Evaluation of the usefulness of early leaf analysis to improve nutrition management of citrus

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Abstract

The response of *Citrus sinensis* 'Midknight' (Nelspruit, Mpumalanga, South Africa) and *Citrus paradisi* 'Orri' (De Wet, Western Cape, South Africa) to excessive fertilisation (double the normal rate) with nitrogen (N), phosphorus (P), potassium (K) and magnesium (Mg) was investigated. The goal was to determine whether early-season leaf mineral compositions respond to fertilisation rates so that in-season adjustments of the fertilisation programme can be made. A specific focus was the changes in the nutritional status of the trees as expressed by leaf analysis. Except for N, a lack of responsiveness of the trees to excessive rates of mineral nutrition was observed. Consequently, it was concluded that using foliar analysis to make in-season changes to fertilisation rates of orchards that are amply fertilised cannot be justified.

Keywords: leaf analysis, citrus, nutrition, nitrogen, potassium, phosphorus

INTRODUCTION

Citrus fruit quality is a large determining factor in the export value of a carton and determines the markets to which the producers will have access. Fruit quality is affected by various factors: genetic characteristics, climate, weather, light intensity, water supply, plant growth regulators, fruit canopy position, rootstock-scion combinations and tree nutrient balance (Castle, 1995). Nutrition management affects fruit quality in several ways, since one mineral nutrient can have different effects depending on whether it is deficient, in the sufficient range or at excessive levels (Obreza et al., 2020; Taiz et al., 2018; Wutscher and Smith, 1993).

Leaf analysis is widely used within the citrus industry to establish tree nutritional status, with well-established norms to interpret the analysis (Menino, 2012). The normal protocol in the South African industry is to sample leaves from behind fruit bearing terminals during autumn. This is too late for in-season fertilisation adjustments.

Over-fertilisation is common, and there are mounting pressures on producers to reduce fertiliser inputs due to the negative effects that over-fertilisation can have on the environment (Snyder et al., 2009). The cost of fertiliser is another factor that affects the viability of production (Omarjee, 2021).

Accepting that excessive fertilisation will impact fruit quality, this study investigated the extent to which excessive fertilisation is expressed by early season leaf analysis, and whether early season leaf analysis can be used to make in-season adjustments to the fertilisation rates.

MATERIALS AND METHODS

Experimental orchards

The trial was conducted in two commercial orchards. The first was a micro-irrigated, non-ridged six-year-old *Citrus sinensis* 'Midknight'/Swingle citrimelo block, located in Nelspruit, Mpumalanga, South Africa (25°28'24.7"S, 31°04'04.1"E), planted at 4×6.5 m on a deep sandy loam soil (Leptosol). The area has a sub-tropical climate with an average annual rainfall of 667 mm (Masereka et al., 2018). The nutrient treatments were applied by hand, using granular fertiliser (Table 1).

Table 1. Exposition of the various treatments that were applied to both experimental sites during the 2019/20 and 2020/21 seasons.

Main treatment	Symbol used for treatment	Description	Product used as nutrient source	
			Midknight	Orri
Control	C	Fertilisation applied as per standard procedure on the farm	-	-
Nitrogen	N	Application of 200% N of the recommended standard N fertilisation	LAN(28)[a]	
Phosphorus	P	Application of 200% P of the recommended standard P fertilisation	Single super phosphate[b]	MAXIPHOS[c]
Potassium	K	Application of 200% K of the recommended standard K fertilisation	KCl	5:1:15(40)
Magnesium	Mg	Application of 200% Mg of the recommended standard Mg fertilisation	$MgSO_4$	

[a]LAN(28): limestone ammonium nitrate with 28% nitrogen.
[b]Single super phosphate contains 10.5% phosphorus.
[c]MAXIPHOS: superphosphate fertiliser with 20% phosphorus.

The second site was a 2 year old ‘Orri’ mandarin/C35 citrange orchard in De Wet, Western Cape province, South Africa (33°35’55.3”S, 19°30’43.9”E). The trees were established a 40 cm high ridge prepared from the deep sandy soil (Fluvisol). Tree spacing was 5×2.5 m (800 trees ha^{-1}). The area has a temperate climate with an average annual rainfall of 400 mm (Directorate of Water Resources Planning, 2003). The hand aplied treatments were in addition to the orchard’s fertiliser program, which was applied constantly in a fertigation system where irrigation water electrical conductivity (EC) was adjusted according to the soil EC. Annual total irrigation amounted to 4000 L water tree^{-1}.

