IAEA TECDOC 1721

IAEA TECDOC SERIES

TECDOC No. 1721

Optimizing Productivity of Food Crop Genotypes in Low Nutrient Soils

Prepared by the Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture

Joint FAO/IAEA Programme
Nuclear Techniques in Food and Agriculture

IAEA
International Atomic Energy Agency

IAEA-TECDOC-1721

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Nuclear Techniques in Food and Agriculture

INTERNATIONAL ATOMIC ENERGY AGENCY
VIENNA, 2013

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http://www.iaea.org/books

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Printed by the IAEA in Austria
November 2013

IAEA Library Cataloguing in Publication Data

Optimizing productivity of food crop genotypes in low nutrient
soils. – Vienna : International Atomic Energy Agency, 2013.
p. ; 30 cm. – (IAEA-TECDOC series, ISSN 1011-4289
; no. 1721)
ISBN 978-92-0-113113-3
Includes bibliographical references.

1. Food crops – Yields – Research. 2. Genotype-environment interaction. 3. Agriculturally marginal lands. 4. Food crops – Soils. I. International Atomic Energy Agency. II. Series.

IAEAL 13-00843

PHOSPHORUS USE EFFICIENCY BY BRAZILIAN COMMON BEAN GENOTYPES ASSESSED BY THE ^{32}P DILUTION TECHNIQUE

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Abstract

The objectives of this work were to identify the most efficient common bean (*Phaseolus vulgaris* L.) genotypes on phosphorus (P) utilization, and verify if P from the seed affects the classification of common bean genotypes on P uptake efficiency when the ^{32}P isotopic dilution technique is used. The experiment was conducted in a greenhouse, and plants were grown in pots with surface samples of a dystrophic Typic Haplustox. The treatments consisted of 50 common bean genotypes and two standard plant species, efficient or inefficient in P uptake. The results were assessed through correlation and cluster analysis (multivariate). Sangue de Boi, Rosinha, Thayú, Grafite, Horizonte, Pioneiro and Jalo Precoce common bean genotypes were the most efficient on P uptake, and Carioca 80, CNF 10, Pérola, IAPAR 31, Roxão EEP, Aporé, Pioneiro, Pontal, Timbó and Rudá were the most efficient in P utilization. The P derived from seed influences the identification of common bean genotypes for P uptake efficiency.

1. INTRODUCTION

Common bean is one of the main crops grown in the off-season under irrigation in the Cerrado (Savannah) areas of Brazil [1]. The low P content and the high P fixation capacity in the Cerrado soils is one of the main limitations to agricultural productivity. To reach satisfactory production of beans it is necessary to apply high rates of P fertilizer [2]. Besides liming and fertilizer application to minimize such problems, another strategy would be to identify and to explore the use of the genotypic differences in common bean for efficiency in P use (uptake and utilization), which can reduce the expenses with P fertilizers [3, 4]. The P recovery efficiency by the bean plant is less than 10% in the Cerrado soils, depending on the application rate [5]. This low value of P efficiency by beans can be increased with the use of genotypes more efficient in P uptake. There are common bean genotypes which can increase P uptake significantly through the capacity to modify the rhizosphere by organic acid exudation, surface root architecture and longer basal root hairs under stressed conditions [6]. In other words some common bean cultivars can increase soil P use efficiency by different adaptations [7, 8].

The objectives of this study were to identify common bean genotypes more efficient in P uptake using the ^{32}P isotope dilution technique, and also for P utilization. Furthermore, we investigated whether P from the seed affects the classification of common bean genotypes in P uptake efficiency when the ^{32}P isotopic dilution technique is used.

2. MATERIALS AND METHODS

2.1. Experimental

The experiment was conducted in the greenhouse at the Center for Nuclear Energy in Agriculture (CENA / USP), located at latitude 22°42'30" S, longitude 47°38'01" W and 554 m altitude, in Piracicaba, Sao Paulo, Brazil.

The study were performed in 3.0 l plastic pots, containing 2.5 kg of air-dried soil, collected from the 0 to 0.20 m layer of a dystrophic Typic Haplustox [9]. The soil had 280, 70 and 650 g kg^{-1}content of clay, silt and sand, respectively, and the following chemical characteristics: pH (0.01 mol l^{-1} $CaCl_2$), 4.5; organic matter, 18.0 g dm^{-3}; P extracted by resin, 5 mg dm^{-3}; K, 0.6 $mmol_c$ dm^{-3}; Ca, 11.5 $mmol_c$ dm^{-3}; Mg, 5.2 $mmol_c$ dm^{-3}; H + Al, 35.4 $mmol_c$ dm^{-3}; CEC, 52.7 $mmol_c$ dm^{-3}; sum of bases, 17.3 $mmol_c$ dm^{-3}; base saturation, 32.8%, according to methodology described by [10] and P by Mehlich-1, 3 mg dm^{-3} [11].

After application of lime (Calcium carbonate equivalent = 110%) to raise the base saturation to 70%, according to the official recommendation of Bulletin 100 [12], the soil was incubated for 30 days, maintaining the moisture content at approximately 70% of water holding capacity. To evaluate the efficiency of bean genotypes for P uptake, a mixture of triple superphosphate (20 mg P kg^{-1}) as a source of readily available P, and Patos rock phosphate (150 mg P kg^{-1}) were applied to raise the total soil P content to 170 mg P kg^{-1} soil in each pot. N and K were applied at rates of 200 mg N kg^{-1} as urea and 200 mg K kg^{-1} as potassium sulfate. Micronutrients were also applied as nutrient solution in all treatments at rates of 0.5 mg B kg^{-1}, 1.5 mg Cu kg^{-1}, 3.0 mg Fe kg^{-1}, 2.0 mg Mn kg^{-1}, 3.0 mg Zn kg^{-1} and 0.1 mg Mo kg^{-1}.

The experimental design was completely randomized with four replications. The treatments consisted of 50 common bean genotypes and two standard species described in the literature as efficient or inefficient in P uptake: Sunhemp (*Crotalaria juncea* L.) as inefficient in absorbing P [13] and white lupin (*Lupinus albus* L.) as efficient [13, 14]. The common bean genotypes evaluated in this study were: Carioca 80, Rudá, Aporé, Princesa, Pérola, Requinte, Pontal, BRS Horizonte, BRSMG Talismã, BRSMG Pioneiro, IPR Colibri, IAC Tybatã, IAC Alvorada, LP01-38, CV-48, CNF 10, Roxão EEP, Sangue de Boi, Roxão, Roxinho, Safira, BRS Timbó, Roxo 90, BRS Pitanga, Gen 99TG50-47, Ouro Negro, Ônix, Macanudo, Chapecó, Xodó, Diamante Negro, Xamego, IAC UNA, BRS Valente, BRS Grafite, FT Nobre, BRS Triunfo, Thayú, Rosado, Rosinha de Cipó, Rosinha G2, Rosinha, Rosinha Brilhosa, Rubi, BRS Vereda, IAC Boreal, Gen99TGR1-10, Jalo Precoce, IAPAR 31 and Gen99TG34-50.

