Book Chapter

Creating Foliar Diagnosis Rules for Almond Trees (*Prunus dulcis*, Mill.) Grown Under Different Watering Regimes: Irrigation vs Rainfed

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Abstract

Agriculture in the 21st Century must be performed considering sustainability criteria to mitigate the effects of climate change. For this, adequate fertilization is necessary for avoiding the excess application of fertilizers, which could contaminate the environment. For the efficient management of fertilization, it is necessary to know the optimum levels of each nutrient for each specie and type of environment. The most common method is to interpret foliar analyses results with traditional tools such as the Range of Normality (RN) or through more precise and complex techniques, such as the Diagnosis and Recommendation Integrated System (DRIS), or the Compositional Nutrient Diagnosis (CND). However, for almonds, little information is available on the nutritional requirements of the different varieties, and those cultivated in rainfed vs irrigated lands are not differentiated. In the present work, 384 samples from each of four almond varieties (*Prunus dulcis*, Mill.) Desmayo, Ramillete, Marcona and Tuono, grown in rainfed or irrigated lands (a total of 1,536 samples) were analyzed, corresponding to sampling every two weeks between the months of June and September, both months included, for a period of two consecutive years. The main objective of the work was to establish RN, DRIS and CND standards for the interpretation of the nutritional analysis of these four almond varieties grown under different watering regimes. With the data from mineral analysis, through the application of different mathematical and statistical models, the RN, DRIS, and CND standards were obtained, with the conclusion that the optimal period for sampling this crop was in the month of July. These standards could be useful for developing algorithms that could be utilized to develop decision support systems (DSS) that interpret the foliar analyses more precisely as compared to the simple RN, and which manage, based on this information, the fertilization of the crops.

Keywords

Woody Fruit Trees; Fertilization; Desmayo; Ramillete; Marcona; Tuono

Introduction

Almonds are one of the most important rainfed nut crops in Mediterranean climate areas. This fruit tree does not require great quantities of water, and is well-adapted to adverse conditions of soil and climate, and therefore occupies areas which are not normally apt for other fruit species. The current world production of shell fruits is 3.5 Tg, with the most important countries being the USA (more than 50%), Spain (9%), and Iran (5%) [1]. In Spain, specifically, the productive varieties, which flower from March, are the most cultivated [2] to avoid the late frost. Presently, to improve the economic performance of the exploitations, the technical advances in this crop consist on the development of more productive varieties, the implementation of irrigation and fertilization systems, the improvement in mechanical harvesting, and the increase in the orchard density. Among these, the installation of irrigation and fertilization systems is, in the short term, the easiest to implement, and the one which is obtaining the best results.

A generalized method utilized to design the fertilization regime of crops consists on conducting a diagnostic analysis of the nutritional state of the plant, through foliar mineral analysis, and the application of different rules or standards for its interpretation, such as the Range of Normality (RN), the Diagnosis and Recommendation Integrated System (DRIS), the Modified Diagnosis and Recommendation Integrated System (M-DRIS), or the Compositional Nutrient Diagnosis (CND) method. Traditionally, the most-utilized interpretation method has been the Range of Normality (RN), although the other methods are more precise, as they take into account the equilibrium between nutrients, with the inconvenience that they are more complex due to the series of standards that are dependent on many factors, among which we find the type of soil, environmental conditions, or type of irrigation [3]. This methodology of interpretation has been applied to fruit crops such as banana, orange, pear, guava, or almonds [4-7].

