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Macronutrients Use Efficiency and Phosphorus Exportation by Melon Plants in Response to Fertilization

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Abstract

This study aimed to evaluate macronutrients use efficiency and phosphorus accumulation, partition and partial balance in the melon hybrid Goldex F1, in response to mineral and organic fertilizers. The following fertilizations were evaluated: mineral fertilizer; bovine manure; bovine manure associated with mineral fertilizer; poultry litter; and poultry litter associated with mineral fertilizer. Plants were collected and separated into leaves, stem, and flowers and, when there were, unripe and ripe fruits for chemical analysis. Phosphorus accumulation increased along the melon crop cycle. Phosphorus partition between leaves + stems + flowers and unripe fruits + ripe fruits showed that about 80% of P was allocated to the fruits. The decreasing order of use by the plant was S > P > Mg > Ca > N > K. Only the treatment with poultry litter was within the range considered as adequate for P recovery. Mineral and organic fertilizers did not interfere with nutrient accumulation and P partition by the melon plants.

Keywords: *Cucumis melo*, nutritional status, organic fertilizers, phosphorus recovery

1. Introduction

Melon (*Cucumis melo* L.) is a vegetable crop in the *Curcubitaceae* family and its fruit is appreciated worldwide. In the Northeast region of Brazil, the states of Ceara and Rio Grande do Norte stand out as the largest producers and exporters of the fruit (Instituto Brasileiro de Geografia e Estatística [IBGE], 2016).

Although the Northeast region has favorable climatic conditions for melon development, its soils do not always meet the nutritional demand of the crop. Since melon is a short-cycle crop, with high growth rate and high demand for nutrients, and combined with the low natural fertility of the soils, practices of liming and high rates of fertilizers are justified to make cultivation viable (Crisóstomo, Santos, Raij, Faria, Silva, Fernandes, & Costa, 2002).

In soils of tropical regions, phosphorus (P) availability is often a limiting factor for crop yield. Thus, there is a large application of phosphate fertilizers. In 2014, more than 5 million tons of P_2O_5 were consumed in Brazil (International Plant Nutrition Institute [IPNI], 2016). To rationalize the use of fertilizers, achieve higher profitability and reduce environmental impacts, it is important to know the crop, the nutrients uptake during its cycle and its relationship with the phenological stages, as well as to use varieties with higher nutritional efficiency.

Knowledge on the nutritional efficiency of a given genotype allows for adopting different fertilization regimes in this crop and planting in soils with varied fertility (Pinto, Furtini Neto, Neves, Faquin, & Moretti, 2011). Nutrient use efficiency is one of the main parameters employed to differentiate, characterize and classify species with respect to nutritional behavior (Fontes, Gama-Rodrigues, & Gama-Rodrigues, 2013). This feature depends on root-shoot transport and plant metabolic demand and, according to Siddiqi and Glass (1981) is obtained by the quotient between (total biomass)^2 and total nutrient accumulation in the plant, which indicates its capacity to convert the nutrient uptake into total dry matter.

Another tool used to measure nutrient use efficiency by crops is the Partial Nutrient Balance (PNB) or "balance" method (Syers, Johnston, & Curtin, 2008). In this method, under certain conditions of soil use and management, P inputs are equal to the removal by harvest; the sum of P immediately available in the solution + P readily available and extractable (Labile P) remain constant. According to Syers et al. (2008), Roberts and Johnston (2015), P balance is considered as adequate when P recovery is within the range from 50 to 70%, or even higher.

In addition, there are also the peculiarities of a given crop, such as the biomass and nutrient accumulation patterns, which are fundamental to define fertilizer rates and periods of application, besides the minimum amounts which must be replaced to the soil to maintain its fertility (Mauad, Garcia, R. Silva, T. Silva, Schroeder, & Knudsen, 2015).

In this context, this study aimed to evaluate macronutrients use efficiency and phosphorus accumulation, partition and partial balance in the melon hybrid Goldex F1, in response to mineral and organic fertilizers.