The soil was labeled with ^{32}P solution (9.25 MBq of ^{32}P) and 0.2 mg P kg^{-1} carrier. Five bean seeds were sown in each pot and the plants were thinned to three plants pot^{-1}. Soil moisture was maintained at approximately 70% of water retention capacity during plant development.

The above-ground parts of the plants were sampled on two occasions: (i) two plants from the total of three grown in each plot were harvested at 30 days after emergence, and (ii) the one remaining plant, at the stage of grain physiological maturity. The shoot samples were separated into stem, branches, leaves, bark and grain. The P contained in seed was discounted for calculating the L-value, which was used to compare the efficiency of P uptake among the genotypes, considering that from the total P stored in the seeds of bean genotypes, 60% is used for plant growth [15], i.e. 40% of seed P is not used by the plant and remains in the cotyledon.

2.2. Calculations of P and ^{32}P

With shoot dry matter (Sdm), grain weight (Gw), P concentration in Sdm and Gw the P content in the shoot and in grain were calculated.

P uptake = P concentration × Sdm , where Sdm is shoot dry matter.

P content = P concentration × Gw, where Gw is grain weight.

With the data of plant P concentration and 32P activity of the plant, the specific activity, L-value, and the L-value subtracting the amount of seed-derived P from the total P content of shoots were calculated [14,16].

$$SA = \frac{^{32}P}{^{31}P}$$

where SA is specific activity (dpm μg^{-1}P); ^{32}P is radioisotope activity in the plant (dpm); ^{31}P is plant P content (μg of P plant^{-1});

$$Lvalue = X\left(\frac{SA_0}{SA_p} - 1\right)$$

where L-value (mg P kg^{-1} soil); SA_0 is specific activity of applied solution (dpm μg^{-1} P); SA_p is specific activity of the plant (dpm μg^{-1}P); X is amount of applied P;

$$L - s\,value = \left(Y\frac{(X_T - Z)}{Y_T} - X\right)$$

where L-s value is L-value subtracting P in the plant derived from the seed (mg of P kg^{-1} soil); Y is ^{32}P activity in the applied solution (dpm); X_T is plant P uptake (mg); Y_T is ^{32}P activity in the plant shoot dry matter (dpm); X is ^{31}P carrier applied rate pot^{-1} (mg); Z = total P content derived from the seed (mg).

2.3. Statistical analysis

Sdm, Gw, P concentration and P content in the shoot or in the grain, specific activity (SA), L-value and L-value subtracting the P derived from the seed (L-s value) were submitted to analysis of Pearson linear correlation, and hierarchical cluster analysis with the objective for grouping similar genotypes. Cluster analysis of bean genotypes was carried out with the SAS 9.1 - “Statistical Analysis System” [17] and SYSTAT version 10.2 software programs, using the UPGMA (un-weighed pair group arithmetic average clustering) The cluster analysis was preceded by the standardization of data before the Euclidian distances calculation, as the variables presented different scales. After standardization, all the variables were equally important in the determination of these distances. Final results of the groups were presented as dendrograms. The P uptake efficiency by plants is inversely proportional to SA and directly proportional to L- and L-s values.

The common bean genotypes were grouped into four or five groups, aiming to achieve greater homogeneity within each group and greater heterogeneity among the different groups. The results are presented and discussed in three parts: (1) first sampling - shoot; (2) second sampling - shoot, and (3) second sampling - grain. The term shoot dry matter (Sdm) refers to all above ground tissues (stem, branches, leaves and bark of legumes) except the grain.

3. RESULTS AND DISCUSSION

3.1. First sampling - shoot

Plant data for the first sampling are given in Table 1. The results obtained with the two standard species were: (i) White lupin - Sdm = 0.56 g pot^{-1}, P in Sdm = 1.34 mg pot^{-1}, SA = 17.71 dpm g^{-1} P, L-value = 47.44 mg P kg^{-1} soil and L-s value = 29.5 mg P kg^{-1} soil, (ii) Sunhemp - Sdm = 3.49 g pot^{-1}, P content in Sdm = 5.40 mg pot^{-1}, SA = 75.49 dpm mg ^{1} P^{-}, L-value = 10.26 mg P kg^{-1} soil and L-s value = 9.95 mg P kg^{-1} soil. The white lupin plant was, as expected, more efficient in absorbing P (the lowest SA, and highest L-value and L-s values) than all common bean genotypes evaluated in this study.

Mean values of shoot dry matter (Sdm), P concentration (P conc) and P uptake (P uptake) in Sdm, specific activity (SA), L-value and L-value discounting the P from the seed (L-s value) of 50 common bean genotypes at the first sampling are given in Table 1.. The values of Sdm correlated significantly and negatively with P concentration (–0.625***) and positively with P uptake (0.675***). P uptake in Sdm increased with increasing Sdm, but the P concentration in plant tissue decreased by the dilution effect of P in the Sdm. By cluster analysis with these three variables (Fig. 1), the following five groups of common bean genotypes were identified:

1st: Rubi;

2nd: Grafite, CV-48, Pioneiro, Xamego, IAC UNA, Carioca 80, Roxão, Horizonte, Thayú, Triunfo, Sangue de Boi, Gen99TG3450, Timbó, Talismã, Pontal, Pérola, Requinte, Gen99TG50-47, Vereda, IAC Alvorada and Rosinha Brilhosa;

3rd: Pitanga, Roxo 90, FT Nobre, Ônix, LP01-38, Rudá, Colibri, Aporé, Tybatã, Macanudo, Rosinha Cipó, Princesa, Xodó, Valente, Diamante Negro, CNF 10, Roxinho, IAPAR 31, Rosado and Chapecó;

4th: Gen99TGR1-10, Ouro Negro, Rosinha, Safira, Rosinha G2, Jalo Precoce and Roxão EEP; and

5th: IAC Boreal.