The current technological development has resulted in great advances in the agricultural sector, thanks to the development of data acquisition systems, Big Data, the application of artificial intelligence techniques, etc. [8]. Therefore, these technologies facilitate the interpretation of foliar analysis following the DRIS and CND standards. These standards are more complex than the Range of Normality, but are more precise as well, taking into account the equilibrium between nutrients. In the future, growers will introduce the mineral analysis of leaves from their fields into Decision Support Systems (DSS), to interpret the data with the help of a series of algorithms which utilize these types of standards. Therefore, the development of these standards is needed. Among the factors which determine the numerical value of these types of standards, the variety cultivated is one of the most important. Thus, for almonds, Ferrandez-Camara et al., [7] developed the DRIS, CND, and RN standards for the varieties Ferraduel, Ferragnes, and Garrigues in Spain, observing that these standards were similar for the first two varieties, but not for the Garrigues one. **Chaleshtori et al.**, [9,10] obtained the DRIS standards for a wide collection of ornamental almond trees, observing that there were great differences between the varieties. Presently, it is observed that the DRIS standards for the same variety depend on many factors, such as environmental conditions, rootstock utilized, etc. [11,12]. The standards for each variety and climate scenario will be useful in the future for developing the algorithms with which to interpret the foliar analysis. Therefore, the main objective of the present work is to establish the RN, DRIS and CND standards for the interpretation of the nutritional analysis of four cultivated almond varieties in Spain, Desmayo, Ramillete, Marcona and Tuono, in different environmental conditions established by different watering regimes: rainfed vs irrigation. Also, one of the aspects that will try to be solved with this study is to establish the period in the year that is the most adequate for the analysis of leaves to establish/apply these types of standards. Thus, the present study intends to contribute to the improvement of the design of sample collection, and the interpretation and comprehension of the leaf analysis results to provide support to the making of decisions for the fertilization of crops in general, and these almond varieties in particular.

Materials and Methods

The plots of the four varieties, Desmayo, Ramillete, Marcona and Tuono, utilized in the present study, are located in Jumilla (Murcia, Spain), separated by a distance of less than 10 Km. The irrigated plots are located near the coordinates: Latitude 38º 21' 57.32" N, Longitude 1º 15' 29.15" W, and the rainfed plots close to the coordinates: Latitude 38º 22' 20.02" N and Longitude 1º 15' 8.21" W (Figure 1). The trees were cultivated under both rainfed and irrigation regimes, with the usual agronomic management for this area. In the rainfed plots, the average rainfall in the last 10 years was 256 mm. The irrigated plots received a mean of 650 mm of water (mean of precipitation + irrigation). In the rainfed plots, the mean annual fertilization in N-P_2O_5-K_2O units of fertilizer (UF), was 50-20-60, while for the irrigated ones, it was 140-60-160. The mean performance of the rainfed crops varied between 450-600 kg ha^{-1} of kernels, while in the irrigated one, it oscillated between 1200-1700 kg ha^{-1} of kernels. The age, plantation pattern, and location of the plots used in the study can be observed in Table 1 and Figure 1.

Table 1: Characteristics of the sampling plots according to variety and irrigation scheme.

	Rainfed		Irrigated	
Variety	Age	Plantation	Age	Plantation
Desmayo	21	6x6	18	7x6
Ramillete	21	6x6	18	7x6
Marcona	26	7x7	21	7x6
Tuono	18	6x6	24	6x6

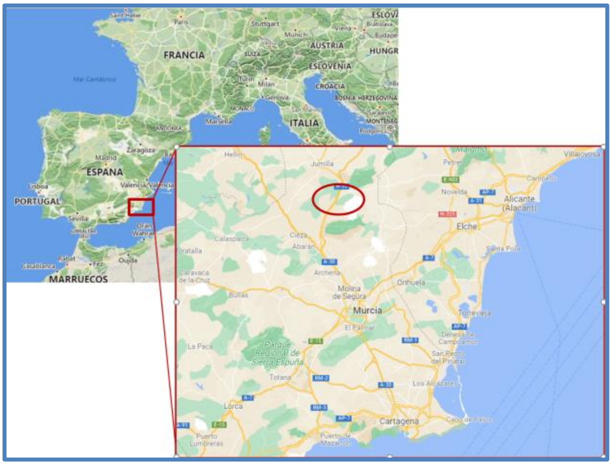

Figure 1: Location of the sampling plots.

The foliar samples were collected starting in the first half of June until the second half of September in two consecutive years, 2019 and 2020, without significant differences observed between the samples from both years. The data provided correspond to the mean of this time interval. For each year, eight sampling dates were established between June and September, with sample collection performed every two weeks. For each variety and watering regime, 192 samples were collected from 100 mature leaves. For each sample, the contents of N, P, K, Ca and Mg were analyzed. The leaves were washed with de-ionized water, dried in an oven at 60 ºC for 48 hours, weighted, and milled with a hammer mill. Afterwards, the leaves were digested with nitric:perchloric acid (2:1), at 90 ºC. The K, Ca, and Mg analysis was performed with atomic absorption spectrometry (Perkin / Elmer 5500, New York, USA). The total N was determined through the semi-micro Kjeldahl method. The total P was measured through colorimetry, by utilizing the molybdenum blue method from Murphy and Riley [13].