Trial layout and treatments

The trial was carried out over two seasons (2019/20 and 2020/21) in a randomised block design with five treatments replicated four times. Treatments at both sites entailed an oversupply of nitrogen (N), phosphorus (P), potassium (K), and magnesium (Mg) (Table 1), applied monthly (Tables 2 and 3). The method of fertiliser application differed between the two sites, i.e., in the ‘Midknight’ orchard fertilisers were applied as granules placed within the wetted area of the micro-sprinklers, whereas at ‘Orri’ orchard the fertilisers were dissolved in water and applied in the wetted area under the drippers of each of the two dripper lines on the ridge on both sides of the trees. Each replicated experimental plot consisted of 11 trees of which the middle nine trees were used for data collection, and the two trees on each side as buffer trees.

Data collection

On a monthly basis during the 2019/20 and 2020/21 seasons, mature leaves were sampled from fully hardened, non-fruiting and purely vegetative shoots, firstly in spring from vegetative shoots that developed during the previous season’s vegetative shoot flushes, then through summer (samples collected from vegetative shoots that developed during the current season’s spring vegetative shoot flush), and in autumn (samples collected from vegetative shoots that developed during the summer vegetative shoot flush). On at least four shoots tree^{-1}, at 1.5 m above the ground, 20 leaves were selected from the latest applicable flush at the third to fifth position. An additional sample from fruit bearing shoots was collected in autumn.

After sampling, the leaves were analysed by a commercial laboratory (www.labserve.co.za). The fresh leaves were washed with a Teepol solution, rinsed with de-ionised water and dried overnight at 70°C in an oven. The dried leaves were then milled and ashed at 480°C, shaken up in a 50:50 HCl (32%) solution for extraction through filter paper (Campbell and Plank, 1998; Miller, 1998). The extract’s P, K, Ca and Mg concentration was measured with a Varian ICP-OES optical emission spectrometer. Total N content of the ground leaves was determined through total combustion in a Leco N-analyser.

Table 2. Fertilisation programme followed throughout both seasons (standard farm practice) on the 'Midknight' orchard – the indicated amounts were doubled as the respective treatments (i.e., N, P, K and Mg).

Nutrient applied	Month					Total annual application
	July	August	September	October	November	
First season (2019-2020)						
N (kg ha^{-1})	60	3	27	9	2	100
P (kg ha^{-1})	24	0	5	2	0	31
K (kg ha^{-1})	0	0	82	27	5	114
Mg (kg ha^{-1})	0	0 (36)	0	0	0	0 (36)[a]
Second season (2020-2021)						
N (kg ha^{-1})	50	36	27	9	0	122
P (kg ha^{-1})	0	24	5	2	0	31
K (kg ha^{-1})	0	0	82	27	0	109
Mg (kg ha^{-1})	0	0 (36)	0	0	0	0 (36)[a]

[a]The total annual Mg applied as treatment was based on the estimated annual crop removal, e.g., 80 t ha^{-1} × 0.45 kg t^{-1}.

Statistical analysis

Analysis of variance (ANOVA) was performed using SAS data analysis software (Version 9.4; SAS Institute Inc., Cary, USA). The mean separations were done by means of Fisher's least significant difference (Fisher's LSD) test. A significance level of 95% was used ($p \leq 0.05$).

RESULTS AND DISCUSSION

Seasonal changes in foliar nutrient concentration

1. 'Midknight' orchard.

A response in the leaf N concentration of the trees that were fertilised at a 200% rate of the standard practices could be observed from 30 days after full bloom in the first season (Figure 1). This indicates the ability of citrus trees to respond quickly to additional N fertilisation – Scholberg et al. (2002) even found that a residence time of 8 h of increased N is sufficient to obtain a response. However, the same rapid response to the excessive fertilisation did not occur for P, K or Mg (Figure 1). The trees were especially non-responsive to the additionally applied P, with no shift in the leaf P concentrations even in the second season of the additionally applied P treatment. This corresponds to Coetzee (2007) who maintains that well supplied citrus trees do not respond to additionally applied P (Figure 1). A delayed response to the excessive K applications was observed and only became significant towards the end of the second season, i.e., 2020/2021 (Figure 1).

