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LONG TERM FIELD EVALUATION OF PHOSPHATE ROCK AND SUPERPHOSPHATE IN ACID SOILS OF HUNGARY: INCUBATION AND POT EXPERIMENTS

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Abstract

A series of experiments was conducted to compare the agronomic effectiveness of phosphate rock (from Algeria) and of single superphosphate (from Russia, Kola) on a moderately acidic pseudogley brown forest soil (Szentgyörgyvölgy) and on a slightly acidic chernozem brown forest soil (Kompolt). Dynamics of water-soluble and ammonium lactate-soluble P-contents (AL-P) and soil pH-H_2O changes were studied in a half-year long incubation experiment. A follow-up pot experiment with the same soils was carried out with winter rape as test plants. Both experiments were set up with similar P fertilizer sources and P rates (100, 200, and 400 mg mineral acid soluble P_2O_5 per kg soil).

At the beginning of incubation experiment, the water-soluble P content of the pseudogley brown forest soil was influenced by both the sources of P and the experimental conditions. The water-soluble P content decreased with time. After the 15^{th} to 20^{th} day of incubation, when the fast binding process of the water-soluble P ended, the effects of the P forms decreased. In this stage, the effects of environmental conditions depended on the form of the P fertilizer. The water-soluble P content of the phosphate rock-treated samples was affected to a great extent by soil water content, while the incubation temperature had a greater effect in soils treated with superphosphate.

The AL-P content of soils was increased similarly by addition of equal rates of phosphate rock and superphosphate at the beginning of incubation. The AL-P content of phosphate rock-treated soils was higher throughout the incubation period than of the superphosphate-treated soils -treated. Temperature had a greater effect on the AL-P content of soils than soil water content. As the AL-extraction may dissolve a substantial amount of the undecomposed phosphate rock, this method is not applicable to soil testing of available P forms from phosphate rock-treated soils.

Initial soil pH decreased on average by 0.5 units in the superphosphate treatments. Phosphate rock slightly increased the pH of the slighly acidic chernozem brown forest soil. The increase in the moderately acidic pseudogley brown forest soil was greater, but no "liming effect" could be observed.

In the pot experiment, the effects of P sources and P doses were compared both in incubated (for 202 days) and in non-incubated (fertilizers freshly mixed into the soil) experimental soils with winter rape as a test plant. In the moderately acidic pseudogley brown forest soil, the dry matter yield, P concentration, and P uptake of winter rape was affected similarly by the phosphate rock and superphosphate treatments. In the slightly acidic chernozem soil, superphosphate proved to be a more efficient P fertilizer, by significantly increasing the P concentration and P uptake of the plants. Incremental P doses in the chernozem brown forest soil increased P concentration, P uptake, and also dry matter yield of rape. In the case of the pseudogley brown forest soil, only the P concentration of the plants increased. These increases were dominant in the superphosphate treatments. Previous incubation of the soil with the P fertilizers significantly decreased all plant parameters in the pseudogley brown forest soil, but the incubated superphosphate treatments produced higher yields in the chernozem brown forest soil, as compared to the non-incubated P fertilizer treatments.

1. INTRODUCTION

Strongly acidic soils cover about 13 % of Hungary, and nearly 43 % of the soils are slightly acidic [1]. In the past decades, superphosphate was the main P fertilizer source on both calcareous and acidic soils. As soils are becoming more acidic and the costs of superphosphate application are rising, attention should be drawn to the direct use of reactive phosphate rock (PR) as P fertilizer.

Plant roots absorb only phosphate ions [2] as a source of phosphorus to satisfy their needs. Thus phosphate rocks, which are considered as insoluble P fertilizers, must first be dissolved in soils to yield phosphate ions. After PR dissolution, these ions will either be taken up by plant roots or react with soil components. Dissolution of a given phosphate rock depends mainly on soil characteristics, climate, plant and the properties of the phosphate rock (chemical reaction, size of particles). Some important soil characteristics that influence favourably the solubility of phosphate rock in soil are low available P, low exchangeable Ca, low pH (<pH 6), low base saturation, high cation exchange capacity, high humus content, and adequate soil water content [3-5].

Environmental factors have a major role in the transformation processes of phosphorus in the soil (soil water content, temperature) and on the dissolution of phosphate rock. The rate-limiting step in the dissolution of phosphate rock is the diffusion of soluble products (Ca and phosphate ions) from the surface of the particles [6, 7]. Increasing soil water contents increase the effective diffusion coefficients of ions [8]. Thus, precipitation and increasing soil water contents help the dissolution of phosphate rock [3, 4, 9-11]. In contrast, temperature has little effect on the dissolution of phosphate rock in the soil [12, 13].

A series of experiments was carried out with the aim to compare the agronomic effectiveness of single superphosphate (Kola, Russia) that is currently used in Hungary and a phosphate rock from Algeria in two main types of acidic soils of Hungary. In this paper, the effects of these two P fertilizers on available soil P in a half-year-long incubation experiment at different soil water contents and temperatures are discussed. Similarly the results on yield and P uptake of winter rape from a pot experiment are presented.

2. MATERIAL AND METHODS

2.1. Soils

The soils included in the incubation and pot experiments were a moderately acidic pseudogley brown forest soil (Szentgyörgyvölgy) and a slightly acidic chernozem brown forest soil (Kompolt). These soils originated from the control plots of comparative long-term field trials with Algerian phosphate rock [14]. The main characteristics of the soils are shown in Table I.A and I.B.

2.2. Single superphosphate and phosphate rock

Single superphosphate and phosphate rock were applied in powder form in both incubation and pot experiments. The total P contents of single superphosphate and phosphate rock were determined after extraction of the mineral acid-soluble phosphates (in HNO_3 + HCl mixture, according to method A described in ISO 7497-1984 E 1984. [25]). Phosphate concentrations in the filtrates of the extraction procedure were measured colorimetrically by the molybdovanado-phosphate method. The quantity of total P_2O_5 was 27.60% (w/w) in the Algerian phosphate rock, and 18.40% (w/w) in single superphosphate.

2.3. Incubation experiment

Four hundred g of air-dried soil passed through a 2-mm sieve was used per pot. Algerian phosphate rock and single superphosphate were applied to soils at three rates: 100, 200, 400 mg P_2O_5 kg^{-1} soil. The soil water contents were set at 30 and 50% of the maximum water-holding capacity and the incubation temperatures at 25 and 40°C.

Soils were mixed with the required amount of fertilizers to give 100, 200, and 400 mg P_2O_5 kg^{-1} based on the their total P contents. Samples were taken ten times. The first sampling was carried out on the first day followed by mixing in the P forms. The duration of the incubation was 202 days. Changes with time of the water-soluble P contents, AL-soluble P contents and pH-H_2O were measured.

TABLE IA. CHARACTERISTICS OF THE SOILS USED IN THE EXPERIMENTS

	Soils	
	Pseudogley brown forest soil (Szentgyörgyvölgy)	Chernozem brown forest soil (Kompolt)
pH_{H_2O} [a]	5.90	6.40
pH_{KCl} [b]	4.40	5.00
AL-P_2O_5 [c], mg kg^{-1}	130	60
Water sol.-P [d], mg kg^{-1}	14.0	11.9
Total-P [e], mg kg^{-1}	1110	499
Cation exchange capacity, (CEC) [f] meq/100g	9.31	30.1
Base saturation, meq/100g	8.70	29.4
Exchangeable Ca, meq/100g	6.51	24.3
Exchangeable Mg, meq/100g	2.01	4.42
Oxalate-soluble Fe [g] mg kg^{-1}	6090	3660
Oxalate-soluble Al, mg kg^{-1}	422	568
Total salt content [h], %	<0.02	0.04
Saturation [i], % (SP)(plasticity)	52	50
Hydrolytic acidity [j], %, (y_1)	13.3	9.3
Organic matter [k], % (Humus)	1.86	3.49

[a] pH_{H2O} = 1: 2.5, soil:H_2O, [b] pH_{KCl} = 1: 2.5, soil: 1 M KCl, [c] AL-P_2O_5 =extracted by 0.1 mol L^{-1} ammonium lactate + 0.4 mol L^{-1} acetic acid (pH=3.75) [15], [d] Water soluble-P [16], [e] Total-P; determined by inductively coupled plasma emission spectrometry (ICP) after digestion of soil samples by cc. HNO_3 + H_2O_2, [f] Exchangeable Ca, Mg and CEC, neutral 1M NH_4-acetate method [17], [g] Oxalate-soluble Fe, Al [18], [h] Total salt content [19], [i] Saturation [20], [j] Hydrolytic acidity measured after first extraction by applying 0.5 mol/l Ca acetate at pH 8.2 [21], [k] Organic matter [22].