Determination of the Foliar Sampling Period

With the results from the foliar analysis, the best period of the year for foliar sampling of almonds was established, simultaneously considering the four varieties and the nutrients analyzed. For this, a common stability period of the concentration of all the macronutrients analyzed was selected, that is, the period in which each of the nutrients simultaneously reached a stable value in various consecutive sampling events during the period of vegetative growth activity.

Diagnosis Method: Range of Normality (RN), DRIS Standards, and CND Standards

Range of Normality

Knowing the adequate periods for foliar sampling, the range of normality (RN) interpretation tables were created by only using the foliar analysis corresponding to the most ideal period obtained. Afterwards, the ranges of normality for each nutrient were obtained. The "normal" interval was calculated as the arithmetic mean (m) ± standard deviation (s). For the interval "low" and "high", the value was added or subtracted from the normal interval, two times the standard deviation. The "very low" and "very high" interval was determined as the highest and lowest data from the previous interval.

Acquisition of the DRIS Standards

The DRIS calculation methodology was applied, as described by diverse authors [14], to obtain the DRIS reference standards for the macronutrients, for each cultivar and watering regime studied. For each nutrient, the arithmetic mean, standard deviation and the coefficient of variability were used in the sampling period in which these were stable. All the calculations for all the possible relationships between nutrient pairs were performed (A/B; B/A and A*B) for all the macro-elements: total Nitrogen (%), total Phosphorus (%), total Potassium (%), total Calcium (%), and total Magnesium (%). The selection of the type of ratio was dependent on the variation coefficient, and those with the smallest value were selected.

Acquisition of the CND Standards

The calculation of the CND standards was performed according to Aitchison [15] and Khiari *et al.* [16]. A non-dimensional parameter named "*Sd*" was calculated with the sum of all nutrients (N + P + K +…), plus a value "*Rd*", which represents all the values that were not determined analytically. The sum of all the nutrients, plus the "*Rd*" factor must equal to 100, so that "*Rd*" is calculated with the following formula:

$$Rd = 100 - (N + P + K + \cdots) \quad (1)$$

The parameter "*G*" is calculated, which is the geometric mean of all the nutrients, including the parameter *Rd*. The calculation of *G* is calculated as:

$$G = (N \cdot P \cdot K \cdot \ldots \cdot Rd)^{\frac{1}{d+1}} \quad (2)$$

Once the two parameters (*Rd* and *G*) are calculated, "*Vx*" is calculated for each nutrient starting with expression (3), where "*X*" represents the nutrient analyzed.

$$V_x = Ln\left(\frac{x}{G}\right) \quad (3)$$

$$V_{Rd} = Ln\left(\frac{R_d}{G}\right) \quad (4)$$

The sum of all the components from a plant tissue must be equal to 100%. Thus, the sum of all the *V*x* must be zero. Once the guidelines were defined, the analytical results of a sample can be interpreted with the CND indices [17]:

$$ID_i = \frac{(V_i - v_i)}{SD}$$

Where,

Vi = multi-nutrient variables in the cultivation field evaluated; *vi* = mean of the reference population; *SD* = standard deviation of the reference population.

Experimental Design and Statistical Analysis

Using the data from the foliar analysis for each nutrient, variety, watering regime, and date, the means, standard deviations, standard errors, and coefficient of variations were calculated. For the change of nutrients with time, an ANOVA and a separation of means were performed, for each of the five nutrients from the four varieties. The separation of means was conducted with Tukey's test, with significant differences defined at $p<0.05$. Twelve replicates for each variety, watering regime, year, and harvest date were utilized. The statistical analysis of the RN, DRIS, and CND standard was performed with the data from the stability period, once the parameters of the descriptive statistics (mean, standard deviation, coefficient of variation, and standard error) were determined, as well as the analysis of variance (ANOVA) and Tukey's test for the separation of means ($p<0.05$) between the varieties and watering regimes. The software utilized was SPSS v25 (SPSS statistical package, Chicago, IL, USA).