Table 3. The applied amounts of each nutrient to the 'Orri' orchard during the two seasons of 2019/2020 and 2020/2021.

Supply	Nutrient	Month												Total
		Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	(kg ha^{-1})
Standard farm applications, i.e., Control treatment[a]	N	11.5	17.3	34.6	51.9	69.2	75	75	75	69.2	34.6	34.6	28.9	577
	P	0.2	0.3	0.6	0.9	1.2	1.3	1.3	1.3	1.2	0.6	0.6	0.5	10
	K	4.3	6.5	12.9	19.4	25.8	28	28	28	25.8	12.9	12.9	10.8	215
	Mg	1.8	2.7	5.4	8.1	10.8	11.7	11.7	11.7	10.8	5.4	5.4	4.5	90
Additional applications applied to the other treatments[b]	N	23.1	34.6	69.2	103.9	138.5	150	150	150	138.5	69.2	69.2	57.7	1154
	P	0.3	0.45	0.9	1.35	1.8	1.95	1.95	1.95	1.8	0.9	0.9	0.75	15
	K	8.6	12.9	25.8	38.7	51.6	55.9	55.9	55.9	51.6	25.8	25.8	21.5	430
	Mg	3.6	5.4	10.8	16.2	21.6	23.4	23.4	23.4	21.6	10.8	10.8	9	180

[a]The control treatment received the standard programme followed.

[b]N, P, K and Mg represent the additional amounts applied for each of the treatments.

