COMPARATIVE EVALUATION OF THE EFFECT OF ROCK PHOSPHATE AND MONOAMMONIUM PHOSPHATE ON PLANT P: NUTRITION IN SOD-PODZOLIC AND PEAT SOILS

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Abstract

The direct application of finely ground rock phosphate (RP) imported from Russia has been suggested as an alternative to the almost twice more expensive water-soluble monoammonium phosphate (MAP) on acid (moderately limed) sod-podzolic and peat soils. A pot experiment was conducted in 1997-1998 for a comparative evaluation of P availability from RP and MAP using the ^{32}P isotope dilution technique. The lupine was grown on sod-podzolic silty clay loam soil with pH 6.0 and a medium level of available P. Ryegrass plants were grown on peat soil with pH 4.9 and a low level of native soil P fertility.

Application of RP and MAP at a rate of 40 mg P/kg soil supplied similar moderate mount of P to lupine plants. The Pdff values, i.e. the fractions of P in the plants derived from the applied RP and MAP, were 7.4 and 8.4%, respectively. The application of the same P fertilizers to the peat soil had different effects on P nutrition of ryegrass plants. The Pdff values were 14.9% for RP and 22.1% for MAP. It may be concluded that for most annual crops water-soluble P forms such as MAP should be preferred. Direct application of RP is recommended for plants with an adequate rhizosphere ability to utilize P, such as lupine on acid sod-podzolic silty clay loam soils (pH<6.0). Considering cost differences of the P fertilizers, RP application on acid peat soil (pH<5.0) may be reasonable for major improvement of radionuclide-contaminated grassland.

The results of the second pot experiment suggested that direct application of RP may be more effective than the use of water-soluble P fertilizers in reducing the plant uptake of ^{137}Cs on contaminated, moderately limed sod-podzolic silty clay loam and peat soils. These soils are widely spread in the radioactive contaminated area of Belarus after the Chernobyl accident. Direct application of RP may be one of the effective countermeasures for the decrease of ^{137}Cs transfer from the contaminated acid soils to crop production.

1. INTRODUCTION

From 1965 to 1990, as a result of large-scale water engineering, liming and the intensive use of organic and mineral fertilizers, the productivity of arable land in Belarus has risen from 1.5 to 4.3 t/ha in grain equivalents. Significant improvement of soil fertility status was also achieved. However, the fertilizer consumption and productivity of agricultural land has been strongly declining over the last decade during the transition to a market economy. This decrease in available phosphorus and other nutrients was revealed by the results of soil testing. The available soil phosphate content has gone down from 1990 to 1997 to levels of 2 to 4 mg P/kg soil. Of a total of 118 districts in Belarus 50 districts showed a negative balance of phosphorus on arable land.

The main types of P-fertilizers produced in Belarus are monoammonium phosphate (MAP) and single ammonium superphosphate, which are water-soluble fertilizers and very expensive. During the period from 1991 to 1995 its consumption has decreased from 194 to 27 thousands tons of P per year. In 1997-1998 the application of P fertilizers has increased again up to 53 thousands tons of P per year. However, there is still evidence of a poor P balance in agriculture and a possible depletion of soil fertility in the future.

Field experiments carried out with various crops on sod-podzolic soils in the former USSR found that cheap rock phosphate with the correct choice and application might be an effective and valuable P fertilizer. The response to rock phosphate for crops grown on acid soils with low phosphorus reserve was larger than for those on limed soils that were better supplied with phosphorus [1-3].

Direct application of rock phosphate has been practiced in Belarus in the 1960s. Field and pot experiments (using the ^{32}P isotope technique) were carried out to study the comparative effectiveness of RP and superphosphate. It was found that there is a considerable scope for effective direct application of RP as a P fertilizer in the cultivation of legumes and other crops on acid soils [4, 5]. After intensive liming of acid soils in Belarus, the consumption of RP for direct application has declined rapidly. During the last 20 years, RP has not been used as a P fertilizer. Currently all imported RP into Belarus is used for the production of compound fertilizers. A significant RP deposit was found in Belarus, which also needs studied in forthcoming years.

Therefore, it is important to study the possibility of a profitable application of finely ground RP imported from Russia, which is sufficiently cheaper than locally produced water-soluble P fertilizers. There is a potential for a direct application of suitable kinds of RP to acid, moderately limed sod-podzolic and peat soils, which comprise about 30% of agricultural land in Belarus.

