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CONDITIONS PROMOTING AND RESTRAINING AGRONOMIC EFFECTIVENESS OF WATER-INSOLUBLE PHOSPHATE SOURCES, IN PARTICULAR PHOSPHATE ROCK (PR): III. ^{32}P-AIDED SOIL-PR INTERACTION STUDIES AIMED AT ENHANCING P BIOAVAILABILITY FROM PR

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Abstract. Mobilization of PR and bioavailability of PR-P for plants takes place through complex chemical and biochemical processes that occurs during prolonged soil interaction with PR. There is a high probability that certain processes of a biochemical nature are also involved through proteinaceous ion carriers whose concentration and physiological activity in plant roots may be influenced by means of specially formulated foliar fertilizer compositions. ^{32}P-aided studies have contributed to identify possibilities of enhancing PR-P bioavailability through foliar fertilizer application.

1. INTRODUCTION

There are several ways to enhancing PR-P bioavailability. Some authors reported the positive influence of nitrogen and potassium fertilizers on P absorption in plants. There is also a positive role of water-soluble sources of P enhancing PR-P bioavailability [1]. Results showed a positive effect of PR acidulation on Cd and PR-P availability in upland rice [2]. There is a significant positive influence of ammonium ions at pH 6.5 and 7.5 on absorption of phosphate ion in sunflower from foliar applied-fertilizers [3]. There are also some indications of ammonium salts enhancing P bioavailability from soil and different phosphate fertilizer sources [4-7]. A series of ^{32}P-aided studies was carried out to explore several ways to enhance the PR-P bioavailability.

2. ESSENTIAL METHODOLOGICAL ASPECTS OF ^{32}P AIDED STUDIES AIMED AT ENHANCEMENT OF PR-P BIOAVAILABILITY IN PLANTS

^{32}P aided studies aimed at enhancing PR-P bioavailability were carried out with ryegrass (*Lolium multiflorum* Lam. cv. Arina) on a soil sample taken from plow-layer of Albota Hapludalf soil in small cubic form pots of 1250 g dry soil capacity. Surface mineral phosphates of the soils used in these studies were labeled with 0.05 mCi of carrier - free ^{32}P supplied by Amersham UK laboratories. Total amount of ^{32}P label (0.05 mCi/pot) contained in 120 cm^3 was divided in 6 separate increments each of these (0.00833 mCi) applied successively on 200 g dry soil with 20 cm^3 solution. Pots were seeded with 0.6 g of seeds and covered with 50 g of soil. The plants were continuously watered with distilled water raised by capillarity from a silica sand water saturated bed. The plastic pots had 5 circular holes on their bottom (perforations) that were 2 mm in diameter. For the first harvest, the soil in pots received 100 ppm of N and K from ammonium nitrate and potassium sulfate. For the second harvest, N and K were supplemented with 50 ppm of N and 140 ppm of K from KNO_3. Radioactive measurements of β particles were performed as described in the second paper of this series. The AS (specific activity as counts per minute/mg of P in plants) as well as total P determinations in plants were performed as described in the first and second paper of this series. Specific activities (SA) and their use have been calculated and used in a way to address the situation of labeling the non-occluded surface mineral soil phosphates with ^{32}P. Some other procedural details are mentioned in the tables along with results presented.

3. RESULTS AND DISCUSSIONS

3.1. Enhancement of PR-P bioavailability by means of water-soluble P sources

Chien et al. [1] have explained effects of enhanced PR-P bioavailability with water-soluble P sources with reference to the positive influence soluble fertilizer sources have on development of branched root system able to explore the soil and make use of less available P sources. As a result of this, availability of PR-P is increased. We also found similar results (Tables I, II, and III).

3.2. Influence of aminoacid and ureide complex (AAUC) applied on ryegrass plants on PdfPR

Enhancement of PR-P bioavailability has also been tried by using amino acid ureide (AAUC) applied on ryegrass plants as 0.25% solution 2 times, each time with 30 cm^3 of diluted solution per pot, 10 days before grass harvest. The AAUC was prepared by hydrolysis of collagen with 2.5 N nitric acid (one part of collagen with 3 volumetric parts of acid at 95 - 100°C for 3 h). The results are recorded in Tables IV and V. The data show that AAUC applied as 0.25% diluted solution had a statistically significant positive effect on enhancing PR-P bioavailability for ryegrass plants. A tentative explanation of these findings may be due to the role of proteinaceous ion-carriers on PR-P uptake in plants. Collagen used to produce AAUC contained a trace amount of P (~ 0.25% P).

