



## Kinetic parameters related to nitrogen uptake efficiency of pear trees (*Pyrus communis*)

Paula Beatriz Sete<sup>a,\*</sup>, Betania Vahl de Paula<sup>b</sup>, Matheus Severo de Souza Kulmann<sup>b</sup>,  
Andrea de Rossi<sup>c</sup>, Danilo Eduardo Rozane<sup>d</sup>, Jacson Hindersmann<sup>b</sup>, Amanda Veridiana Krug<sup>b</sup>,  
Gustavo Brunetto<sup>b</sup>

<sup>a</sup> Federal University of Santa Catarina, Rodovia Admar Gonzaga, 1346, Cep 88034-000, Florianópolis, SC, Brazil

<sup>b</sup> Federal University of Santa Maria, Avenida Roraima, 1000, C.P. 221, Cep 97105-900, Santa Maria, RS, Brazil

<sup>c</sup> Agricultural Research Centre for Temperate Climate Fruit, BR 285, Km 115, 95200-000, Vacaria, RS, Brazil

<sup>d</sup> São Paulo State University Julio De Mesquita Filho, Registro Campus, Rua Nelson Brihi Badur, 430, Cep 13900-000, Registro, SP, Brazil

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### ABSTRACT

Genetic improvement programs for pear trees in Brazil are characterized by rootstock (hypobiotic) selection mainly considering physiological attributes such as vigor, breakage of dormancy, propagation easiness, and sanitary characteristics, such as resistance to pests and diseases. However, kinetic parameters that determine nutrient uptake efficiency are not usually considered as, for example, nitrogen (N) in forms of NO<sub>3</sub><sup>-</sup> and NH<sub>4</sub><sup>+</sup>. The objective of this study was to evaluate the kinetic parameters related to N uptake in pear selection '54' and '971' as additional criteria for rootstock selection. The plants were acclimatized in a half-strength Hoagland solution and tested to assess the depletion of the internal reserves at 15 and 30 days, in CaSO<sub>4</sub> solution to evaluate the depletion period during 65 h. The selection '971' showed more significant NO<sub>3</sub><sup>-</sup> and NH<sub>4</sub><sup>+</sup> uptake efficiency, because presented higher V<sub>max</sub> values and Influx. The internal reserve depletion (IRD) period for the evaluated selections was 30 days in CaSO<sub>4</sub> solution. The evaluation period of the depletion period to reach the C<sub>min</sub> for selections '971' and '54' was 64 and 65 h for NO<sub>3</sub><sup>-</sup> respectively, and 65 h for NH<sub>4</sub><sup>+</sup>. The selection '971' had a higher affinity with the NO<sub>3</sub><sup>-</sup> ion when correlated with the physiological parameters of minimum fluorescence (Fo) and electron transport rate (ETR<sub>m</sub>).

### 1. Introduction

The world's breeding programs for pear trees utilize about 20 species from Europe and Asia, and the most used species are *Pyrus communis* L. (European), *Pyrus piriifolia* (Burm. F.) Nakai (Japanese) and the interspecific hybrid specie *Pyrus bretschneideri* Rehd. (Chinese) (Kumar et al., 2017; Janick, 2002). In Brazil, the most used rootstocks are *Pyrus calleryana* Decne and quinces from the *Cydonia* sp. gender (Machado et al., 2015; Pasa et al., 2011). The *P. Calleryana* is a tall tree highly vigorous and adaptable with a large treetop projection area. Such characteristics may hinder the conduction of this plant on modern orchards due to its high planting density (Machado et al., 2015; Pasa et al., 2011). The *Cydonia* sp. is less a vigorous rootstock, which enables a higher planting density and early fruiting. However, it may present treetop compatibility problems and lower edaphoclimatic adaptation (Pasa et al., 2011, 2010).

Pear trees orchards in Brazil are located in subtropical regions of

colder and higher altitude, where predominate low pH soils with a lot of organic matter, which usually requires liming and mineral or organic fertilization, for fruit production (Brunetto et al., 2016, 2015; Neto et al., 2008, 2011). Therefore, the study of kinetic parameters of nutrient uptake by pear trees may be an alternative to select germplasm more adapted to soils with different fertilities and nutrient demands.

The kinetic parameters of nutrient uptake are defined by the maximum rate of absorption (V<sub>max</sub>), which refers to the number of nutrients absorbed when all the sites transporters situated in the membranes of the root cells are saturated. The Michaelis-Menten constant (K<sub>m</sub>) that indicates the concentration of nutrient/ion solution, where half of the maximum rate of absorption is reached. The minimum concentration (C<sub>min</sub>), which specifies the minimum concentration amount that roots can uptake nutrients from the solution. Also, the Influx (I) that is the amount of nutrient absorbed per unit mass of roots per unit of time (Martinez et al., 2015; Yang et al., 2007). Thus, selections with lower values of C<sub>min</sub> and K<sub>m</sub> and higher values of V<sub>max</sub> and I, have a greater

\* Corresponding author.

E-mail address: [paulasete@gmail.com](mailto:paulasete@gmail.com) (P.B. Sete).

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chance to adapt to soils with low N availability.