TABLE 1. MEAN VALUES OF SHOOT DRY MATTER (SDM), P CONCENTRATION (P CONC) AND P UPTAKE IN SDM, SPECIFIC ACTIVITY (SA), L-VALUE AND L-VALUE DISCOUNTING THE P FROM THE SEED (L-S VALUE) OF 50 COMMON BEAN GENOTYPES AT THE FIRST SAMPLING

Genotype	Sdm (g pot^{-1})	P conc (g kg^{-1})	P uptake (mg pot^{-1})	SA (dpm µg^{-1} P)	L-value (mg kg^{-1} soil)	L-s value (mg kg^{-1} soil)
Chapecó	5.33	1.42	7.57	56.06	11.81	11.00
IAPAR 31	5.56	1.51	8.38	65.40	10.10	9.38
Rosado	5.62	1.45	8.11	63.48	10.42	9.28
Roxinho	5.77	1.51	8.69	51.04	13.00	12.23
CNF 10	5.78	1.51	8.71	58.81	11.25	10.25
Rubi	5.80	1.71	9.92	49.47	13.43	12.43
Diamante Negro	5.82	1.52	8.82	65.87	10.03	9.29
Pitanga	6.00	1.33	7.97	51.16	12.98	11.83
Grafite	6.06	1.59	9.60	44.86	14.82	13.44
Valente	6.07	1.46	8.86	60.08	11.02	10.05
CV-48	6.20	1.56	9.65	53.00	12.51	11.05
Xodó	6.32	1.43	9.04	58.42	11.33	10.69
Princesa	6.43	1.43	9.20	57.95	11.43	10.61
Colibri	6.47	1.32	8.50	66.46	9.94	9.18
Rosinha de Cipó	6.47	1.43	9.26	53.42	12.41	11.58
FT Nobre	6.47	1.27	8.24	47.68	13.95	12.50
Aporé	6.49	1.34	8.65	57.00	11.62	10.28
Roxo 90	6.53	1.23	8.03	76.04	8.66	7.81
Xamego	6.53	1.52	9.93	56.38	11.75	11.08
IAC UNA	6.56	1.51	9.93	52.85	12.54	11.34
Horizonte	6.58	1.55	10.18	44.28	15.02	13.80
Macanudo	6.59	1.36	8.95	55.39	11.96	11.15
Pioneiro	6.60	1.49	9.82	43.33	15.37	14.33
Tybatã	6.60	1.34	8.82	50.49	13.15	11.77
Carioca 80	6.63	1.51	10.01	53.68	12.34	11.36
Vereda	6.66	1.43	9.51	51.21	12.99	11.96
Thayú	6.67	1.57	10.44	46.21	14.40	13.54
Roxão	6.68	1.51	10.10	52.91	12.53	10.85
Ônix	6.68	1.27	8.47	49.53	13.41	12.20
Rudá	6.79	1.30	8.83	52.53	12.62	11.75
Pérola	6.80	1.44	9.81	53.40	12.41	11.37
LP01-38	6.85	1.23	8.46	54.93	12.08	10.81
Gen99TG50-47	6.88	1.41	9.70	48.87	13.58	11.08
Requinte	6.91	1.42	9.78	59.88	11.05	10.31
Talismã	6.97	1.45	10.12	57.35	11.54	10.71
Rosinha Brilhosa	7.01	1.33	9.33	54.86	12.07	11.23
Pontal	7.02	1.42	9.96	55.58	11.92	10.99
IAC Alvorada	7.05	1.35	9.49	60.09	11.01	9.86
Timbó	7.20	1.39	10.03	49.39	13.44	12.63
Gen99TG34-50	7.22	1.38	9.97	46.67	14.23	12.51
Sangue de Boi	7.40	1.37	10.13	47.30	14.05	13.06
Triunfo	7.42	1.38	10.25	51.75	12.82	11.61
Safira	7.86	1.33	10.45	52.61	12.60	11.86
Ouro Negro	7.98	1.19	9.45	58.96	11.23	10.31
Rosinha G2	7.99	1.31	10.48	57.90	11.44	10.72
Jalo Precoce	8.01	1.31	10.51	39.72	16.77	15.14
Gen99TGR1-10	8.14	1.15	9.34	51.52	12.88	11.39
Mean	6.78	1.40	9.44	53.80	12.51	11.43
CV (%)	12.46	9.10	9.43	12.58	12.42	12.42

