Influence of nitrogen and potassium on yield, fruit quality and mineral composition of kiwifruit

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***Abstract*—** Fertilization is one of the main factors affecting the yield and quality of kiwifruit (*Actinidia deliciosa).* Therefore, suitable cultural practices, including fertilization, should be studied in order to guarantee high production levels and the maintenance of fruit quality. On the other hand, physiological disorders during fruit storage are common, leading to important losses of marketable yield and can be strongly affected by the mineral composition of fruits. This study lasted for 3 years (2004 to 2006) and experimental data was obtained from a fertilizer trial arranged into completely randomized blocks, with three replications, installed in an orchard located in the Portuguese Region of Bairrada (central Portugal). This experiment was established in order to evaluate the influence of nitrogen and potassium fertilization on the yield and fruit quality of kiwifruit cv. Hayward. Three levels of nitrogen (30, 60 and 90 kg ha^{-1}N) and four levels of potassium (0, 45, 90 and 135 kg ha^{-1} K_2O) were used, arranged into 12 experimental treatments. Since 2004, nitrogen and potassium were applied annually. The total yield of each plot was evaluated and fruits were graded into six categories according to the weight and deformations: fruits < 65g, [65 -75g], [75 -85g], [85 -105g], ≥105g and deformed fruits. After harvest, fruits were stored in normal atmosphere at 0ºC and 90-95% hygrometry conditions. After 50 days of storage, one sample of each experimental treatment consisting of 10 fruits from [85-105g] size was taken to assess some quality parameters namely, firmness of the pulp, titratable acidity, and soluble solids content, at harvest. Other sample of 16 fruits of each marketable fruit size ([65-75g], [75-85g], [85-105g] and ≥105 g) was taken from each plot and analysed for its mineral composition (N, P, K, Ca, Mg, S, Na, Fe, Mn, Zn, Cu, and B).The present paper reports experimental results of a study with the main propose of establishing the effect of nitrogen and potassium fertilization on yield, fruit quality and fruit mineral composition of *Actinidia deliciosa* 'Hayward' at 50 days after storage, corresponding to the experimental period 2004 to 2006. Results showed a significant mean effect of interaction NxK fertilization on fruit yield. The annual mean application of 60 kg ha^{-1} N, with the highest rate of potassium, 135 kg ha^{-1} K_2O, led to the highest level of marketable fruit yield (19.1 tonnes ha^{-1}). The acidity and soluble solids contents of fruits were not affected by nitrogen and potassium content supply. However, both nutrients decreased the flesh firmness. The interaction NxK fertilization influenced fruit calcium concentration. The lowest level of calcium was observed with 90 kg ha^{-1} N associated with 90 kg ha^{-1} or 135 kg ha^{-1} K_2O. Both N/Ca and K/Ca ratios increased with nitrogen and potassium supply.

Keywords* - *Actinidia *deliciosa*, fruit mineral composition fruit quality, nitrogen, potassium, yield.

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I. INTRODUCTION

IN spite of the increasing importance of kiwifruit (*Actinidia deliciosa* 'Hayward') in the Portuguese Region of "Beira Litoral" (central Portugal), limited experimental work has been done regarding the nutrient levels of the fruits, associated with adequate levels of fertilization, in order to minimize fruit losses during storage, due to premature softening.

Fertilization is one of the cultural practices with a greater effect on the kiwifruit yield, as well as on fruit mineral composition. The supply of nutrients usually results in yield increase, although excessive or unbalanced application has negative effects. Johnson et al. [1] found that high nitrogen levels were associated with more rapid fruit softening during storage. Also, excess nitrogen at harvest increases the incidence of botrytis storage rot of kiwifruit [2].

To have a high quality product at harvest, it is of major importance to ensure that preharvest conditions are optimised [3], being correct fertilization one of the most important factors.

Sustainable development integrates economic, social and environmental factors [4], [5]. The excess of fertilization causes also a detrimental effect on environment and is not economically sustainable.

Some studies concerning the nutritional status of the kiwifruit in the Portuguese Region of Bairrada were previously published. Pacheco *et al*. [6] estimated the annual removal of nutrients and Vieira *et al*. [7], established preliminary reference values for leaf-analysis of kiwifruit.

Despite the referred experiments had shown that limited quantities of nitrogen are annually removed from the kiwifruit orchard [6], large amounts of nitrogen fertilizer are still supplied by producers.