2. Material and Methods

The experiment was carried out at the Experimental Field of Embrapa Tropical Agroindustry, in the municipality of Pacajus (Ceará State, Brazil), in soil classified as Arenic Haplustults (Lima, Oliveira, & Aquino, 2002). The climate of the region is Aw (hot climate with temperature higher than 18 °C in the coldest month, rainy summer and dry winter), according to Köppen's classification (Peel, Finlayson, & McMahon, 2007). During the experiment, from July 13 to September 21, 2015, no rainfall occurred (Figure 1).

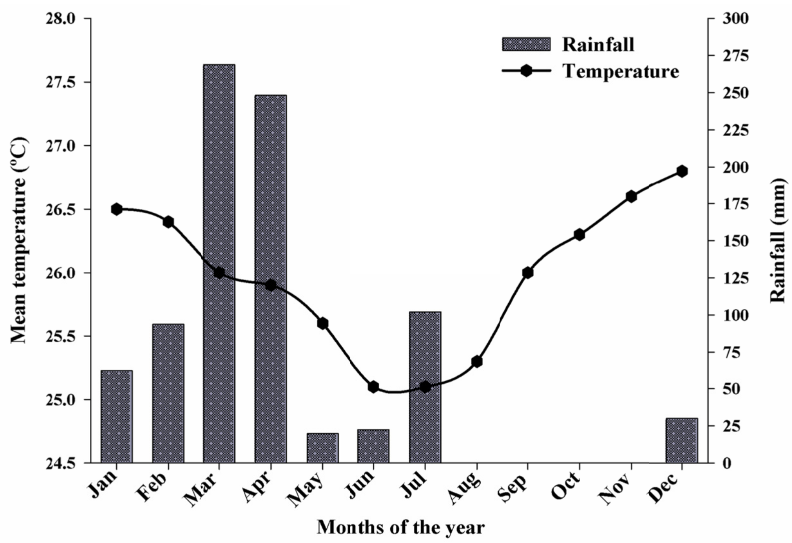

Figure 1. Rainfall and average temperature in Pacajus, Ceará State, Brazil, in 2015 (FUNCEME, 2015)

Before the experiment was set up, soil samples were collected in the layer of 0-20 cm deep for the characterization of the area, according to Empresa Brasileira de Pesquisa Agropecuária [EMBRAPA], (2009) (Table 1).

Table 1. Soil chemical analysis of the experimental area

P (Mehlich 1)	OM	pH H_2O	K^+	Ca^{2+}	Mg^{2+}	Na^+	H+Al	Al^{3+}	SB[1]	CEC[2]	BS[3]	Cu	Zn	Mn	Fe
--- mg kg^{-1} ---	g kg^{-1}		------------ $cmol_c$ kg^{-1} ------------								%	--------- mg kg^{-1} ---------			
19	8	6.2	0.09	1.47	0.87	0.19	0.6	0.0	2.6	3.2	80	0.07	0.27	5.3	5.3

Note. [1] SB: Sum of bases. [2] CEC: Cation Exchange Capacity. [3] BS: Base saturation.

The experimental design was randomized complete blocks with 5 treatments (mineral fertilization [MF, as triple superphosphate, urea and potassium chloride]; bovine manure [BM]; bovine manure + mineral fertilization [BM + MF]; poultry litter [PL]; poultry litter + mineral fertilization [PL + MF]) and 4 replicates.

Each experimental unit consisted of one 20-m-long row at spacing of 2.0 × 0.5 m between rows and plants, respectively, totaling 40 plants per plot. Organic fertilizers were applied at rates equivalent to 15 m^3 ha^{-1} (3 L of bovine manure per linear meter) and 5 m^3 ha^{-1} (1 L of poultry litter per linear meter), as recommended by

Crisóstomo et al. (2002). The fertilizers were characterized according to the methodologies described in Ministério da Agricultura, Pecuária e Abastecimento [MAPA] (2014) and Carmo, Araujo, Bernardi, and Saldanha (2000) (Table 2).

