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RESEARCH PAPER

# Nutritional diagnosis norms for three olive tree cultivars in superhigh-density orchards

Miguel Gimenez[1], Manuel Nieves[2], Helenio Gimeno[3], Juan Martínez[1], and Juan José Martínez-Nicolás[1]

[1]Universidad Miguel Hernández de Elche, Escuela Politécnica Superior de Orihuela, Plant Production Department. Ctra, Beniel, Km 3.2, 03312 Orihuela, Alicante, Spain.

[2]Universidad Miguel Hernández de Elche, Escuela Politécnica Superior de Orihuela, Department of Edaphology and Agricultural Chemistry. Ctra, Beniel, Km 3.2, 03312 Orihuela, Alicante, Spain.

[3]Fertiberia S.A. Paseo Castellana, 259 - D, Planta 48, Edif. Torre Espacio, 28046. Madrid, Spain.

**Abstract**

**M. Gimenez, M. Nieves, H. Gimeno, J. Martínez, and J.J. Martínez-Nicolás. 2021. Nutritional diagnosis norms for three olive tree cultivars in superhigh-density orchards. Int. J. Agric. Nat. Resour. 34-44.** The preferred olive tree cultivation strategy has evolved towards high-density cultivations to increase profitability and satisfy the global demand for olive oil. However, there is a lack of specific norms for the nutritional diagnosis of new growing systems and the varieties adapted to these systems. The objective of this study is to determine the sufficiency range and the diagnosis and recommendation integrated system and compositional nutritional diagnosis norms for Arbequina, Arbosana and Picual cultivars under superhigh-density olive tree cultivation. Leaves were sampled every fifteen days, from July to December, from high-productivity trees with production densities exceeding 8000 kg $ha^{-1}$. The results show two periods of stability for the three varieties of olives: July-first two weeks of August and October-November. The three varieties showed substantial variability in their macronutrient concentrations, i.e., N, P, K, Ca and Mg, during both periods. The three aforementioned methods have improved the reliability of such diagnosis and provided concurrent diagnoses. Nevertheless, all the resulting norms need to be validated through an analysis of the results obtained in practice after their application.

**Keywords:** Arbequina, Arbosana, CND, DRIS, Picual, SR.

**Abbreviations:**

CND: Compositional Nutritional Diagnosis norms

DRIS: Diagnosis and Recommendation Integrated System

DRIS BI: DRIS balance index

$NBI_{CND:}$ Nutrient Balance Index of the CND

Dmi: Dry matter index

M-DRIS: Modified-DRIS

SR: Sufficiency Range

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Corresponding author: juanjose.martinez@umh.es

## Introduction

The worldwide cultivation of olive trees exceeds 10.65 million ha and mostly occurs in the form of traditional cultivation (FAOSTAT, 2018). Spain possesses the highest number of olive trees in the world at more than 300 million trees, of which 94% are utilized for the production of oil and 6% for the manufacture of table olives. Thus, in the world ranking, it is the highest-ranked producer and exporter of olive oil. Since the 1970s, traditional dry land olive groves with locally selected varieties with a slow production entry, which are long-lived and manually harvested, have been progressively substituted by plantations designed for mechanized harvests with early entries into production, high productivities and short lifespans. Additionally, the industry is moving away from traditional dry-land cultivation (<100 trees $ha^{-1}$) to intensive systems with various irrigation schemes (200–400 trees $ha^{-1}$), wide rows (high density 450–800 trees $ha^{-1}$) or narrow rows or superintensive systems (1000–1500 trees $ha^{-1}$) (Rallo *et al*., 2018; Fernández *et al*., 2020), which reduce the cost of the produced oil to less than half. These changes in plantation systems require varieties with new characteristics that are being obtained through different genetics programs at different Spanish universities and research centers (Rugini *et al*., 2016; Romero-Gámez *et al*., 2017).

To ensure the maximum possible agronomic performance of these new varieties of olive trees cultivated in high-density systems, it is essential to know their nutritional demands; this is where nutritional diagnoses play an important role. Conventionally, leaf or foliar analysis has provided a guide for the application of fertilizers. With the results from these analyses, a guide has been established based on the sufficiency range (SR) of the studied cultivars (Erel *et al*., 2018; Haberman *et al*., 2019; Zipori *et al*., 2020). However, at present, more sophisticated methods have been established that take into account the relationships between nutrients. One of these methods is the Diagnosis and Recommendation Integrated System, referred to as "DRIS norms". This method provides a series of indices related to nutrient pairs (Beaufils, 1973). The sensitivity of plant age is one of the shortcomings of DRIS, especially of DRIS-Ca. This problem is rooted in the fact that DRIS diagnoses Ca as being deficient in more cases than actually observed. A variation proposed for DRIS is the addition of the dry matter index (Dmi), referred to as the modified DRIS model (M-DRIS), to address the issues associated with Ca, Mg or Mn (Hallmark & Beverly, 1991). For M-DRIS, only elements with index values more negative than the dry matter index were considered potentially limiting nutrient. A highly negative dry matter index is observed when samples are collected earlier than the stage of development at which tissue is usually sampled, meaning that the element concentrations would be higher than those in the reference population.