The present paper reports the first set of experimental results from a three-years survey (2004 to 2006) carried out in order to evaluate the influence of nitrogen and potassium fertilization on the yield and fruit quality parameters (flesh firmness, titratable acidity and soluble solids content) and fruit mineral composition of *Actinidia deliciosa* cv. Hayward.

II. Materials and Methods

The study was based on data obtained from a fertilizer trial conducted in an experimental kiwifruit orchard, cultivar Hayward, planted in 1990, with spacing of 5.0m × 3.0m, in the Portuguese Region of Bairrada.

The results of soil samples, taken from 0-30 cm depth, under the canopy of the vines before the establishment of the experiment, are shown in table 1.

Soil chemical analyses were performed on air dried and sieved (<2 mm) soil samples. - The % sand, % silt and % of clay were determined using a Bouyoucos hydrometer and, as dispersing agents, sodium hexametaphosphate and sodium carbonate (hydrometer method).

The pH(H_2O) was measured in 1:2.5 soil:water suspension. Organic matter was obtained multiplying organic carbon content by 1.724. Total carbon was determined by dry combustion, according to ISO Standard 10694, using a CNS elemental analyzer.

Phosphorus and potassium were extracted by a solution of ammonium lactate 0.1N and acetic acid 0.4N buffered at pH 3.65-3.75 (Egner-Riehm method) and determined by ICP-Optical Emission Spectrometry (ICP-OES) at 185.9 and 766.5 nm, respectively.

Potential cation exchange capacity, exchangeable basic cations (Ca, Mg, K and Na) and exchangeable acidity were extracted by a solution of ammonium acetate 1M, buffered at pH 7.0, in a soil-solution ratio of 1:4 (m/v) and shaking for 2h on an orbital shaker at 120 r.p.m..

Calcium and magnesium were determined by atomic absorption spectrophotometry (Flame-AAS) and K and Na by flame emission spectrometry (FES). Exchangeable acidity was determined by titration of the ammonium acetate extract of the soil with a 0.1M sodium hydroxide solution up to pH 7.0. Fe, Mn, Zn and Cu were extracted by a solution of ammonium acetate 0.5M, acetic acid 0.5M and EDTA 0.02M and determined by Flame-AAS; B was extracted by distilled water in a soil-to-solution ratio of 1:2 and determined by ICP-OES.

Table 1 - Soil chemical characteristics of the experimental orchard before establishment of the trial

Soil parameters (<2mm fraction) depth 0-30 cm		
Sand	%	76.1
Silt	%	14.0
Clay	%	9.9
pH(H_2O)		6.18
Organic matter	%	4.98
Extractable P (P_2O_5)	mg kg^{-1}	817
Extractable K (K_2O)	mg kg^{-1}	200
Exchangeable Ca	cmol (+) kg^{-1}	3.98
Exchangeable Mg	cmol (+) kg^{-1}	0.62
Exchangeable K	cmol (+) kg^{-1}	0.44
Exchangeable Na	cmol (+) kg^{-1}	0.19
Exchangeable acidity	cmol (+) kg^{-1}	3.22
Cat exchange capacity	cmol (+) kg^{-1}	8.45
Base saturation	%	61.89
Extractable Fe	mg kg^{-1}	103
Extractable Mn	mg kg^{-1}	8.5
Extractable Zn	mg kg^{-1}	12.7
Extractable Cu	mg kg^{-1}	4.0
Extractable B	mg kg^{-1}	0.87

In 2004, a factorial fertilizer trial, with three replications, arranged into completely randomized blocks, was installed. Three levels of nitrogen fertilizer (N_1=30, N_2=60 and N_3=90 kg ha^{-1} N), and four levels of potassium (K_0=0, K_1=45, K_2=90 and K_3=135 kg ha^{-1} K_2O) were applied.

The experiment was arranged into 12 experimental treatments, as follows: N_1K_0, N_1K_1, N_1K_2, N_1K_3, N_2K_0, N_2K_1 N_2K_2, N_2K_3, N_3K_0, N_3K_1, N_3K_2, N_3K_3. Nitrogen was supplied as controlled release (Entec 26-0-0) with nitrification inhibitor, and potassium as potassium sulphate.

Each year, two applications of nitrogen and potassium were performed: nitrogen in May/June and one month later, and potassium at the end of March and three months later. In addition, soil magnesium and manganese were corrected by supply of 32 kg ha-1 magnesium sulphate and 25 kg ha-1 manganese sulphate.