Table 2. Chemical analysis of bovine manure [BM] and poultry litter [PL] used in the experiment

	Org-C	Total-N	NH_4^+-N	NO_3^--N	P	K	Ca	Mg	S	Cu	Fe	Zn	Mn
	---- g kg^{-1} ----									---- mg kg^{-1} ----			
BM	156	12.6	1.5	1.5	3.8	13.5	9.9	6.9	2.2	39	7.859	93	661
PL	342	31.6	4.4	0.6	7.2	13.7	25.9	3.2	2.8	19	1.255	142	173

In the mineral fertilization, nitrogen (N) was applied based on expected melon fruit yield from 20 to 30 t ha^{-1}, and phosphorus (P) and potassium (K) were applied based on soil analysis results. Liming was not necessary because base saturation was close to the 80 % recommended by Crisóstomo et al. (2002) for a melon crop.

The soil of the experimental area was prepared by plowing and harrowing, and the beds were raised with 0.2 m height and 0.5 m width. Mineral phosphate fertilizer was applied as the beds were prepared and the fertilizer was distributed along the row and incorporated to the soil; nitrogen and potassium fertilizers were supplied daily through irrigation water.

Organic fertilizers (poultry litter and bovine manure) were applied as the beds were raised and incorporated to the soil using a hoe, 15 days before transplanting the seedlings. The amounts of P_2O_5 applied were: 160; 98; 258; 44; and 204 kg ha^{-1} for MF; BM; BM + MF; PL; and PL + MF, respectively. A drip irrigation system was used in the area, which consisted of a drip tape with ½ inch diameter and 1.5 L h^{-1} flow rate. Irrigation was controlled considering the estimates of evapotranspiration and crop coefficient (Kc) for the melon crop proposed by Miranda, Souza, and Ribeiro (1999). After fertilizations, the beds were covered with plastic mulch and holes were opened on the plastic mulch, close to each dripper, for the transplanting of the yellow melon seedlings. Seedlings of the melon hybrid Goldex F1 were produced on polyethylene trays filled with commercial substrate and transplanted when they had two true leaves.

In beds receiving mineral fertilizers (MF; BM + MF; and PL + MF), the irrigation began after seedlings transplantation and lasted from 7 to 60 days after transplanting (DAT), whereas the beds exclusively receiving organic fertilizers (BM and PL) were irrigated only with water.

Plants were collected 21; 30; 39; and 63 DAT, which corresponded to the beginning of the flowering stage; the beginning of the fruiting stage; the fruit growth stage; and the fruit harvest period, respectively. In each sampling time, plants were collected and then separated into leaves, stem, and flowers and, when there were, unripe and ripe fruits. Subsequently, plants were washed in a solution of hydrochloric acid at 3% (v:v) and deionized water. Plants were placed in paper bags, dried in forced-air oven at 65 °C until constant weight and then weighed to determine dry matter. The samples were ground in a Wiley-type mill.

Contents of P were determined in plants harvested in all sampling time, in order to quantify its accumulation and partition along the crop cycle. In plants of the fourth sampling time (fruit harvest period), macronutrient contents were determined in the shoots (leaves + stem + flowers + unripe fruits + ripe fruits). Contents of N; P; K; Ca; Mg; and S in the plant tissue were determined according to EMBRAPA (2009).

P accumulation was calculated by multiplying the P content determined in each plant part by the respective dry matter production. The sum of P accumulated in the plant parts corresponds to the total accumulation (mg $plant^{-1}$). Phosphorus exportation, expressed in mg $plant^{-1}$, was calculated by multiplying the P content of ripe fruits by the respective dry matter production.

Macronutrients use efficiency by the melon crop was calculated using the following formula, represented by Equation 1:

Nutrient use efficiency (NUE), in grams (g) of dry matter squared per mg of the nutrient accumulated (Siddiqi & Glass, 1981):

$$NUE = (\text{g of total dry matter})^2/(\text{mg of the nutrient in the plant}) \quad (1)$$

Partial Nutrient Balance (PNB) for P was calculated considering the ratio between the P removed by harvest (which may have come from either the fertilizers applied or the native P from the soil) and the P applied in the form of fertilizers (Equation 2). The PNB or "balance" method for P (Syers et al., 2008) was established to verify the behavior of phosphate fertilizers in the soil and to predict P recovery in the cultivation area, according to the type of fertilizer applied.

$$PNB = (\text{P removed by harvest})/(\text{P applied in the form of fertilizers}) \times 100 \quad (2)$$

Results relative to macronutrients use efficiency and partial phosphorus balance were subjected to analysis of variance and treatment means were compared by Tukey test (SAS Institute, 2004).

