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Macronutrients requirement of a snap bean genotype with determinate growth habit in Brazil

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Obtaining nutrient accumulation curves is very important in knowing the plant nutritional requirement dynamics and to direct the strategies for its supply. The aim of this work was to study the uptake, compartmentalization and exportation of macronutrients of a snap bean genotype with determinate growth habit. An experiment at field conditions at Londrina State University – UEL, Londrina-PR, Br azil, was performed in a randomized block design with five replications, using UEL-1 genotype. It was observed that dry matter production, as nutrients accumulation, were slow until 20 days after emergence (DAE), V4 stage, and became more pronounced after that period. The macronutrients were more accumulated in the pods, except for Ca, which had the leaves as preferred organ. The maximum amounts of N, P, K, Ca, Mg and S uptaken were 91.0; 35.2; 131.1; 35.2; 9.1 and 4.7 kg ha^{-1}, respectively, while exportation to produce each ton of pod's fresh matter were 7.01 kg of N; 3.30 kg of P; 7.91 kg of K; 0.6 kg of Ca; 0.48 kg of Mg and 0.31 kg of S. One must pay attention to the proper management of quantity and epoch of N and K supply, because of the high demand and exportation of these nutrients.

Key words: *Phaseolus vulgaris* L., plant nutrition, accumulation, demand.

INTRODUCTION

The snap bean (*Phaseolus vulgaris* L.) is a Fabaceae plant, the same species of the common bean, but differing from it by the consumption of the immature fruits (pods), which are succulent with reduced fiber (Myers and Baggett, 1999). The world production of green beans in 2013 was estimated to be 21.37 million tons, more than 90% is being produced in Asia (FAOSTAT, 2013). The snap bean may have two distinct growth habits,

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determinate or indeterminate. In the first case, the plant presents the inflorescence and in the second case, the vegetative bud is present at the apexes of the stems.

In Brazil, the commercial production of snap bean occurs with the usage, mainly, of indeterminate growth habit genotypes. However, the reduced cycle, exemption from staking, concentrated harvest and the possibility of total mechanization are some of the advantages that make the determinate genotypes attractive to producers (Vidal et al., 2007; Moreira et al., 2009).

The study on nutrient uptake together with development is very relevant to crop fertilizer management. With it, the quantities and the stages of higher accumulation can be accessed (Zobiole et al., 2010), enabling to match nutrient supply to crop requirements as advocated by Zhang et al. (2011) and, thus, avoiding both limitation at plant growth and wastage by excess application.

Despite this great importance, such studies are scarce in snap bean with determinate growth habit. Therefore, the aim of this work was to describe the dynamics of nutrient uptake and compartmentalization of this vegetable crop grown in the fall/winter season in Brazil.

MATERIALS AND METHODS

The experiment was carried in field conditions at the Agrarian Sciences Center of the State University of Londrina – UEL, Londrina-PR, Brazil (23° 23' S; 51° 11' W; 560 m altitude), between April and June 2014. The climate, according to Köppen classification, is Cfa type. The data for meteorological variables obtained during the months the experiment was performed were, respectively, 21.6; 18.3 and 16.9°C air mean temperature; 71, 74 and 75% air relative humidity and 162.5; 96.7 and 65.7 mm of rainfall, IAPAR (2015).

The soil was classified as a Red Oxisol (Santos, 2013) and presented the following characteristics of the arable layer (0.0 - 0.2 m): pH $_{CaCl2}$ = 4.82; P $_{Mehlich-1}$ = 1.84 mg dm^{-3}; Ca^{2+} = 5.1 cmol$_c$ dm^{-3}; Mg^{2+} = 1.7 cmol$_c$ dm^{-3}; K^+ = 0.82 cmol$_c$ dm^{-3}; H + Al^{3+} = 6.22 cmol$_c$ dm^{-3}; Al^{3+} = 0.1 cmol$_c$ dm^{-3}; CEC $_{pH\ 7.0}$ = 13.84 cmol$_c$ dm^{-3}; Organic Matter = 28.14 g dm^{-3} (Pavan et al., 1992).

