Effect of Potassium Metaphosphate on the Dry Matter Yield and the Nutrient Uptake of Rye Seedlings, Cow-Pea (Vigna sinensis L.) and Tobacco Plants in Pot Experiments

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Although potassium metaphosphate (the so-called Kurrol's salt) has been produced as a chemical for more than a century, it could be counted among the PK-fertilizers applicable in practice only in the last decade [3, 6]. Although it presented itself, because of its high nutrient content, as a good basic material for the up-to-date fertilizer production, for a long time it did not prove to be a suitable fertilizer basis because of the inhomogenity of the products obtained [12, 17]. It was only in 1960 that the Scottish Agricultural Industries Ltd. (SAI) obtained a patent for a potassium metaphosphate preparation [6, 14] that can be produced, at a relatively low temperature (450°C), of unexpensive materials (wet-process phosphoric acid and potassium chloride) of technical grade. The number of experiments carried out with this preparation is not large [1, 3, 6] but on the basis of experiences gained up to now it seems that, as regards both efficiency and economy it becomes an ever more competitive basic material in the production of mixed fertilizers. This is due, principally, to the favourable physical and chemical properties of the preparation. It has a high nutrient concentration but does not contain ions harmful to the plants as it is illustrated by the table showing the composition of potassium metaphosphate preparations produced in the SAI works in Scotland and the Ferchem-works in Israel [3, 6].

Component	Average content %	
	in the SAI product	in the Ferchem product
P_2O_5 (total)	58	55—57
K_2O	37	36—38
MgO	0,4	0,2—0,5
Fe_2O_3	0,2	0,5—1,0
Cl	0,1	0,5—1,0
SO_3	1,5	1,0—3,0

It is also advantageous that potassium metaphosphate can be easily granulated, and it is neither adhesive nor hygroscopic. Consequently it can be stored well and transported even over longer distances without any harm. It can be easily mixed with other fertilizers. Other salts, especially the nitrates, improve the solubility of the phosphorus content of potassium metaphosphate [18]. Since potassium metaphosphate is free of chloride and dissolves in water slowly, it does not affect the quality of plants sensitive to chloride [1, 7, 8], it has no harmful salt effect [6] and can be applied in larger quantities even for several years in advance without any hazard. In the soil it becomes enzymatically hydrolized [15], its potassium ions get quickly hold on the adsorbing surfaces [5]. The metaphosphate (PO_3) ions are absorbed by the plants directly only in small quantities and — when applied in higher concentrations — they get fixed in the soil to a 2—3-fold lower degree than the orthophosphate ions [16]. From potassium metaphosphate the potassium becomes sooner available for the plants than the phosphorus [2, 5]. With the PO_3 and PO_4 ions, respectively, deriving from the metaphosphate, the Ca-ions contained in the soil get precipitated and, as a consequence, the availability of potassium ions increases [11].

On the basis of pot and field experiments numerous authors [3, 6, 9, 10, 12, 13] have found potassium metaphosphate to be equivalent — on the same nutrient level — with the mixture of superphosphate and KCl or K_2SO_4, respectively, as regards both the dry matter yield and nutrient uptake in the case of plants of slow initial development and soils with a not very low phosphorus content. On calcareous soils it was the fine-grain material and on very acidic soils (pH $<$ 5) the coarse grain material (⌀ $>$ 0,5 mm) that exerted a good effect [4, 5]. K metaphosphate can be produced economically in areas where both P and K minerals are available together and the HCl obtained as a by-product can be utilized. Owing to its high nutrient concentration and to the possibility of the relatively simple way of its completion with nitrogen fertilizers, its application may be perspective mainly in the production of complex fertilizers in countries having no PK raw materials, thus in Hungary, too.

Materials and methods

The effect of potassium metaphosphate was compared with the effect of superphosphate and potassium salt in pot experiments on various Hungarian soils in which rye seedlings, cow-pea and tobacco were used as test plants.