3.3. Influence of N chemical form and of solution pH on P absorption and translocation in sunflower plant from leaf applied complex foliar fertilizer solution (CFFS)

A 1% diluted solution of a Complex foliar fertilizer solution (CFFS) labeled with ^{32}P was foliar applied to study the influence of chemical form of N (nitrate, ammonium, and ureic) and pH (4.5; 6.5 and 7.5) on the P absorption and translocation in sunflower plants (*Helianthus annuus*, L, cv. Select). The CFFS was prepared by diluting by 100 times (1%) a solution containing 1000 ppm N, P and K along with equal concentrations of minor nutrients in chelated forms. The P in CFFS was labeled with 0.2 mCi of ^{32}P. Sunflower plants were grown till head formation in Mitscherlich type pots of 8.0 kg dry soil capacity uniformly dressed with N, P, and K and watered to 60% of soil water holding capacity. The solutions were applied 3 times at 3 day time intervals starting on 22 of June 1995 on pieces of cheese cloth firmly attached to leaves utilizing 0.5 cc pipettes with special Brand dispensers. The pH of CFFS was adjusted to pH 4.5, 6.5, and 7.5 with sulfuric acid and sodium hydroxide. Radiometric measurements were taken from representative samples from plants (leaves, stems, tops-inflorescences to be), which were not in contact with labeled CFFS solution in the course of solution application on plants. Effects of N chemical forms and solution pH were determined by means of specific activities of P. The data are recorded in Tables VI, VII, VIII (cv. Select) and IX (cv. Romsun 59).

There were statistically significant effects of tested N chemical forms and of solution pH on P absorption through leaves and on P translocation in sunflower plants. Further systematic and comprehensive experimental work is needed.

TABLE I. THE INFLUENCE OF APPLYING TOGETHER EQUAL RATES OF P FROM TSP AND PR IN ALBOTA[1] AGRUDALF SOIL ON P PRODUCTIVE USE FROM BOTH THESE SOURCES IN RYEGRASS (FIRST CUT-27 JULY 1995)

Treatments: P sources and P rates in mg of P/pot[2]	SA of P in plants, cpm/mg of P	P uptake in plants, mg of P/pot	P in plant derived from applied sources, %
Check: NK+^{32}P	15718	17.4	-
NK+125 mg P (N.Carolina PR)+^{32}P	11852	21.0	24.6
NK+125 mg P (Gafsa PR)+^{32}P	11258	24.0	28.4
NK+62.5 mg P (TSP)+125 mg P (N.C. PR)+^{32}P	9832	31.1	37.4
NK+62.5 mg P (TSP)+62.5 mg P (Gafsa PR)+^{32}P	9981	33.2	36.5
LSD for X% level of probability			
X = 5	1475	2.9	
X = 1	2045	3.9	
X = 0.1	2836	5.3	

[1] Some of relevant to PR-P mobilization chemical properties are recorded in Table I from the first paper.
[2] Incorporation of TSP and PR sources in the soil was prior to ^{32}P labeling of soil phosphates.
^{32}P was carrier free.

TABLE II. THE INFLUENCE OF APPLYING TOGETHER EQUAL RATES OF P FROM TSP AND PR IN ALBOTA AGRUDALF SOIL ON P PRODUCTIVE USE FROM BOTH THESE SOURCES IN RYEGRASS (SECOND CUT-14 AUGUST 1995)

Treatments: P sources and P rates in mg of P/pot[1]	SA of P in plants, cpm/mg of P	P uptake in plants, mg of P/pot	P in plant derived from applied sources, %[2]
Check: NK+^{32}P	3861	1.83	-
NK+125 mg P (N.Carolina PR)+ ^{32}P	3052	2.29	21.0
NK+125 mg P (Gafsa PR)+ ^{32}P	2894	3.07	25.0
NK+62.5 mg P (TSP)+125 mg P (N.C. PR)+ ^{32}P	2623	2.73	32.1
NK+62.5 mg P (TSP)+62.5 mg P (Gafsa PR)+ ^{32}P	2508	2.99	35.0
LSD for X% level of probability			
X = 5	160	0.25	
X = 1	223	0.34	
X = 0.1	309	0.47	

[1] ^{32}P was carrier free.

[2] Data in Tables I and II have shown that water-soluble source of P had a statistically highly significant effect of enhancing PR-P bioavailability.

