days from emergence; 18.5 days after emergence, it increased by 13.5%; and 32.5 days after emergence it increased by 20.4%. The application of ammonium phosphate increased the yield of plant dry mass, as compared with superphosphate, by 10.6% after the lapse of 10.5 days from emergence, by 16.5% after 18.5 days from emergence and by 22.8% after 32.5 days from emergence. Band fertilization, in comparison with broadcasting fertilization, increased the yield of plant dry mass by 20.0% after the lapse of 10.5 days from emergence; by 35.3% after 18.5 days from emergence; and by 52.5% after 32.5 days from emergence. This indicates that the highest positive effect on the accumulation of dry mass in the initial period of maize development was exerted by the fertilization method, by the fertilizer type applied in an almost twice smaller amount and by the lowest level of phosphorus fertilization.

A more favourable effect of increased phosphorus dose, the use of ammonium phosphate and the application of band fertilization exerted on the uptake of mineral components was intensified with the lapse of time in the initial developmental stage of maize. The same situation was observed for the accumulation of dry mass (Tables 5 and 6). For example, the increase of phosphorus dose from 17.4 to 56.7 kg P ha^{-1}, after the lapse of 10.5 days from emergence, increased the accumulation of P by 25.5%, N accumulation by 11.5% and K accumulation by 9.9%. After 18.5 days from emergence, P accumulation increased by 38.2%, N by 18.7% and K by 16.3%. After 32.5 days from emergence, P accumulation increased by 52.1%, N by 26.2% and K by

T a b l e 6. Calculated values of dry mass accumulation and nutrients used by maize in dependence on the studied factors

Mean number of days after emergence	Studied factors	Dry mass (kg ha^{-1})	Accumulation (g ha^{-1})					
			P	N	K	Mg	Na	Ca
4.25 days (2-3 leaves)	17.4 kg P ha^{-1}	6.36	30.22	271.02	188.85	16.87	39.88	1.22
	30.5 kg P ha^{-1}	6.16	30.50	266.02	186.19	15.48	36.45	1.13
	43.6 kg P ha^{-1}	6.24	33.06	283.79	184.26	16.80	39.31	1.17
	56.7 kg P ha^{-1}	6.18	32.51	273.70	189.52	15.50	38.18	1.05
	superphosphate	6.18	31.67	266.46	185.87	16.26	38.56	1.16
	ammonium phosphate	6.29	31.70	280.94	188.83	16.03	38.30	1.14
	broadcast fertilization	6.28	30.62	274.75	187.59	16.39	39.16	1.16
	band fertilization	6.22	32.49	274.13	187.25	16.01	37.92	1.09
10.5 days (4-5 leaves)	17.4 kg P ha^{-1}	33.42	135.89	1305.10	1047.90	73.54	186.38	6.10
	30.5 kg P ha^{-1}	33.60	147.94	1335.23	1041.65	77.02	182.06	6.29
	43.6 kg P ha^{-1}	33.98	159.42	1393.58	1021.13	79.01	188.01	6.30
	56.7 kg P ha^{-1}	35.74	170.51	1455.36	1151.24	79.64	197.87	6.53
	superphosphate	32.59	138.13	1259.95	1035.94	72.66	182.78	6.18
	ammonium phosphate	36.04	168.39	1484.17	1097.95	82.07	194.65	6.51
	broadcast fertilization	30.96	120.44	1206.69	991.80	68.88	173.71	6.50
	band fertilization	37.14	182.11	1522.90	1137.98	85.19	202.37	6.29
18.5 days (6-7 leaves)	17.4 kg P ha^{-1}	94.49	348.40	3492.51	3064.50	184.88	489.50	16.72
	30.5 kg P ha^{-1}	97.22	397.71	3667.02	3061.94	210.35	498.51	18.42
	43.6 kg P ha^{-1}	98.23	426.95	3775.19	2983.84	208.30	500.97	18.10
	56.7 kg P ha^{-1}	107.25	481.36	4144.04	3563.08	222.24	554.41	20.47
	superphosphate	92.32	347.40	3333.31	3037.92	185.58	484.33	17.59
	ammonium phosphate	107.59	479.20	4208.87	3306.26	228.20	538.80	19.42
	broadcast fertilization	84.05	283.91	3048.23	2814.01	169.25	441.52	14.55
	band fertilization	113.72	535.92	4456.85	3523.06	242.66	577.50	18.90
32.5 days (8-9 leaves)	17.4 kg P ha^{-1}	265.75	888.86	9298.69	8912.31	462.58	1279.21	45.57
	30.5 kg P ha^{-1}	279.77	1063.74	10018.57	8950.64	571.53	1357.91	53.61
	43.6 kg P ha^{-1}	282.41	1137.63	10174.39	8670.89	546.41	1328.11	51.77
	56.7 kg P ha^{-1}	320.05	1351.62	11736.22	10963.57	616.86	1545.11	63.77
	superphosphate	260.06	869.56	8774.40	8859.43	471.69	1276.94	49.75
	ammonium phosphate	319.32	1356.36	11871.58	9899.62	631.18	1483.63	57.61
	broadcast fertilization	227.03	666.31	7663.38	7941.25	413.96	1116.83	38.28
	band fertilization	346.18	1568.35	12971.10	10843.48	687.50	1639.11	56.49