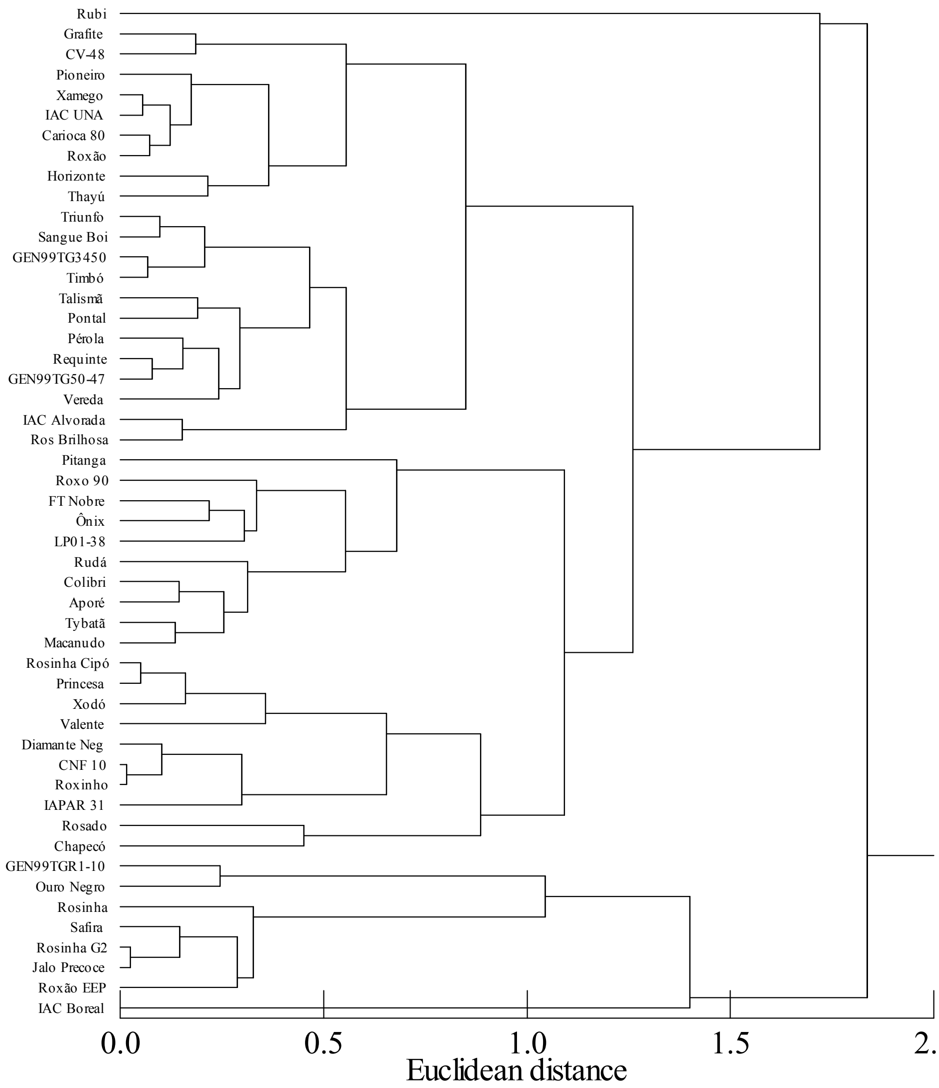

FIG. 1. Dendrogram resulting from hierarchical cluster analysis of 50 common bean genotypes, based on shoot dry matter (Sdm), P concentration and P uptake at the first sampling.

Of the five groups of common bean genotypes formed by hierarchical cluster analysis (Fig. 1) and considering the values of Sdm and P uptake shown in Table 1, it was found that the genotype IAC Boreal presented higher values of Sdm and P uptake, while the genotypes in contrast, Pitanga, Roxo 90, FT Nobre, Ônix, LP01-38, Rudá, Colibri, Aporé, Tybatã, Macanudo, Rosinha Cipó, Princesa, Xodó, Valente, Diamante Negro, CNF 10, Roxinho, IAPAR 31, Rosado and Chapecó presented lower values of Sdm and P uptake. Jalo Precoce was classified in the second group that presented higher values of Sdm and P uptake. Among eight common bean genotypes grown under a low P rate (24 mg dm^{-3} P_2O_5) in the substrate (pots with 16 kg of sand) and harvested at 45 days after germination, genotypes BAT 477, Jalo Precoce and Roxo produced the most Sdm [4].

Rubi did not group with the other genotypes, because it had high P concentration and P uptake, but low production of Sdm. This probably indicates that this genotype was not efficient in utilizing P taken up to produce the Sdm, at the beginning of plant development. We emphasize that genotypes more productive in terms of Sdm, are not necessarily more efficient in P uptake under conditions of low P availability in the substrate; the P in the plant derived from the seed, from which the plant originates, is an important source of P at the early developmental stage, in evaluating the efficiency of P uptake by plants. Moreover, the production of Sdm also involves the concept of efficiency of use, and genotypes more efficient in P use are those that best convert the nutrient uptake into Sdm. It was observed that the variables SA, L-value and L-s value of 50 common bean genotypes, harvested in the first sampling, were the ones with the highest Pearson correlation coefficients between them. The SA correlated significantly and negatively with the L-value (–0.982***) and the L-s value (–0.960***), and the L-value correlated positively with the L-s value (0.974***).

By cluster analysis with the variables SA and L-value (Fig. 2) four groups of common bean genotypes were identified:

1st: low efficiency in P uptake (Roxo 90);
2nd: moderately efficient in P uptake (Colibri, Diamante Negro, IAPAR 31, Rosado, IAC Alvorada, Valente, Requinte, Ouro Negro, CNF 10, Xodó, Princesa, Rosinha G2, Talismã, Aporé, Xamego, Chapecó, Pontal, Macanudo, LP01-38 and Rosinha Brilhosa);
3rd: efficient in P uptake (Carioca 80, Rosinha Cipó, Pérola, CV-48, Roxão, IAC UNA, Safira, Rudá, Triunfo, Gen99TGR1-10, Vereda, Pitanga, Roxinho, Tybatã, Ônix, Rubi, Timbó, Roxão EEP, GenTG50-47, IAC Boreal, FT Nobre, Sangue de Boi, Rosinha, Gen99TG3450 and Thayú);
4th: very efficient in P uptake (Grafite, Horizonte, Pioneiro and Jalo Precoce).

Grafite, Horizonte, Pioneiro and Jalo Precoce genotypes were those with lower values for SA and higher L-values. Thus, these common bean genotypes were classified as more efficient in P uptake. It is noteworthy that in this classification of genotypes for the P uptake efficiency, P was not discounted in the plant from the seeds. In another study evaluating the efficiency of P uptake by eight genotypes of common bean, without the use of the technique with ^{32}P, the Jalo Precoce was also classified as efficient in P uptake [4].

By cluster analysis with the variables SA and L-s value (Fig. 3), four groups of common bean genotypes were identified:

1st: low efficiency in P uptake (Roxo 90);
2nd: moderately efficient (Colibri, Diamante Negro, IAPAR 31, Rosado, IAC Alvorada, Valente, Requinte, Ouro Negro, CNF 10, Aporé, Talismã, Princesa, Rosinha G2 and Xodó);
3rd: efficient in P uptake (Rosinha Brilhosa, Macanudo, Pontal, Chapecó, Xamego, LP01-38, Roxão, CV-48, IAC UNA, Pérola, Carioca 80, Rosinha Cipó, Gen99TGR1-10, Triunfo, Rudá, Safira, Vereda, Pitanga, Tybatã, Gen99TG50-47, IAC Boreal, Roxinho, Ônix, Rubi, Roxão EEP, Timbó, FT Nobre and Gen99TG3450);
4th: very efficient in P uptake (Sangue de Boi, Rosinha, Thayú, Grafite, Horizonte, Pioneiro and Jalo Precoce).