To determine the kinetic parameters of N uptake in annual crops, the plants must be acclimatized in half-strength Hoagland nutrient solution for about 15 days (Sanes et al., 2013). After this period, the solution is replaced by distilled water for 24 h to reach the internal nutrient reserves depletion. It is expected that after this period, the plant will be able to max out its nutrient uptake capacity. Then, the plants are re-acclimatized in half-strength Hoagland's solution, to establish the depletion N rate. To achieve it, solution aliquots are collected every 1 h for 24 h (Claassen and Barber, 1974). However, for the evaluation of kinetic parameters with fruit species, such as in pear trees selection, the methodology needs to be adjusted since the plants can maintain more abundant internal N reserves, mainly allocated in perennial organs such as roots and stems (Dar et al., 2015; Neto et al., 2008; Rubio-Covarrubias et al., 2009).

The objective of this study was to evaluate N kinetic parameters of selection '54' and '971', as additional criteria for rootstock selection.

## 2. Material and methods

### 2.1. Location and treatments

The study was carried out in a greenhouse (latitude 29° 42' 57.4"S and longitude 53° 43' 12.2"W of Greenwich, average altitude of 115 m), at the Federal University of Santa Maria (UFSM), in Santa Maria city, state of Rio Grande do Sul, southern region of Brazil. The average relative air humidity in the greenhouse was 60 % and the average air temperature was 25 °C.

The selection '54' and '971' used in this study were two rootstock (hypobiotic) from open pollination of the germplasm bank of agricultural research (Embrapa) - Embrapa Uva e Vinho Unit, situated in the city of Vacaria (RS), in partnership with the State University of Santa Catarina (UDESC), located in Lages (SC). The selections are still in the process of genetic improvement and not available in the market.

The young plants after acclimation were grown on commercial substrate for about 12 months, and the most uniform specimens were used in the current study. In sequence, they were removed from the vessels to be washed carefully in running water until complete removal of the substrate. The plants with clean roots were conditioned in 5 l pots containing quarter-strength Hoagland nutrient solution (Jones Junior, 1983), composed by (in mg L): N-NO<sub>3</sub><sup>-</sup> = 196, N-NH<sub>4</sub><sup>+</sup> = 14, P = 31, K = 234, Ca = 160, Mg = 48.6, S = EDTA = 5, Cu = 0.02, Zn = 0.15, Mn = 0.5, B = 0.5 and Mo = 0.01, where they remained for 7 days until the completion of the first acclimation step.

The pots were then arranged on metal tables inside the greenhouse in a completely randomized design, using ten plants of each selection, having an equal division for each nutrient reserves depletion period. On the surface of each pot, it was added a 3 mm thick styrofoam blade to prevent evaporation of the nutrient solution and assist plants fixation. The styrofoam blade had a central hole to allow pear tree stem to grow and a second hole for a Polyvinyl chloride tube (PVC), which was connected to an oil-free air compressor for continuous aeration in each pot (Fig. 1).

For 7 days, the young pear trees rested in quarter-strength Hoagland solution to be replaced to a half-strength solution. The pear trees remained another 21 days in this solution concluding the second period of acclimation. The solution pH was read daily and maintained between 6.0 ± 0.2, adding 1.0 mol L<sup>-1</sup> HCl or 1.0 mol L<sup>-1</sup> NaOH whenever necessary. After the acclimation period, pear trees were induced to the depletion of internal nutrient reserves in a 0.01 mol L<sup>-1</sup> CaSO<sub>4</sub> solution (de Paula et al., 2018), which provided only Ca and S needed to maintain the electrochemical potential of the cell membrane and preserve cell wall integrity.

The plants were then separated into two groups of 15 days and 30 days, both kept in a solution of CaSO<sub>4</sub> (0.01 mol L<sup>-1</sup>), to evaluate the depletion of pear tree nutrient reserves. Thus, the experiment was

conducted in experimental design of two levels factor (selection x period of reserve depletion) with 5 repetitions per treatment.

### 2.2. Fluorescence of chlorophyll 'a'

The chlorophyll fluorescence at night time was determined using a JUNIOR-PAM (Walz, Germany) pulse amplitude modulated fluorometer (PAM), in the last day of each evaluation period at 15 and 30 days. The initial fluorescence (Fo) was determined and the leaf sample was subjected to a pulse of saturating light (10,000 μmol m<sup>-2</sup> s<sup>-1</sup>) for 0.6 s to establish the maximum fluorescence (Fm).

### 2.3. Depletion period evaluation

After each depletion period, the plants returned to the half-strength Hoagland nutrient solution for one hour, in order to reach steady-state uptake condition required for the application of the kinetic model proposed by Claassen and Barber (1974). The solution was again replaced by the same nutrient concentrations of the original half-strength Hoagland solution, to start the collection period of the solution aliquots. Ten milliliters from each 5 l pot was collected at time zero and every 6 h in the first 24 h, every 3 h between 24 and 48 h, and every 1 h between 48 and 65 h. At the end of the 65 h evaluation period, the plants were removed from the pots and separated into leaves, stems and roots. The stem height was identified using a metric measuring tape and the diameter was determined using a digital caliper.