TABLE IB. INITIAL ISOTOPIC CHARACTERISATION OF THE SOILS

Soils	C_p, mg P L^{-1}	r_1/R	n	E_1/C_p	Total P mg kg^{-1}
Pseudogley brown forest soil (Szentgyörgyvölgy)	0.33	0.37	0.31	24	1050
Chernozem brown forest soil (Kompolt)	0.11	0.18	0.29	57	298
		P pools, mg P (kg soil)$^{-1}$			
Soils	E_1	A	B	C	D
Pseudogley brown forest soil (Szentgyörgyvölgy)	9.0	70	180	92	699
Chernozem brown forest soil (Kompolt)	6.3	37	71	29	154

Isotopic characterization of the soils [23]: c_p is the concentration of phosphate ions in the soil solution,
R is the total quantity of radioactivity applied to the soil solution system as phosphate ions, r_1 is the quantity of radioactivity in the solution after one minute, r_1/R can reflect soil P-fixing capacity [24], n is the exponent of the power function describing the rate of exchange of the radioactivity in the solution with time t, *total-P* was determined by $HClO_4$- method, *pool* E_1 is the quantity of isotopically exchanged P within one minute, E_1/c_p is the P-buffering capacity of the soil, *pool A* corresponds to the ions exchangeable between 1 minute and 1 day, *pool B* corresponds to the ions exchangeable between 1 day and 3 months, *pool C* corresponds to the ions exchangeable between 3 months and 1 year, *pool D* corresponds to the ions exchangeable in more than 1 year.

2.4. Pot experiment

Soils of the incubation experiment (incubated, "I" treatments) and soils freshly mixed with P fertilizers (non-incubated, "NI" treatments) were used in the pot experiment. In the NI treatments, the P sources and rates described in the incubation experiment as well as 200 mg N and 200 mg K per kg soil as aqueous solutions of NH_4NO_3 and KCl, respectively, were freshly mixed into the soil at the beginning of the pot experiment. In the incubated treatments, equal amounts of soils previously incubated for 202 days with the same P fertilizer forms and P rates but at different soil water contents and temperatures were mixed to give the various "incubated" treatments in the pot experiment. Thus, the P forms and rates in the incubated treatments were 100, 200, and 400 mg P_2O_5 given either as phosphate rock or as single superphosphate (at the beginning of the incubation). These soil samples were also supplemented with N and K as done for the NI treatments.

A quantity of 0.8 kg air-dried soil was used per pot. Fertilizers were mixed into the soils on the day winter rape was sown. The randomized block experiment was conducted with 3 replications. Moisture levels were maintained at approximately 60% of field capacity at the beginning of the experiment and later according to the requirement of plants. Plants were harvested at 6 weeks of age. The air-dried plant samples were digested with a mixture of HNO_3 and H_2O_2, P contents were measured by the inductively-coupled plasma emission spectrophotometry method (ICP).

The incubation and pot experiments were carried out in triplicates, in a randomized block arrangement. Data were subjected to analysis of variance, using the FVA 7 and the SPSS ANOVA statistical programs. A 3-factorial (P rate, P form, soil water content) random block design was used to calculate the significant differences for the combinations of the treatments by the F-test and by calculation of the Least Significant Difference at the 0.05 probability level, $LSD_{5\%}$. The CV% values were calculated for a randomized block arrangement with 14 treatments to take into account the additional control treatments.

3. INCUBATION EXPERIMENT RESULTS

3.1. Effect of superphosphate and phosphate rock treatments on the available P content of experimental soils

3.1.1. Changes in the water-soluble P content

Due to the effect of the equal rates (100, 200, 400 mg P_2O_5 kg^{-1} active agent content) of the phosphate rock and superphosphate treatments, the water soluble P content of the pseudogley brown forest soil from Szentgyörgy increased at the beginning of the experiment in accordance with the solubility of the P fertilizers (Fig. 1A), P rates (Fig. 1B) and experimental conditions (temperature of incubation and soil water content — Figs. 2 and 3). The effects of the studied factors are shown as the average of other parameters.

The water-soluble P content of the soil samples treated with phosphate rock hardly changed in the first days of incubation, as a result of the biotic and abiotic dissolution and fixation processes. There was a 20-40% decrease in the values with time. Our findings are in accordance with Fardeau et al. [26], who also experienced a decrease in the water-soluble P content of soils treated with phosphate rock.

The water-soluble P content of soil was more greatly influenced by the soil water content than by temperature (Figs. 2A, 3A). In the experiment with phosphate rock from North Carolina, Chien et al. [12] also found that temperature had no significant effect on the water-soluble P levels in the soil. Irrespective of the application rate of phosphate rock, higher water-soluble P contents were measured throughout the incubation period at both temperatures in the case of higher soil water content.

At the beginning of incubation, the water-soluble P fertilizer, i.e. superphosphate increased the water-soluble P content of the initial samples to a greater extent than phosphate rock applied on the basis of equal active agent content (Fig. 1). The availability of applied P decreases when the time of contact between soil and water-soluble P fertilizers increases [27-29]. The changes in water-soluble P content of soils as a function of time differed in the samples treated with superphosphate and phosphate rock (Figs. 1 and 2). Water-soluble P content of superphosphate-treated soils decreased with time. This is similar to literature findings [29-32] and authors' previous kinetic studies [33-35]. In the first days of incubation (approx. up to 10-20 days), a rapid decrease could be observed, which was followed by a slow change.

The water-soluble P content of soils treated with superphosphate, in contrast to the phosphate rock-treated soils, was influenced to a greater extent by temperature than soil water content (Figs. 2B and 3B). Higher-water soluble P contents were measured at the lower temperature. On the basis of literature [28, 36] and authors' analytical results [37] this can be explained by the higher rate constants for the fixation of water-soluble P content of superphosphate in the soil at high temperatures. Such temperature effect can be mainly observed in the first half of the incubation period. In the case of similar temperature, higher-water soluble P contents were generally measured at higher soil water content.

The results of the experiment carried out with the moderately acidic pseudogley brown forest soil (Szentgyörgyvölgy) showed that at the beginning of incubation the water-soluble P content of samples was affected both by the P source and the experimental conditions, but the P source played the dominant role. After 15-20 days of incubation, when the fast binding process of soluble P fertilizer ended, the P form had a slighter influence on the water-soluble P content of soil. After 40 days, slightly higher or similar values were obtained for the phosphate rock-treated samples as compared to the superphosphate treated samples (Fig. 1B).

Due to filtration problems, we were unable to measure changes of water-soluble P contents as a function of time in the slightly acidic chernozem brown forest soil (Kompolt).

3.1.2. Change in the AL-soluble P content of the soils

In Hungary, AL-extractant has been used conventionally as the extractant to assess soil P availability. For this reason, changes in the AL-soluble P content of the experimental soils were also studied.

3.1.2.1. AL-soluble P content of the pseudogley brown forest soil (Szentgyörgyvölgy)

At the beginning of incubation, the low-medium initial AL-soluble P content of the soil increased to a similar extent due to the effect of equal rates of phosphate rock and superphosphate (Fig. 4).