The sowing was done manually in April 3, after the soil tillage with rotary hoe, in a randomized block design with five replications. The treatments consisted of different epochs of plant evaluation. The snap bean genotype was UEL-1 (Castiglioni et al., 1993). The plots were constituted by six sowing rows with six meters long, spaced 0.5 m apart, and with 12 seeds m^{-1} (240 000 plants ha^{-1}). The borders were the two external rows, as well as 0.5 m at the end of each row.

Representative plants were sampled weekly, the plant cycle, accounted by the days after emergence (DAE), which occurred April 10. Ten plants were collected per evaluation epoch (two per plot), by cutting them close to soil surface. The plant shoots were separated in leaves, stems and pods (when present), and washed in deionized water. The stage of development was noted according to scale proposed by Fernandez et al. (1982).

After being separated and washed, plant parts were dried in forced air system (60°C) till constant matter. Then, the plant tissues were weighed in analytical balance for obtaining dry matter (DM), ground in Wiley mill and submitted to acid digestion (sulfuric for N determination and nitricperchloric for P, K, Ca, Mg and S). The extracts were analyzed for macronutrients contents using the methods described by Silva (2009).

The accumulation of macronutrients (mg plant^{-1}) at different plant parts, in each sampling time, was obtained by multiplying its content (g kg^{-1}) by the DM (g plant^{-1}). Then, accumulation curves was adjusted as a function of time using the regression model "Gaussian" with three parameters, described by Equation 1, in which: $\hat{y}$ = accumulation (mg plant^{-1}); a = value of maximum accumulation (mg plant^{-1}); $x0$ = value of x, in DAE, that proportionate the maximum accumulation; b = amplitude of the interval of x between the point of inflection (when the rate of daily accumulation, still positive, begins to decay) and the value of $x0$. (Zobiole et al., 2010)

$$\hat{y} = a\,e^{\left[-0,5\left(\frac{x-x0}{b}\right)^2\right]} \quad (1)$$

With the data of nutrients accumulation in each sampling time and each plant part, it was possible to obtain their percentage distribution between plant organs, calculating the relative accumulation (%). The curves and percentage distribution of DM were obtained similarly for those of the nutrients. The fresh pod yield (kg plant^{-1}) in ten plants harvested randomly at the blocks was evaluated, converting data to kg ha^{-1} multiplied by population density (plants ha^{-1}). With the accumulation in the pods at the end of the cycle and the estimated yield, the exportation rates of macronutrients required to produce each ton of pod fresh matter was obtained.

RESULTS AND DISCUSSION

The DM accumulation was low until the beginning of V4 stage, near 20 DAE, when the plant had only 13% in comparison with the maximum value. By this time, the DM was allocated mainly at the leaves (above 80%). From this point, the increment of the accumulation was accentuated and the stems participation in the relative DM was increased (Figure 1).

Higher accumulation for pods, followed by leaves and stems was observed in the respective points of maximum (Table 1). The fresh pod yield was 6 921.6 $\pm$ 2 219.6[1] kg ha^{-1}, similar to that obtained by Moreira et al. (2009) for different snap bean genotypes with determinate growth habit at the same location in summer season.

The leaves and stems presented a resembling dynamics of DM accumulation, reaching the point of inflection between the stages R6 and R7, while the point of maximum was observed between R7 and R8. In the reproductive phase, there was a gradual decrease in the DM accumulation of vegetative organs, especially the leaves, and a simultaneous increase in the proportion accumulated in the pods (Figure 1). This shows a redistribution of photosynthates from the sources to the reproductive sinks (Taiz and Zeiger, 2010) and also the loss of biomass, represented by the falling senescent leaves (Larcher, 2003).