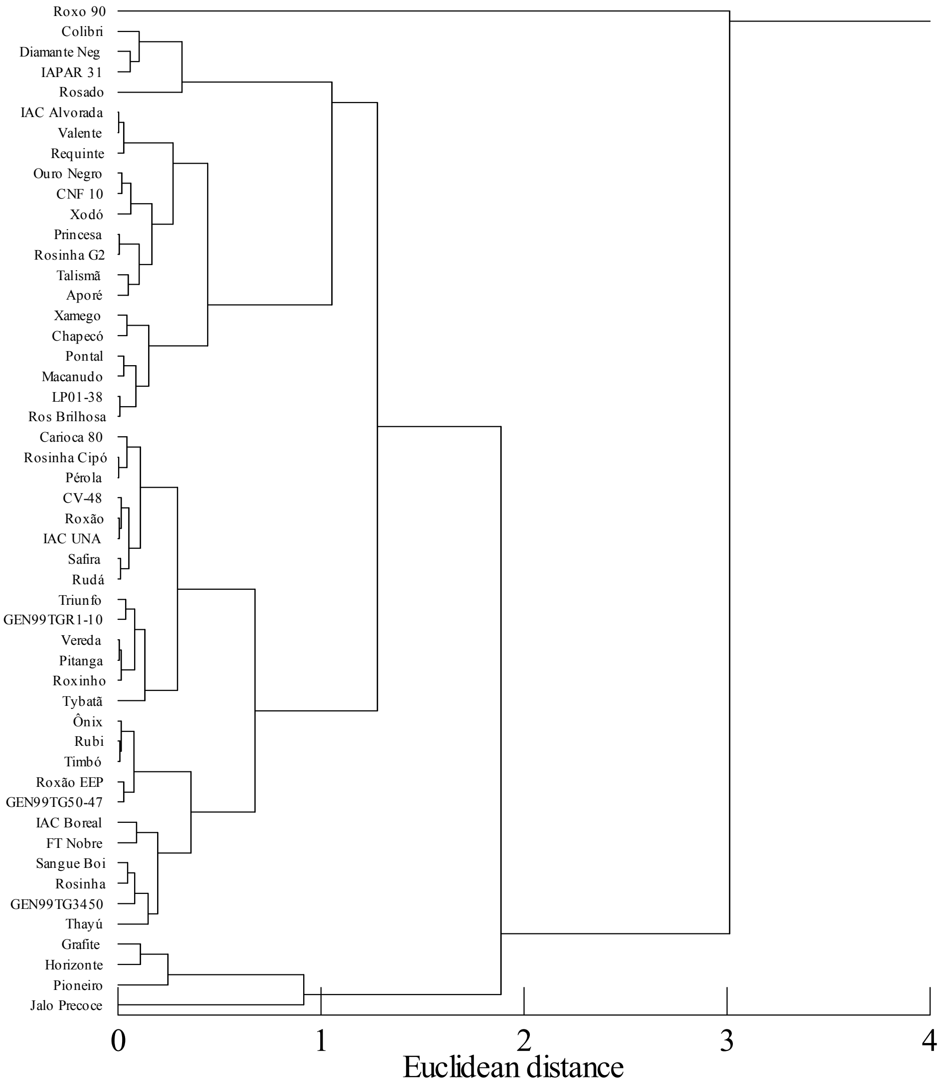

FIG. 2. Dendrogram resulting from hierarchical cluster analysis of 50 common bean genotypes based on specific activity (SA) and L-value at the first sampling.

Xamego, Chapecó, Pontal, Macanudo, LP01-38, Rosinha Brilhosa, Sangue de Boi, Rosinha and Thayú genotypes were classified into different groups, when the hierarchical cluster analysis was performed based on L-value discounting (Fig. 3) or not (Fig. 2), the P in the plant derived from the seed. Therefore, the P present in the seed affected the assessment and classification of common bean genotypes on P uptake efficiency.

Xamego, Chapecó, Pontal, Macanudo, LP01-38 and Rosinha Brilhosa genotypes were placed in the third group, when the P in the plant derived from the seed was discounted in the calculation of the L-value, and were classified as efficient in P uptake. Sangue de Boi, Rosinha and Thayú genotypes were grouped in the fourth group, when discounting the seed P, and were classified as very efficient in P uptake.

When plants are grown under P limiting condition, the roots become a strong drain of carbohydrates and this causes major limitation to the growth of the shoot than the root [18]. Roots of bean plants grown under conditions of P deficiency had much higher concentrations of sugars in the roots compared with plants with an adequate P supply, due to the increased shoot translocation of photo-assimilates [19]. In another study it was observed that the difference in the selection of bean genotypes and the P-use efficiency and dry matter production was related to the translocation of P from roots to shoots [4]. The root architecture is another factor that differentiates the P uptake among genotypes, and relates to the spatial configuration of the root system, i.e. the geometry of the development of the root axes [20].

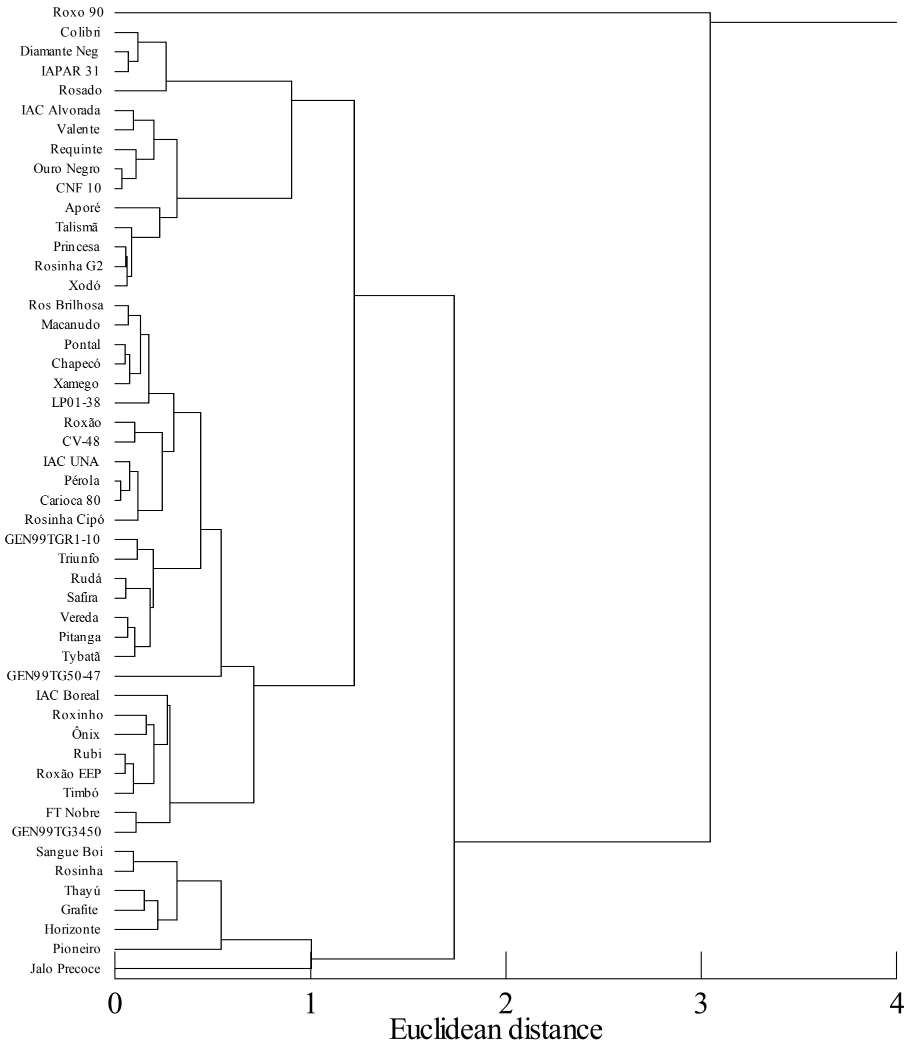

FIG. 3. Dendrogram resulting from hierarchical cluster analysis of 50 common bean genotypes, based on specific activity (SA) and L-value, discounting the P in the plant derived from the seed at the first sampling.