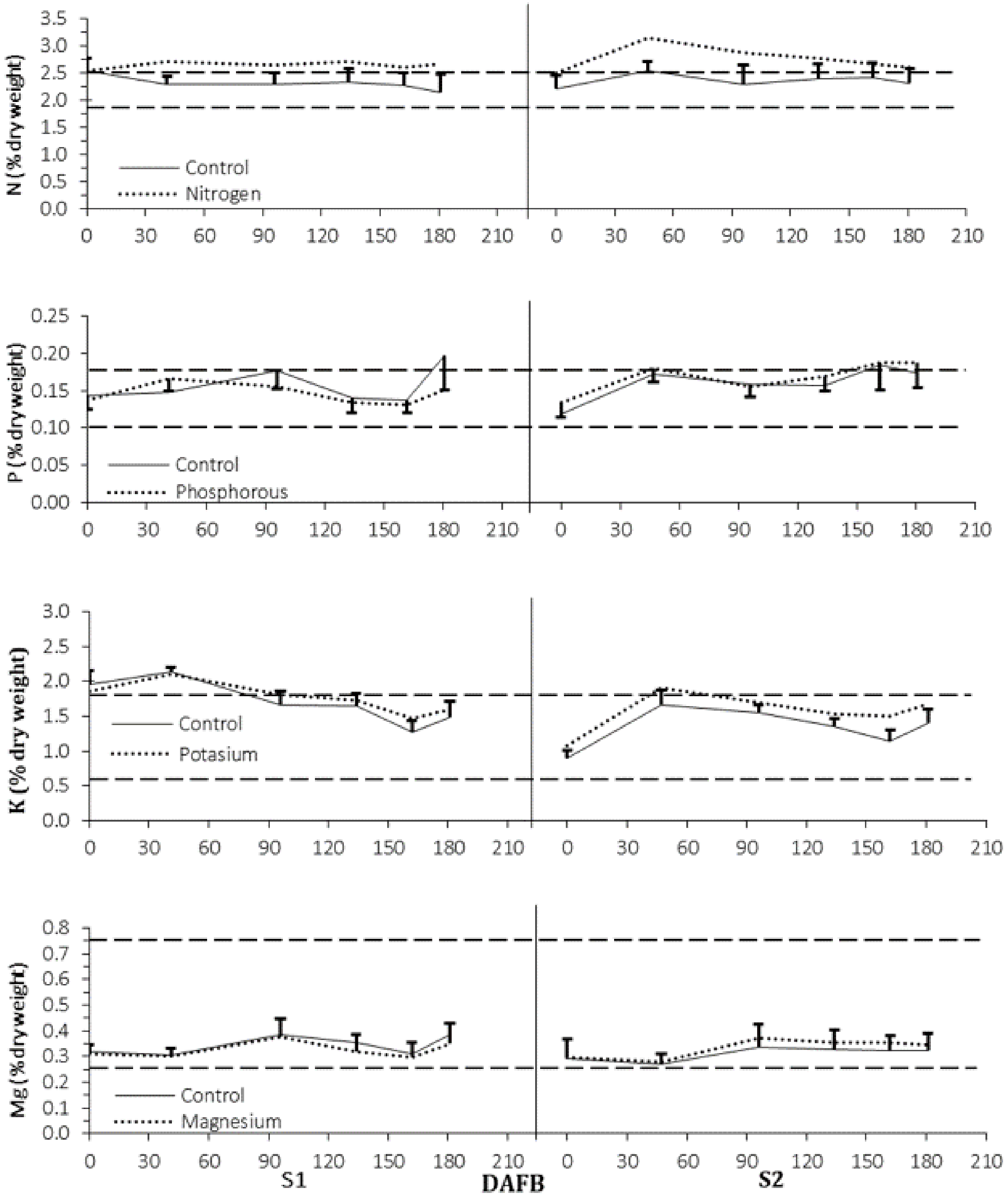

Figure 1. Seasonal leaf nutrient concentration of the 'Midknight' orchard in response to application rates of 200% of the commercially applied rates. The LSD is indicated by vertical bars (p≤0.05) – the analysis results of only the controls and each specific nutrient is indicated in each graph. The broken lines indicate respectively the excessive and deficient levels for 4 to 6 month old leaves from non-fruit bearing terminals (Obreza et al., 2020; Raath, 2021).

2. 'Orri' orchard.

No response in the leaf nutrient concentration of the trees that were fertilised at a 200% rate compared to the standard practices were obtained in the first season (Figure 2). During the second season the additional fertilisation resulted in a higher leaf K concentration – which became significant merely from the middle of the 2020/21 season – but not for any of the other nutrients. The K treatment maintained the leaf K concentration, while the K concentration of the control decreased towards the latter part of the second season. This is ascribed to antagonism for uptake created by the excessive N fertilisation (Mengel and Kirkby, 1987; Raath, 2021), even in the control treatment – the K treatment negated this. Despite excessive fertilisation (Table 3), the foliar nutrient concentration did not exceed levels regarded as excessive for any of the nutrients (Figure 2). Similarly to the 'Midnight' orchard, these trees were non-responsive to the additionally applied P and Mg.

The above results from both orchards showed that N and K are the only nutrients to which the trees responded to in its uptake of additional fertilisation. Given the young age of the 'Orri' trees, the excessive N of the Control treatment was utilised by vigorous vegetative growth (data not shown). There was a lack of vigour between the five treatments (data not shown), which could indicate that the N application rates of the control was close to, or exceeded, the limit at which the tree could utilise soil applied N. Furthermore, additional fertilisation in a scenario of luxurious to excessive fertilisation did not result in a quick response regarding leaf nutrient K concentration, and not at all for P and Mg.

Nutrient concentration of leaves sampled from fruit-bearing and non-fruit bearing shoots

It was only for N in the 'Midknight' orchard that the effect of the excessive fertilisation on the mineral composition of leaves from both fruit bearing and non-fruit bearing terminals, sampled in autumn showed a significant increase in response to the fertilisation treatments (data not shown).

To elucidate the difference in mineral nutrient concentration of leaves (sampled during the normal autumn sampling time (±180 days after full bloom)) from non-fruit bearing terminals to those on fruit bearing terminals, the averages over all the treatments were compared (Figure 3) for both trial sites. With the exception of S for the 'Midknight' and Mg for the 'Orri' orcahards, respectively in 2019/20, the differences between leaves from the different positions are consistent for both cultivars, i.e., the concentration of leaves from non-fruit bearing terminals were higher than that of fruit bearing terminals. The Ca concentration of leaves from fruit bearing terminals is, however, higher than that of non-fruit bearing terminals.