Results and Discussion

Selection of the Sampling Period

For the changes in the concentrations of N, P, K, Ca, and Mg throughout the sampling period of the four almond varieties, Desmayo, Ramillete, Marcona, and Tuono, grown in rainfed fields, the maximum and minimum values, expressed as mg/100mg dw, the leaf concentration of P, Mg, K, N, and Ca were 0.11/0.06, 1.09/0.60, 1.34/0.28, 2.08/0.95 and 6.56/3.22, respectively (Figure 2). It was observed that the nutrients P and Mg were stable throughout the months of June and September. The values of N concentration also showed a stable change, with a slight decrease in time for all the varieties. However, in the Desmayo variety, a strong decrease was observed in the first half of July, from a concentration of 2% to 1%, although this value recovered to the initial values in the following sampling event. For the concentration of K, a decreasing trend was observed in all the varieties, except for Marcona, for which the concentration was stable or slightly increasing. The concentration of Ca showed an irregular trend as compared to the other mineral nutrients. In general, for this nutrient, the lowest values were found in the second half of July, and the highest in the second half of August.

As for the irrigated plots, the maximum and minimum values for P, Mg, K, N, and Ca were 0.28/0.06, 1.04/0.51, 2.29/0.26, 2.88/1.01 and 5.54/2.64, respectively (Figure 3). The changes in the nutrients analyzed were similar to those found in the rainfed plots, underlining the great variability of Ca, with a drastic decrease observed at the halfway sampling point in all the varieties, except for Ramillete. Starting with this decrease, the concentration of Ca recovered (Figure 2).

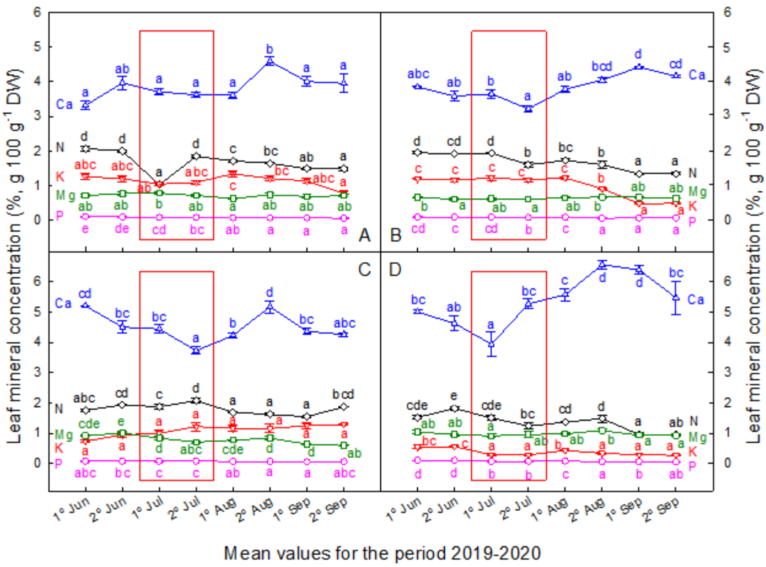

Figure 2: Evolution of the macronutrients concentration (N: black diamond; P: pink circle; K: red triangle; Ca: blue triangle; and Mg: green square) in the different leaf collecting dates for the varieties Desmayo (A), Ramillete (B), Marcona (C), and Tuono (D) in **rainfed.** Square red indicates the period of greater stability simultaneous in the five nutrients. Values are the average ± standard error (n=24). For every variety and nutrient, the different lowercase letters indicate significant differences between the sampling date for p<0.001 established by Tukey’s multiple range test.