23%. In relation to superphosphate, as a result of ammonium phosphate application, after 10.5 days from emergence the accumulation of P increased by 21.9%, N accumulation by 17.8% and that of K by 6%; 18.5 days after emergence, the values increased respectively by: 37.9% for P, 26.3% for N and 8.8% for K; and 32.5 days after emergence, the corresponding values increased by 56% for P, by 35.3% for N and by 11.7% for K. Band fertilization, in comparison with broadcast fertilization, after the lapse of 10.5 days from emergence, increased the accumulation of the respective elements by the following percentage values: P by 51.2%, N by 26.2% and K by 14.7%. After 18.5 days from emergence, the accumulation of the respective elements increased: P by 88.8%, N by 46.2% and K by 25.2%. After 32.5 days from emergence, the accumulation increased: P by 135.4%, N by 69.2% and K by 36.5%. Similar dependences referred to magnesium, calcium and sodium. The fertilization method was the studied factor which exerted the highest effect on

Table 7. Coefficients of regression equations for the relation between the uptake of mineral components and the accumulation of dry mass in the initial stage of maize development

Nutrients	Coefficients*	Studied factors							
		P dose (kg ha^{-1})				Kind of fertilizer		Method of fertilization	
		17.4	30.5	43.6	56.7	super-phosphate	ammonium phosphate	broadcast fertilization	band fertilization
P	a	-0.0782	-0.0048	0.1381	0.0187	-0.0236	0.1572	0.2026	0.0149
	b	4.0190	4.2471	3.8759	4.3032	3.7461	3.9190	2.7078	4.6628
	c	-0.2054	-0.0651	0.148	0.1183	0.0706	0.1607	0.1771	0.0920
	R^2	0.9923	0.9921	0.993	0.9953	0.9927	0.9789	0.9936	0.9753
N	a	37.015	37.922	38.641	38.920	36.387	39.563	35.808	39.688
	b	0.9525	0.9481	0.9430	0.9538	0.9384	0.9557	0.9275	0.9609
	R^2	0.9969	0.9976	0.9971	0.9977	0.9965	0.9966	0.9965	0.9966
K	a	32.788	31.871	30.667	33.112	33.528	30.963	33.762	31.190
	b	1.0455	1.0253	1.0351	1.0409	1.0543	1.0212	1.0656	1.0171
	R^2	0.9884	0.9866	0.9888	0.9878	0.9885	0.9852	0.9886	0.9800
Mg	a	1.9747	2.1261	2.1168	2.0634	2.0102	2.1007	1.9760	2.1285
	b	0.8875	0.9339	0.9164	0.9359	0.8842	0.928	0.7869	0.9293
	R^2	0.9968	0.9911	0.9904	0.9873	0.9821	0.9901	0.9886	0.9898
Ca	a	5.2133	5.1448	5.1291	5.2137	5.3015	5.0564	5.2023	5.1456
	b	0.9256	0.9335	0.9244	0.9390	0.9359	0.9228	0.9301	0.9276
	R^2	0.9801	0.9814	0.9854	0.9848	0.9807	0.9839	0.9784	0.9853
Na	a	0.1912	0.1978	0.1937	0.2013	0.1998	0.1845	0.1992	0.1927
	b	0.9980	1.0234	1.0314	1.0611	1.026	1.0165	1.0237	1.0329
	R^2	0.9646	0.9773	0.9818	0.9636	0.9652	0.9672	0.9657	0.9718

Explanations as in Table 5.

maize nutrition level in all the analysed mineral components, expressed by their accumulation percentage. It indicates that, in practice, the optimal nutrition of maize plant in the initial period of development can be obtained with a decreased dose of the nutritive component in the fertilizer when it is used in the adequate form and in a localized way, as compared with the traditional broadcasting fertilization method and higher doses.