Changes in the AL-soluble P content of phosphate rock-treated samples with time were similar to those of the control treatment. In the first days of incubation (up to about 30 days) the AL-soluble P contents of the phosphate rock-treated and control soils dropped to a similar extent, then there were practically no changes.

The AL-soluble P content of superphosphate-treated soils also decreased to a greater extent in the first days of incubation (up to 20-30 days). This decrease, however, was much greater than that of the control or phosphate rock-treated samples.

In the case of equal rates of P addition to soil, the AL-soluble P content of the phosphate rock-treated soils was higher than that of superphosphate treated soils. The probable explanation for this is that the AL-extractant with pH 3.75, dissolved part of the Ca-phosphate content of the phosphate rock not yet in soluble form.

Fig. 5 illustrates the effect of incubation temperature and water content of soil on the changes in AL-soluble P content during incubation. Temperature had a more expressed effect on soil AL-soluble P content than soil water content. Abd El-Galil et al. [38] reached similar results on calcareous sandy soil. The AL-soluble P content of soil was higher at lower temperature both in phosphate rock and superphosphate treatments. This effect was slighter at the beginning of incubation in control and phosphate rock-treated samples. On the contrary, temperature had an effect on the AL-P content of samples treated with superphosphate throughout the incubation period.

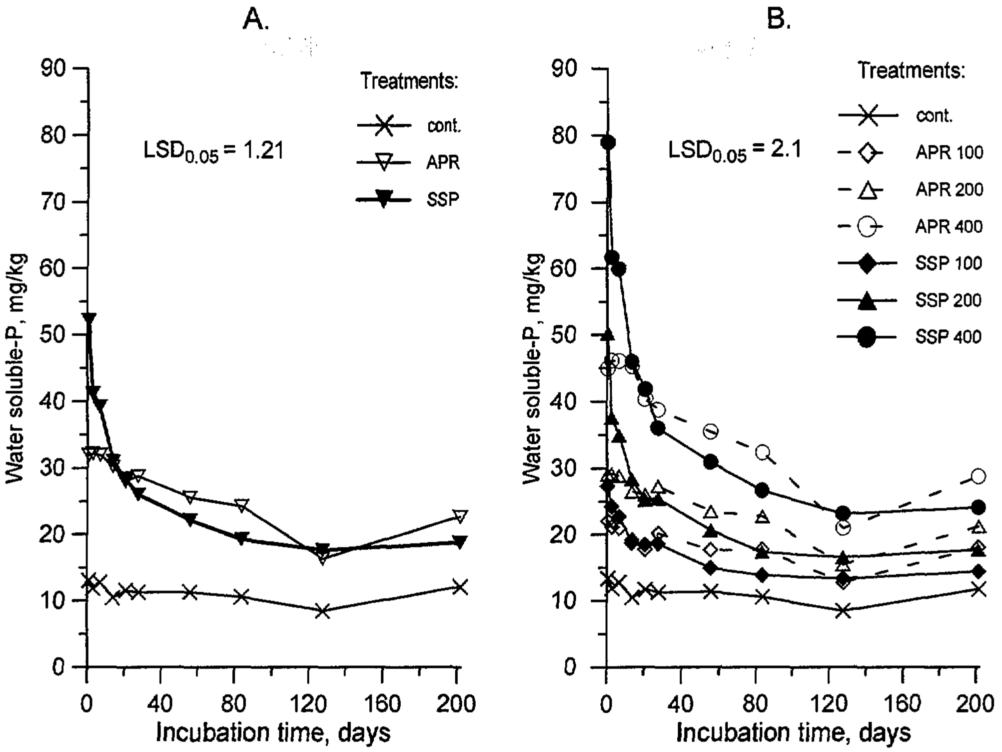

Fig. 1. Effect of Algerian phosphate rock (APR) and single superphosphate (SSP) on the water-soluble P content of the pseudogley brown forest soil (Szentgyörgyvölgy), as a function of incubation time. A. On the average of P doses. B. Separately. (Treatments: 100, 200, 400 = Active P ingredients, mg P_2O_5 kg^{-1} soil).

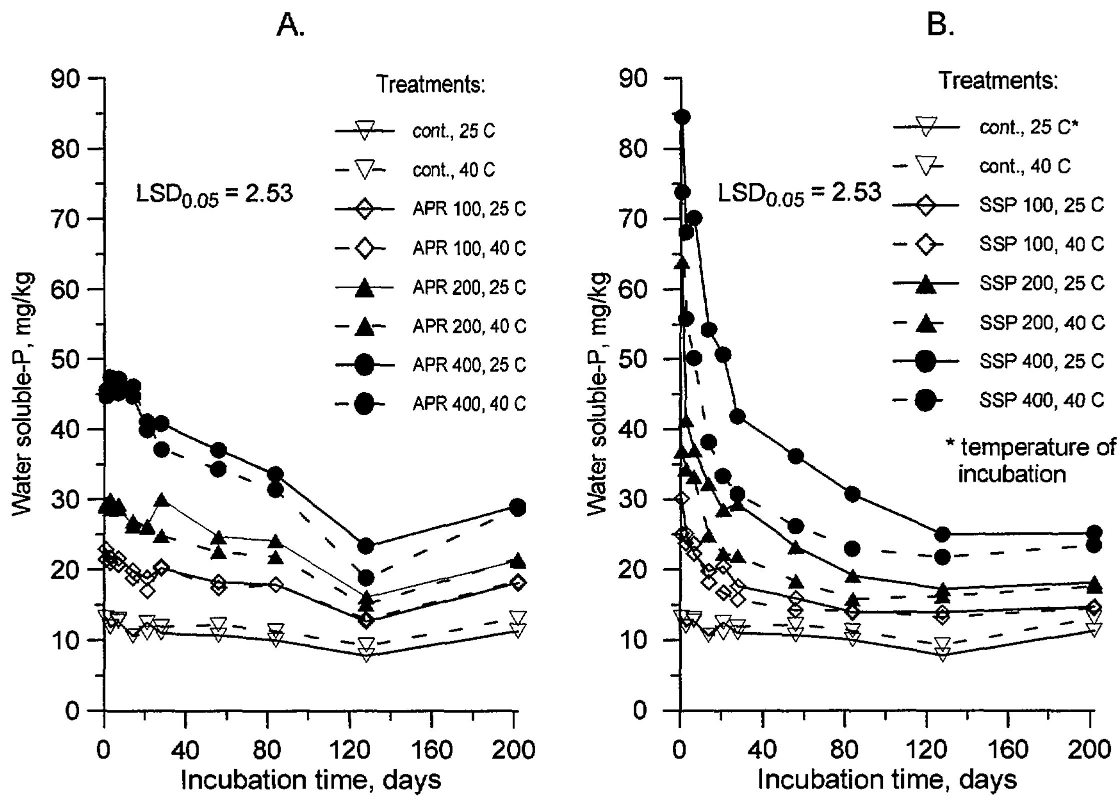

Fig. 2 Effect of temperature on the water-soluble P content of the pseudogley brown forest soil (Szentgyörgyvölgy) in the case of Algerian phosphate rock (APR) (A) and single superphosphate (SSP) (B) application (Treatments: 100, 200, 400 = Active P ingredients, mg P_2O_5 kg^{-1} soil).