Vines were trained to a standard T-bar structure and received standard prunning. Irrigation was performed with microsprinklers. Were applied 4800 m3 of water along four months.

The experimental treatments were assigned to plots with 12 plants and all the observations were performed on the 4 plants of the central row of each plot. In each experimental plot, total yield and its distribution according to fruit size (<65g, [65 -

75g], [75-85g], [85-105g], ≥105g), as well as deformed fruits, were evaluated.

After harvest, fruits were stored in normal atmosphere at 0ºC and 90-95% hygrometry conditions. After 50 days of storage one sample consisting of 10 fruits from [85-105g] size were taken from each experimental plot and flesh firmness, titratable acidity and soluble solids content were measured.

Other sample consisting of 16 fruits from each experimental treatment including all marketable fruit size [65-75g], [75-85g], [85-105g] and ≥105g) was taken and its mineral composition (N, P, K, Ca, Mg, S, Na, Fe, Mn, Zn, Cu and B) was evaluated.

Total N and S were determined by catalytic pyrolisis under 1350 ºC in an apparatus Leco NS 2000. The other elements were determined by inductively coupled plasma optical emission spectrometry (ICP-OES) radial and simultaneous, after dry ashes (500 ± 10ºC) were treated with HCl 3M. Results are referred to fresh weight.

The statistical analysis was performed using ANOVA II and Duncan multiple range test (p=0.05) was used in order to establish the differences among means.

The present results were obtained throughout three years (2004 to 2006).

III. Results and discussion

A. *Kiwifruit yield*

The distribution of total yield according to fruit size (Fig.1) showed that the majority of the fruits (82.6%) were within the marketable production range, from 65 to 200 g weight.

Concerning fruit yield, a significant mean effect of the interaction NxK fertilization was observed (Table 2). During the experimental period the highest level of marketable yield (19.1 tonnes ha^{-1}) was obtained with 60 kg ha^{-1} N and 135 kg ha^{-1} K_2O and the lowest (11.0 tonnes ha^{-1}) with 60 kg ha^{-1} N without potassium.

On average, the application of the 60 kg ha^{-1} N led to an increment of 30.4% of the marketable fruit-yield as compared with the application of the highest level nitrogen (90 kg ha^{-1} N) with the same potassium level. A negative influence of nitrogen supply on fruit yield was also found by Vizotto e*t al*. [9].

Despite the variation on the leaf concentration of some nutrients with fertilization (data not shown), the mineral concentrations of the last fruit attached leaves collected at fruit enlargement were according with those referred by Vieira et al. [7].

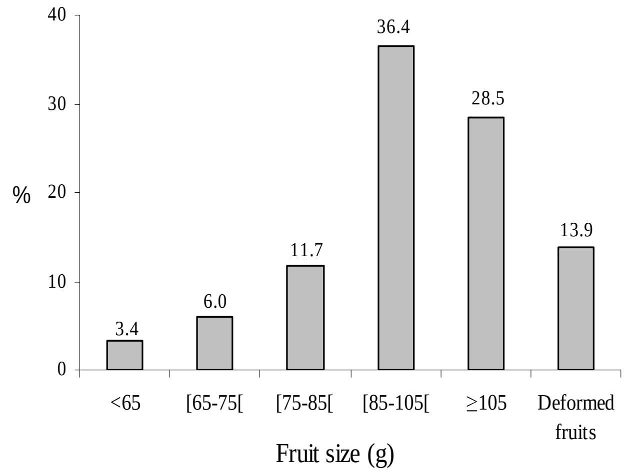

Figure 1 - Distribution of total yield according to fruit size (%).

Table 2 - Mean effect of interaction NxK fertilization on fruit yield (tonnes ha^{-1})

Yield		K_0	K_1	K_2	K_3
[85-105g] Size	N_1	6.5 bc	6.5 bc	5.3 bc	6.8 abc
	N_2	4.8 c	7.9 ab	6.7 abc	9.2 a
	N_3	7.5 ab	7.8 ab	6.2 bc	5.7 bc
≥105 g Size	N_1	5,3 abc	3.8 c	4.7 bc	3.5 c
	N_2	3,3 c	7.7 a	5.9 abc	6.4 ab
	N_3	5.6 abc	6.8 ab	5.2 abc	5.2 abc
Deformed Fruits	N_1	3.02 ab	2.4 bc	2.3 bc	2.3 bc
	N_2	1.7 c	2.3 bc	2.8ab	3.4 a
	N_3	2.2 bc	2.8 ab	2.7 abc	2.9 ab
Marketable Yield	N_1	14.7 abcd	14.4 bcd	13.5 cd	13.9 cd
	N_2	11.0 d	18.9 ab	15.4 abcd	19.1 a
	N_3	16.7 abc	17.7 abc	15.2 abcd	13.3 cd
Total	N_1	18.2 abc	17.5 bc	16.8 bc	16.6 bc
	N_2	13.4 c	21.9 ab	18.7 abc	23.0 a
	N_3	19.7 ab	21.1 ab	18.7 abc	16.7 bc