The fresh mass (FM) of leaves, stem and roots were determined on a digital scale (Bel Engineering, Brasil). The volume of nutrient solution that remained in each pot was measured with the aid of a graduated cylinder.

### 2.4. Solution and leaves nutrient analysis

The plants organs were dried in a forced air circulation oven at 65 °C until maintain a constant weight to determine its dry mass (DM). Sequentially, the dried leaf fractions were milled, prepared and subjected to sulfuric acid digestion (Tedesco et al., 1995). For this purpose, 0.200 g dry mass of each fraction was added to a digestion tube (25 × 250 mm) with 1 ml de H<sub>2</sub>O<sub>2</sub>, 2 ml of H<sub>2</sub>SO<sub>4</sub> and 0.7 g of digestion mixture (90.9 % Na<sub>2</sub>SO<sub>4</sub> + 9.1 % CuSO<sub>4</sub> 5H<sub>2</sub>O). The tubes were then heated in a digester block at 150 °C, in which the temperature was raised gradually, 50 °C every 30 min up to 350 °C. After the complete digestion of the leaves, the tubes remained in the digester block for another 60 min at 350 °C.

After the digestion, the volume of the sample was adjusted by adding 50 ml of distilled water. In sequence, ten milliliters of the extract was collected and pipetted in another 100 ml capacity digestion tube along with 10 ml of NaOH NaOH 10 mol L<sup>-1</sup>. The sample was then distilled with a semi-micro Kjeldahl steam distillation unit (Tecnal TE-0364, Brazil), until the accumulation of 35 ml in Erlenmeyer flask containing 5 ml of indicator-boric acid mixture. The extract was then titrated with standardized H<sub>2</sub>SO<sub>4</sub> 0005 mol L<sup>-1</sup> to calculate the total N content (Tedesco et al., 1995). The NH<sub>4</sub><sup>+</sup> and NO<sub>3</sub><sup>-</sup> content in the solution collected during depletion period were determined by molecular absorption spectrophotometry in an automatic segmented flow analyzer (Skalar San<sup>+</sup>, 1074 sampler, The Netherlands).

### 2.5. Determination of kinetic parameters

The parameters of V<sub>max</sub>, C<sub>min</sub> and K<sub>m</sub> were calculated using the software Cinetica (RUIZ et al., 1985), using NO<sub>3</sub><sup>-</sup> and NH<sub>4</sub><sup>+</sup> aliquot concentrations in function of time, the fresh mass of the roots, and the initial and final solution pot volumes. C<sub>min</sub> was determined by considering the concentration of N present in the 65-h depletion period, whereas the Inflow (I) was calculated according to Eq. 1, proposed by Michaelis-Menten and modified by Nielsen and Barber (1978).

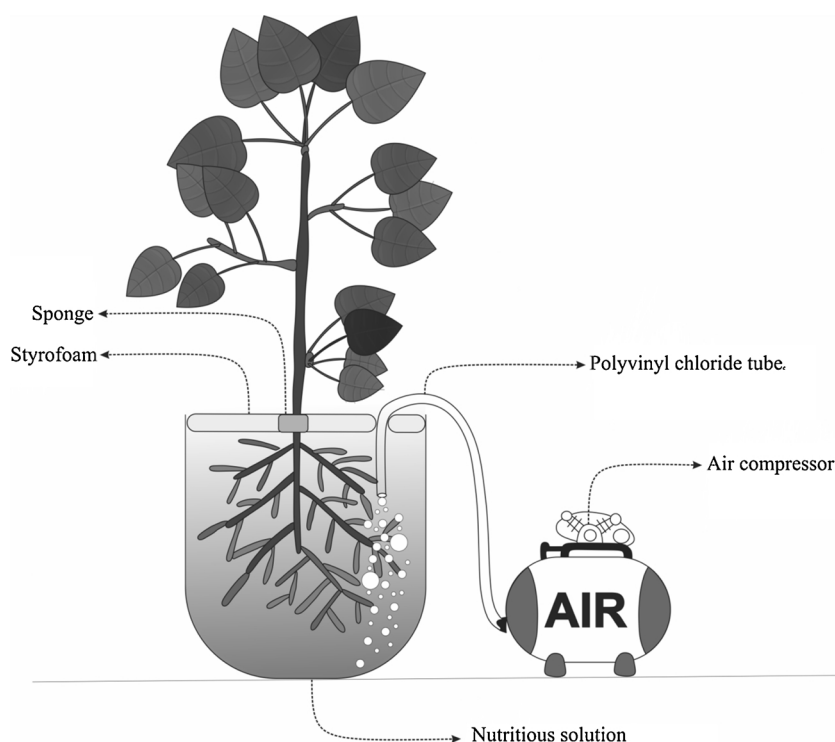


Fig. 1. Illustrative schematic of N-absorption kinetic experiment assembly in a pear tree.

$$IL = \left[ \frac{V_{max} \times (C - C_{min})}{K_m + (C - C_{min})} \right] \quad (1)$$

Where: I = Nutrient Influx Rate, C = Nutrient concentration collected in each period,  $V_{max}$  = maximum uptake rate,  $K_m$  = Michaelis-Menten constant, and  $C_{min}$  = minimum concentration.