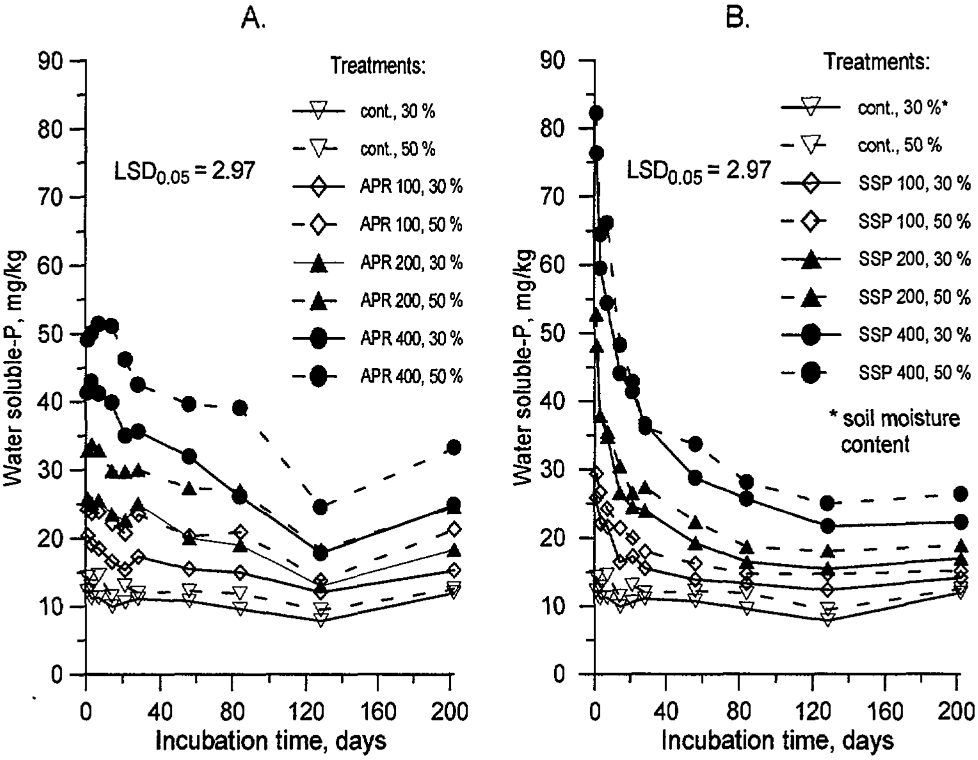

Fig. 3. Effect of soil moisture on water-soluble P content of the pseudogley brown forest soil (Szentgyörgyvölgy); A. Algerian phosphate rock (APR) application. B. Single superphosphate (SSP) application (Treatments: 100, 200, 400 = Active P ingredients, mg P_2O_5 kg^{-1} soil).

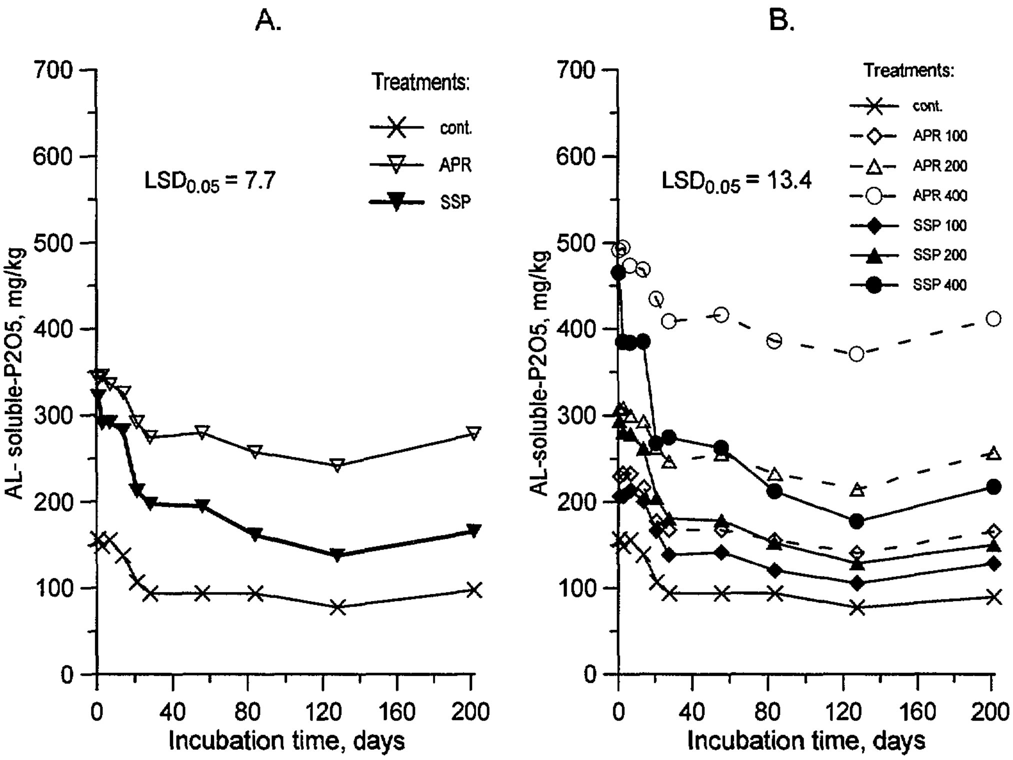

Fig. 4. Effect of Algerian phosphate rock (APR) and single superphosphate (SSP) on the AL-soluble P content of the pseudogley brown forest soil (Szentgyörgyvölgy) as a function of incubation time. A. On average of P doses. B. Separately. (Treatments: 100, 200, 400 = Active P ingredients, mg P_2O_5 kg^{-1} soil).

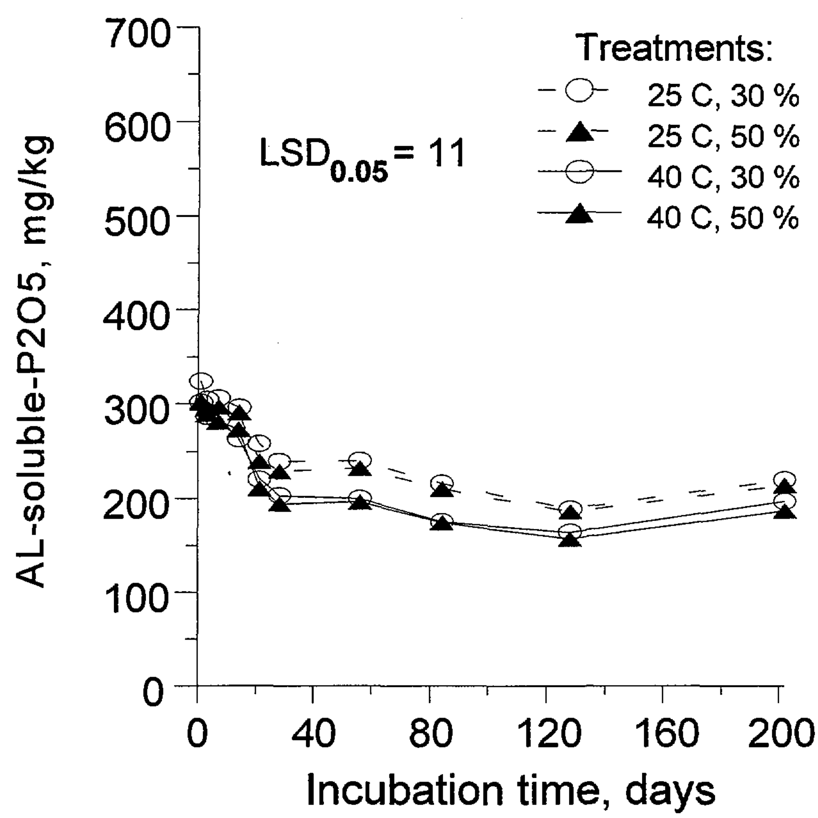

Fig. 5. The effect of incubation temperature and soil water content on the AL-soluble P content of the pseudogley brown forest soil (Szentgyörgyvölgy).

3.1.2.2. AL-soluble P content of the chernozem brown forest soil (Kompolt)

At the beginning of incubation the very low initial AL-soluble P content (60.0 mg kg^{-1}) of the chernozem brown forest soil from Kompolt increased to a similar extent due to the effect of the equal rates of phosphate rock and superphosphate (Fig. 6).