The aims of these studies were: 1) to determine the P fraction in plants derived from P fertilizers (rock phosphate and monoammonium phosphate) by means of ^{32}P isotopic techniques, 2) to make a comparative evaluation of availability of phosphorus rock phosphate and monoammonium phosphate for lupine and ryegrass, 3) to determine the effect of P fertilizers on the reduction of the root uptake of radionuclide ^{137}Cs in sod-podzolic and peat soils, and 4) to evaluate the possibility of direct application of a cheaper ground RP as an alternative to water soluble P fertilizer.

2. MATERIALS AND METHODS

Pot experiments were set up in the greenhouse of the Belorussian Research Institute for Soil Science and Agrochemistry in Minsk, using sod-podzolic silty clay loam soil (1997) and peat soil (1998). The soil characteristics are shown in Table I.

The sod-podzolic silty clay loam soil with medium content of extractable and available phosphorus and medium level of acidity was suitable for testing the effectiveness of RP. The peat soil had a higher level of acidity and low level of extractable and available P content. Both soils are typical for the area contaminated with radionuclide ^{137}Cs after the Chernobyl accident.

2.1. Pot experiment A: using the ^{32}P isotopic dilution method

A rock phosphate of the Briansk deposit in Russia was used in this study. The RP contained 8.3% total P, 0.04% water-soluble P and 2.9% citric acid-soluble P. Another tested fertilizer was the mono-ammonium phosphate which contained 21.8% total P and 20.4% water-soluble P.

Samples of the sod-podzolic soil untreated and amended with fertilizers studied were sent to Jean-Claude Fardeau, Centre de Cadarache, France, to determine the soil P status using the ^{32}P isotopic exchange kinetics method [6].

Evaluation of RP in comparison with MAP was made using the ^{32}P-isotope dilution technique [7]. A solution of NaH_2PO_4 labeled with ^{32}P used at low concentration ($3.7*10^6$ Bq ^{32}P diluted in 200 ml of distilled water per 5 kg of soil) was added to soil and thoroughly mixed. The soil was placed in plastic pots (5 kg per 1 pot) and it was allowed to reach equilibrium for a week. After that, the unlabelled fertilizers were applied according to the following treatments on sod-podzolic soil with lupine as a test crop:

1. Control
2. Rock phosphate (40 mg P/kg soil)
3. Monoammonium phosphate (40 mg P/kg soil)

Potassium was used in all treatments as muriate of potash at a rate of 140 mg K/kg soil. There was no need in applying N fertilizer for the experimental lupine crop. A minimal rate of 22 mg N/kg soil was applied as NH_4NO_3 in treatments 1 and 2 to equalize the amount of N applied with P in treatment 3.

TABLE I. SELECTED PROPERTIES OF THE SOD-PODZOLIC AND PEAT SOILS USED IN THE STUDY

Characteristics	Method used[1]	Value	
		Sod-podzolic soil	Peat soil
(pH H_2O)	1:2.5-25 (soil: water)	6.00	4.90
(pH KCl)	1:2.5-25 (soil: KCl)	5.00	4.15
Organic matter, %	$K_2Cr_2O_7$ oxidation	1.34	-
Extractable P (mg/kg)	0.2M HCl	67.0	30.3
Available P (mg/l)	0.01M $CaCl_2$	0.14	0.12
Cation exchange capacity (cmol(+)/kg)	Buffer solution $BaCl_2$	18.1	70.0
Exchangeable cations (cmol(+)/kg)			
Ca	1M KCl	5.20	25.0
Mg	1M KCl	1.30	12.8
K	1M NH_4OAc, pH 7.0	0.23	0.60
Texture, %	Pipette method		
Clay		24.7	-
Silt		55.7	-
Sand		19.6	-

[1]Ratio soil: water for the peat soil is 10 times lower than for sod-podzolic soil.

On peat soil with ryegrass as a test crop, fertilizers were applied according to the treatments:

1. Control
2. Rock phosphate (40 mg P/kg soil)
3. Monoammonium phosphate (40 mg P/kg soil)

Potassium and nitrogen were used in all treatments as muriate of potash and applied at 170 mg K/kg soil. Nitrogen was applied at 80 mg N/kg soil with ammonium nitrate. Since some N was applied with P in treatment 3, only 58 mg N/kg as ammonium nitrate was needed for this treatment. The fertilizers were mixed with the soil and the soil was placed in plastic pots. There were four replications per treatment.