Table 1

Some analytical data of the experimental soils

Place of origin	Texture	pH		$CaCO_3$ %	hy_1	Humus %	"Total" mg%			Available mg%	
		H_2O	KCl				N	P_2O_5	K_2O	P_2O_5	K_2O
Nagykálló	loamy sand	5,9	5,7	—	1,0	1,5	80	100	490	1,5	10,4
Mezőnagymihály	clay	5,9	5,6	—	4,1	4,9	220	120	970	4,7	10,7
Őrszentmiklós	sand	7,1	6,8	3,1	0,5	0,9	43	66	290	3,4	8,6
Nyírlugos	sand	5,8	5,1	—	0,9	0,7	63	42	202	3,9	9,7

The potassium metaphosphate used in the pot experiments was the product of the Scottish Agricultural Industries Ltd. (SAI) and its composition was the following: P_2O_5 57,0%, K_2O 36,5%, Cl 0,35%. The pH value of the water extract is 5,7. Maximum 5% of the phosphorus and potassium content is water-soluble. The potassium metaphosphate was powdered before use. The phosphorus content of the superphosphate was 17,5% P_2O_5 (2,5% free acid) and the K content of the K salt was 39,9% K_2O. The K_2SO_4 was of reagent grade (54% K_2O).

In the experiments the following soils were used: brown forest soil on slightly acid loamy sand (from Nagykálló), clay meadow soil (from Mezőnagymihály), humous, calcareous sandy soil (from Örszentmiklós) and brown forest soil with "Kovárvány" on acid sand (from Nyirlugos). The principal characteristics of the soils are given in Table 1. The pH value was determined in water extract and N KCl extract with a glass electrode, the $CaCO_3$ according to Scheibler, the hy_1 (hygroscopicity) above $CaCl_2 \cdot 6H_2O$, the humus and the total N content according to Tyurin, the "total" phosphorus and potassium content from the digestion of concentrated sulphuric acid and $HClO_4$, the available phosphorus and potassium in the calcareous sandy soil from Örszentmiklós according to Machigin (from a 1% $(NH_4)_2CO_3$ extract) and in the remaining soils with the Egner--Riehm double lactate method.

All pot experiments were carried out in 4 replications in a green-house.

1. Experiment with rye seedlings (according to Neubauer)

In the experiment winter rye seedlings were raised on a mixture consisting of 500 g of pure quartz sand and 100 g of soil (100 grains were sown in each pot). At an age of 18 days the plants were cut off 1 cm above the soil. The experiments were carried out in October. Treatments applied to the soils from Nagykálló and Mezőnagymihály: Ø N, NP_1K_1, NP_2K_2 and $NP_2K_2(KPO_3)$. Nutrient levels: 32 mg of $N(NH_4NO_3)$, 23 and 46 mg of P_2O_5 and 15 and 30 mg of K_2O/pot, respectively. The cut-off plants were dried at 60°C and the weight of the dry matter was determined afterwards. The dried plants were digested with sulphuric acid $+H_2O_2$ and the NPKCa contents were determined.

Having removed the majority of roots, we added 5 mg of N/pot (NH_4NO_3) to the soil—quartz mixture which then was incubated at 37°C for 10 days in order to decompose the residual roots. After incubation 32 mg of N/pot (NH_4NO_3) were added to all soils except the control. Then rye was sown again to test the residual effect of PK. The experiment was carried out at the end of November and at the beginning of December so that artificial lighting had to be applied. The plants were cut off at the age of 18 days and processed in the manner described previously.

2. Pot experiments with cow-pea

In the first series 8 kg of soil and 2 kg of washed river gravel were put in each pot and 3 plants were raised to full ripening. Treatments applied to the soils from Nyirlugos and Örszentmiklós: N, NPK, N-KPO_3. Nutrient levels: 200 mg of N (NH_4NO_3), 1000 mg of P_2O_5 and 638 mg of K_2O/pot. The experiments were carried out in the spring–summer period. The leaves were picked continuously and the seed, the pod and the stem (cut off 1 cm above the soil) at full ripening. The yield — divided into seed, pod, leaf and stem — was weighed in air-dry condition. The yield portions were ground to flour, digested with sulphuric acid $+H_2O_2$ and their NPKCa contents were determined.