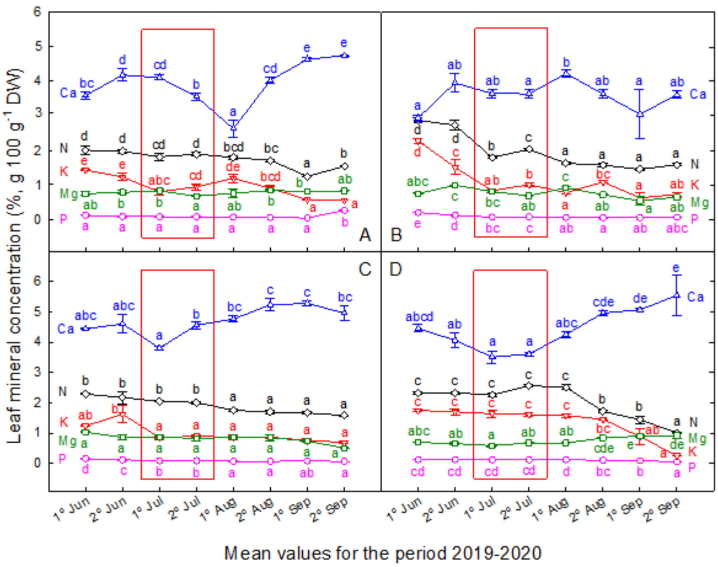

Figure 3: Evolution of the macronutrients concentration (N: black diamond; P: pink circle; K: red triangle; Ca: blue triangle; and Mg: green square) in the different leaf collecting date in the varieties Desmayo (A), Ramillete (B), Marcona (C), and Tuono in **irrigation**. Square red indicates the period of greater stability simultaneous in the five nutrients. Values are the average ± standard error (n=24). For every variety and nutrient, the different lowercase letters indicate significant differences between the sampling date for $p<0.001$ established by Tukey's multiple range test.

Using the previous data, the optimum foliar sampling point was established, considering the four varieties and nutrients simultaneously. Although each variety has a specific period of nutritional stability, the period of stability for all four varieties simultaneously coincided for all the nutrients analyzed (N, P, K, Ca and Mg), in July (Figures 2 and 3, red rectangle area). Thus, considering these data, we can state that the optimum foliar sampling dates is in July, as it is the period in time in which the mineral nutrients analyzed were the most stable, simultaneously between them and the four varieties. This part of the vegetative growth cycle corresponds to phenological stages in which the fruits reach their final size.

With the data obtained in this sampling interval, the main descriptive statistics values were calculated for each nutrient and variety, as shown in Table 2. It was observed that the concentration of the nutrients followed the following pattern: Ca> N > K≥ Mg > P. In the rainfed plots, the nutritional state of the Tuono leaves was different from the nutritional state of the rest of the varieties, as it showed the smallest concentration of N and P, and the greatest concentration of Mg and Ca, P, however, was similar in all the varieties. In the case of the irrigated trees, the differences were less evident and sharp. Thus, Tuono had a significantly higher concentration of P, K, and Ca, but without these values being as disparate as those observed in the rainfed fields. In the four varieties, significant differences were observed for the concentration of N between the irrigated and rainfed cultivation regimes, with it being the highest in the irrigated fields. Higher P concentrations were also observed in irrigated versus rainfed fields for Desmayo, Marcona and Tuono, and in Mg for Desmayo, Marcona nd Ramillete. However, higher values in rainfed versus irrigated plots were found in K for Marcona, and in Ca for Tuono (Table 2).

Within each column, the mean values of the nutrient concentration with the same letter do not represent significant differences at $p<0.05$. SD indicates standard deviation of the samples, CV coefficient of variation, and SE standard error. n=96 (2 years x 2 2-week periods per year x 2 years x 12 samples) for each crop, rainfed, and irrigated. “*” indicates significant differences for each nutrient between irrigated and rainfed, for each variety.

Range of Normality

Table 3 shows the ranges of normality for each variety and watering regime. For both rainfed and irrigated regimes, it was observed that the varieties Desmayo, Ramillete, and Marcona, had very similar values between them, although these were different from Tuono. The latter variety had ranges of normality that were lower for N and K, and higher for Ca and Mg as compared to the other three. As for rainfed and irrigated plots, strong differences were not found, indicating that this crop is perfectly adapted for both production systems.

Table 2: Mean values of leaf macronutrient concentration (%, g 100 g^{-1} DW) in the July for the varieties Desmayo, Ramillete, Marcona, and Tuono grow in rainfed and irrigated plots.