## 2.6. Statistical analysis

The results obtained from the morphological and physiological parameters were submitted to homogeneity and normality test (Biostat 5.0 2008), and later, the analysis of variance in the statistical environment R (R Core Team 2018). When the effects of the treatments were considered significant, the means of the results of  $V_{max}$ ,  $C_{min}$ ,  $K_m$  and I for each selection were compared by the Tukey test ( $p < 0.05$ ); and the concentration difference of  $N-NH_4^+$  and  $N-NO_3^-$  over 65 h for each selection were compared by the Scott Knott test ( $p < 0.05$ ).

The principal component analysis (PCA) was performed using the software Canoco version 4.5 (Ter Braak & Similauer, 2002). It was calculated from the mean of depletion response variables in the 30 days of evaluation in calcium sulfate, considering the kinetic parameter variables (Dry mass of roots, stem and leaves, height and stem diameter, N in leaves, stem and roots) and physiological parameters (minimum fluorescence -  $F_o$ , maximum fluorescence -  $F_m$ ,  $F_v / F_m$  relation and the maximum electron transport rate - ETRm).

## 3. Results and discussion

### 3.1. Morphological parameters and fluorescence of chlorophyll a

The selection '54' and '971' presented high dry mass values of root and stem, having the stem diameter measured after 30 days of IRD (Table 1). The increase of the morphological parameter indicates that the plants continued to grow even after the end of the study. The '54' selection had a higher N content in the roots when compared to the selection '971' (Table 1) after 15 days of nutrient reserves depletion. This fact is due to a higher production of selection '54' dry mass form

Table 1

Morphological parameters of selection '54' and '971' in Hoagland nutrient solution for 15 and 30 days, after the internal reserves depletion of (IRD) in  $CaSO_4$  solution ( $0.01 \text{ mol L}^{-1}$ ).

Morphological parameters	'54'		'971'		P (anova)
	15 IRD	30 IRD	15 DRI	30 IRD	
Root dry matter (g)	2.44 aB <sup>(1)</sup>	3.99 aA	1.60 aB	3.72 aA	0.00
Stem dry matter (g)	3.62 aB	6.07 aA	3.46 aA	5.21 aA	0.00
Leaf dry matter (g)	0.94 aA	1.49 aA	1.35 aA	1.43 aA	0.00
Height (cm)	42.93 aA	53.46 aA	49.23 aA	51.36 aA	0.00
Stem diameter (cm)	0.47 aB	0.57 aA	0.43 aB	0.53 aA	0.00
Total N in leaves (%)	2.59 aA	2.66 aA	2.77 aA	2.52 aA	0.00
Total N in stems (%)	1.75 aA	1.79 aA	1.76 aA	1.67 aA	0.00
Total N in roots (%)	3.40 aA	3.38 aA	2.85 bA	3.33 aA	0.00

<sup>(1)</sup> Averages followed by lowercase letters differ from the selections between periods and averages followed by the upper case letters differ the periods within each selection using the Tukey test ( $p < 0.05$  %).

the roots, in which N accumulation is favored mainly in the form of proteins (Moriwaki et al., 2019). Another essential factor is that the dry mass production in the leaves being smaller than in the roots and stem, decreased the need for redistribution of N forms from perennial organs to growing annual organs, in other words, from roots to leaves (Brunetto et al., 2016; Harrison-Kirk et al., 2014; Neto et al., 2008). The dry leaf mass, tree height, and total N content in the leaves and stem did not present any statistical divergence during the conduction of the experiment (Table 1).

The  $F_v/F_m$  relationship for both selections was obtained by the difference between the maximum fluorescence ( $F_m$ ) and minimum fluorescence ( $F_o$ ) read at daybreak. The ratio is represented by a 0–1 scale, where the number closer to 1 means higher energy absorption efficiency by the plant. The fluorescence results showed that both selections lost low levels of energy, having an equal ratio  $F_v/F_m$  of 0.83 at the 30 days of IRD (Table 2). It means that the energy was transfer more efficiently from the light collecting system to the reaction center (Mascia et al., 2017). When compared to the 15 days of IRD in  $CaSO_4$

**Table 2**

Physiological parameters of selection '54' and '971' in Hoagland nutrient solution for 15 and 30 days after the internal reserves depletion of (IRD) in CaSO<sub>4</sub> solution (0.01 mol L<sup>-1</sup>).

Physiological parameters	'54'		'971'		P (anova)
	15 IRD	30 IRD	15 IRD	30 IRD	
Minimum fluorescence (Fo)	135.66 aA <sup>(1)</sup>	123.66 aA	129.33 aA	126.33 aA	0.00
Maximum fluorescence (Fm)	677.00 aA	732.66 aA	665.00 aA	688.00 aA	0.00
Fv/Fm ratio*	0.79 aB	0.83 aA	0.80 aB	0.83 aA	0.00
Electron transport rate (ETRm)	80.03bA	59.66 bB	102.16aA	85.46 aA	0.00

<sup>(1)</sup> Averages followed by lowercase letters differ from the selections between periods and averages followed by the upper case letters differ the periods within each selection using the Tukey test ( $p < 0.05$  %). \*Fv/Fm ratio: Fv = variable fluorescence and Fm = maximum fluorescence.

solution, it is evident that the photosynthetic process of the selections was not impaired.