The relationships between the uptake of mineral components and the dry mass of the aboveground parts per plant were determined for all the studied factors. This dependence was described for phosphorus by the model of second order regression and for the remaining components by a power function. The equations have the following general form:

$$y = ax^2 + bx + c \quad \text{or} \quad y = ax^b,$$

where: y – uptake of mineral component (mg per plant), x – dry mass of 1 plant (g), a, b, c – regression coefficients.

High coefficients of determination R^2 (Table 7) indicate that the model for the description of the relationships was selected well; they are graphically presented for the particular forms and fertilization methods (Figs 1 and 2), for the range of dry mass corresponding to real values. In the case of phosphorus doses, the course of some functions overlapped, making the graph illegible. The relationships between the uptaken amount of mineral components for all the investigated factors and the dry mass of the aboveground plant were similar. The studied factors differed, however, in the amount and accumulation rate of dry mass - hence, the amounts of mineral components taken up by plants in the particular developmental stages were different. The amounts of mineral components calculated according to the equation for the mean value of dry mass of one plant (Table 7) related to the studied factors in the particular developmental stages are shown in Table 8.

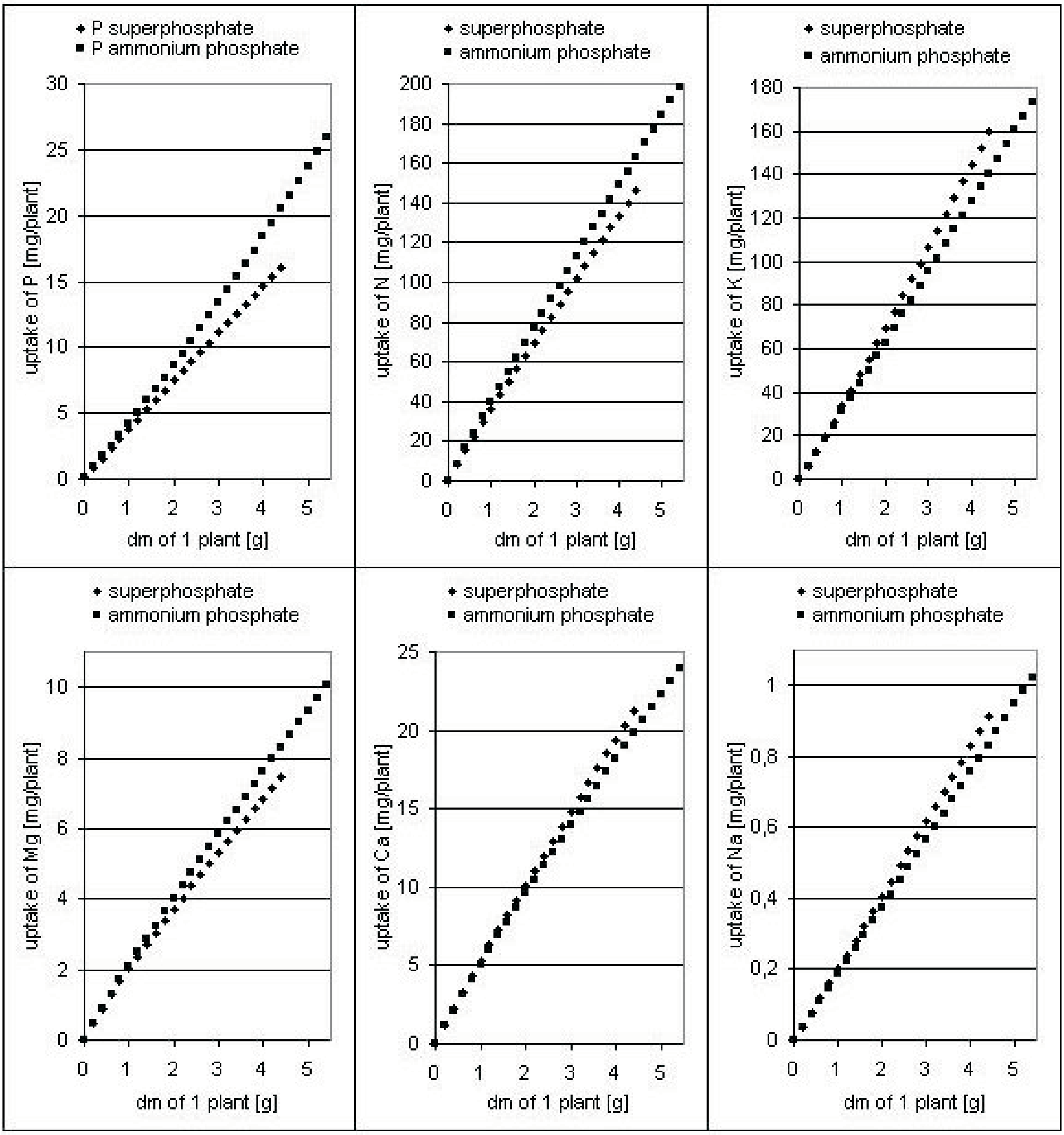

Fig. 1. Relationship between the uptake of mineral components and dry mass (dm) accumulation during the initial period of maize development for the given fertilizer types.