The pregerminated seeds of yellow lupine (cultivar Pava) were sown in each pot in early June 1997 and seeds of ryegrass (cultivar Avante) in 1998. Pots were arranged in a randomized design. The soil moisture was adjusted to 40 to 60% of the field capacity with distilled water. The tested plants were grown for two months.

The plants of lupine and ryegrass were harvested, cut into small pieces and oven dried at 65°C until a constant weight achieved. Dry matter yield was calculated. Two-gram plant samples from each pot were ashed at 450°C, dissolved in 20 ml of 1 M HCl and filtered. The ^{32}P activity in the samples was measured using Cerenkov counting in a liquid scintillation counter. After dry ashing, the total P content in the plants was also measured by the molybdate blue method. The amount of P derived from the soil and from the tested fertilizers was calculated using the isotope dilution procedure [7, 8].

Since the specific activity (S.A.) of labeled soil = S.A. of the plant in treatment 1, the fraction of P in the plant which was derived from the tested fertilizers (or % Pdff) was calculated from the following equations:

% Pdff RP = (1- (S.A. plant treatment 2/ S.A. plant treatment 1)) x 100 (1)
% Pdff MAP = (1- (S.A. plant of treatment 3/ S.A. plant of treatment 1)) x 100 (2)

The relative availability as determined by isotope dilution (RAID) for comparing the availability of RP with MAP was calculated from the following:

RAID = %Pdff RP / %Pdff MAP x 100 (3)

2.2. Pot experiment B: with ^{137}Cs contaminated soil

The effect of P-fertilizers on the reduction of the root uptake of radionuclide ^{137}Cs was studied on the same soils with a parallel set of above-mentioned treatments.

A solution of $CsCl_2$ labelled with ^{137}Cs (900 Bq ^{137}Cs diluted in 200 ml of distilled water per 1 kg of soil) was added to soil and thoroughly mixed. After that, the soil was placed in plastic pots (5 kg per 1 pot) and it was allowed to reach equilibrium for a week. Then, unlabelled fertilizers were applied according to the treatments on sod-podzolic soil with lupine as the test crop.

1. Control
2. Rock phosphate (40 mg P/kg soil)
3. Monoammonium phosphate (40 mg P/kg soil)

On peat soil with ryegrass as the test crop, fertilizers were applied according to the treatments:

1. Control
2. Rock phosphate (40 mg P/kg soil)
3. Monoammonium phosphate (40 mg P/kg soil)

Nitrogen and K were applied as described for pot experiment A. The fertilizers were mixed with the soil and the soil was placed in plastic pots. There were four replications per treatment. The seeds of lupine and ryegrass were sown in each pot and were grown. When the plants were harvested, they were cut into small pieces and oven dried at 65° C. The ^{137}Cs activity was determined by a Gamma-spectrometer.

3. RESULTS AND DISCUSSION

3.1. Prediction of the effectiveness of P fertilizer application on sod-podzolic soil

The experimental results obtained in the laboratory of Dr. Fardeau using the ^{32}P-isotope exchange kinetic method are presented in Tables II and III. The fixing capacity of this soil (r_1/R) remained low to medium after 40 days of incubation in moist conditions at a temperature from 25 to 28° C. The C_p value (intensity factor) of the control treatment was slightly lower than 0.2 mg/L and directly available P (E_1) was medium at 4.4 mg P/kg. Therefore, the native soil P fertility is medium and P was not a main limiting factor for crop production.

After application of RP at the rate 50 mg P/kg soil, the directly available P (E_1) and other more mobile pools (A, B, and C) did not increase (Tables II and III). After harvesting, the available P content of the soil (E_1 values as high as 20 mg P/kg) was significantly increased for MAP treatment. Since the fixing capacity was low to medium, a large part of the P applied as MAP remained directly available. The kinetic exchange constants (Table III) indicated the mobility of the P ions was not significantly increased by RP application.