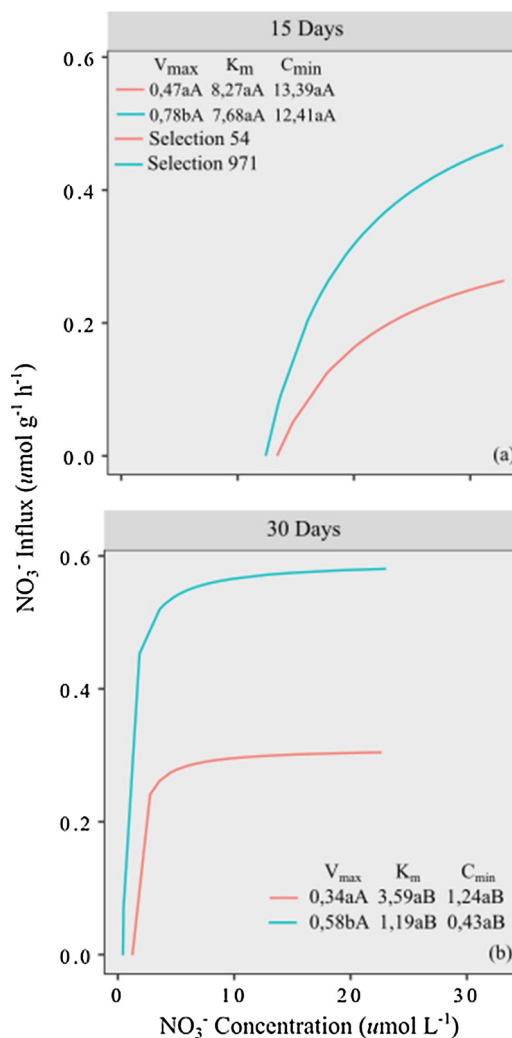
The physiological parameters of minimum fluorescence (Fo) and maximum fluorescence (Fm), did not differ statistically for 15 and 30 days of IRD in both selections analyzed (Table 2). Yet, selection '971' presented the highest rate of maximum electron transport (ETRm) at 15 and 30 days IRD (Table 2). This portrait that this selection is possibly better adapted to low N concentrations since it was able to absorb more of electrons in the chlorophyll 'a' antenna system. As a consequence, more solar energy was converted into photochemical energy, contributing effectively for the reduction of NADP<sup>+</sup> to NADPH. Therefore, is expected from selection '971' a higher demand of N and a greater uptake of the same N, because it is capable of converting more solar energy into chemical energy.

### 3.2. N reserve depletion period

At 15 and 30 days of internal nutrient reserves depletion, the selection '971' presented the highest  $V_{max}$  values from NO<sub>3</sub><sup>-</sup> absorption than selection '54' (Fig. 2). However, the values of  $K_m$  and  $C_{min}$  related to NO<sub>3</sub><sup>-</sup> absorption were statistically equal for both selections and higher after 15 days of IRD (Table 2). The  $V_{max}$  value was statistically equal between 15 and 30 days of IRD for both selections. The selections '54' and '971' have presented lower  $C_{min}$  values of NH<sub>4</sub><sup>+</sup> after 30 days of IRD (Fig. 3). The  $V_{max}$  and  $K_m$  values analyzed for the NH<sub>4</sub><sup>+</sup> were statistically equal for both IRD periods (15 and 30 days). These results show that after 15 days IRD, both selection still had internal reserves of NH<sub>4</sub><sup>+</sup> and, for this reason, the plants continued to absorb NH<sub>4</sub><sup>+</sup>. The NH<sub>4</sub><sup>+</sup>  $C_{min}$  results suggest that the selection '54' and '971' after 30 days IRD, demonstrated greater ability in NH<sub>4</sub><sup>+</sup> uptake, absorbing even at low concentrations in the solution. The NH<sub>4</sub><sup>+</sup>  $C_{min}$  results suggest that the selection '54' and '971' after 30 days IRD, have a greater ability in NH<sub>4</sub><sup>+</sup> uptake by absorbing even at low concentrations in the solution, due to a larger number of absorption sites on the roots.

The influx rates of NO<sub>3</sub><sup>-</sup> and NH<sub>4</sub><sup>+</sup> were higher in selection '971' (Fig. 2 and 3), possibly because they had a higher demand for N and, as an adaptation mechanism, acquired a more considerable amount of NO<sub>3</sub><sup>-</sup> and NH<sub>4</sub><sup>+</sup> in the root uptake sites (Mota et al., 2011). Moreover, the selection '54' presented physiological parameters (Fv/Fm ratio and ETRm), that indicates a higher energy loss by fluorescence and a lower NO<sub>3</sub><sup>-</sup> and NH<sub>4</sub><sup>+</sup> uptake. The highest rates of NO<sub>3</sub><sup>-</sup> and NH<sub>4</sub><sup>+</sup> uptake by roots of '971' selection cannot be justified by morphological characteristics since there is no difference in dry mass content in any assessed organs. However, there is a clear difference in the way that photosynthetic selection apparatus captures the solar energy, which may have generated a higher demand for N, supplied by a higher effectiveness of root's uptake. This possible adaptation of selection '971' is very positive since a vast amount of N is required in the adult phase of the plant due to its export increase via fruit.