In case of equal rates of P, similar to the results gained for the pseudogley brown forest soil, the AL-soluble P content of the chernozem brown forest soil samples treated with phosphate rock were higher throughout the incubation period. After a few days the AL-soluble P content of phosphate rock-treated samples showed practically no changes during the incubation period (202 days) (Fig. 6). Neither temperature nor soil water content had an expressed effect.

The AL-soluble P content of superphosphate-treated samples decreased to a greater extent in the first days of incubation (Fig. 6). In the first days of incubation in the superphosphate treatments, both soil water content and incubation temperature affected the AL-soluble P content of samples. However, the effects could hardly be separated from each other. Throughout the experiment, the AL-soluble P contents of superphosphate-treated soils were higher at lower temperature. Figure 7 shows average values for the effect of incubation temperature and soil water content on the AL-soluble P content of the chernozem brown forest soil from Kompolt throughout the incubation experiment.

In Hungary, the AL-extractant is used conventionally as the extractant to measure soil available P. This method, however, was developed for fertilizer recommendation for water-soluble P-sources. The AL-extractant (pH = 3.75) may dissolve a substantial amount of the undecomposed phosphate rock during extraction and thus the available P from phosphate rock in the soils can be overestimated

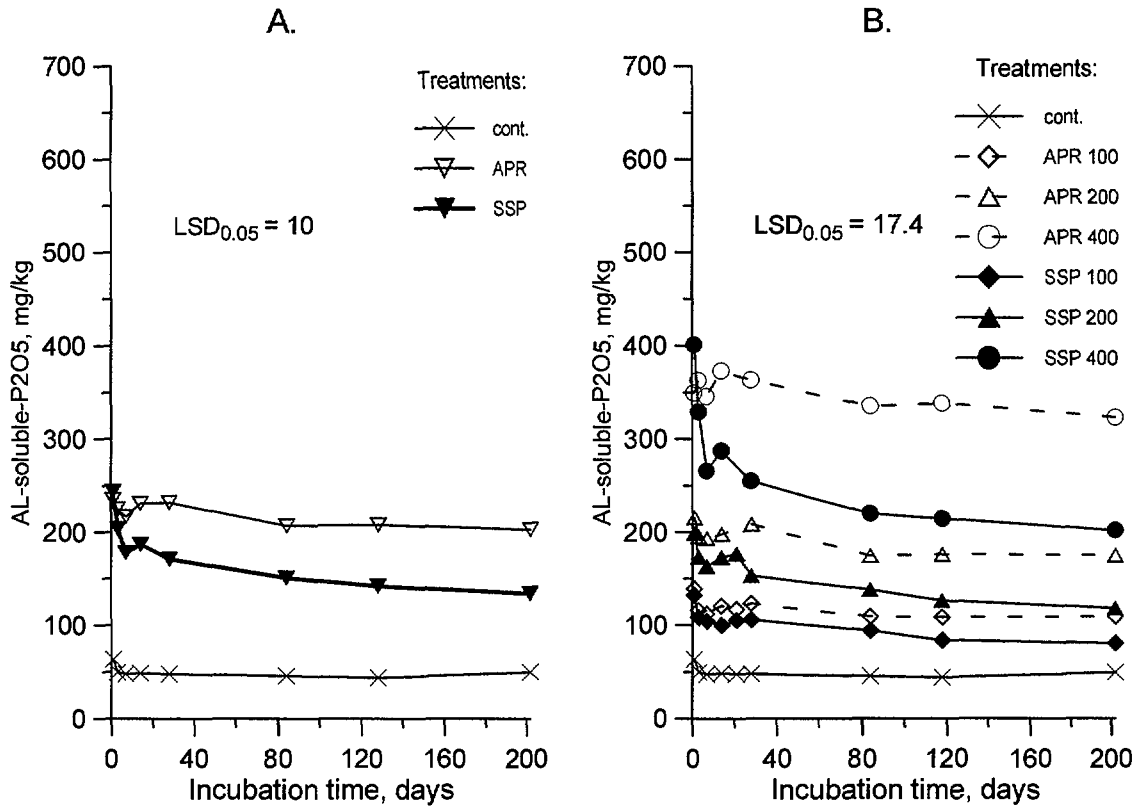

Fig. 6. Effect of Algerian phosphate rock (APR) and single superphosphate (SSP) on the AL-soluble P content of the chernozem brown forest soil (Kompolt) as a function of incubation time.
***A.** On the average of P doses. **B.** Separately. (Treatments: 100, 200, 400 = Active P ingredients, mg P_2O_5 kg^{-1} soil).*

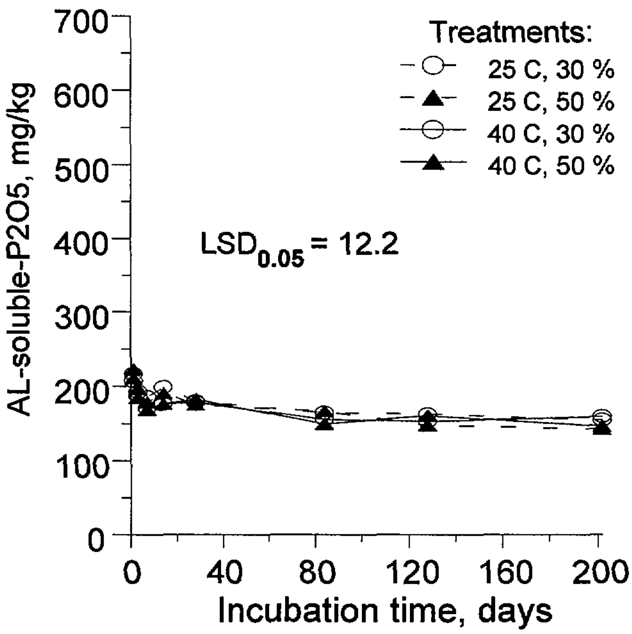

Fig. 7. The effect of incubation temperature and soil water content on the AL-soluble P content of the chernozem brown forest soil (Kompolt).

as compared to that from single superphosphate. Bray-II and double acid methods have been observed to solubilize phosphate rock in soil [4]. Our experimental results confirm the inapplicability of the AL-method for soil testing of available P from phosphate rock-treated soils.

3.2. Effect of superphosphate and phosphate rock treatments on the soil pH-H_2O

3.2.1. Pseudogley brown forest soil (Szentgyörgyvölgy)

At the beginning of the experiment, the initial soil pH (5.90) increased by 0.3 due to the effect of the 400 mg P_2O_5 kg $^{-1}$ P dose given in the form of phosphate rock - Thus no liming effect could be observed. Fardeau [39] and Xiong [40] obtained similar results in incubation experiments conducted with phosphate rock. The same P dose of superphosphate decreased the initial soil pH by 0.5 unit pH (Fig. 8). At the beginning of incubation, the rate of the P dose had a greater effect for both P forms. This effect, however, became less expressed with time. Studying the changes in pH on the average of incubation temperature and soil water content (Fig. 8). The decrease in pH was more expressed at the beginning of incubation while with time this decrease became slighter. The pH value of the control sample ranged between that of the two P forms throughout the incubation experiment.

Changes in the pH-H_2O value of the soils differed at 25 and 40 °C incubation temperature (Fig. 9). In the control and phosphate rock treatments in the first days of incubation (up to 20 days) pH decreased to a greater extent (to 5.1-5.2) at 40°C than at 25°C, and changed no further during incubation (Fig. 9A). At lower temperature, however, pH decreased continuously throughout the incubation period (to 4.6-4.9). In the second half of the incubation period, temperature had a greater effect on the pH of samples with higher soil water content. Similar effects were observed in the superphosphate treatments as in the phosphate rock treatments during incubation (Fig. 9B).