The second series was carried out in the same pattern. Treatments applied to the soil from Örszentmiklós: Ø, N, NP, NK, NPK, N-KPO_3. The experiment was carried out in the summer–autumn period and the plants were processed in the same manner as in the first series.

Table 2
Dry matter production and nutrient uptake of rye seedlings

Treatment	Number of plants/pot	Dry matter g/pot	Nutrient uptake, mg/pot			
			N	P_2O_5	K_2O	CaO
(1. cutting)						
Soil of Nagykálló						
∅	76	1,10	53,9	13,2	24,8	12,5
N	78	1,22	75,8	13,8	22,6	15,2
N P_1K_1	77	1,28	79,1	20,7	33,8	18,7
N P_2K_2	80	1,36	79,4	29,2	45,3	19,7
N P_2K_2 (KPO_3)	82	1,34	77,5	22,4	42,0	15,3
Soil of Mezőnagymihály						
∅	76	0,96	38,7	12,8	26,8	9,9
N	77	1,12	57,1	16,0	32,7	13,7
N P_1K_1	80	1,18	59,4	22,8	43,0	15,2
N P_2K_2	70	1,16	58,8	28,2	52,3	16,2
N P_2K_2 (KPO_3)	79	1,23	59,5	24,3	49,5	13,9
$LSD_{5\%}$	7,7	0,15	9,4	2,8	4,7	2,1
F values						
Treatment	—	×××	×××	×××	×××	×××
Soil (S)	—	×××	×××	—	×××	×××
Fertilizer (F)	—	×××	×××	×××	×××	×××
S×F	—	—	—	—	—	—
(2. cutting)						
Soil of Nagykálló						
∅	70	0,84	36,6	13,2	18,0	6,8
N	77	0,92	54,5	15,5	17,4	7,5
N P_1K_1	74	0,87	54,4	17,4	17,9	8,6
N P_2K_2	55	0,74	44,8	14,8	16,1	8,7
N P_2K_2 (KPO_3)	68	0,88	53,7	19,6	19,0	6,9
Soil of Mezőnagymihály						
∅	70	0,81	32,6	14,2	24,1	7,0
N	72	0,94	50,0	14,8	22,4	9,5
N P_1K_1	72	0,95	54,6	16,8	22,2	10,0
N P_2K_2	67	0,86	52,2	18,3	23,3	10,0
N P_2K_2 (KPO_3)	70	0,90	49,2	17,8	24,9	8,7
$LSD_{5\%}$	10,5	0,14	7,0	2,6	2,2	1,2
F values						
Treatment	×	—	×××	×××	×××	×
Soil (S)	—	—	—	×××	×××	—
Fertilizer (F)	×	+	×××	×	×××	×
S×F	—	—	+	—	—	—

3. *Pot experiments with tobacco*

In the first series 7 kg of soil and 2 kg of washed river gravel were put into each pot. The tobacco was of the Virginia type, variety Tisza. Uniformly well developed tobacco plants raised in garden earth compost were planted in the pots at the age of 6 weeks (1 plant per pot). Treatments applied to the soil from Örszentmiklós: ∅, N, NP, NK, NPK, N-KPO_3. Nutrient levels: 200 mg of N (NH_4NO_3), 1200 mg of P_2O_5 and 765 mg of K_2O/pot. The experiment was carried out in the period from November to February and no arti-

Table 3

Dry matter production and nutrient uptake of cow-pea (Vigna sinensis L.)