3.2. Second sampling - shoot

Mean values of shoot dry matter (Sdm), P concentration (P conc) and P uptake (P uptake) in Sdm of 50 common bean genotypes AT the second sampling are given in Table 2. The Sdm of common bean genotypes in the second sampling, correlated significantly and positively with P uptake (0.587***), but not with P concentration.

TABLE 2. MEAN VALUES OF SHOOT DRY MATTER (SDM), P CONCENTRATION (P CONC) AND P UPTAKE (P UPTAKE) IN SDM OF 50 COMMON BEAN GENOTYPES AT THE SECOND SAMPLING

Genotype	Sdm (g plant^{-1})	P conc (g kg^{-1})	P uptake (mg plant^{-1})
CNF 10	6,12	0,68	4,19
Macanudo	6,25	0,56	3,48
Ouro Negro	6,35	0,76	4,80
Rosinha G2	6,38	0,84	5,34
Gen99TG50-47	6,41	1,00	6,38
Aporé	6,47	0,62	3,98
Carioca 80	6,71	0,62	4,14
Sangue de Boi	6,90	0,94	6,52
Safira	6,96	0,72	4,99
CV-48	6,99	0,76	5,30
Colibri	7,03	0,98	6,86
Gen99TG34-50	7,32	0,79	5,77
LP01-38	7,37	0,76	5,57
Xamego	7,37	0,80	5,87
Princesa	7,43	0,72	5,36
IAPAR 31	7,45	0,78	5,78
Pontal	7,52	0,83	6,23
Jalo Precoce	7,53	0,87	6,58
Horizonte	7,55	0,89	6,71
IAC Alvorada	7,59	0,64	4,86
Rubi	7,67	0,71	5,43
Xodó	7,69	0,74	5,70
Pioneiro	7,82	0,60	4,71
Valente	7,85	0,74	5,77
Triunfo	7,88	0,71	5,57
Roxão EEP	7,96	0,59	4,67
Talismã	7,99	0,79	6,32
Pérola	8,03	0,63	5,03
Pitanga	8,11	0,58	4,65
Rosinha	8,13	0,86	6,95
IAC UNA	8,20	0,65	5,31
Rosinha de Cipó	8,22	0,94	7,69
Chapecó	8,25	0,91	7,52
Diamante Negro	8,36	0,78	6,48
Rosinha Brilhosa	8,37	0,87	7,30
FT Nobre	8,39	0,67	5,62
Roxinho	8,43	0,73	6,18
Vereda	8,48	0,64	5,39
Rudá	8,63	0,82	7,08
Timbó	8,63	0,54	4,68
Rosado	8,64	0,57	4,94
Gen99TGR1-10	8,79	0,82	7,18
Roxo 90	8,89	0,75	6,64
Thayú	8,89	0,58	5,14
Requinte	8,90	0,85	7,55
Ônix	9,05	0,80	7,28
Roxão	9,26	1,15	10,68
Mean	7,91	0,76	5,99
CV (%)	13,10	14,26	15,12

The dendogram obtained by grouping these two correlated variables is presented in Fig. 4.

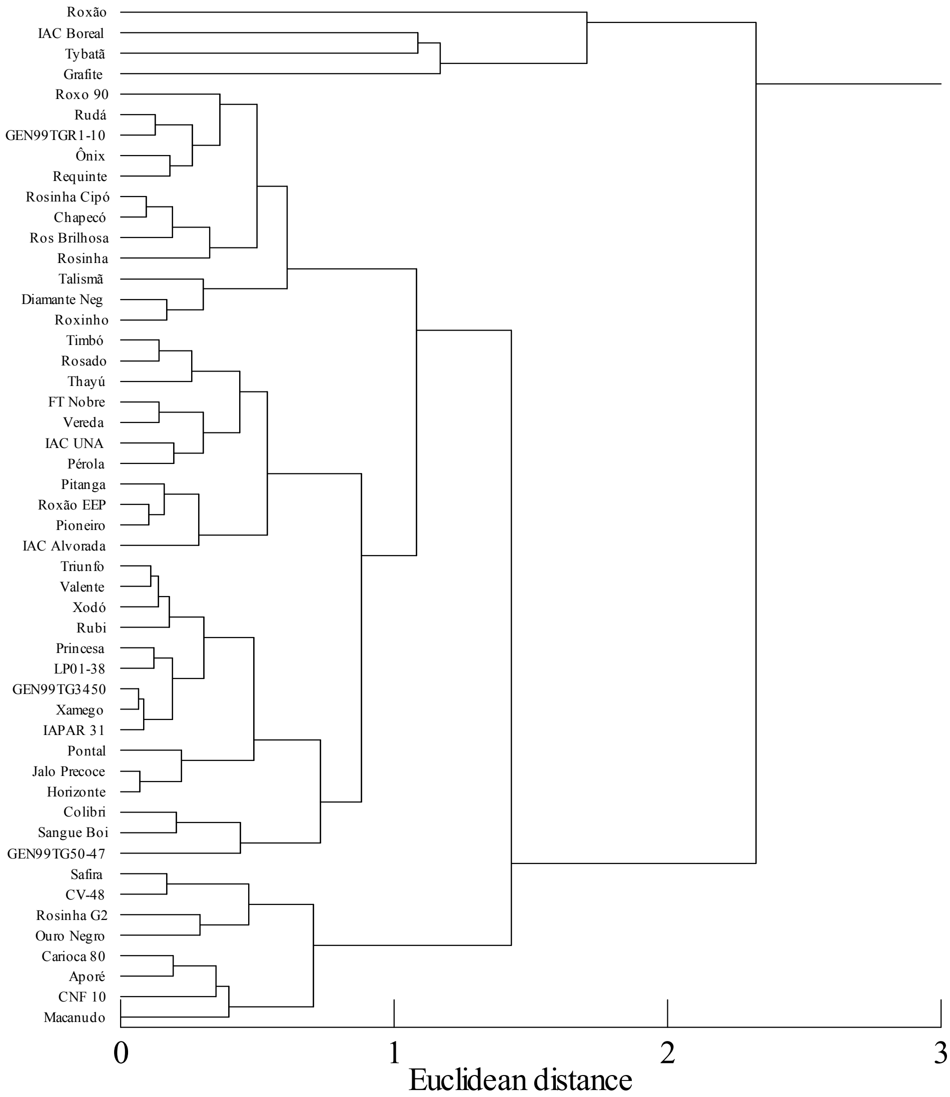

FIG. 4. Dendrogram resulting from hierarchical cluster analysis of 50 common bean genotypes, based on shoot dry matter (Sdm) and P uptake in Sdm at the second sampling.