3.2.2. Chernozem brown forest soil (Kompolt)

Changes in the pH-H_2O value of the chernozem brown forest soil from Kompolt were evaluated on the average of incubation temperature and soil water content. As shown in Fig. 10, phosphate rock treatments resulted in a very slight increase (0.10), while superphosphate treatments decreased the initial soil pH-H_2O by 0.3 to 0.6 at the beginning of incubation.

In the first days of incubation, the decrease in pH was not as expressed as in the case of the pseudogley brown forest soil (Szentgyörgyvölgy). Incubation temperature and soil water content also had a slighter influence on the pH-H_2O value of the chernozem brown forest soil (Kompolt) than on that of the pseudogley brown forest soil (Szentgyörgyvölgy).

4. POT EXPERIMENT RESULTS

In the pot experiment, the effects of different P forms, P doses and incubation were studied on the dry matter yield, P concentration and P uptake of winter rape as a test plant. The experimental soils were a moderately acidic pseudogley brown forest soil (Szentgyörgyvölgy) and a slightly acidic chernozem brown forest soil (Kompolt).

4.1. The effect of superphosphate and phosphate rock treatments on the dry matter accumulation of winter rape grown in pot experiment

The effect of P treatments and incubation on the dry matter mass of rape is shown in Table II. P treatments on the pseudogley brown forest soil (Szentgyörgyvölgy) increased the quantity of dry matter both in the incubated and non-incubated soils as compared to the control. Based on the F-test, this increase however (Tables II and V) was not significant between superphosphate and phosphate rock treatments.

Incremental P doses had no effect on yields either in the incubated (I) or in the non-incubated (NI) pseudogley soils. The application of phosphate rock and superphosphate fertilizers resulted in similar dry matter yields (Incubated soil: R = 1.90 and S = 1.95 g pot^{-1} and Non-incubated soil: R = 2.31 and S = 2.45 g pot^{-1}).

In case of the pseudogley brown forest soil, the effect of incubation on dry matter yields was much more expressed than that of P forms or the amount of P applied. Higher rape yields were obtained on non-incubated soils than on incubated soils. On the basis of the F test, the difference in rape yield of incubated and non-incubated samples on the average of P form and dose (1.93 and 2.38 g pot^{-1}) was significant ($LSD_{5\%}$ 0.34) (Tables II and V). As it can be seen from Table V, the incubation treatment was the only factor that had a significant effect on the dry matter yield of winter rape grown on the pseudogley brown forest soil (Szentgyörgyvölgy).

TABLE II. THE EFFECT OF P TREATMENTS AND INCUBATION ON ON THE DRY MATTER MASS[1] OF RAPE (g POT^{-1})

	Soils					
	Moderately acidic pseudogley brown forest soil (Szentgyörgyvölgy)			Slightly acidic chernozem brown forest soil (Kompolt)		
Treatment	Incubated soil (I)	Non-incubated soil (NI)	Average of I and NI	Incubated soil (I)	Non-incubated soil (NI)	Average of I and NI
NK	1.64	1.70	1.67	1.95	2.07	2.01
NKP_{R100}	1.44	2.27	1.85	2.12	1.87	2.00
NKP_{R200}	2.46	2.51	2.48	1.88	2.08	1.98
NKP_{R400}	1.80	2.14	1.97	2.09	2.05	2.07
Average of R treatments	*1.90*	*2.31*	*2.10*	*2.03*	*2.00*	*2.02*
NKP_{S100}	1.89	2.70	2.30	2.37	1.89	2.13
NKP_{S200}	1.88	2.27	2.07	2.13	1.74	1.94
NKP_{S400}	2.09	2.39	2.24	2.84	2.13	2.49
Average of S treatments	*1.95*	*2.45*	*2.20*	*2.45*	*1.92*	*2.18*
Main average			2.083			2.086
CV%			24.25			16.56
$LSD_{5\%}$			0.845			0.578

[1] Average of three replications;
R = Phosphate rock, S = Single Superphosphate;
100, 200, 400 = Active P ingredients, mg P_2O_5 kg^{-1} soil;
N = 200 mg kg^{-1} soil; K = 200 mg kg^{-1} soil.

In spite of the lower total and available P content of the chernozem brown forest soil (Kompolt), the dry matter yield obtained in its control treatment was higher than that of the control samples of the pseudogley brown forest soil (Szentgyörgyvölgy). In contrast with the pseudogley brown forest soil (Szentgyörgyvölgy), there was no increase in yield as compared to the control in the phosphate rock and superphosphate treatments on non-incubated soils. In the incubated soil only superphosphate increased the yield in comparison to the control. This yield increase was significant for the highest superphosphate dose. On the average of P forms and P doses, incubation had a significant effect on rape yield in the chernozem soil. The yield of the incubated sample of the chernozem brown forest soil (Kompolt) was higher than that of the incubated pseudogley brown forest soil (Szentgyörgyvölgy) (2.24 and 1.96 g pot^{-1}, $LSD_{5\%} = 0.24$).

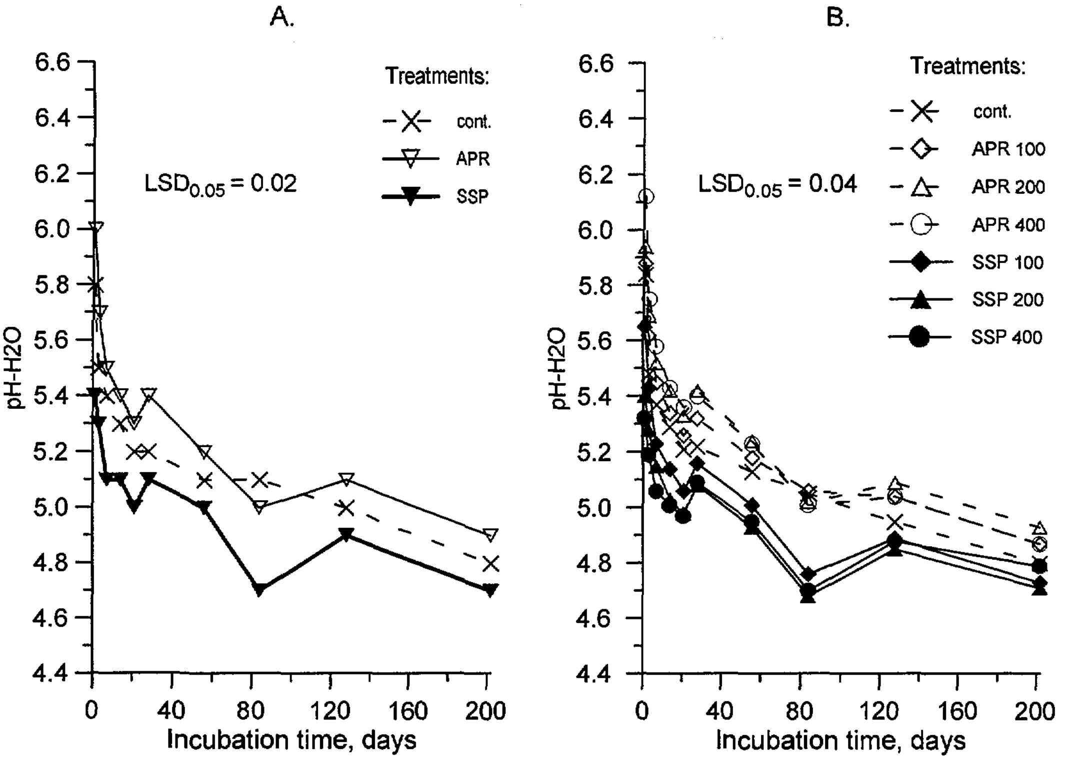

Fig. 8. The effect of Algerian phosphate rock (APR) and single superphosphate (SSP) on soil pH (H_2O) of the pseudogley brown forest soil (Szentgyörgyvölgy) as a function of incubation time.
A. On the average of P doses. B. Separately. (Treatments: 100, 200, 400 = Active P ingredients, mg P_2O_5 kg^{-1} soil).