Marketable yield - consists of fruits with size ranging from 65 to 200 g; For each fruits size mean values folowed by the same letter, within the column, do not differ significantly (p=0.05); (N_1=30; N_2=60; N_3=90 kg ha^{-1}, N; K_0=0; K_1=45; K_2=90 and K_3=135 kg ha^{-1}, K_2O).

The annual mean values of fruit yield, graded into six categories according to the weight throughout the experimental period, showed that the higher marketable yield was obtained on the second experimental year (Table 3). In fact the climate conditions observed in 2005 were particularly favorable for this culture: the chilling requirements were well satisfied until February and temperature and humidity were adequate during the flowering period.

Table 3 - Annual mean values of yield (tonnes ha^{-1}) of kiwifruit according to size

Fruit size	2004	2005	2006
<65g	1.2 a	0.4 b	0.3 b
[65-75g]	1.7 a	1.0 b	0.6 c
[75-85g]	2.8 a	2.3 a	1.3 b
[85-105g]	6.5 ab	7.5 a	6.2 b
≥105g	3.2 b	6.2 a	6.4 a
Deformed fruits	2.1 b	3.4a	2.2 b
Marketable yield	14.3 b	17.1 a	14.5 b
Total	17.6 b	20.9 a	17.0 b

Mean values followed by the same letter, within the rows, do not differ significantly (p=0.05; Marketable yield consists of fruits with size ranging from 65 to 200 g.

B. *Quality parameters of the fruits*

No significant mean effects of nitrogen and potassium fertilization (p>0.05) were found regarding some fruit parameters, namely the acidity (F[11;69] = 1.30) and soluble solids content ($F_{[11;69]}$ = 0.66). The mean values of these parameters are shown in table 4.

The mean value of soluble solids content of the pulp was higher than the lowest limits proposed for this culture at harvest (6.5 - 8 % ºBrix).

This may be related with the reduction of fruit acidity levels during the short period of storage before analysis (50 days), since 'Hayward' kiwifruit increases ripening mostly in the first 2 months of storage [8].

Table 4 - Mean values of titratable acidity and soluble contents fruits [85 -105 g] size

	Titratable acidity ($g\ L^{-1}$) citric acid	Soluble solids content (% ºBrix)
Mean	13.83	13.11
sm (±)	0.219	0.271

sm (±) - standard error

The nitrogen and potassium supply influenced significantly ($p \leq 0.01$) the flesh firmness of the fruits [85-105g] size ($F_{[2;69]}$=4.97 and $F_{[3;69]}$= 4.67 respectively). The lowest value for this parameter was obtained with the highest levels of both N and K supply (Fig. 2). Similar results were obtained by Johnson *et al.* [10]. However, Vizotto *at al*. [9] did not find any effect of the nitrogen on the flesh firmness with the application of 150 kg ha^{-1} N, at harvest and 90 days after storage.

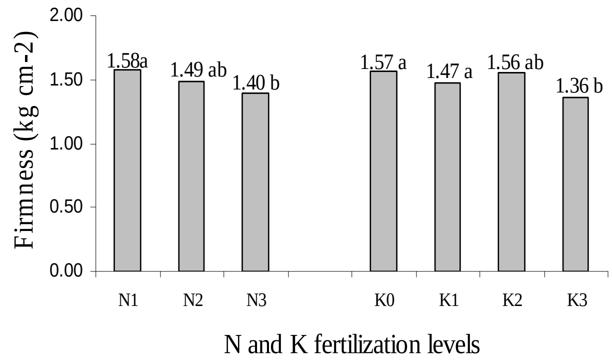

Figure 2 - Mean effect of N and K fertilization on flesh firmness (fruits [85-105g] size); (N_1=30; N_2=60; N_3=90 kg ha^{-1} N and K_0= 0, K_1=45; K_2=90; K_3=135 kg ha^{-1} K_2O).