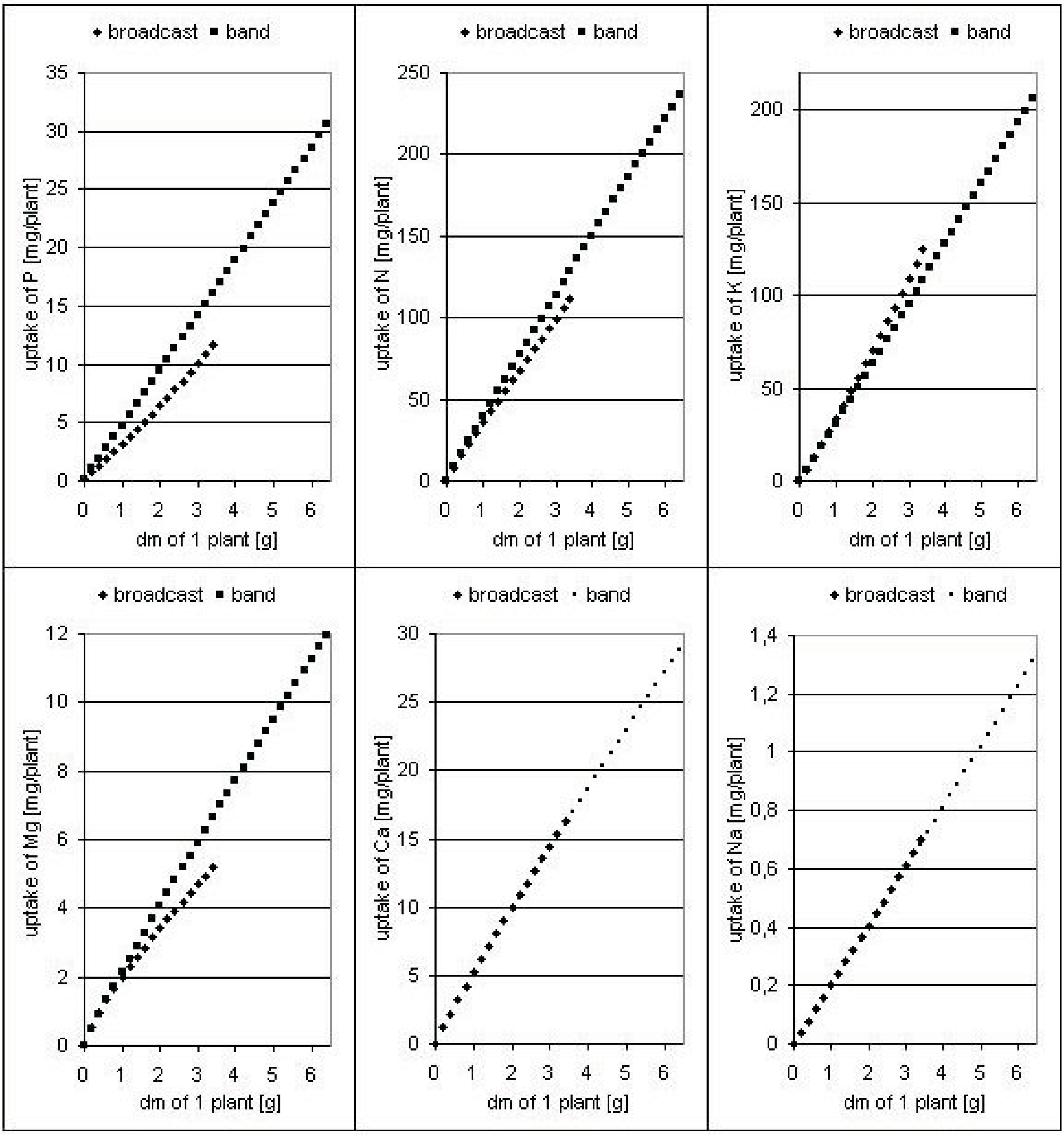

Fig. 2. Relationship between the uptake of mineral components and dry mass (dm) accumulation during the initial period of maize development for the given fertilization methods.