The four genotype groups formed were:

1st: Roxão (genotype with highest values of dry matter yield and P accumulation in MSPA);
2nd: IAC Boreal, Tybatã and Grafite;
3rd: Roxo 90, Rudã, Gen99TGR1-10, Ônix, Requinte, Rosinha Cipó, Chapecó, Rosinha Brilhosa, Rosinha, Talismã, Diamante Negro, Roxinho, Timbó, Rosado, Thayú, FT Nobre, Vereda, IAC UNA, Pérola, Pitanga, Roxão EEP, Pioneiro, IAC Alvorada, Triunfo, Valente, Xodó, Rubi, Princesa, LP01-38, Gen99TG3450, Xamego, IAPAR 31, Pontal, Jalo Precoce, Horizonte, Colibri, Sangue de Boi and Gen99TG50-47;
4th: Safira, CV-48, Rosinha G2, Ouro Negro, Carioca 80, Aporé, CNF 10 and Macanudo (genotypes with lower Sdm and P uptake).

3.3. Second sampling - grain

Mean values of grain yield (Gw), P concentration (P conc) and P uptake (P uptake) in Gw of 50 common bean genotypes at the second sampling are presented in Table 3. The grain yield was significantly correlated with bean Sdm ($Y = -2610.23 + 5.58\ X - 0.0013\ X^2$, $R^2 = 0.60$ **), where Y = grain yield (kg ha^{-1}) and X = Sdm (kg ha^{-1}), and the maximum productivity of approximately 3200 kg ha^{-1} of grain was obtained with the production of 2098 kg ha^{-1} of Sdm [5] . It was observed in this study that a quadratic model was used to explain the relationship between grain yield and Sdm, which are two quantitative variables and dependent. It is recommended to apply Pearson linear correlation analysis to these types of variables.

Considering the 50 common bean genotypes evaluated in the second sampling, a linear and positive correlation was observed between Sdm and Gdm, but with a low correlation coefficient (0.292***). This indicates that the relationship between dry matter yield and grain yield depends on the bean genotype, i.e. this effect does not seem to be general with all common bean genotypes. For example, Roxão showed higher values of dry matter yield and P uptake, but was ranked as moderately productive and moderately rich in grain P (Fig. 5). Thus, in comparative studies of production between genotypes, even if conducted in a greenhouse, the plants should be developed to the production of grain. There was a significant and positive correlation between the P content in grain and bean grain productivity [5]. Therefore, according to these authors, it is possible to increase the productivity of common bean by increasing the absorption and accumulation of P in grains, with the use of efficient genotypes.

The Gdm values correlated significantly and negatively with P concentrations in the Gdm (–0.654***) and positively with P content in the Sdm (0.604***). The P content in the Gdm was higher with increasing dry matter yield, but decreased P concentrations, so probably there was a dilution on P content in Gdm. By cluster analysis with these three variables the following five groups of common bean genotypes were identified (Fig. 5):

1st: little productive and high P in grain (Talismã);

2nd: little productive and low P in grain (Ouro Negro and Horizonte);

3rd: moderately productive and moderately rich in grain P (IAC Boreal, Roxão, Jalo Precoce, Gen99TG50-47, Gen99TGR1-10, Rubi, Gen99TG3450, Rosinha G2, Princesa, Safira, Rosinha Brilhosa, Macanudo, IAC Alvorada, Pitanga, CV-48, Diamante Negro, Rosinha Cipó, LP01-38, Grafite, Colibri, Chapecó and Xamego);

4th: productive and rich in P in grain (Valente, Rosado, Ônix, Roxo 90, Tybatã, Roxinho, IAC UNA, Thayú, Sangue de Boi, Rosinha, Vereda, FT Nobre, Xodó, Requinte and Triunfo);

5th: very productive and very rich in grain P (Carioca 80, CNF 10, Pérola, IAPAR 31, Roxão EEP, Aporé, Pioneiro, Pontal, Timbó and Rudá).

TABLE 3. MEAN VALUES OF GRAIN YIELD (GW), P CONCENTRATION (P CONC) AND P UPTAKE (P UPTAKE) IN GW OF 50 COMMON BEAN GENOTYPES AT THE SECOND SAMPLING

Genotype	Gw (g plant^{-1})	P conc (g kg^{-1})	P uptake (mg plant^{-1})
IAC Boreal	6.48	3.62	23.45
Talismã	6.74	4.51	30.30
Ouro Negro	6.86	3.95	26.99
Roxão	6.87	3.29	22.57
Horizonte	7.15	3.78	27.02
Jalo Precoce	7.26	3.24	23.54
Rosinha G2	7.30	3.44	25.09
Princesa	7.34	3.49	25.57
Gen99TGR1-10	7.46	3.30	24.65
Gen99TG50-47	7.49	3.20	23.93
Rubi	7.64	3.34	25.48
Gen99TG34-50	7.81	3.22	25.04
Safira	7.85	3.41	26.77
Xamego	8.04	3.06	24.56
IAPAR 31	8.11	3.83	31.09
Rosinha Brilhosa	8.18	3.28	26.84
CV-48	8.19	3.44	28.21
Chapecó	8.26	3.16	26.06
IAC Alvorada	8.39	3.31	27.75
CNF 10	8.46	3.62	30.66
Macanudo	8.46	3.27	27.60
Pitanga	8.47	3.32	28.09
Carioca 80	8.58	3.49	29.94
Pérola	8.64	3.62	31.21
Roxão EEP	8.69	3.82	33.10
Triunfo	8.72	3.33	29.05
Rosinha de Cipó	8.73	3.15	27.44
Grafite	8.74	2.92	25.55
Diamante Negro	8.76	3.18	27.82
LP01-38	8.84	3.11	27.44
Colibri	8.91	2.98	26.49
Requinte	9.14	3.23	29.50
Aporé	9.16	3.58	32.78
Xodó	9.30	3.19	29.62
Thayú	9.59	3.04	29.12
Roxinho	9.63	2.87	27.63
FT Nobre	9.64	3.17	30.50
Rudá	9.65	3.32	32.01
Pioneiro	9.67	3.41	32.94
Pontal	9.68	3.39	32.80
Rosinha	9.69	3.09	29.97
IAC UNA	9.70	2.85	27.57
Timbó	9.71	3.31	32.14
Sangue de Boi	9.76	3.03	29.56
Tybatã	9.77	2.92	28.47
Vereda	9.85	3.10	30.54
Roxo 90	9.95	2.95	29.17
Mean	8.64	3.29	28.20
CV (%)	12.68	10.56	9.70