The uptake drop in NO<sub>3</sub><sup>-</sup> and NH<sub>4</sub><sup>+</sup> by the roots of selection '54' may be related to a solution concentration decrease or plant activity reduction (transport rate or reaction) of NRT1 and NRT2 absorption



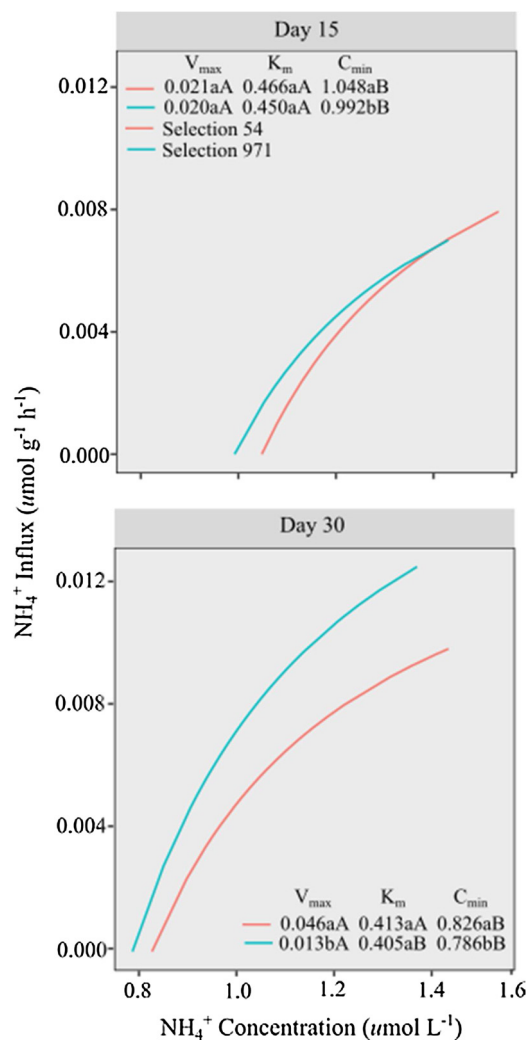
**Fig. 2.** Influence Rate,  $C_{min}$ ,  $K_m$  and  $V_{max}$  of NO<sub>3</sub><sup>-</sup> in selection '54' and '971', cultivated in Hoagland solution after 15 (a) and 30 days (b) of internal nutrient reserves depletion in a CaSO<sub>4</sub> solution (0.01 mol L<sup>-1</sup>). Averages followed by lowercase letters differ from the selections between periods and averages followed by the upper case letters differ the periods within each selection using the Tukey test ( $p < 0.05$  %).

proteins, since such proteins are involved in nutrients uptake affecting negatively the enzymes engaged in NO<sub>3</sub><sup>-</sup> and NH<sub>4</sub><sup>+</sup> assimilation (Giri et al., 2017).

### 3.3. The best depletion period period to evaluate N uptake

The selection '54' absorbed NO<sub>3</sub><sup>-</sup> more intensively and longer than selection '971' reaching its  $C_{min}$  at the end of the assessment period