The mean contents of the macronutrientes were generally higher in the leaves, with a large reduction of N, P and K, the development in this organ. The content of Ca, on the other hand, was raised, while Mg

[1] Standard deviation

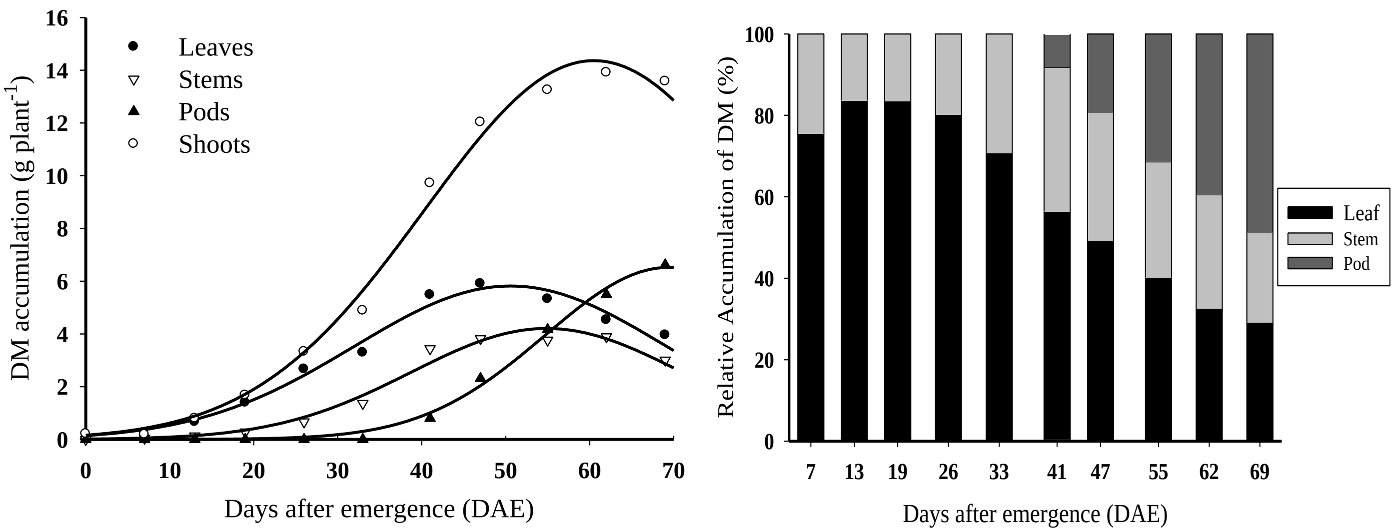

Figure 1. Dry matter (DM) accumulation curves and its percentage distribution between organs of the snap bean plant during its development.

Table 1. Estimated parameters of Gaussian model for dry matter (DM) accumulation in different parts of determinate growth habit of snap bean.

Plant part	Estimated parameters of adjusted model [(1)]			PI [(2)]	R^2
	a	b	$x0$	($x0$ - b)	
	g plant^{-1}	Days after emergence			
Leaves	5.82**	18.60**	50.57**	31.97	0.98
Stems	4.21**	16.11**	54.88**	38.77	0.98
Pods	6.52**	14.73**	69.46**	54.73	0.99
Shoots	14.36**	20.14**	60.51**	40.37	0.99

[1] a = maximum accumulation (g plant^{-1}); $x0$ = value of x, in days after emergence (DAE), which is proportional to the maximum accumulation; b = amplitude of the interval of x between the point of inflection and the value of $x0$. [2]PI = point of inflection. **Significant at 1% probability by *t* test.

and S changed a little (Table 2). These behaviors are similar to those found by Haag et al. (1967) studying the common bean. The dynamics of contents of N, P, K, Mg and S in the stems were like that in the leaves. The content of Ca, however, was the opposite. In the pods, the contents of N, P, K, Ca and S decreased progressively, while Mg, again, remained almost constant (Table 2).

The content reduction through time can be explained, especially in the vegetative phase, by the dilution effect resulting from the DM increment. This also must be the main reason why there is a decrease in pod's content. In the reproductive phase, on the other hand, the decline of nutrients contents, especially N, P and K in the source organs (leaves and stems) is due to translocation towards the developing sinks (pods) (Marschner, 2011). The low redistribution of calcium occurs because of the little mobility in the phloem (Biddulph et al., 1958) and the input to the pods depends on the xylem stream (Grusak and Pomper, 1999).

The accumulation of nutrients was slow until close to 20 DAE (beginning of V4 stage), when related to the maximum extraction, only 18% of N, 17% of P, 21% of K, 17% of Ca, 16% of Mg and 15% of S were already accumulated in the shoots (Figures 2 and 3). The incline of uptake curves was accentuated after that period, similar to what happened for DM, reaching the log phase (Epstein and Bloom, 2005). The dynamics of accumulation of N, K, Mg and S in different parts of the plant was similar, with redistribution initially from the leaves to the stems, in V4 stage, and, from both to the pods in the reproductive phase.