	Rainfed					**Irrigation**				
Variety	N	P	K	Ca	Mg	N	P	K	Ca	Mg
Desmayo										
Mean (%, g 100 g^{-1} DW)	1.72* b	0.08* a	1.19 b	3.87 a	0.69* a	1.80 a	0.09 a	0.98 a	3.95 a	0.79 a
SD	0.05	0.05	0.49	0.84	0.24	0.28	0.03	0.37	0.65	0.14
C.V. (%)	1.46	6.58	4.14	2.16	3.42	1.56	2.76	3.75	1.65	1.72
SE	0.02	0.00	0.03	0.06	0.02	0.04	0.00	0.05	0.09	0.02
Ramillete										
Mean (%, g 100 g^{-1} DW)	1.69* b	0.08 a	1.06 b	3.80 a	0.65* a	1.89 ab	0.09 a	0.99 a	3.70 a	0.78 a
SD	0.23	0.01	0.27	0.41	0.04	0.36	0.03	0.38	0.58	0.16
C.V. (%)	1.36	1.44	2.55	1.07	0.68	1.91	3.47	3.78	1.56	1.98
SE	0.04	0.00	0.04	0.06	0.01	0.04	0.00	0.05	0.07	0.01
Marcona										
Mean (%, g 100 g^{-1} DW)	1.76* b	0.08* a	1.14* b	4.42* b	0.79 b	1.87 ab	0.09 a	0.88 a	4.63 b	0.84 a
SD	0.28	0.02	0.58	0.80	0.22	0.27	0.02	0.34	0.82	0.35
C.V. (%)	1.59	2.73	5.07	1.82	2.75	1.44	2.28	3.87	1.77	4.19
SE	0.02	0.00	0.05	0.06	0.02	0.02	0.00	0.03	0.07	0.03
Tuono										
Mean (%, g 100 g^{-1} DW)	1.36* a	0.08* a	0.37* a	5.63* c	0.99* c	2.00 b	0.11 b	1.33 b	4.47 b	0.76 a
SD	0.38	0.00	0.13	0.14	0.18	0.56	0.02	0.55	0.76	0.14
C.V. (%)	2.78	2.53	3.59	1.85	1.85	2.81	2.15	4.16	1.71	1.86
SE	0.05	0.00	0.02	0.12	0.02	0.10	0.00	0.10	0.15	0.01

Table 3. Ranges of normality for the varieties Desmayo, Marcona, Ramillete and Tuono in rainfed and irrigated plots.

	No irrigation								**Irrigation**							
	Desmayo								**Desmayo**							
Nutrient	**Very low**	**Low**		**Normal**		**High**		**Very high**	**Very low**	**Low**		**Normal**		**High**		**Very high**
N	< 1.21	1.21	1.46	1.47	1.98	1.99	2.24	> 2.24	< 1.23	1.23	1.51	1.52	2.08	2.09	2.37	> 2.37
P	< 0.03	0.03	0.05	0.06	0.09	0.10	0.12	> 0.12	< 0.03	0.03	0.06	0.07	0.12	0.13	0.15	> 0.15
K	< 0.19	0.19	0.68	0.69	1.68	1.69	2.18	> 2.18	< 0.23	0.23	0.60	0.61	1.35	1.36	1.73	> 1.73
Ca	< 2.19	2.19	3.02	3.03	4.71	4.72	5.55	> 5.55	< 2.63	2.63	3.28	3.29	4.60	4.61	5.26	> 5.26
Mg	< 0.21	0.21	0.45	0.46	0.93	0.94	1.18	> 1.18	< 0.51	0.51	0.64	0.65	0.92	0.93	1.07	> 1.07
	Ramillete								**Ramillete**							
	Very low	**Low**		**Normal**		**High**		**Very high**	**Very low**	**Low**		**Normal**		**High**		**Very high**
N	< 1.22	1.22	1.45	1.46	1.92	1.93	2.16	> 2.16	< 1.16	1.16	1.52	1.53	2.25	2.26	2.63	> 2.63
P	< 0.05	0.05	0.06	0.07	0.10	0.11	0.12	> 0.12	< 0.02	0.02	0.05	0.06	0.12	0.13	0.17	>0.17
K	< 0.51	0.51	0.78	0.79	1.33	1.34	1.61	> 1.61	< 0.19	0.19	0.61	0.62	1.37	1.38	1.75	>1.75
Ca	< 2.97	2.97	3.38	3.39	4.20	4.21	4.62	> 4.62	< 2.54	2.54	3.12	3.13	4.28	4.29	4.86	>4.86
Mg	< 0.55	0.55	0.59	0.60	0.69	0.70	0.75	> 0.75	< 0.46	0.46	0.62	0.63	0.94	0.95	1.10	>1.10
	Marcona								**Marcona**							
	Very low	**Low**		**Normal**		**High**		**Very high**	**Very low**	**Low**		**Normal**		**High**		**Very high**
N	< 1.19	1.19	1.47	1.48	2.03	2.04	2.32	> 2.32	< 1.32	1.32	1.59	1.60	2.14	2.15	2.42	> 2.42
P	< 0.02	0.02	0.04	0.05	0.09	0.10	0.13	> 0.13	< 0.04	0.04	0.06	0.07	0.11	0.12	0.14	> 0.14
K	< 0.02	0.02	0.55	0.56	1.71	1.72	2.30	> 2.30	< 0.19	0.19	0.53	0.54	1.22	1.23	1.57	> 1.57
Ca	< 2.80	2.80	3.61	3.62	5.22	5.23	6.04	> 6.04	< 2.99	2.99	3.81	3.82	5.45	5.46	6.28	> 6.28
Mg	< 0.34	0.34	0.56	0.57	1.00	1.01	1.23	> 1.23	< 0.13	0.13	0.48	0.49	1.18	1.19	1.54	> 1.54
	Tuono								**Tuono**							
	Very low	Low		Normal		High		Very high	**Very low**	**Low**		**Normal**		**High**		**Very high**
N	< 0.60	0.60	0.98	0.99	1.74	1.75	2.13	> 2.13	< 0.87	0.87	1.43	1.44	2.56	2.57	3.13	> 3.13
P	< 0.03	0.03	0.05	0.06	0.10	0.11	0.13	> 0.13	< 0.05	0.05	0.08	0.09	0.14	0.15	0.17	> 0.17
K	< 0.09	0.09	0.23	0.24	0.50	0.51	0.64	> 0.64	< 0.21	0.21	0.77	0.78	1.88	1.89	2.45	> 2.45
Ca	< 3.54	3.54	4.58	4.59	6.67	6.68	7.72	> 7.72	< 2.93	2.93	3.69	3.70	5.23	5.24	6.00	> 6.00
Mg	< 0.62	0.62	0.80	0.81	1.18	1.19	1.37	> 1.37	< 0.47	0.47	0.61	0.62	0.90	0.91	1.05	> 1.05