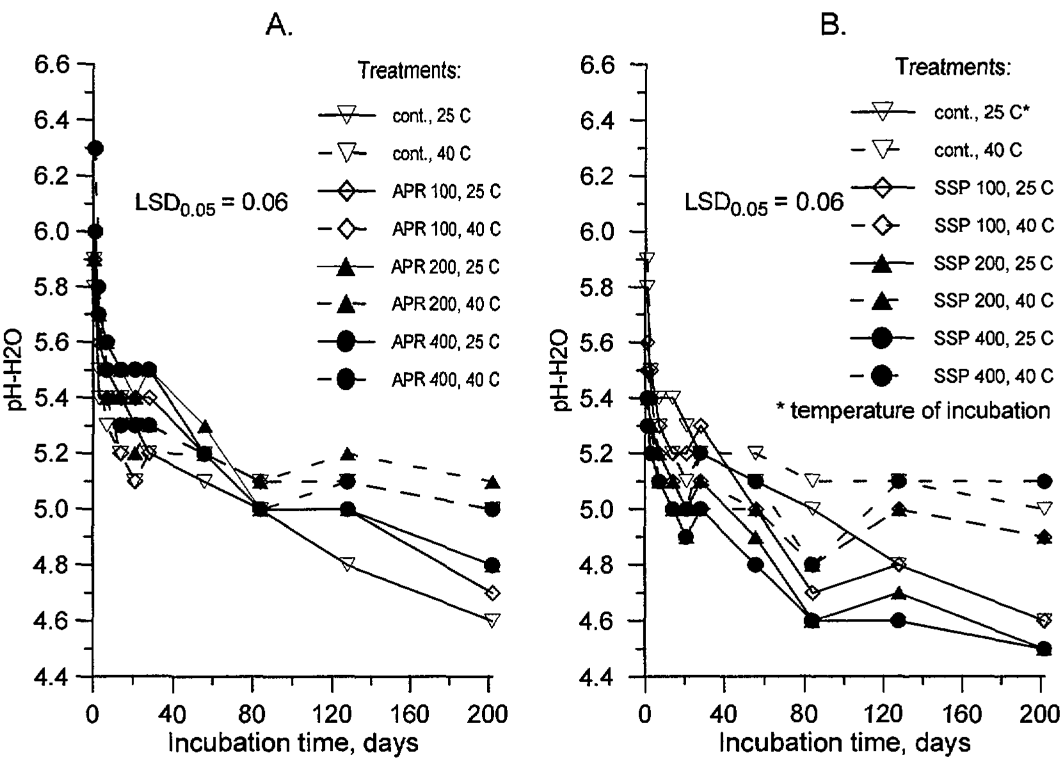

Fig. 9. The effect of Algerian phosphate rock (APR) (A) and single superphosphate (SSP) (B) on the pH-H_2O of the pseudogley brown forest soil (Szentgyörgyvölgy) (Treatments: 100, 200, 400 = Active P ingredients, mg P_2O_5 kg^{-1} soil).

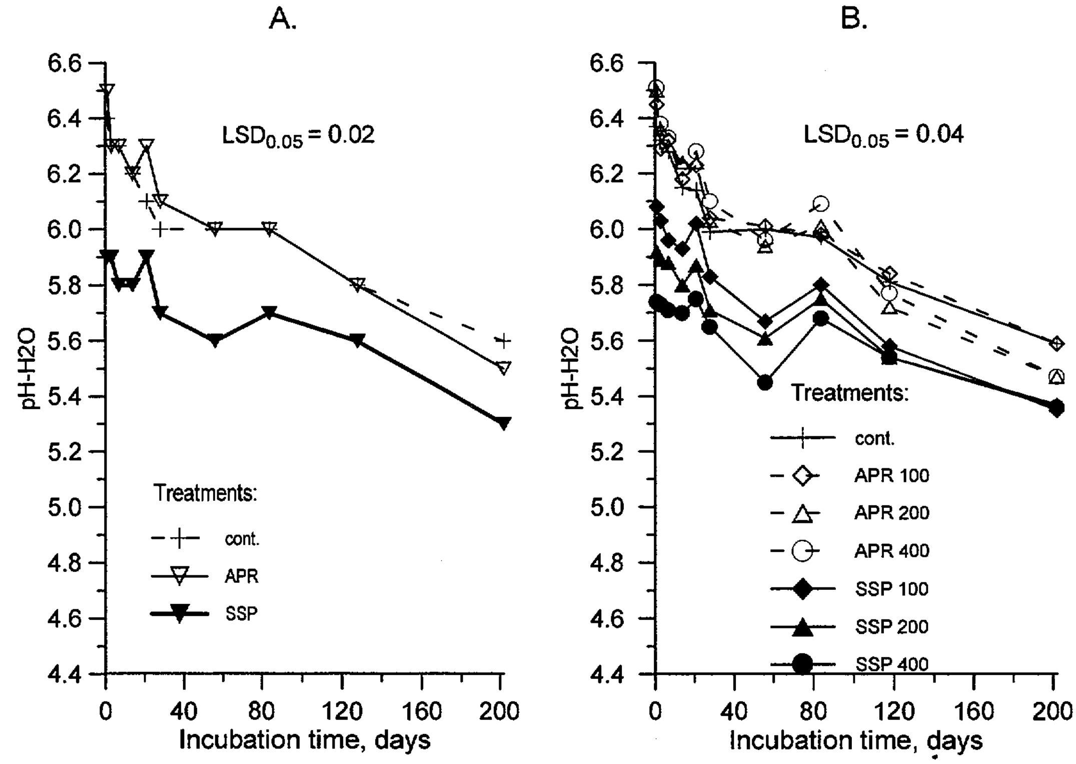

Fig. 10. The effect of Algerian phosphate rock (APR) and single superphosphate (SSP) on the soil pH-H_2O of the chernozem brown forest soil (Kompolt), as a function of incubation time.
A. On the average of P doses. B. Separately. (Treatments: 100, 200, 400 = Active P ingredients, mg P_2O_5 kg^{-1} soil).

4.2. Comparison of P concentration of plants grown in the pot experiment

The P concentration of winter rape grown in the pseudogley brown forest soil (Szentgyörgyvölgy) increased to a significant extent as a consequence of P treatments, as compared to the control samples (Table III). In the non-incubated soil this increase in P concentration, with the exception of one sample, was significant at all P doses. In the incubated soil, however, only the highest P rates of phosphate rock and superphosphate increased the P concentration significantly as compared to the control samples.

On the average of incubation and P forms, the highest P treatment increased the P concentration of winter rape significantly in comparison to the lowest P dose. On this soil, similarly to the dry matter quantity, the P concentration of rape was the highest in the non-incubated soils. Tables III and V show that, on the average of P dose and P form, incubation had a significant effect on the P concentration of winter rape (I = 5180 and NI = 5840 ppm, $LSD_{5\%}$ 490).

The P concentration of winter rape grown on the chernozem brown forest soil (Kompolt) also showed a marked increase due to the effect of P treatments in comparison to the control samples. This increase was significant in all P treatments in the non-incubated soil. In the incubated soil, however, the increase was significant only in case of the highest P doses.

On the average of incubation and P form, it was found that the higher P doses increased the P concentration of winter rape significantly as compared to the lower P doses. In case of the chernozem brown forest soil the incubation did not affect the P concentration of the test plant, while P form, on the average of P dose and incubation, had a significant influence (6070 ppm for phosphate rock, 6610 ppm for single superphosphate; $LSD_{5\%}$ 380). A significant interaction was found between P dose and incubation, as well as P dose and P form (Table V).