3. Results and Discussion

Although the applied amount of P_2O_5 varied from 44 to 258 kg ha^{-1}, phosphorus accumulation in the shoots of the melon hybrid Goldex F1 was not influenced by the fertilizers (Table 3).

Table 3. Phosphorus accumulation in the shoots and phosphorus exportation by ripe fruits of the melon hybrid Goldex F1, in response to mineral and organic fertilizers

Fertilizers[1]	Phosphorus accumulation in the shoots[2]	Phosphorus exportation by ripe fruits[3]
	mg $plant^{-1}$	
MF	1799	1053
BM	1780	833
BM + MF	1581	977
PL	1477	666
PL + MF	1825	982
	F test[4]	
Fertilizers	1.349^{ns}	2.536^{ns}
C.V. (%)	15.72	21.44

Note. [1] Fertilizers: MF (mineral fertilizer); BM (bovine manure); BM + MF (bovine manure + mineral fertilizer); PL (poultry litter); and PL + MF (poultry litter + mineral fertilizer). [2] Phosphorus accumulation in the shoots (leaves + stem + flowers + unripe fruits + ripe fruits). [3] Phosphorus exportation by ripe fruits of the melon hybrid Goldex F1. [4] ^{ns}: Not significant.

The lack of response to P application may be related to the low P requirement by the melon crop, compared with other nutrients, which is frequently reported by different authors. Kano, Carmello, Cardoso, and Frizzone (2010), in experiment with the netted melon hybrid Bônus nº 2 (*Cucumis melo* L. var *reticulatus* Naud.), obtained P accumulations of 708 mg $plant^{-1}$ at the end of the cycle, and it was the least accumulated macronutrient.

Melo (2011), studying the netted melon variety *cantalupensis* (muskmelon) cultivated in substrate (sand and peanut shell), found P accumulation of 910 mg $plant^{-1}$ in the harvest period, the fourth most accumulated nutrient, behind N; K and Ca. Aguiar Neto, Grangeiro, Mendes, Costa, and Cunha (2014) studying two melon hybrids from the groups Canary and Santa Claus (Iracema and Gran Prix, respectively), cultivated in Baraúna, Brazil, found P accumulations of 3119 and 3890 mg $plant^{-1}$ at the end of the cycle, respectively, with the following sequence of accumulation of macronutrients: K > N > P > Ca > Mg. In the present study, P was the second least accumulated nutrient, only superior to S.

Low P requirement in the melon crop and, particularly, the fact that phosphate fertilizations are mostly overestimated in relation to its needs, since part of the nutrient applied may become unavailable, can be among the main causes for the lack of response to fertilizations.

In addition, the soil in which the melon crop was cultivated had P content considered as "good", according to Guimarães, Alvarez, and Ribeiro (1999), which can justify the absence of response to phosphate fertilization.

Dry matter production in the shoots (leaves + flowers + stem + unripe fruits + ripe fruits), and fruit yield were not influenced by mineral and organic fertilizers (Souza, Artur, Taniguchi, & Pinheiro, 2018), in evaluations of these parameters for the melon hybrid Goldex F1 in the same experiment, indicating that the applications of both bovine manure and poultry litter were efficient to provide P to the melon crop. Organic fertilizers is often related only to N supply but, as observed in the chemical compositions of bovine manure and poultry litter, the contributions of P and K are substantial.

Regarding P exportation by ripe fruits, the values ranged from 666 to 1053 mg $plant^{-1}$; however, these values did not differ statistically (Table 3). Aguiar Neto et al. (2014), studying hybrids from the groups Canary and Santa

Claus (Iracema and Gran Prix, respectively), found values of 1460 and 1620 mg plant^{-1}, respectively, which were higher than those observed in the present study.

The percentage of P accumulated along the phenological cycle of the melon hybrid Goldex F1 was low in the early stage of development (21 days after transplanting, DAT), representing only 5% of the total accumulated by the plant (Figure 2).