TABLE III. THE INFLUENCE OF APPLYING TOGETHER EQUAL RATES OF P FROM TSP AND PR IN ALBOTA AGRUDALF SOIL ON P PRODUCTIVE USE FROM BOTH THESE SOURCES IN RYEGRASS (THIRD CUT-20 SEPTEMBER 1995)

Treatments: P sources and P rates in mg of P/pot[1]	SA of P in plants, cpm/mg of P	P uptake in plants, mg of P/pot	P in plant derived from applied sources, %
Check: NK+^{32}P	1414	7.22	-
NK+125 mg P (N.Carolina PR)+ ^{32}P	1317	9.33	6.9
NK+125 mg P (Gafsa PR)+ ^{32}P	1136	10.18	19.7
NK+62.5 mg P (TSP)+125 mg P (N.C. PR)+ ^{32}P	1072	10.51	24.2
NK+62.5 mg P (TSP)+62.5 mg P (Gafsa PR)+ ^{32}P	1179	8.58	16.6
LSD for X% level of probability			
X = 5	95	0.72	
X = 1	132	0.98	
X = 0.1	183	1.35	

[1] ^{32}P was carrier free.

TABLE IV. THE INFLUENCE OF FOLIAR APPLIED AMINOACID UREIDE COMPLEX (AAUC) ON P DERIVED IN RYEGRASS FROM ROCK PHOSPHATES APPLIED IN ALBOTA AGRUDALF SOIL (FIRST CUT)

Treatments applied[1] in soil	in plants	SA[2] of P in plants, cpm/mg of P in plants	P uptake in plants, mg of P per pot	P in plant derived from PR, % from total plant P
No P, NK + ^{32}P	distilled w.	15719	17.4	-
No P, NK + ^{32}P	AAUC 0.25%	16542	17.8	-
NK+125ppmP from N.C. PR+^{32}P	distilled w.	11857	21.0	24.6
NK+125ppmP from N.C. PR+^{32}P	AAUC 0.25%	11258	26.8	32.0
NK+125ppmP from Gafsa PR+^{32}P	distilled w.	10982	24.0	31.1
NK+125ppmP from Gafsa PR+^{32}P	AAUC 0.25%	10681	33.5	35.4
DL for X% level of probability				
X = 5		545	2.70	
X = 1		758	3.65	
X = 0.1		1052	5.04	

[1] ^{32}P was carrier free.
[2] SA = P specific activity in plants = counts per minute (cpm) per mg of P in plants.

TABLE V. THE INFLUENCE OF FOLIAR APPLIED AMINOACID UREIDE COMPLEX (AAUC) ON P DERIVED IN RYEGRASS FROM ROCK PHOSPHATES APPLIED IN ALBOTA AGRUDALF SOIL (SECOND CUT)

Treatments applied[1] in soil	on plants	SA[2] of P in plants, cpm/mg of P in plants	P uptake in plants, mg of P per pot	P in plant derived from PR, % from total plant P
No P, NK + ^{32}P	distilled w.	3861	1.83	-
No P, NK + ^{32}P	AAUC 0.25%	3980	1.83	-
NK+125ppmP from N.C. PR + ^{32}P	distilled w.	3052	2.29	21.0
NK+125ppmP from N.C. PR + ^{32}P	AAUC 0.25%	2661	2.65	33.1
NK+125ppmP from Gafsa PR + ^{32}P	distilled w.	2894	2.07	25.0
NK+125ppmP from Gafsa PR + ^{32}P	AAUC 0.25%	2654	2.41	33.3
DL for X% level of probability				
X = 5		159	0.25	
X = 1		221	0.34	
X = 0.1		307	0.47	

[1] ^{32}P was carrier free.
[2] SA = P specific activity in plants = counts per minute (cpm) per mg of P in plants.

TABLE VI. INFLUENCE OF NITROGEN CHEMICAL FORMS (A) IN COMPLEX FOLIAR FERTILIZER SOLUTIONS AND OF THEIR REACTION (B) ON P UPTAKE AND TRANSLOCATION IN SUNFLOWER PLANTS (CROSSED CVR. SELECT) AS DISCLOSED BY SA (SPECIFIC ACTIVITY OF P IN LEAVES OPPOSITE TO THOSE ON WHICH ^{32}P LABELLED DILUTED COMPLEX FOLIAR FERTILIZER SOLUTIONS WERE APPLIED)