DRIS Standards

The DRIS standards obtained for each of the four varieties is shown in Table 4. The criteria utilized to select these standards was to choose those which had the smallest coefficient of variation for each variety. Other authors have created standards for different other conditions, such as for citrus trees treated with an iron chelate, as compared to trees to which iron chelates were not applied [18], pomegranate trees that were either affected or not to the bacterial disease *Xanthomonas axonopodis* pv. *Punicae* [19], or almonds from different locations in Iran, Chaharmahal and Bakhtiari [20]. In our study, we calculated the DRIS standards from healthy, high productivity almond orchards in two environmental scenarios, so that they could be utilized as a reference for their use in future decision support systems (DSS), through the calculation of DRIS indices **De Assis**, [22]. The main advantage of the DRIS system, with respect to other methods such as range of normality, is that these standards do not depend on the age, variety, or part of the plant utilized for the analysis, as they utilize the relationship between nutrients instead of their absolute and/or individual concentrations [22]. However, to improve the precision of the interpretation, it is necessary to establish standards starting with regional and local studies that take into account different factors of the crop, such as edaphological, climatic, level of production characteristics, etc.

Table 4: DRIS standards established for the varieties Desmayo, Ramillete, Marcona and Tuono.

	Rainfed	Irrigation		Rainfed	Irrigation
Ratio	**Desmayo**		**Ratio**	**Ramillete**	
N/P	24.08	20.57	**P/N**	0.05*	0.05
K/N	0.69a	0.55a	**K/N**	0.62a	0.52a
N*Ca	6.59a	7.03a	**N*Ca**	6.38a	6.96a
N*Mg	1.19a	1.41a	**N*Mg**	1.09a	1.48a
K/P	16.12a	11.15a	**K/P**	12.63a	10.95a
K*Mg	0.75a	0.76a	**K*Mg**	0.68a	0.77a
P*Ca	0.28a	0.35a	**P*Ca**	0.32*a	0.33a
P*Mg	0.05*a	0.12a	**P*Mg**	0.05*a	0.07b
K*Ca	4.50a	3.81a	**K/Ca**	3.97a	3.60a
Mg/Ca	0.18*a	0.20a	**Ca/Mg**	5.88*	4.74
	Marcona		**Ratio**	**Tuono**	
N/P	24.44*	20.00	**P/N**	0.06*	0.05