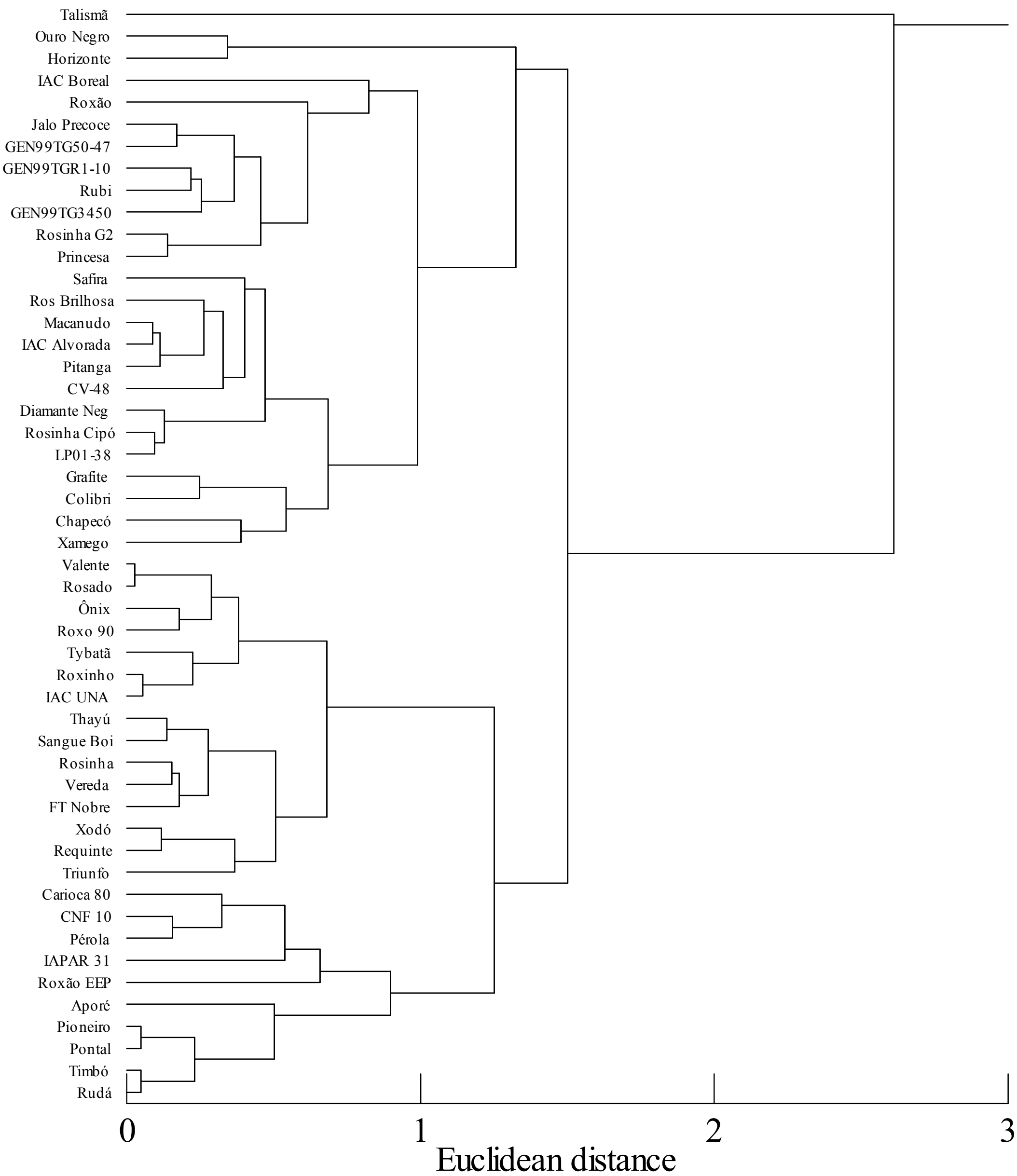

FIG. 5. Dendrogram resulting from hierarchical cluster analysis of 50 common bean genotypes, based on grain dry matter yield (Gdm), P concentration and P content in Gdm at the second sampling.

Talismã did not form a group with other genotypes because it had low grain yield, but high P concentration and P content of Gdm. Therefore, other groups were classified in four groups in terms of grain yield and P in Gdm.

Carioca 80, CNF 10, Pérola, IAPAR 31, Roxão EEP, Aporé, Pioneiro, Pontal, Timbó and Rudá were the most productive genotypes when grown under low P availability conditions. The 10 bean genotypes most productive in terms of grain had higher P utilization efficiency, defined as the ability to convert the element taken up by the plants into agricultural product of commercial value (leaf, fruit, root and stem) [21]. The efficiency of utilization (EU) is generally associated with productivity, that is, the greater the EU, the higher is the grain yield [22]. Among these genotypes, only Pioneer was rated as efficient in P uptake (Fig. 3).

4. CONCLUSIONS

- The common bean genotypes Sangue de Boi, Rosinha, Thayú, Grafite, Horizonte, Pioneiro and Jalo Precoce were the most efficient in P uptake;

- The common bean genotypes Carioca 80, CNF 10, Pérola, IAPAR 31, Roxão EEP, Aporé, Pioneiro, Pontal, Timbó e Rudá were the most productive in grain under conditions of low available soil P (genotype more efficient in P utilization);

- The seed derived P in the plant, when the ^{32}P L-value technique is used, affects the identification and classification of common bean genotypes.

ACKNOWLEDGMENTS

The work was supported by IAEA (International Atomic Energy Agency) research contract 13779. Vinícius Ide Franzini acknowledges a graduate fellowship from CAPES (Coordenação de Aperfeiçoamento de Pessoal de Nível Superior, Brazil).

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