All variables studied were influenced by management practices and climate conditions ($p \leq 0.001$) throughout the experimental period (Table 5), justifying the significant effect of the year ($F_{[2;69]}$=225.72).

Table 5 - Annual mean values of fruit quality parameters during the experimental period

Year	Titratable acidity ($g\ L^{-1}$ citric acid)	Soluble solids content (%)	Firmness kg cm^{-2}
2004	13.83 b	13.73 a	2.16 a
2005	14.27 a	12.91 b	1.21 b
2006	13.40 c	12.67 b	1.10 b
Mean	13.83	13.11	1.49
sm (±)	0.110	0.135	0.039

sm (±) - standard error

C. *Fruit mineral composition*

Nitrogen fertilization significantly increased fruit nitrogen concentration ($F_{[2;394]}$=31.17; $p \leq 0.001$). The highest value was obtained with the highest level of nitrogen fertilization (Fig.3). Also, the supply of nitrogen significantly increased the sulfur fruit concentration ($F_{[2;394]}$=5.50; $p \leq 0.01$), and decreased zinc ($F_{[2;394]}$=11.02; $p \leq 0.001$) and boron ($F_{[2;394]}$=4.38; $p \leq 0.05$) fruit concentration (Table 6).

Concerning sulfur, 90 kg ha^{-1} N fertilization led to the highest concentration of this element. The influence of nitrogen supply on the fruit sulfur concentration may be related to the amount of this element provided by the nitrogen fertilizer (13% S).

Regarding zinc and boron fruit concentrations, the supply of 90 kg ha^{-1} N led to the lowest concentration of these nutrients in fruits, suggesting a dilution effect of the applied nitrogen fertilizer (Table 6). The fruit potassium concentration was significantly increased (F[3;394]=5.86; p≤0.001) with the potassium supply (Fig.4). Conversely, the concentration of this element significantly decreased with nitrogen fertilization ($F_{[2;394]}$=4.40; p≤0.05) ≤0.001).

Table 6 - Mean effect of N fertilization on S, Zn and B mineral composition of kiwfruit (fresh weight)

N level	S mg per100 g	Zn µg per100 g	B
N_1	20.2 b	124 a	271 a
N_2	20.3 b	116 b	260 b
N_3	21.2 a	109 c	259 b
sm (±)	0.23	2.3	3.3

Mean values followed by the same letter, within the column, do not differ significantly (p=0.05); sm (±) - standard error; (N_1=30; N_2=60; N_3=90 kg ha^{-1} N).

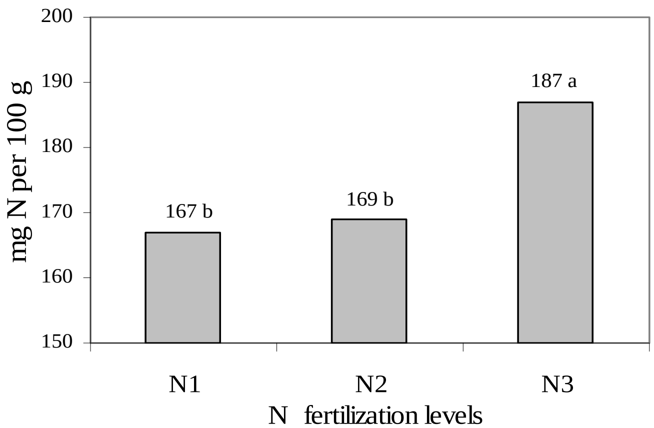

Figure 3 - Mean effect of N fertilization on N mineral composition of fruits (fresh weight). (N_1=30; N_2=60; N_3=90 kg ha^{-1} N)

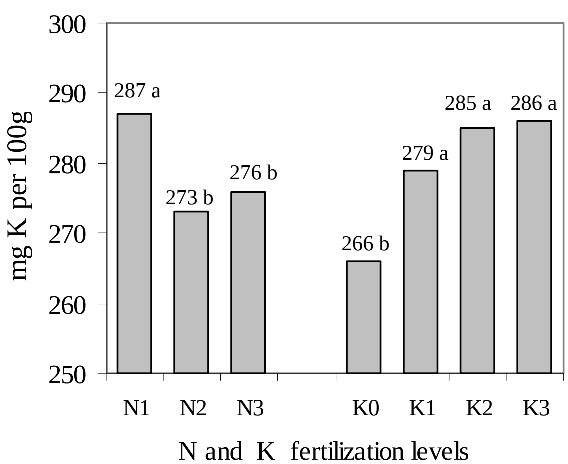

Figure 4 - Mean effect of N and K fertilization on K mineral composition of kiwifruit (fresh weight). (N_1=30; N_2=60; N_3=90 kg.ha^{-1} N and K_0= 0, K_1=45; K_2=90; K_3=135 kg ha^{-1} K_2O).