Particular behaviors were observed for P and Ca, in which the first had great accumulation in the pods, with almost linearly increase, and the second had major allocation in the leaves, reinforcing the issue of low Ca

Table 2. Mean contents of macronutrients nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg) and sulfur (S) at different parts of the snap bean plant in each cycle epoch.

Macronutrient	N	P	K	Ca	Mg	S
Epoch of cycle (days after emergence)			**g kg^{-1} (1)**			
			Leaves			
7 DAE (V2)	59.74	20.02	72.64	11.52	3.11	2.25
13 DAE (V3)	55.85	22.70	74.65	12.16	3.11	1.84
19 DAE (V4)	46.66	17.48	59.60	13.28	3.47	2.04
26 DAE (V4)	34.29	11.27	55.59	13.13	3.62	2.35
33 DAE (R6)	34.29	9.40	52.58	17.18	3.39	2.12
41 DAE (R7)	34.29	7.64	45.56	18.73	3.26	1.37
47 DAE (R7)	33.23	7.49	39.54	21.29	3.72	1.64
55 DAE (R8)	27.22	7.27	41.55	17.51	3.20	1.53
62 DAE (R8)	29.69	8.48	53.58	18.42	2.82	1.57
69 DAE (R8)	28.99	8.89	46.56	21.64	3.28	1.36
			Stems			
7 DAE (V2)	43.13	21.22	105.31	6.23	2.31	1.20
13 DAE (V3)	33.23	22.00	81.67	6.18	2.10	1.05
19 DAE (V4)	25.45	17.15	77.65	5.69	2.21	1.27
26 DAE (V4)	18.03	11.02	60.60	6.44	1.99	2.29
33 DAE (R6)	14.14	9.88	56.59	6.72	2.18	1.53
41 DAE (R7)	15.91	6.50	37.54	4.60	2.26	1.54
47 DAE (R7)	24.04	6.83	28.51	4.09	2.28	1.18
55 DAE (R8)	18.03	5.98	23.50	2.82	2.27	1.02
62 DAE (R8)	21.92	6.17	33.53	3.06	2.31	1.45
69 DAE (R8)	14.49	4.81	34.53	3.78	3.08	0.98
			Pods			
41 DAE (R7)	33.23	19.28	57.60	7.70	2.37	1.70
47 DAE (R7)	27.57	13.66	44.56	6.75	2.34	1.63
55 DAE (R8)	24.75	13.11	40.55	5.73	2.41	1.29
62 DAE (R8)	31.11	13.15	35.53	3.80	2.21	1.47
69 DAE (R8)	30.40	14.62	35.53	2.85	2.14	1.35

[1]Mean of the plots.

redistribution. Still, except for calcium, all the nutrients evaluated had the pods as the main residence organ at the end of the cycle, with approximately 56% of N, 66% of P, 45% of K, 39% of Mg and 52% of S, which shows high exportation rates of these elements (Figures 2 and 3). The inflection points at the curves of nutrients shoot accumulation occurred in the interval of 35 to 40 DAE (R6 to R7 stage), except for phosphorus, obtained at 44 DAE (Table 3). According to Zobiole et al. (2010), the inflection point is important for the determination of index leaf sampling period. The macronutrient uptaken in higher amount by the snap bean with determinate growth habit was K, with maximum value corresponding, in the population density used, to 131.1 kg ha^{-1}, followed by N with 91.0 kg ha^{-1}, Ca and P with both 35.2 kg ha^{-1}, Mg with 9.1 kg ha^{-1} and S with 4.7 kg ha^{-1} (Table 3). The amounts of macronutrients required for uptake and exportation by plants for the production of each ton of pod's fresh matter are shown in Table 4. Lower demand of P and higher demand of N, Ca, and S for the common bean than that observed for snap bean has been reported (Soratto et al., 2013; Pegoraro et al., 2014).