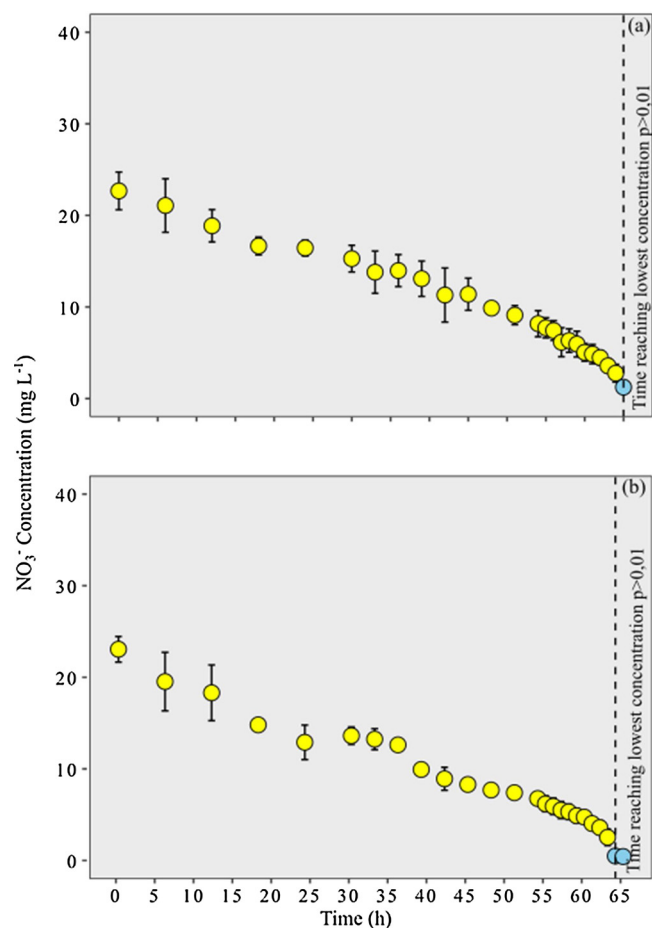


**Fig. 3.** Influence Rate,  $C_{\min}$ ,  $K_m$  and  $V_{\max}$  of  $\text{NH}_4^+$  in selection '54' '971', cultivated in Hoagland solution after 15 (a) and 30 days (b) of internal nutrient reserves depletion in a  $\text{CaSO}_4$  solution ( $0.01 \text{ mol L}^{-1}$ ). Averages followed by lowercase letters differ from the selections between periods and averages followed by the upper case letters differ the periods within each selection using the Tukey test ( $p < 0.05 \%$ ).

(Fig. 4a and 4b). The  $C_{\min}$  identified for both selection '54' and '971' were similar, therefore is recommended that in future experiments the extension of collections period for at least 70 h (Martinez et al., 2015; de Paula et al., 2018). It portrays that access '54' and '971' have similar morphological characteristics which provide similar  $\text{NO}_3^-$  like uptake mechanisms.

The access reached  $C_{\min}$  for  $\text{NH}_4^+$  after 65 h from the beginning of the experiment, demonstrating the same depletion period (Fig. 5 a). The results of  $C_{\min}$  parameters obtained with fruit trees differ from the studies carried out with annual crops, where the recommended collection period can be 15 h, having 60 min intervals between each collection (Li et al., 2017).

The same depletion period for both selection, can occur when  $\text{NH}_4^+$  uptake is carried out by several  $\text{NH}_4^+$  transporting agents (Mota et al., 2011). There are at least five  $\text{NH}_4^+$  transporters that belong to AMT1 (CoAMT\_1 to CoAMT1\_5) subfamily contained in pear tree roots, which can partake in  $\text{NH}_4^+$  uptake during the vegetative cycle (Mota et al., 2011). The results presented by these authors (Batista et al., 2016; Mota et al., 2011; de Paula et al. (2018); Pii et al., 2014; Tomasi et al., 2015) reinforce the understanding that N forms in perennial trees is quite different from annuals, and that kinetic uptake parameters of N forms



**Fig. 4.**  $\text{NO}_3^-$  concentrations in selection '54' (a) and '971' (b) after 30 days of internal nutrient reserves depletion. Average  $\text{NO}_3^-$  concentrations in blue differ significantly from averages of concentrations in yellow ( $\alpha = 0.05$  (Scott Knot's test)). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article).

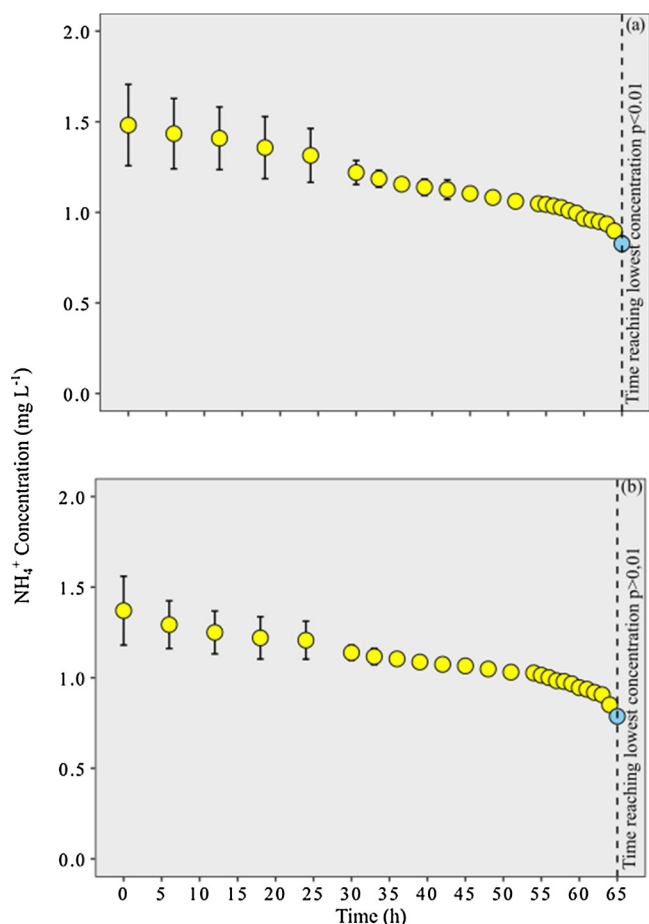
may contribute to a better understanding of nitrogen fertilization in pear orchards.

In previous studies by de Paula et al. (2018), kinetic parameters related to N uptake in rootstocks (hypobiotics) of peach trees Tsukuba 1, Aldrich and Clone 15 were evaluated. Both the peach trees and selection pear trees '54' and '971' from the current study, found that the best period for N internal reserves depletion was at 30 days.