Chemical form and concentration of N in CFF (A)	pH of diluted 1% CFF solutions (B) 4.5	6.5	7.5	Average
No nitrogen	430	235	239	301
N-NH_4 nitrogen (1000 ppm N)	367	231	236	278
$(NH_2)_2CO$ nitrogen " " "	350	510	949	603
NH_4NO_3 nitrogen " " "	278	271	376	308
Average=	356	312	450	
LSD for X % level of probability	A (up-down)		B (left-right)	A x B
X = 5.0	67		58	116
X = 1.0	91		79	158
X = 0.1	123		106	213

TABLE VII. INFLUENCE OF NITROGEN CHEMICAL FORMS (A) IN COMPLEX FOLIAR FERTILIZER SOLUTIONS AND OF THEIR REACTION (B) ON P UPTAKE AND TRANSLOCATION IN SUNFLOWER PLANTS (CROSSED CVR. SELECT) AS DISCLOSED BY SA (SPECIFIC ACTIVITY OF P IN INFLORESCENCES (TOPS)

Chemical form and concentration of N in CFF (A)	pH of diluted 1% CFF solutions (B) 4.5	6.5	7.5	Average
No nitrogen	670	543	554	622
N-NH_4 nitrogen (1000 ppm N)	860	932	944	912
$(NH_2)_2CO$ nitrogen " " "	791	836	716	813
NH_4NO_3 nitrogen " " "	1242	1098	1143	1161
Average=	891	902	839	
LSD for X % level of probability	A (up-down)		B (left-right)	A x B
X = 5.0	139		120	240
X = 1.0	189		163	327
X = 0.1	254		220	439

TABLE VIII. INFLUENCE OF NITROGEN CHEMICAL FORMS (A) IN COMPLEX FOLIAR FERTILIZER SOLUTIONS AND OF THEIR REACTION (B) ON P UPTAKE AND TRANSLOCATION IN SUNFLOWER PLANTS (CROSSED CVR. SELECT) AS DISCLOSED BY SA (SPECIFIC ACTIVITY OF P IN STEMS BENEATH THE TOUCHED LEAVES WITH ^{32}P LABELLED DILUTED CFF SOLUTIONS)

Chemical form and concentration of N in CFF (A)	pH of diluted 1% CFF solutions (B) 4.5	6.5	7.5	Average
No nitrogen	535	576	481	537
N-NH_4 nitrogen (1000 ppm N)	610	863	768	757
$(NH_2)_2CO$ nitrogen " " "	650	678	611	646
NH_4NO_3 nitrogen " " "	1056	924	863	948
Average=	718	760	681	
LSD for X % level of probability	A (up-down)		B (left-right)	A x B
X = 5.0	134		116	233
X = 1.0	183		158	317
X = 0.1	246		213	436

TABLE IX. PDFF, % (PHOSPHORUS DERIVED FROM FOLIAR FERTILIZERS) IN SUNFLOWER (CVR. ROMSUN 59) PLANT ORGANS, EVALUATED FROM THE SPECIFIC ACTIVITY RATIOS AFTER SIX APPLICATIONS OF DILUTED CFF SOLUTIONS WITH 1000 PPM P ON LEAVES (POT EXPERIMENT ON FUNDULEA-CĂLĂRAŞI, HAPLUDAL SOIL)

Sunflower plant organs	pH of 1% CFFS when N was present solely as NH_4^+ ion			LSD for a probability of 5%
	4.5	6.5	7.5	
Opposite[1] leaves	0.12[2]	0.21[2]	0.20[3]	0.04
Plant tops (inflorescence)	0.24[2]	0.43[2]	0.49[3]	0.16
Plant stems below the CFF treated leaves	0.08[3]	0.34[2]	0.05[3]	0.30

[1] to those on which ^{32}P labeled solution of CFF has been applied.
[2] significant at a level of at least 5% probability.
[3] the difference between two neighbouring averages, not significant.

4. CONCLUSIONS

Plant experimental and laboratory chemical research using ^{32}P dilution methodology have confirmed the possibility of enhancing PR-P bioavailability to ryegrass plants through a) the application of water-soluble P sources along with PR in an Agrudalf soil and b) the foliar application of an amino-acid ureide complex that possibly influences the PR-P absorption and accumulation in ryegrass.

Experiments with ^{32}P labeled foliar fertilizers on sunflower plants have shown the important role of N chemical forms in the composition of complex foliar fertilizers and the pH of diluted solutions in P absorption and translocation from CFFS applied on plants.

These findings need to be studied further in view of their practical importance to increase PR-P bioavailability to plants.

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