Treatment	Dry matter g/pot					Total nutrient uptake mg/pot			
	Seed	Pod	Leaf	Stem	Total	N	P_2O_5	K_2O	CaO
(1. experiment)									
Soil of Nyírlugos									
N	7,0	3,2	5,0	3,1	18,3	366	120	395	533
NPK	5,0	3,0	7,0	4,5	19,5	346	148	579	685
N + KPO_3	6,6	3,1	6,5	3,7	19,9	401	148	509	582
Soil of Őrszentmiklós									
N	5,3	2,2	3,7	2,3	13,5	297	76	219	553
NPK	5,7	3,1	5,3	3,4	17,5	356	113	459	710
N + KPO_3	5,8	2,8	5,9	3,3	17,8	383	122	422	670
$LSD_{5\%}$	1,2	0,5	1,3	0,7	2,6	121	17	59	66
F values									
Treatment	××	××	×××	×××	××	—	×××	×××	×××
Soil (S)	×××	×××	×××	×××	×××	+	×××	×××	×××
Fertilizer (F)	×××	×	×××	×××	××	—	×××	×××	+
S×F	×××	×××	—	—	+	—	—	+	—
(2. experiment)									
Ø	8,2	2,9	3,8	1,8	16,7	401	119	296	591
N	10,1	3,4	5,3	2,0	20,8	517	140	355	789
NP	10,0	3,4	5,6	2,1	21,1	577	158	352	761
NK	9,4	3,2	5,1	2,2	19,9	503	127	468	753
NPK	10,7	4,3	5,2	2,6	22,8	528	162	552	826
N + KPO_3	10,2	4,3	5,8	3,2	23,5	549	178	484	858
$LSD_{5\%}$	2,5	0,9	1,5	0,4	3,8	91	31	42	151

ficial lighting was applied. The tobacco leaves were picked continuously at the same state of ripeness, cured at room temperature and constant air humidity until a uniform brown colour was obtained and then they were weighed in air dry condition. The stem was cut off 1 cm above the soil at the end of the experiment and weighed similarly in air dry state. For the purpose of chemical analyses the tobacco leaves were ground to flour, then one part was digested with sulphuric acid $+H_2O_2$ and NPKCa were determined in it. The total alkaloid content was determined according to the relevant Hungarian Standard in the aliquot part.

The second series was carried out in the same pattern. Treatments applied to the soil from Örszentmiklós: Ø, N, NP, NPK (KCl), NPK (K_2SO_4), N-KPO_3. The experiment was carried out in the period from April to July. The plants were processed in the same way as in the first series of tobacco experiments.

Results

1. Experiment with rye seedlings (according to Neubauer)

The fertilizer treatments caused significant differences principally in the P, K and Ca uptakes of the seedlings in the case of both soils. (Table 2). The effect of KPO_3 on the K uptake corresponded to that of the super-

Table 4

Dry matter production and nutrient uptake of tobacco

Treatment	Dry matter g/pot			Total alkaloid		Nutrient uptake of leaves mg/pot			
	Leaf	Stem	Total	mg/pot	%	N	P_2O_5	K_2O	CaO
(1. experiment)									
∅	3,6	3,0	6,6	31	0,63	108	4,1	105	183
N	4,1	3,6	7,6	36	0,84	128	6,4	122	230
NP	11,6	9,7	21,3	106	0,93	310	28,3	72	1030
NK	4,8	3,7	8,2	42	0,86	155	6,8	256	252
NPK	12,4	9,3	21,9	129	1,04	369	29,3	471	875
N + KPO_3	12,5	10,5	23,0	116	0,92	352	21,4	314	855
$LSD_{5\%}$	0,2	1,8	4,0	34		67	0,9	57	185
(2. experiment)									
∅	3,8	1,3	5,1	21	0,52	35	7,1	90	157
N	7,6	5,1	12,7	51	0,66	105	5,2	94	338
NP	11,8	9,1	20,9	44	0,38	96	47,3	70	483
NPK (KCl)	16,1	12,0	28,1	96	0,61	141	58,7	472	616
NPK (K_2SO_4)	16,7	12,8	29,5	72	0,44	106	61,7	486	539
N + KPO_3	14,5	10,5	25,0	60	0,42	98	59,9	300	485
$LSD_{5\%}$	0,9	2,9	2,7	11		36	8,5	32	84

phosphate and potassium chloride mixture of equivalent nutrient content in the case of both series, but the effect of metaphosphate on the P uptake in the first series and on the Ca uptake in both series, was smaller than that of the mixture of simple fertilizers. The high dose of superphosphate and potassium chloride mixture, however, significantly reduced the number of seedlings in the first series on the heavy soil and in the second series on the sandy soil.