Faquin and Andrade (2004) highlighted the vegetable crops larger requirement of K in relation to N, a fact observed by authors such as Grangeiro et al. (2004) for watermelon, Silva Júnior et al. (2006) for melon, Vidigal et al. (2007) for pumpkin and Tetsukabuto and Fernandes et al. (2011) for potato. However, the epoch of cultivation in this study was made and has also contributed to this result, because of the lower water supply in the region during this period, which may interfere with N mineralization from soil organic matter (Sierra et al., 2001).

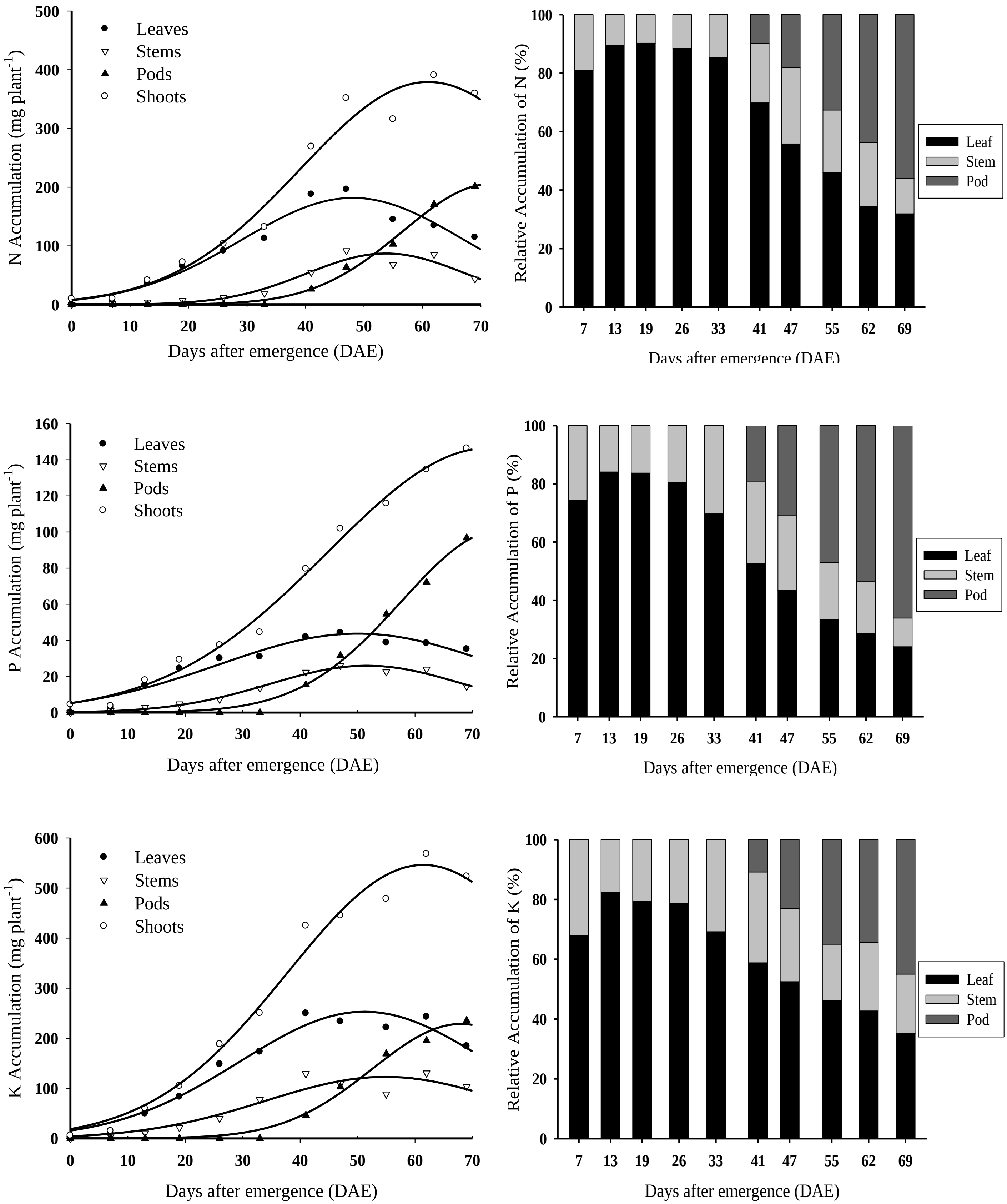

Figure 2. Accumulation curves of the primary macronutrients nitrogen (N), phosphorus (P) and potassium (K) and its percentage distribution between organs according to the development of determinate growth habit snap bean plant.