The higher concentration of N, P, K in the leaves from non-fruit bearing terminals was also found by Carranca et al. (1993) for 'Valencia late', and is ascribed to the mobility of these nutrients, i.e., the crop is a strong sink for these nutrients (Mirsoleimani et al., 2014). On the other hand, the higher Ca concentration in the fruit-bearing terminals is ascribed to the immobility of Ca (Raath, 2021) and a longer period of progressive accumulation of Ca that has taken place in the fruit-bearing terminals.

Due to the consistent trend, it was concluded that the interpretation of analysis results of leaves from both fruit bearing and non-fruit bearing terminals can be used to assess tree nutritional status. The necessary adjustments, i.e., +5.0 to +6.8% for N, +31 to +39% for P, +18 to +30% for K, -18 to -12% for Ca and +7 to +9% for Mg, should be used to convert analysis results from non-fruit bearing terminals to be compared to the reference norms for leaves from fruit bearing terminals (as provided in Coetzee, 2007).

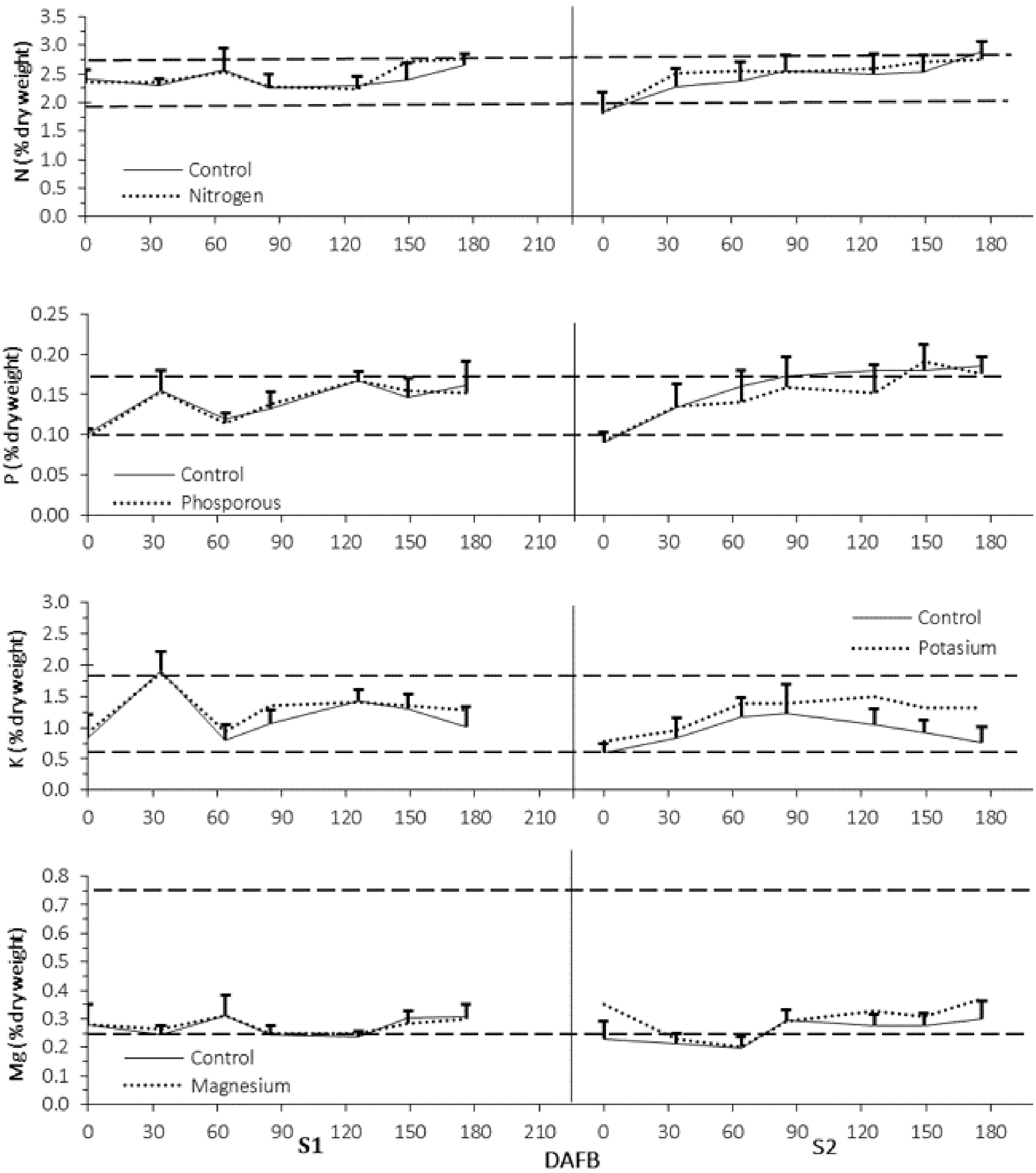

Figure 2. Seasonal leaf nutrient concentration of the 'Orri' orchard in response to application rates of 200% of the commercially applied rates. The LSD is indicated by vertical bars (p≤0.05) – the analysis results of only the controls and each