TABLE II. BIOAVAILABLE SOIL P PARAMETERS FOR THE SOD-PODZOLIC SOIL (AFTER AN INCUBATION PERIOD OF 40 DAYS)

Treatment	PH (H_2O)	C_p (mg P/L)	r_1/R	n	E_1 (mg P/kg)	E_1/C_p (L/kg)	Total P (mg P/kg)
Control	6.2	0.15	0.34	0.30	4.4	29.3	473
RP 50 mg P/kg soil	6.2	0.20	0.36	0.25	5.5	27.5	523
MAP 50 mg P/kg soil	6.0	1.10	0.54	0.14	20.0	18.2	523

TABLE III. COMPARTMENTAL ANALYSIS AND KINETIC PARAMETERS OF SOIL P (AFTER AN INCUBATION PERIOD OF 40 DAYS)

	P pools (mg P/kg soil)				K_m	T_m	F_m
Treatment	A	B	C	D	min^{-1}	$min \cdot 10^{-2}$	$mg \cdot min^{-1}$
Control	32	78	50	319	11.0	9	16.4
RP 50 mg P/kg soil	27	56	28	407	15.0	7	30.0
MAP 50 mg P/kg soil	31	38	15	420	11.0	9	125.0

3.2. Experiment A

The shoot dry-weights, P concentrations and P uptake values are shown in Table IV. The shoot yields of lupine and ryegrass were highest in the treatment with MAP, followed by the treatment with RP. Plants of the treatment with RP grew significantly better than did plants of the control treatment, but worse than the MAP treatment. Lupine shoots supplied with P from RP and MAP took up 2.6 and 4.3 mg P/pot more than did plants with no P treatment. The yields of dry mass of lupine shoots were also increased 9 and 15% compared to the control treatment. The highest difference between RP and MAP was observed on peat soil. The shoots of ryegrass took up 2.7 and 9.4 mg P/pot more than did plants on the control treatment.

The data on specific activity (S.A.) of cultivated plants determined at harvest time are shown in Table V. In comparison to the treatment without P, S.A. of the plants decreased as a result of an extra supply of P from RP and MAP added to the soil-plant system.

The Pdff values for lupine (the fraction of P in the plants derived from the applied RP and MAP) were almost the same at 7.4 and 8.4%, respectively. Phosphorus fertilizer recovery values for RP and MAP were only about 1% because of the relative high content of available soil native P. It is evident that for lupine plants 1 kg P as MAP is nearly equivalent to 1 kg P as RP. The high relative availability of RP compared with MAP (RAID = 88%) was due to a high root ability of lupine to utilize P from insoluble forms.

For ryegrass on peat soil, the Pdff values were 14.9 for RP and 22.1% for MAP. Phosphorus fertilizer recovery values for RP and MAP were 1.5 and 2.9%. The higher P uptake efficiency of ryegrass from MAP was due to the water-soluble source of phosphorus in this fertilizer. For the ryegrass plant, 1 kg P as MAP was equivalent to 1.48 kg of RP. The application of MAP proved to have a better agronomic effect on ryegrass than RP application (RAID = 67%) on acid peat soil. However, the application of RP on the peat soil with rather low level of the native P fertility provided a statistically significant increase in ryegrass shoot yield compared to the control treatment without P.

TABLE IV. SHOOT DRY WEIGHT OF LUPINE AND RYEGRASS AND P UPTAKE BY PLANTS

Treatment		Shoot dry weight (g/pot)	P concentration (%)	Total P uptake (mg P/pot)
Lupine (sod-podzolic soil)				
Without P fertilizer		12.8	0.188	24.1
RP 40 mg P/kg soil		14.0	0.191	26.7
MAP 40 mg P/kg soil		14.7	0.193	28.4
	LSD_{05}	0.3	0.01	0.7
Ryegrass (peat soil)				
Without P fertilizer		15.4	0.110	16.9
RP 40 mg P/kg soil		16.3	0.120	19.6
MAP 40 mg P/kg soil		18.8	0.140	26.3
	LSD_{05}	0.6	0.01	0.9