P accumulation increased in the next stage, a period with fast leaf growth and beginning of fruiting. In the fruiting stage (39 DAT, third sampling), P accumulation reached 52% of the total, and the remainder was accumulated until reaching the end of the fruiting stage. Such increase is attributed to the formation and development of fruits, which are the main sinks for nutrients along the crop cycle.

According to Haag, Oliveira, Barbosa, and Silva Neto (1981), nutrient uptake varies along plant development stages and is intensified with flowering and fruit formation and growth. In the study of Kano et al. (2010) with the netted melon hybrid Bônus nº 2 (*Cucumis melo* L. var *reticulatus* Naud.), P accumulation percentages at 15; 20; 52; and 72 DAT were 0.8; 4; 56; and 87%, respectively, which were lower than those found in the present study.

Until fruit development, leaves and stems are the organs with highest accumulation of nutrients. Following that, fruits become the main destination of nutrients, which demonstrates that fruits are the preferential sink for nutrients and other photoassimilates, according to Vidigal, Pacheco, and Facion (2007).

Phosphorus partition in the leaves + stem + flowers, unripe fruits, and ripe fruits followed a similar distribution pattern among the treatments evaluated (Figure 2).

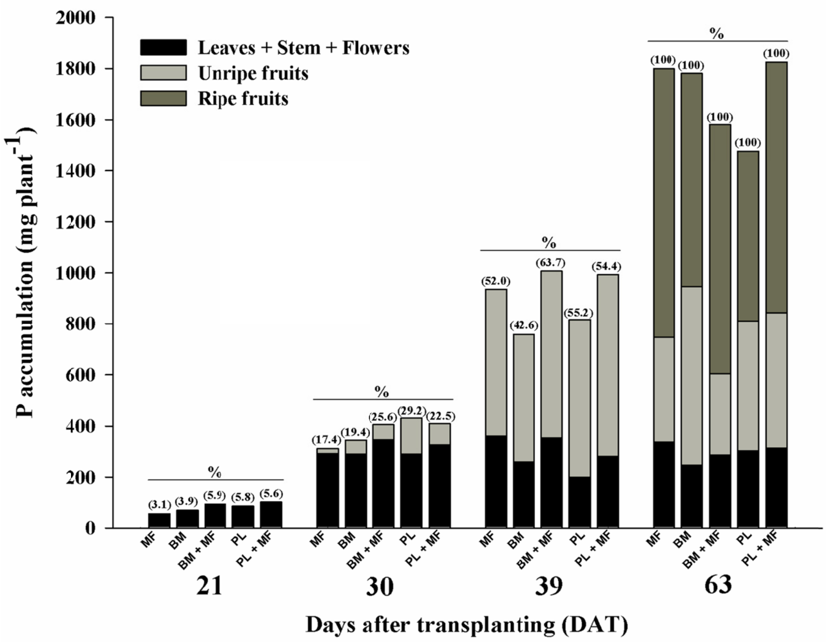

Figure 2. Phosphorus partition (in mg plant^{-1}) in Goldex F1 melon plants, in response to mineral and organic fertilizers and plant sampling time

Note. Fertilizers: MF (mineral fertilizer); BM (bovine manure); BM + MF (bovine manure + mineral fertilizer); PL (poultry litter); and PL + MF (poultry litter + mineral fertilizer). Plant sampling time (21; 30; 39; and 63 days after transplanting-DAT), which corresponded to the beginning of flowering stage, beginning of fruiting stage, fruit growth stage and fruit harvest period, respectively. The number in parenthesis represent the percentage of P, in each stage of plant development, in relation to total P accumulated in the shoot (at 63 days of transplanting).