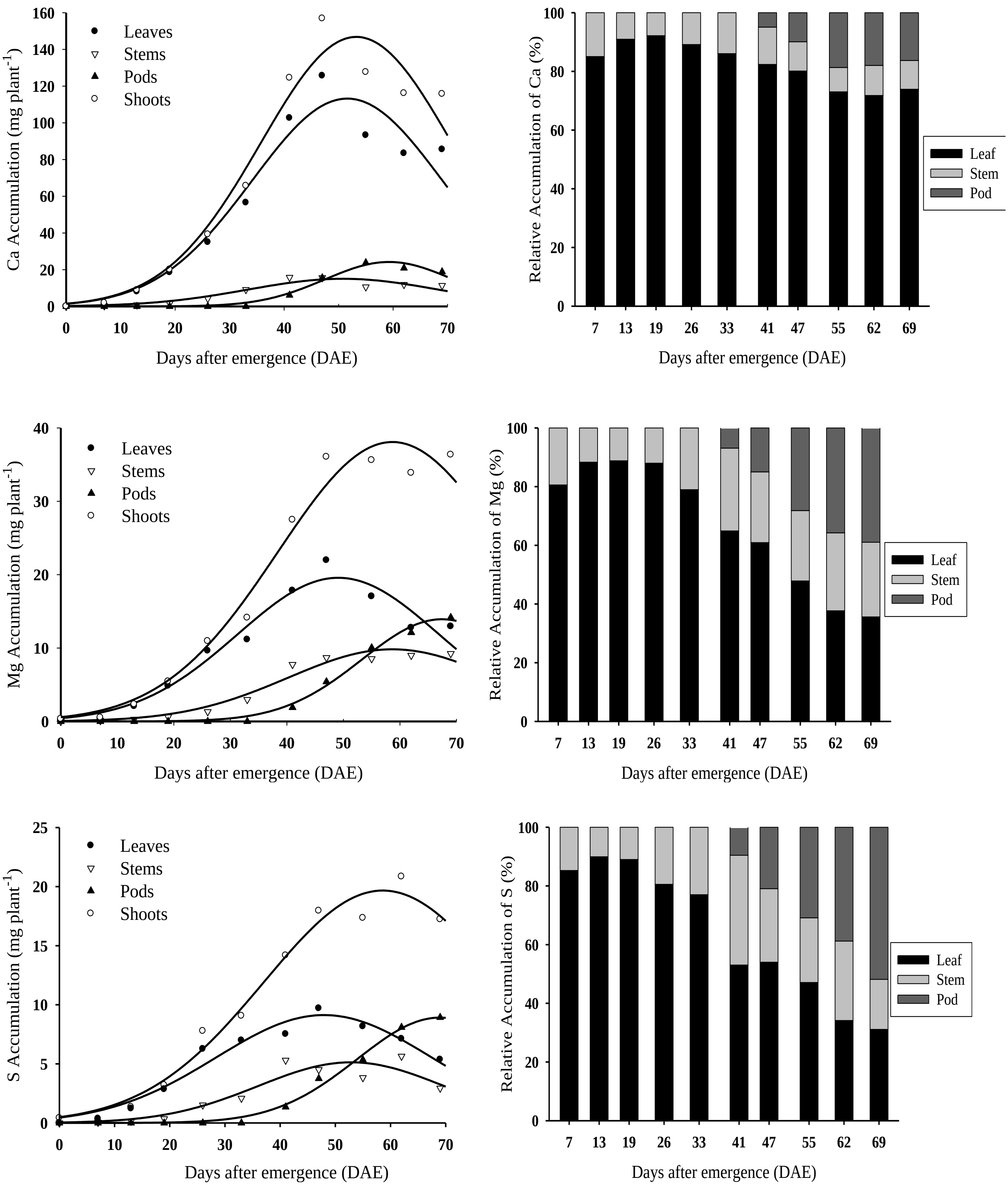

Figure 3. Accumulation curves of the secondary macronutrients, calcium (Ca), magnesium (Mg) and sulfur (S) and its percentage distribution between organs according to the development of determinate growth habit snap bean plant.