Table 8. Calculated values of mineral components taken up by maize depending on the mean dry mass of aboveground parts of one plant resulting due to the studied factors

Mean number of days after emergence	Studied factors	Dry mass (g)	Uptake (mg per plant)					
			P	N	K	Mg	Na	Ca
4.25 days (2-3 leaves)	17.4 kg P ha^{-1}	0.0946	0.174	3.917	2.786	0.244	0.588	0.018
	30.5 kg P ha^{-1}	0.0906	0.320	3.892	2.717	0.226	0.567	0.017
	43.6 kg P ha^{-1}	0.0918	0.505	4.065	2.589	0.237	0.564	0.017
	56.7 kg P ha^{-1}	0.0918	0.514	3.990	2.757	0.221	0.554	0.016
	superphosphate	0.0910	0.411	3.838	2.679	0.241	0.563	0.017
	ammonium phosphate	0.0970	0.542	4.256	2.859	0.241	0.587	0.017
	broadcast fertilization	0.0916	0.427	3.901	2.644	0.301	0.563	0.017
	band fertilization	0.0920	0.521	4.006	2.755	0.232	0.563	0.016
10.5 days (4-5 leaves)	17.4 kg P ha^{-1}	0.327	1.100	12.764	10.190	0.732	1.853	0.063
	30.5 kg P ha^{-1}	0.320	1.294	12.874	9.909	0.734	1.776	0.062
	43.6 kg P ha^{-1}	0.327	1.430	13.467	9.642	0.760	1.825	0.061
	56.7 kg P ha^{-1}	0.350	1.627	14.299	11.102	0.772	1.946	0.066
	superphosphate	0.318	1.259	12.417	10.019	0.730	1.814	0.062
	ammonium phosphate	0.344	1.527	14.269	10.413	0.780	1.889	0.062
	broadcast fertilization	0.314	1.047	12.229	9.826	0.794	1.771	0.061
	band fertilization	0.348	1.717	14.386	10.660	0.798	1.933	0.065
18.5 days (6-7 leaves)	17.4 kg P ha^{-1}	1.352	5.085	49.333	44.942	2.581	6.892	0.258
	30.5 kg P ha^{-1}	1.403	5.884	52.278	45.100	2.917	7.057	0.280
	43.6 kg P ha^{-1}	1.487	6.217	56.174	46.241	3.045	7.402	0.292
	56.7 kg P ha^{-1}	1.468	6.476	56.130	49.378	2.955	7.477	0.303
	superphosphate	1.306	4.923	46.746	44.427	2.545	6.806	0.263
	ammonium phosphate	1.591	6.794	61.663	49.750	3.232	7.762	0.296
	broadcast fertilization	1.198	3.712	42.340	40.929	2.278	6.154	0.240
	band fertilization	1.699	8.057	66.014	53.474	3.483	8.413	0.333
32.5 days (8-9 leaves)	17.4 kg P ha^{-1}	3.658	13.450	127.311	127.229	6.243	17.316	0.698
	30.5 kg P ha^{-1}	3.865	16.278	136.637	127.468	7.505	18.175	0.789
	43.6 kg P ha^{-1}	4.045	18.086	144.335	130.285	7.618	18.667	0.819
	56.7 kg P ha^{-1}	4.587	20.251	166.395	161.648	8.584	21.793	1.013
	superphosphate	3.569	13.140	120.076	128.221	6.192	17.439	0.737
	ammonium phosphate	4.509	21.028	166.876	144.142	8.499	20.297	0.853
	broadcast fertilization	3.096	10.502	102.141	112.571	4.808	14.883	0.633
	band fertilization	4.982	23.692	185.599	159.715	9.466	22.822	1.012

CONCLUSIONS

1. The effect of the studied factors on dry mass accumulation, uptake and accumulation of mineral components by maize increased with time lapse from the emergence to the 8-9-leaf-stage.

2. Dry mass accumulation and plant nutrition level by phosphorus, nitrogen, potassium, magnesium, calcium and sodium depended in the highest degree on the fertilization method, in a lesser degree on fertilizer type, and in the least degree on phosphorus dose.

3. Localized band fertilization, as well as the 2-component NP fertilizer, had a stimulating effect on the initial growth of maize, which was demonstrated by an increased uptake of mineral components and in effect it gave a greater amount of plant dry mass as compared with broadcast fertilization and superphosphate application, respectively.

4. Band fertilization with a low dose of component allows to obtain the same effect of maize nutrition in the initial developmental stage as can be achieved by broadcast fertilization with higher doses.

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