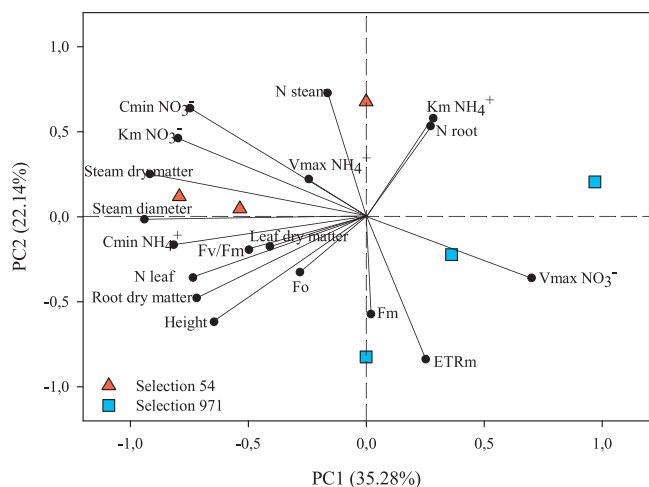
### 3.4. Principal component analysis (PCA)

The principal component analysis (PCA) from selection '54' and '971' explained 57.42 % of data variability (Fig. 6). The first component (PC1) explained 35.28 % of data variation and exposed the difference from kinetic parameter  $\text{NO}_3^- V_{\max}$  uptake, which has an inverse correlation with  $C_{\min}$  and  $K_m$  parameters. The higher influx of selection '971' (Fig. 2b) makes evident its affinity for  $\text{NO}_3^-$  and its high interaction with the physiological parameter ETR<sub>m</sub>, which has an inverse correlation with stem N concentration. However, selection '971' absorbed a considerable amount of N in photosynthetic processes and did not accumulate N in reserve organs like the stem, which is usually expected in fruit trees since it is a passage flow of nutrients (Brunetto et al., 2016).

The highest ETR<sub>m</sub> values and its correlation with '971' selection revealed a higher demand for N by the plant, illustrated by the rise in  $\text{NO}_3^-$  and  $\text{NH}_4^+$  inflows on both periods of IRD (Fig. 2,3). This shows that a more significant amount of energy was harnessed by selection



**Fig. 5.**  $\text{NH}_4^+$  concentrations in selection '54'(a) and '971' (b), after 30 days of internal nutrient reserves depletion. Average  $\text{NH}_4^+$  concentrations in blue differ significantly from averages of concentrations in yellow  $\alpha = 0.05$  (Scott Knot's test). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article).



**Fig. 6.** Relationship between main component 1 (PC1) and main component 2 (PC2) for the variables of kinetic parameters ( $V_{\max}$ ,  $K_m$  and  $C_{\min}$ ), morphological parameters (dry matter of roots, stem and leaves, height, stem diameter; N ratio in leaves, stem and roots) and physiological parameters (minimum fluorescence -  $F_o$ , maximum fluorescence -  $F_m$ ,  $F_v / F_m$  ratio and electron transport rate -  $\text{ETR}_m$ ).

'971' and, consequently, more energy was absorbed and used in photochemical processes of photosynthesis. Also, selection '971' presented a cluster of  $\text{NH}_4^+$   $K_m$  and N results from the roots of component 1, correlating it inversely with the minimum fluorescence (Fo), which explains a rise in the selection nutrient demand. Possibly, the plant suffered stress due to the initial nutrient demand at the beginning of the depletion period and stored more N in its roots due to genetic characteristics, which generated a higher affinity with the  $\text{NO}_3^-$  ion.

#### 4. Conclusion

The selection '971' demonstrated a higher efficiency in  $\text{NO}_3^-$  and  $\text{NH}_4^+$  uptake, as it presented higher values of  $V_{\max}$  and influx for both nutrients. The internal N reserves depletion period for both selection assessed was 30 days in  $\text{CaSO}_4$  solution. The depletion period to reach  $C_{\min}$  for selection '971' and '54' was 64 and 65 h for  $\text{NO}_3^-$  respectively and 65 h for  $\text{NH}_4^+$ . The selection '971' had a higher affinity with the  $\text{NO}_3^-$  ion when correlated with the physiological parameters of minimum fluorescence (Fo) and maximum electron transport rate ( $\text{ETR}_m$ ).

#### CRedit authorship contribution statement

**Paula Beatriz Sete:** Data curation, Formal analysis, Investigation, Visualization, Writing - original draft, Writing - review & editing. **Betania Vahl de Paula:** Conceptualization, Data curation, Formal analysis, Methodology, Writing - original draft, Writing - review & editing. **Matheus Severo de Souza Kulmann:** Investigation, Resources, Writing - review & editing. **Andrea de Rossi:** Resources, Writing - review & editing. **Danilo Eduardo Rozane:** Writing - review & editing. **Jacson Hindersmann:** Investigation, Resources, Supervision. **Amanda Veridiana Krug:** Investigation, Resources, Supervision. **Gustavo Brunetto:** Supervision, Project administration, Writing - review & editing.

#### Declaration of Competing Interest

The manuscript is original, has not been published before, and is not being considered for publication elsewhere in its final form neither in printed nor in electronic format and does not present any kind of conflict of interests.

#### Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:<https://doi.org/10.1016/j.scienta.2020.109530>.

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