Table 3. Estimated parameters from the Gaussian model for the accumulation of nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg) and sulfur (S) of different parts of the determinate growth habit snap bean plant during the development.

Plant part	Estimated parameters of adjusted model [(1)]			PI [(2)]	R^2
	a	b	$x0$	$(x0 - b)$	
	mg plant^{-1}	Days after emergence			
Nitrogen					
Leaves	181.72**	19.03**	48.12**	29.09	0.95
Stems	87.07**	13.65**	53.81**	40.16	0.93
Pods	205.59**	15.23**	71.85**	56.62	0.99
Shoots	379.15**	21.98**	61.02**	39.04	0.97
Phosphorus					
Leaves	43.71**	24.25**	50.05**	25.80	0.94
Stems	25.94**	16.97**	51.59**	34.62	0.98
Pods	101.36**	17.66**	75.27**	57.61	0.99
Shoots	146.63**	28.21**	73.03**	44.82	0.99
Potassium					
Leaves	252.87**	21.68**	51.19**	29.51	0.97
Stems	122.79**	21.06**	54.88**	33.82	0.90
Pods	228.48**	15.47**	68.02**	52.55	0.99
Shoots	546.18**	23.64**	61.47**	37.83	0.99
Calcium					
Leaves	113.20**	17.43**	51.59**	34.16	0.94
Stems	15.04**	17.53**	50.83**	33.30	0.90
Pods	24.19**	11.79**	59.27**	47.48	0.98
Shoots	146.82**	17.54**	53.26**	35.72	0.96
Magnesium					
Leaves	19.57**	17.82**	49.10**	31.28	0.95
Stems	9.83**	18.44**	58.67**	40.23	0.96
Pods	13.92**	14.13**	67.44**	53.31	0.99
Shoots	38.08**	20.26**	58.67**	39.41	0.98
Sulfur					
Leaves	9.13**	19.55**	47.94**	28.39	0.96
Stems	5.13**	16.92**	52.87**	35.95	0.89
Pods	8.91**	14.96**	68.95**	53.99	0.99
Shoots	19.67**	21.54**	58.61**	37.07	0.98

[1] a = maximum accumulation (g plant^{-1}); $x0$ = value of x, in days after emergence (DAE), which proportionate the maximum accumulation; b = amplitude of the interval of x between the point of inflection and the value of $x0$. [2] PI = point of inflection. **Significant at 1% probability by *t* test.

Table 4. Amounts of macronutrients nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg) and sulfur (S) uptake in the shoots and exported by the pods of determinate growth habit snap bean plant, required for production of one ton of pod's fresh matter.

Plant part	Macronutrient					
	N	P	K	Ca	Mg	S
	----------kg t^{-1} of fresh pods----------					
Shoots	13.15	5.08 [(1)]	18.94 [(1)]	5.09 [(1)]	1.32 [(1)]	0.68
Pods	7.01	3.30 [(2)]	7.91 [(2)]	0.60 [(2)]	0.48 [(2)]	0.31
Exportation (%) [(3)]	53.31	64.96	41.76	11.79	36.36	45.59

[1]Values equivalent to 11.66 kg P_2O_5; 22.82 kg K_2O; 7.12 kg CaO and 2.19 kg MgO; [2]Values equivalent to 7.57 kg P_2O_5; 9.53 kg K_2O; 0.84 kg CaO and 0.79 kg MgO; [3]Calculated dividing pods by shoots uptake and multiplied by 100.

Conclusion

The uptake of macronutrients in growth habit snap bean follows the order K > N > Ca = P > Mg > S, while for the exportation rates, the order is K > N > P >> Ca > Mg > S. Except for Ca, the macronutrients are mainly in the pods at the end of the cycle.

The accumulation of all macronutrients in the shoots increased after the beginning of V4 stage, almost 20 days after emergence, and side dress fertilization, especially for N and K, should be done before that period.

Conflict of interest

The authors have not declared any conflict of interest

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