A significant mean effect ($F_{[6;394]}$=6.07; p≤0.001) of the interaction NxK fertilization was observed on the fruit calcium concentration (Table 7 and 8). The lowest content of calcium was found on the experimental treatments with the highest nitrogen fertilizer level, 90 kg ha^{-1} N, associated with 90 kg ha^{-1} K_2O or 135 kg ha^{-1} K_2O (N_3K_2 and N_3K_3).

No significant mean effects of nitrogen and potassium fertilization (p>0.05) were found regarding other fruit nutrient concentrations, namely phosphorus, magnesium, sodium, iron and copper [10].

The fruits from plants fertilized with the highest nitrogen rate showed higher N/Ca and K/Ca ratio than those fertilized with 30 kg ha^{-1} N (Fig. 5 and 6). This effect was also found by Jordão [11] and Duarte *et al.* [12] in pears orchards of cultivar 'Rocha'.

Table 7 - Mean effect of interaction NxK fertilization on fruit calcium concentration (mg per 100 g fresh weight)

N and K levels	N_1	N_2	N_3
K_0	42.4 bc	46.7 a	46.4 a
K_1	45.5 ab	42.7 bc	42.5 bc
K_2	47.3 a	41.0 cd	38.5 d
K_3	42.6 bc	42.2 bc	38.6 d

Mean values followed by the same letter do not differ significantly (p=0.05); (N_1=30; N_2=60; N_3=90 kg.ha^{-1} N and K_0= 0, K_1=45; K_2=90; K_3=135 kg ha^{-1} K_2O)

Table 8 - Mean effect of interaction NxK fertilization on calcium concentration (% dry weight), of the last fruit attached leaves at fruit enlargement

N and K levels	N_1	N_2	N_3
K_0	3.44 abc	3.44 abc	3.69 a
K_1	3.56 ab	3.64 a	3.45 abc
K_2	3.45 abc	3.33 bc	3.47 abc
K_3	3.07 d	3.26 cd	3.34 bc

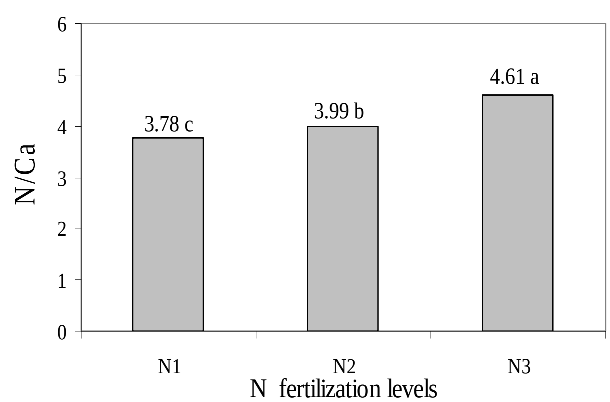

Figure 5 - Mean effect of N and K fertilization on N/Ca mineral composition of kiwifruit - fresh weight. (N_1=30; N_2=60; N_3=90 kg ha^{-1} N).

The application of 90 kg ha^{-1} K_2O also caused a significant (p=0.05) increase of fruit K/Ca (Fig. 6), although without significant differences from the highest potassium application level (135 kg ha-1 K2O).

Differences in calcium concentrations in stored fruit may have commercial implication on quality due to the influence of this element on fruit ripening, cell wall breakdown and softening in fruits.

Calcium alters intracellular and extracellular processes thereby retarding ripening as shown by lower rates of colour change, softening, CO2 and ethylene production, increase in sugar, and a reduction in total acid content [13].