TABLE III. P CONCENTRATION (ppm) OF WINTER RAPE[1] GROWN IN A POT EXPERIMENT

Treatment	Soils: Moderately acidic pseudogley brown forest soil (Szentgyörgyvölgy) — Incubated soil (I)	Non-incubated soil (NI)	Average of I and NI	Slightly acidic chernozem brown forest soil (Kompolt) — Incubated soil (I)	Non-incubated soil (NI)	Average of I and NI
NK	4130	4000	4070	5090	4570	4830
NKP_{R100}	5090	5530	5310	5630	6340	5990
NKP_{R200}	4370	5620	5000	6190	6170	6180
NKP_{R400}	5450	6080	5770	6310	5770	6040
Average of R treatments	*4970*	*5740*	5360	*6040*	*6090*	*6070*
NKP_{S100}	5070	5050	5060	5250	6340	5840
NKP_{S200}	4920	6360	5640	6660	7110	6880
NKP_{S400}	6170	6390	6280	7090	7150	7120
Average of S treatments	*5390*	*5930*	*5660*	*6330*	*6870*	*6610*
Main average		5200			6130	
CV%		13.5			9.00	
$LSD_{5\%}$		1200			930	

[1] Average of three replications; for designations: See Table III.

A significant increase was found in the P uptake of winter rape grown in the incubated and non-incubated chernozem brown forest soil (Kompolt) only in case of the higher doses of superphosphate, as compared to the control. On the average of P forms and incubation, the highest dose increased the P uptake of rape in comparison to the lower doses. On the average of incubation and P dose, P form also had a significant effect (phosphate rock: 12.2; superphosphate: 14.4 mg pot^{-1}; $LSD_{5\%}$ 1.5).

On the basis of the pot experiment carried out with winter rape, the experimental factors studied (P dose, P form and incubation) had different effects on the dry matter yield, P concentration and P uptake of winter rape grown in the moderately acidic pseudogley brown forest soil (Szentgyörgyvölgy) and the slightly acidic chernozem brown forest soil (Kompolt). The P dose only influenced the P concentration of the test plant in the pseudogley brown forest soil (Szentgyörgyvölgy), while the effect of P dose could be proven for all three studied factors in the treatments carried out with the chernozem brown forest soil (Kompolt). The effect of incubation could be confirmed for all three factors in the case of the pseudogley brown forest soil (Szentgyörgyvölgy), but only for the dry matter yield for the chernozem brown forest soil (Kompolt). Fertilizer P forms resulted in significant changes in the P concentration and P uptake of winter rape only in the Kompolt soil. Significant interactions between the factors were found only for the chernozem brown forest soil (Kompolt). These correlations were valid for the 5% probability level of significance.

4.3. Effect of superphosphate and phosphate rock treatments on the P uptake of winter rape in the pot experiment

The P uptake of winter rape grown in the non-incubated pseudogley brown forest soil (Szentgyörgyvölgy) increased significantly in both phosphate rock and superphosphate treatments

TABLE IV. THE EFFECT OF P TREATMENTS AND INCUBATION ON THE P UPTAKE[1] OF WINTER RAPE (mg POT^{-1})

Treatment	Soils: Moderately acidic pseudogley brown forest soil (Szentgyörgyvölgy) Incubated soil (I)	Non-incubated soil (NI)	Average of I and NI	Slightly acidic chernozem brown forest soil (Kompolt) Incubated soil (I)	Non-incubated soil (NI)	Average of I and NI
NK	6.8	7.0	6.90	9.8	9.4	9.60
NKP_{R100}	7.3	12.6	10.00	11.9	11.9	11.90
NKP_{R200}	10.1	14.2	12.10	11.7	12.8	12.30
NKP_{R400}	9.9	13.2	11.50	13.1	11.8	12.50
Average of R treatments	*9.10*	*13.4*	11.20	*12.20*	*12.20*	*12.20*
NKP_{S100}	9.6	13.6	11.60	12.2	12.1	12.10
NKP_{S200}	8.4	14.3	11.40	14.2	12.4	13.30
NKP_{S400}	12.9	15.3	14.10	20.2	15.2	17.70
Average of S treatments	*10.30*	*14.40*	*12.30*	*15.50*	*13.20*	*14.40*
Main average		11.08			12.77	
CV%		23.93			17.7	
$LSD_{5\%}$		4.44			3.78	

[1] Average of three replications; for designations: See Table III.

TABLE V. SIGNIFICANT EFFECTS AND CORRELATIONS ON THE BASIS OF THE 'F' TEST

Designation	Moderately acidic pseudogley brown forest soil (Szentgyörgyvölgy) Dry matter g pot^{-1}	P content of plant ppm	P uptake mg pot^{-1}	Slightly acidic chernozem brown forest soil (Kompolt) Dry matter g pot^{-1}	P content of plant ppm	P uptake mg pot^{-1}
P-dose (A)		*		+	*	**
Incubation (I)	*	**	***	*		
P form (F)					**	**
A x I					*	
A x F					*	*
I x F				*		
A x I x F						
Between any 2 combinations		**	**	+	***	**

Significance levels: + 10%, * 5%, ** 1%, *** 0.1%.
Designations: A: P dose; 100, 200, 400 mg P_2O_5 kg^{-1} (mineral acid soluble);
I: Incubation; incubated for 202 days or fresh; F: P form; phosphate rock or superphosphate.

due to the effect of P doses as compared to the control, while only the effect of the highest superphosphate dose could be proven in the incubated soil (Table IV). Incubation had a significant effect on the quantity of P taken up (I = 9.7 and NI = 13.9 mg pot $^{-1}$; $LSD_{5\%}$ 1.8). This effect was significant at the 0.1% level of probability.

On the pseudogley brown forest soil (Szentgyörgyvölgy), phosphate rock had a similar effect to that of superphosphate on the dry matter yield, P concentration and P uptake of winter rape. This was confirmed by the statistical analysis. In the case of the slightly acidic brown forest soil (Kompolt), the P concentration and P uptake of winter rape in the superphosphate treatments proved to be higher statistically than those values obtained for the plants grown in the phosphate rock treatments. On this soil, superphosphate proved to be a more effective P fertilizer form for the winter rape test plant than phosphate rock.

We compared the effect of phosphate rock and superphosphate in a pot experiment set up previously with spring barley and red clover test plants with the same two acidic soils [41-43]. We obtained similar results for spring barley and red clover as for winter rape where superphosphate proved to be a more effective P fertilizer in case of the slightly acidic Kompolt soil. On the moderately acidic Szentgyörgyvölgy soil, the effect of phosphate rock was similar to that of superphosphate.

4. CONCLUSIONS

In the beginning of incubation, the water-soluble P content of the pseudogley brown forest soil was influenced both by the form of P and by the experimental conditions. The water-soluble P content decreased with time. After the 15th to 20th day of incubation, the effects of the P forms decreased. In this stage, the effects of environmental conditions depended on the form of the P fertilizer. The water-soluble P content of the phosphate rock-treated samples was affected to a great extent by soil water content, while the incubation temperature had a greater effect in soils treated with superphosphate.

The AL-P content of phosphate rock-treated soils was higher throughout the incubation period than that of the superphosphate-treated soils, at equal rates of P-active agent content. The AL-extraction may dissolve a substantial amount of the original phosphate rock and therefore, the available P in the soils from phosphate rock can be overestimated. Thus the AL-method is not applicable for soil testing of available P forms from phosphate rock-treated soils. Temperature had a greater effect on the AL-P content of soils than soil water content. Phosphate rock increased the pH of soils, but no liming effect could be observed.

In the pot experiment set up with the moderately acidic pseudogley brown forest soil, the dry matter yield, P concentration, and P uptake of winter rape was affected similarly by the phosphate rock and superphosphate treatments. In contrast to the slightly acidic chernozem soil, superphosphate proved to be a more efficient P fertilizer. Previous incubation of the soil with the P fertilizers significantly decreased all three-plant parameters in the pseudogley brown forest soil. The incubated superphosphate treatments produced higher yields in the chernozem brown forest soil, as compared to the non-incubated P fertilizer treatments.

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