2. Pot experiments with cow-pea

In the first experiment the treatment with NPK and N-KPO_3 resulted, in comparison with the N control, in a significant increase in the leaf and stem yield as well as in the P and K uptakes on both soils. Between the treatments with NPK and N-KPO_3 there was no significant difference in the majority of the parameters, but on the soil from Nyirlugos the K and Ca uptakes of the plants treated with potassium metaphosphate were significantly smaller than that of the plants treated with NPK. The interaction of the soil and the fertilizer is very significant in the seed and pod yields and slightly significant in the total dry matter yield and K uptake (Table 3).

In the second series of experiments lighting was more favourable and consequently the yields are considerably higher (Table 3). The effect of the NPK treatment corresponded to that of the N-KPO_3 treatment. The N, P and Ca uptakes of the plants treated with potassium metaphosphate are identical while the K uptake is significantly smaller than those of the plants treated with NPK.

3. Pot experiments with tobacco

In both series a very considerable phosphorus effect was observed (Tables 4). As compared to the effect of NPK (KCl) treatment, that of potassium metaphosphate was significantly less on K uptake in the first series and on all parameters except stem yield and P uptake in the second series. Between the effects of the NPK (KCl) and NPK (K_2SO_4) treatments in general no significant difference was found.

Discussion

As it is clearly proved by the pot experiments, KPO_3 is a very effective phosphorus and potassium nutrient source on the soil types tested. In the presence of ammonium nitrate this complex fertilizer increased the dry matter yield as well as the nitrogen and phosphorus uptake of the plants in the two cow-pea and the two tobacco experiments at least to such a degree as the mixture of superphosphate and potassium salt (KCl, for the tobacco K_2SO_4) having the same nutrient content. On the basis of the experiments it can be assumed that in the form of KPO_3 even such large doses of K and P can be applied without harming the plants which, when applied in the form of a mixture of superphosphate and potassium chloride, would hamper germination and, on acidic sandy soils, would reduce the seed yield of cow-pea.

In the course of the experiments it could also be observed that the nutrient elements contained in KPO_3 became gradually available. The rye seedlings indicating the easily available nutrient supply of the soil absorbed potassium from the metaphosphate added to the soil more rapidly than phosphorus, while the rye seedlings sown 4 weeks later also utilized the phosphorus content of KPO_3 well. In the experiments carried out with cow pea and tobacco having a longer vegetation time no significant differences were observed in the uptake of the P content of superphosphate and metaphosphate. With the dry matter yield and nitrogen uptake being identical, the plants absorbed a smaller quantity of the slowly soluble metaphosphate K and a larger quantity of the potassium salts that completely dissolve in water. When on the acid soils KCl was replaced with KPO_3, the Ca uptake of the plants was smaller. This fact refers, in compliance with the references [11], to a decrease of the mobility of the Ca ions present in the soil.

This experience shows that KPO_3 when used as basal and preliminary dressing on calcareous and acid sandy soils as well as on meadow clay soils is, as expected, not only equivalent to the mixture of simple P and K fertilizers used at present but, mainly on very acid soils, is even more successful than that since it neither causes any harmful salt effect nor acidifies the soils if it is applied to the soil in larger doses.

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Summary

Pot experiments were carried out with potassium metaphosphate obtained from the Scottish Agricultural Industries Ltd. on calcareous and acid sandy soils as well as acid meadow clay soils. The effect of KPO_3 applied in addition to ammonium nitrate was compared with the effect of a mixture

of superphosphate and potassium salt having the same nutrient content. The test plants were 18 day old rye seedlings, cow-pea and tobacco. No remarkable difference could be observed in the effects of the two P—K nutrient element sources on the dry matter product and the N and P uptake of the two latter plants having a longer vegetation time. From potassium metaphosphate the plants, cut off first in the course of the seedling experiment, absorbed less P, and cow-pea and tobacco less K than they did from the mixture of superphosphate and potassium salt. (This took place in accord with the gradual solubilization of the nutrient elements contained in potassium metaphosphate.) In acid soils the Ca uptake of the plants was obligatory smaller in the presence of KPO_3 than in the presence of superphosphate +KCl and the metaphosphate did not hamper, in contrast to the P—K fertilizer mixture, the germination of rye and did not reduce the grain yield of cow-pea.

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