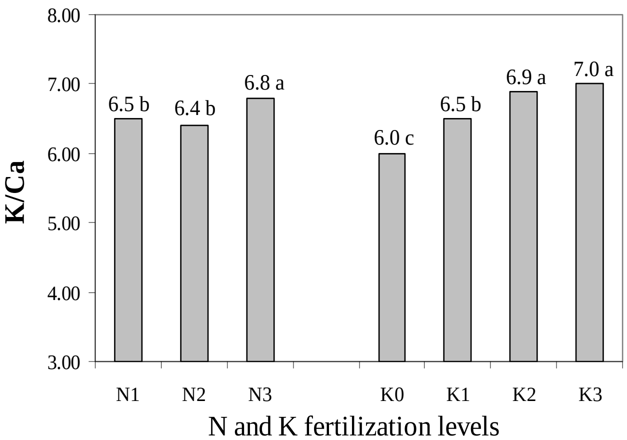

Figure 6 - Mean effect of N and K fertilization on K/Ca mineral composition of kiwifruit - fresh weight. (N_1=30; N_2=60; N_3=90 kg.ha^{-1} N and K_0= 0, K_1=45; K_2=90; K_3=135 kg ha^{-1} K_2O).

The benefits of calcium in kiwifruit storage life capacity were already reported, mainly by keeping flesh firmness through storage time [14], [15] and [16]. This suggests that N/Ca and K/Ca ratios should be studied aiming at finding the most balanced ones.

Accordingly, in the present study the lowest flesh firmness was obtained with the higher level of nitrogen fertilization suggesting one unbalanced N/Ca.

Nitrogen and potassium fertilization showed a significant effect (p=0.05) on the leaf mineral composition at fruit enlargement, although the concentration of all nutrients were within the recommended range values established for kiwifruit 'Hayward' [6].

The mean mineral composition of kiwifruit according to fruit size is presented on Tables 9 and 10 and showed a significant effect (p=0.05) on the fruit mineral composition. These results are consistent with those observed in fifteen kiwifruit orchards selected in 2002 and 2003 in the same region of the reported study (data not shown) and confirm previous studies from other authors [17].

Table 9 - Mean mineral composition of kiwifruit according fruit size: macronutrients (mg per 100 g of fresh weight)

	Fruit size (g)			
	[65 -75]	[75 -85]	[85 -105]	≥105
N	167±9.2	172±8.0	174±7.2	180±10.8
P	28.2±1.28	29.5±1.48	29.8±1.60	30.6±1.56
K	272±11.5	279±14.1	279±13.7	285±15.2
Ca	41.9±2.66	42.9±2.29	43.1±2.47	44.3±2.47
Mg	13.6±0.72	14.0±0.66	14.3±0.72	14.7±0.85
S	20.0±0.94	20.5±0.75	20.6±0.72	21.2±1.22
Na	3.1±0.31	3.2±0.29	3.0±0.24	3.1±0.31

n=108; all means are followed by standard error

Table 10 - Mean mineral composition of kiwifruit according fruit size: micronutrients (μg per 100 g of fresh weight)

	Fruit size (g)			
	[65 -75]	[75 -85]	[85 -105]	≥105
Fe	388 ± 27.1	379 ± 18.3	374 ± 31.7	370 ± 23.3
Mn	62 ± 4.8	64 ± 3.6	64 ± 4.1	67 ± 4.8
Zn	109 ± 10.3	113 ± 8.6	122 ± 9.1	122 ± 9.3
Cu	108 ± 17.6	123 ± 25.9	125 ± 28.5	129 ± 64.8
B	255 ± 12.4	262 ± 13.6	265 ± 14.5	270 ± 14.6

n=108; all means are followed by standard error

IV. CONCLUSION

The experimental results obtained showed that fruit yield was affected by the level of nitrogen and potassium fertilization. The highest marketable yield was obtained with 60 kg ha^{-1} N and 135 kg ha^{-1} K_2O. Higher level of nitrogen, 90 kg ha^{-1} N, with the some amount of potassium caused a fruit yield decrease of 30.4%.

The acidity and soluble solids content were not affected by nitrogen and potassium supply. However, the flesh firmness decreased with the application of these nutrients.

The interaction NxK fertilization influenced fruit calcium concentration. The lowest level of calcium was observed with 90 kg ha^{-1} N associated with 90 kg ha^{-1} or 135 kg ha^{-1} K_2O. Both N/Ca and K/Ca ratios increased with nitrogen and potassium supply.

The commercial implication of calcium on fruit quality during storage suggests the need for further studies aiming at finding the most adequate N/Ca and K/Ca ratios.

The results of this experimental trial allowed the characterization of kiwifruit mineral composition which associated with leaf analysis may support the orchard rational fertilization.

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