In the first sampling, at 21 DAT, 100% of P was present in the leaves and stems, because reproductive structures had not yet been formed (Figure 2). After the first sampling, the reproductive stage began, with the production of the first flowers. In this stage, P is mobilized from leaves and stems to the reproductive primordia in development. In the second sampling, at 30 DAT, P was more intensely mobilized from leaves and stems to the main sink, fruits. In this stage, the treatment with mineral fertilization (MF) showed P accumulation higher than 90% in leaves, stems and flowers, whereas in the treatment with poultry litter (PL) 32.7% of P was already allocated to form unripe fruits. At 39 DAT, more than 60% of P in all treatments was already part of the main sink (unripe fruits) and, in plants receiving poultry litter (PL), this value reached 75%. At the end of the cycle (63 DAT), most of the total P accumulated in the shoots was present in unripe and ripe fruits, above 80% in almost all treatments, which shows that these organs behaved as the main sinks in the plant.

The results found agree with those of F. Oliveira, F. Oliveira, Araujo, R. Rocha, and G. Rocha, (2016) for the Canary melon hybrid Goldex under fertigation. These authors, at the end of the cycle, found P accumulation of 32% in the shoots (leaves + stems) and 68% in fruits and seeds. Other authors have also found, for pumpkin (*Cucurbita* spp.) and melon, that fruits are the main organs for P accumulation (Aguiar Neto et al., 2014; Oliveira et al., 2016). Such P accumulation, particularly in fruits, is related to its high mobility in the phloem. According to Marschner (2012), mobile nutrients are easily mobilized to the fruits. Another fact would be the higher metabolic demand for this essential element by fruits (Duarte & Peil, 2010).

No significant difference was found for macronutrients use efficiency by the melon hybrid Goldex F1 between treatments. The decreasing order of nutrient use efficiency was: S > P > Mg > Ca > N > K (Table 4).

Sousa (2013), also working with the hybrid Goldex F1 in Red Yellow Argisol in Mossoró, Brazil, found the following sequence of use efficiency for macronutrients: Mg > P > Ca > N > K. Compared with our study, only the position of Mg was inverted, which may occur due to the fertilizer sources used and quantities applied in the experiments. In addition, it is related to the plant's capacity to use the nutrients, assimilating them in the best way and converting into biomass. Except for P, the Goldex melon (Inodorous group) also showed higher use efficiency levels than other two cultivars of muskmelon, Caribbean Gold and McLaren, evaluated in the experiment.

Table 4. Macronutrients use efficiency by the melon hybrid Goldex F1, in response to mineral and organic fertilizers

Fertilizers[1]	N	P	K	Ca	Mg	S
	---------------------- (g of total dry matter)^2/(mg of the nutrient in the plant) ----------------------					
MF	30.61	125.19	15.14	42.09	66.03	450.65
BM	34.42	146.71	16.80	50.03	68.15	477.26
BM + MF	28.17	119.70	15.25	34.53	65.58	419.59
PL	31.12	148.30	16.99	33.04	71.63	445.94
PL + MF	26.69	115.35	15.34	40.89	64.07	393.92
	F test[2]					
Fertilizers	0.946^{ns}	0.848^{ns}	0.437^{ns}	1.002^{ns}	0.167^{ns}	0.504^{ns}
C. V. (%)	19.04	23.28	16.52	31.83	20.05	21.48

Note. [1] Fertilizers: MF (mineral fertilizer); BM (bovine manure); BM + MF (bovine manure + mineral fertilizer); PL (poultry litter); and PL + MF (poultry litter + mineral fertilizer). [2] ns: Not significant.

Application of fertilizers promoted availability of nutrients in sufficient amounts to meet the nutritional demand of the melon hybrid Goldex F1, allowing plants to show similar capacity to redistribute and use these nutrients in the growth process. Use efficiency varies according to nutrient availability in the substrate; the lower the availability in the substrate, the higher the efficiency (Silva, Furtini Neto, Vale, & Curi, 1996). In general, the most nutrients uptakes tend to have lower values of use efficiency. The explanation is that, under this condition, the increment in biomass production by plants does not follow the uptake and accumulation of nutrients in the tissues, thus leading to reduction in their internal use for biomass production (Siddiqi & Glass, 1981).

The variations responsible for causing alterations in nutrient use efficiency are related to not obtaining the optimum or critical nutritional balance between soil, plant and nutrients, besides factors associated with the limitation of one or more available nutrients and imbalance in the water relations between soil, plant and atmosphere.