TABLE V. SPECIFIC ACTIVITY OF LUPINE AND RYEGRASS AND P UPTAKE BY PLANTS FROM FERTILIZERS

Treatment	Specific activities (Bq/mg P)	Pdf soil (%)	Pdff (%)	P fertilizer recovery (%)
Lupine (sod-podzolic soil)				
Without P	22.9	100.0	-	-
RP 40 mg P/kg soil	21.2	92.6	7.4	1.0
MAP 40 mg P/kg soil	20.9	91.6	8.4	1.2
Ryegrass (peat soil)				
Without P	73.4	100.0	-	-
RP 40 mg P/kg soil	62.5	85.1	14.9	1.5
MAP 40 mg P/kg soil	57.2	77.9	22.1	2.9

The effect of RP and MAP on soil fertility properties after harvesting the test crops is shown in Table VI. No significant differences were observed between pH value for the treatments without P and the treatments with MAP and RP application. It is known that most of the native phosphorus in soil is fixed in unavailable forms. Also the fertilizer phosphorus becomes more insoluble in soils with time. Even the amounts classified as "available" by most chemical soil testing methods are not directly soluble and available to plants. For example, the P fertility of sod-podzolic soil was signify-cantly increased to the same level after RP and MAP application when tested using the standard Belo-russian method (0.2 M HCl extracting). But, there was only a modest increase in available P tested in 0.01 M $CaCl_2$ solution after RP application. After MAP application, there was a 3-fold greater available P as determined by 0.01 M $CaCl_2$. The 0.01 M $CaCl_2$ extracting method was able to detect difference in available P in sod-podzolic soil amended with RP and MAP relatively close to the ^{32}P-isotope exchange kinetic method of Fardeau (Table II). The local standard method (0.2 M HCl) overestimated the availability of P in natural RP.

The peat soil P fertility was also significantly increased to nearly the same level after application of RP and MAP. The determination of P fertility by the standard method (0.2 M HCl) and 0.01M $CaCl_2$ extracting method did not show the significant superiority of the latter test method for peat soil.

Phosphorus applications on sod-podzolic soils with medium level of available phosphorus have to be mainly for soil fertility maintenance in the rates close to the P output from harvested yields. For most of the crops, there is a preferable application of water-soluble P forms as MAP. But for plants with a high root ability to utilize P such as lupine, buckwheat, and rapeseed, RP may be used for direct application as well as water-soluble P fertilizers on acid soils (pH_{H2O} <6.0, pH_{KCl} <5.0).

The effect of water-soluble P fertilizer MAP on ryegrass was much higher than that of RP on acid peat soil in spite of comparatively low levels of the native soil P fertility. The cost of the fertilizers has to be taken into consideration. The cost of 1 ton of P in the form of MAP delivered to Belorussian market in June 1997 was 773 US$. The cost of 1 ton of P in RP was 481 US$. Therefore, the direct application of finely grounded RP on acid peat soil (pH_{H2O} <5.0), especially for radical improvement of grassland on the radionuclide-contaminated area may be reasonable. Field experiments are needed for the development of economically sound practical recommendations.

TABLE VI. EFFECT OF THE TESTED FERTILIZERS ON AVAILABLE P CONTENT IN SOD-PODZOLIC AND PEAT SOIL EVALUATED BY CHEMICAL METHODS

Treatment	pH (KCl)	Extractable P (0.2M HCl) mg/kg	Available P (0.01M $CaCl_2$) mg/L
Sod-podzolic soil			
Without P	5.00	64	0.14
RP 40 mg P/kg soil	5.20	101	0.19
MAP 40 mg P/kg soil	4.90	111	0.43
LSD (P=0.05)	0.20	16	0.09
Peat soil			
Without P	4.15	30	0.12
RP 40 mg P/kg soil	4.20	62	0.23
MAP 40 mg P/kg soil	4.15	59	0.27
LSD (P=0.05)	0.20	2	0.03

3.3. Experiment B

Phosphorus and K fertilizers applied to radioactive contaminated soil may significantly decrease the radionuclide consumption by plants, as well as increase crop yields. Therefore, the effect of RP and MAP on the root uptake of radionuclide ^{137}Cs was studied on the same soils with a parallel set of pot experiment treatments.

The shoot dry weight of lupine and ryegrass and its ^{137}Cs activity was determined for the same treatments with P fertilizers as in experiment A, but the soils were contaminated with ^{137}Cs (Table VII).