K/N	0.64a	0.48a	**K/N**	0.28*b	0.63a
N*Ca	7.63a	8.58a	**N*Ca**	7.60a	8.61a
N*Mg	1.36a	2.61a	**N*Mg**	1.35a	1.46a
K/P	15.13a	10.09a	**P/K**	0.23*	0.08
K*Mg	0.80a	0.66a	**Mg/K**	2.68*	0.57
P*Ca	0.32a	0.40b	**P*Ca**	0.44a	0.49b
P*Mg	0.06*a	0.12a	**P*Mg**	0.08a	0.08a
K/Ca	0.21a	0.25	**K/Ca**	0.07*	0.30
Mg/Ca	0.18*a	0.16a	**Ca/Mg**	5.73	5.91

Within each column the different ratios between varieties are compared. Mean values of nutrient concentration with the same letter do not represent significant differences at $p<0.05$. * indicates significant differences between rainfed and irrigation for a specific variety and ratio.

CND Standards

The CND standards obtained for the four varieties assays in rainfed and irrigated fields are shown in Table 5. Once the standards are obtained, the CND indices can be calculated for any leaf sample, according to that established by Aitchison [15]. Samples of CND standards for other crops can be found for Aloe vera [19] or date palm [22]. The CND standards utilize ratios with respect to the total composition, so that the effect of the variability of only one element on the rest of the nutrients is considered as a global effect, and not as the contribution of various individual effects of each of the nutrients on the rest of the nutrients, which is a clear advantage with respect to the DRIS guidelines [23].

In the bibliography, we can find important differences between these standards when dealing with different species and varieties, as well as different climatic areas, soils, fertilization, and irrigation management. On the other hand, references related with the CND for the cultivation of almonds do not exist, and even less differentiating between rainfed and irrigated cultivation. Therefore, the standards obtained in this work will be greatly useful for interpreting the leaf mineral analysis from cultivated almond varieties, for both rainfed and irrigated crops. In future studies, these standards will be validated with low-production populations and will be introduced in the DSS to help in the management of fertilizer application.

Table 5: CND standards of the multi-nutrient variables obtained from the nutrient content in every one of almond cultivars.

	Rainfed	Irrigation		Rainfed	Irrigation
Ratio	**Desmayo**		**Ratio**	**Ramillete**	
VN	-0.04a	-0.04b	VN	-0.06a	0.01a
VP	-3.20a	-3.05a	VP	-3.07a	-3.04a
VK	-0.49a	-0.70a	VK	-0.56a	-0.68a
VCa	0.76a	0.74a	VCa	0.75a	0.68a
VMg	-0.99a	-0.87	VMg	-1.01a	-0.88
Va-Ř	3.95a	3.91a	Va-Ř	3.95a	3.91a
Ř	92.45a	92.40a	Ř	92.73a	92.54a
G	1.78a	1.86a	G	1.78a	1.86a
Ratio	**Marcona**		**Ratio**	**Tuono**	
VN	-0.05a	-0.01a	VN	-0.20b	-0.06b
VP	-3.23a	-3.08a	VP	-3.04a	-2.92a
VK	-0.61a	-0.83a	VK	-1.53a	-0.59a
VCa	0.86a	0.90b	VCa	1.23b	0.77a
VMg	-0.88a	-0.88	VMg	-0.50b	-1.00
Va-Ř	3.92a	3.90a	Va-Ř	4.04a	3.80a
Ř	91.83a	91.69a	Ř	91.57a	91.33a
G	1.84a	1.87a	G	1.62a	2.06a

Within each column, the different ratios between varieties are compared. Mean values of nutrient concentration with the same letter do not represent significant differences at $p<0.05$. * indicates significant differences between rainfed and irrigation for a specific variety and ratio.

Conclusion

The optimum period for foliar sampling of the cultivars Desmayo, Ramillete, Marcona and Tuono is the month of July, as in this month, the concentration of the leaf minerals analyzed was simultaneously stable for each of the nutrients. And, this period of stability does not change with respect to the rainfed or irrigated fields. With respect to the nutritional state for the contents of N, P, K, Ca, and Mg, differences were found between varieties and cultivation systems. As for the varieties, Tuono behaved differently from the rest, with stronger differences found in rainfed as compared to irrigated fields. The RD intervals and the DRIS and CND standards specific to each variety and watering regime were developed from the data obtained in the period of stability. These standards were different for each variety and watering regime, so that it can be concluded that for the use of these interpretation techniques, it is necessary to develop specific standards for each variety and climatic scenario within the same cultivated specie.

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