specific nutrient is indicated in each graph. The broken lines indicate respectively the excessive and deficient levels for 4 to 6-month-old leaves from non-fruit bearing terminals (Obreza et al., 2020; Raath, 2021).

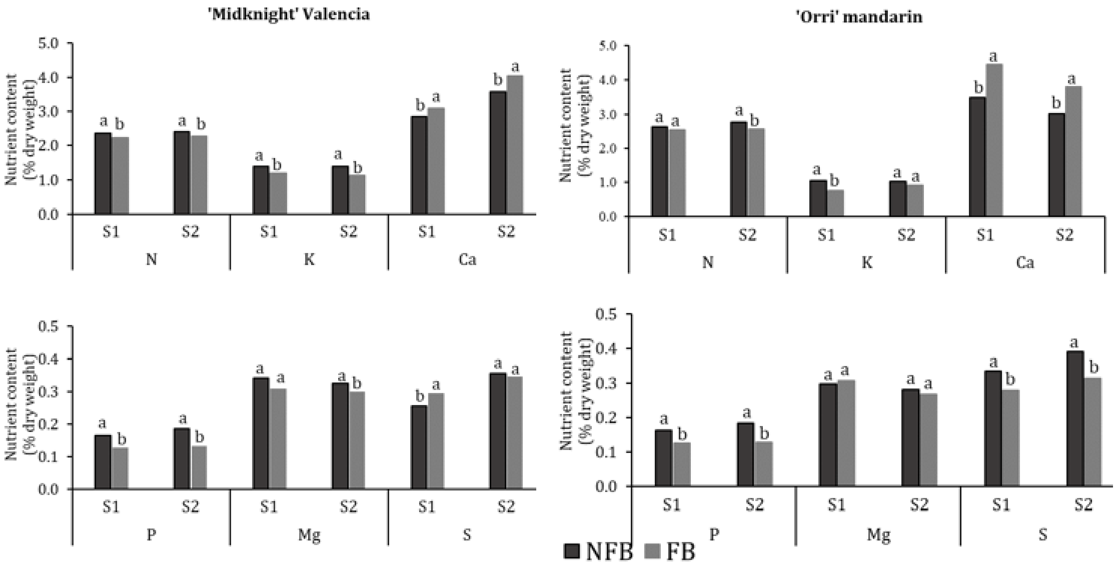

Figure 3. Nutrient concentration (% dry weight) of leaves from non-fruit bearing (NFB) and fruit bearing (FB) shoots, sampled in autumn, as determined over two seasons (S1 = 2019/2020; S2 = 2020/2021) for 'Midknight' and 'Orri' orchards. Adjacent bars with the same letters do not differ significantly at $p \leq 0.05$.

CONCLUSIONS

Nitrogen and K are the only nutrients to which the trees respond to fertilisation, but the response is expected to be slow in the case of K. No response however is obtained when an excessively high rate of N and K is already applied. Additional fertilisation does not affect leaf nutrient P and Mg when the trees are sufficiently supplied with these nutrients.

The consistent differences obtained for both cultivars in nutrient concentration between leaves sampled from non-fruit bearing terminals and fruit bearing terminals allows the interpretation of analysis results of leaves from either fruit bearing or non-fruit bearing terminals to assess tree nutritional status.

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