The yields of tested plants in all treatments were close to those in experiment A. There was significant reduction of the root uptake of ^{137}Cs by lupine on RP treated (16% decrease) and MAP (8% decrease) treated soils in comparison with plant activity of the control treatment. The ^{137}Cs activity of ryegrass plants on peat soil decreased 27% after application of RP, but only a 7% decrease was observed with MAP application. A stronger effect of RP on the plant root uptake of ^{137}Cs may be explained from the higher Ca content of RP compared with MAP.

The results of pot experiments suggest that direct application of RP may be more effective than use of water-soluble P fertilizers in reducing the plant uptake of ^{137}Cs on the acid sod-podzolic and peat soils. These data are very important because the tested soils are widely spread in the radioactive contaminated area. It is necessary to continue the comparative evaluation of RP and MAP effectiveness in field trials. Direct application of RP may be one of the effective countermeasures for decreasing ^{137}Cs transfer from the contaminated acid soils to crop production.

TABLE VII. INFLUENCE OF P FERTILIZERS ON THE ^{137}Cs CONTAMINATION OF LUPINE SHOOTS ON SOD-PODZOLIC SOIL AND RYEGRASS ON PEAT SOIL

Treatments		Shoot dry weight (g/pot)	^{137}Cs activity of shoots Bq/kg
Lupine			
Without P		13.0	109
RP 40 mg P/kg		14.1	91
MAP 40 mg P/kg		14.5	101
	LSD (P=0.05)	0.5	5.0
Ryegrass			
Without P		15.1	1156
RP 40 mg P/kg		16.3	847
MAP 40 mg P/kg		18.7	1084
	LSD (P=0.05)	0.5	65

4. CONCLUSIONS

Direct application of RP and MAP, at a rate of 40 mg P/kg soil, made almost the same moderate contribution to P nutrition of lupine grown on a typical Belarus moderately limed sod-podzolic silty clay loam soil with pH_{H2O} 6.0 and medium level of directly available P. The Pdff values for the RP and MAP applied fertilizers were 7.4 and 8.4%, respectively. It is evident that P applications have to be mainly for soil fertility maintenance in the rates close to the P output by harvested yields. For most of the crops there is a preferable application of water-soluble P forms as MAP. But for the plants with a better rizosphere ability to utilize P such as lupine, buckwheat, rapeseed, RP may be used for direct application as well as water-soluble P fertilizers on acid soils ($pH_{H2O} < 6.0$, $pH_{KCl} < 5.0$).

The effect of water-soluble P fertilizer MAP on ryegrass was much higher than that of RP on acid peat soil (pH_{H2O} 4.9, pH_{KCl} 4.1) with a comparatively low level of the native soil P fertility. The Pdff values for tested RP and MAP were respectively 14.9 and 22.1%. The native peat soil P fertility is one of the main limiting factors for crop production and higher rates of P fertilizers are needed. In general, peat soils prefer application of water-soluble P fertilizers. But, differences in costs of fertilizers have to be considered. The cost of 1 ton of P in form of MAP delivered to Belorussian market in June 1997 was 773 US$, but the cost of 1 ton of P in RP was 481 US$. So the direct application of finely grounded RP on acid peat soil ($pH_{H2O} < 5.0$), especially for major improvement of grassland located in the radionuclide contaminated area may be reasonable.

The results of a second pot experiment suggests that direct application of RP may be more effective than use of water-soluble P fertilizers in reducing the plant uptake of ^{137}Cs on acid sod-podzolic and peat soils. There was a noticeable reduction of the root uptake of ^{137}Cs by lupine on RP-treatment (16% decrease) and MAP (8% decrease) in comparison with plant activity of the control treatment. The activity of ryegrass plants on peat soil decreased by 27% after application of RP, but after MAP application there was only a 7% decrease. The tested soils are widely spread in the radioactive contaminated area. It is necessary to continue the comparative evaluation of RP and MAP effectiveness in field trials for development of economically sound practical recommendation. Direct application of RP may be one of the effective countermeasures for decreasing ^{137}Cs transfer from the contaminated acid soils to crop production.

The studies showed that 0.01 M $CaCl_2$ extracting method was able to detect difference in available P in sod-podzolic soil amended with RP and MAP relatively close to the ^{32}P-isotope exchange kinetic method of Dr. Fardeau. The Belorussian standard soil testing method using 0.2 M HCl overestimated the effect of natural RP on soil available P.

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