Partial Phosphorus Balance (PPB) showed percentages of 77.81; 41.43; 25.74; 20.52; and 14.01% in the treatments with poultry litter; bovine manure; mineral fertilizer; poultry litter + mineral fertilizer; and bovine manure + mineral fertilizer, respectively (Figure 3).

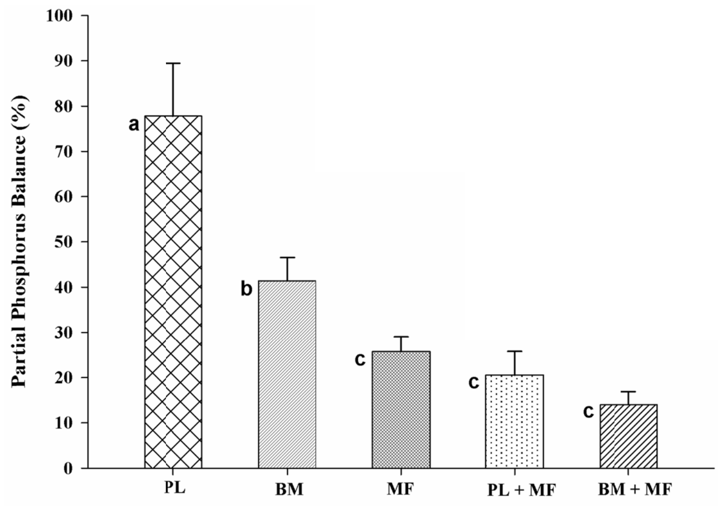

Figure 3. Partial phosphorus balance in the melon hybrid Goldex F1, in response to mineral and organic fertilizers

Note. Fertilizers: MF (mineral fertilizer); BM (bovine manure); BM + MF (bovine manure + mineral fertilizer); PL (poultry litter); and PL + MF (poultry litter + mineral fertilizer). Means followed by the same letter do not differ statistically by Tukey's test at p = 0.05.

Since this index is expressed by the ratio between the P removed at harvest (from fertilizer application + soil reserves) and the P applied as fertilizers, the use of organic fertilizers (poultry litter and bovine manure) led to higher PPB values.

Among the PPB values found, only the treatment with poultry litter (77.81%) is within the range considered as adequate (Syers et al., 2008). This indicates that the P input as fertilizer is similar to the removal by harvest, and the reserves of P immediately available in the solution + the P readily extractable (labile P) remain virtually unchanged. For the cases in which PPB values do not exceed 50%, they represent inefficiency of P use, *i.e.*, the crop has low yield in relation to the applied amount of P. In this case, part of the P applied that is not being used by the crop may be accumulated in the soil and can be used in the future by another crop.

The values of P_2O_5 in kg ha^{-1} applied in the form of organic fertilizers (bovine manure and poultry litter) were lower, whereas PPB values were higher, explaining the higher use efficiency of phosphate fertilizer by the crop in these treatments. Roberts and Johnston (2015), comparing two soils with P contents of 4 and 33 mg kg^{-1} under potato/barley rotation and three fertilizer rates (55; 110; and 165 kg ha^{-1} of P), found PPB values of 85; 52; and 39%, respectively, in the soil with 4 mg kg^{-1} of P. For the soil with 33 mg kg^{-1} of P, PPB values were 140; 72; and 50% for the rates 55; 110; and 165 kg ha^{-1} of P, respectively. These values prove that, as higher P rates are applied, the balance tends to decrease, *i.e.*, a considerable portion of P begins to be used inadequately. Additionally, in soils which naturally contain higher levels of P in solution, such as the soil with 33 mg kg^{-1}, PPB values are higher. However, when these values exceed 100%, the uptake is higher than the applied amount, which requires precaution because part of P reserves in the soil may eventually be consumed (Syers et al., 2008).

4. Conclusions

The P source used, organic or mineral, does not interfere with macronutrients use efficiency or with P accumulation and partition by the melon hybrid Goldex F1.

Fertilization with poultry litter maintain adequate phosphorus balance in the cultivation of the melon hybrid Goldex F1, *i.e.*, the amount of P removed at harvest is equivalent to that applied with the fertilizers.

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