Afterwards, a mixed system was developed, i.e., the Plant Analysis with Standardized Scores (PASS) (Baldock & Schulte, 1996), which is composed of an independent nutrient index (INI), such as the SR system, and another dependent nutrient index (DNI), such as DRIS. Additionally, there is a third global index, the PASS yield index (PASS YI), which has a better performance than the DRIS balance index (DRIS BI). The method of Compositional Nutritional Diagnosis (CND) was developed by Parent and Dafir (1992). With this method, the indices are calculated for each nutrient considering their relationships to the geometric mean of all the nutrients (G) and components constituting the plant material (R). R indicates the quantity not considered by the elements analyzed, corresponding to carbon, oxygen and hydrogen, and it is a more comprehensive parameter than the dry matter index utilized in M-DRIS. CND is the multivariate expansion of SR (univariate) and DRIS (bivariate) and is fully compatible with PCA (principal component analysis).

For the DRIS and CND systems, the high-performance populations contributing to the statistical basis are selected. In the case of DRIS, Walworth and Sumner (1987) proposed the coefficient of variance of nutrient expressions to discriminate between high- and low-performance subpopulations. Additionally, Parent and Dafir (1992) indicated that multivariate analysis was a suitable method for defining high-performance subpopulations. Parent and Dafir (1992) proposed the chi-square distribution function to define the threshold value of CND for the disequilibrium of nutrients when the performance is associated with the function of the coefficient of cumulative variances for each given nutrient. Escano *et al*. (1981) indicated that local calibration could improve the exactness of DRIS diagnosis. However, DRIS offers a nongeneric approach, which utilized small databases, similar to CND, due to the support of the chi-square distribution function.

Although there are data on and recommendations for olive trees from the University of California, the University of Georgia (UGA) and other institutions around the world, no data are available that could be used to derive specific recommendations for high-density plantations (Mulvaney *et al*., 2016). The University of Florida recommends the analysis of plant tissues for perennial crops, as it can better predict the nutrient requirements of these species (Mylavaney *et al*., 2016).

In general, it is recognized that the leaf tissue test is a better indicator of seasonal nutritional requirements than soil tests (Zipori *et al*., 2020) because soil testing may not precisely indicate the needs of a crop in any specific growth stage. The recommendations are only based on the sufficiency range of nutrients in the leaf tissue. These sufficiency ranges have been determined for California but not yet for high-density plantations.

The sufficiency ranges of leaf tissues from olives have been determined for places outside Florida (Bryson & Mills, 2014). These recommended sufficiency ranges are guidelines and are not strictly applicable to all conditions. The Picual variety is the most widely utilized variety in traditional cultivation in Spain (>600,000 ha) due to its high productivity and superior olive oil quality (Talhaoui *et al*., 2016; Navas, 2020). In superhigh-density plantations, the Arbequina variety is the variety of choice and is widely utilized because of its high plantation density due to its low vigor (Diez *et al*., 2016). Although the DRIS and CND norms for the Picual variety have been published, for traditional cultivation under irrigation (Lucena *et al*., 2002), these norms for superhigh-density cultivation are not available in published reports. The CND and DRIS indices possess a very good and good correlation with production, respectively, compared to the average correlation of the SR (Gott *et al*., 2017; Bendaly *et al*., 2018).

The aim of this study was to determine the date of sampling and the effect of the selected genotype on the concentration of leaf nutrients. Additionally, to determine the SR and the DRIS and CND norms that are specific for the cultivation of Arbequina, Arbosana and Picual in superhigh-density plantations and evaluate if these approaches are complementary with the available nutritional diagnosis.

## Materials and Methods

### *Plant Material and Growth Conditions*

The study was conducted in 2016 at the Hacienda San Miguel, at a latitude of 37°47’50” and a longitude of 1°22’11”, located in the city of Alhama in the Region of Murcia (Spain). The soil of the plantation is clayish (sand 25%, lime 30% and clay 45%), with an observed pH of 8.23 (1/2.5), an electrical conductivity (E.C.) of 0.51 dS $m^{-1}$ (1.5), an estimated total carbonate content 32.62%, and an active lime content of 5.95%. The irrigation water is sourced from a well located on the same land, with a measured E.C. of 1.90 dS $m^{-1}$, a pH 8.05, a sulfate composition (meq $L^{-1}$) of 10.15, a bicarbonate content of 4.54 (meq·$L^{-1}$), a chloride content of 8.39 (meq·$L^{-1}$), a calcium content of 8.82 (meq·$L^{-1}$), a magnesium content of 7.81 (meq·$L^{-1}$), a potassium content of 0.13 (meq·$L^{-1}$)

and a sodium content of 5.82 (meq·L$^{-1}$). The climate characteristics of the 2007–2017 period were as follows: an evapotranspiration (ETO-PM-FAO) of 1,450 mm, an average precipitation of 270.6 mm, an appraised sunlight duration of 3,000 h, an average relative humidity of 61.6%, an average of temperature, an average temperature of 17.1 °C, an observed maximum temperature of 29.0 °C and an observed minimum temperature of 3.4 °C. In 2004, 600,000 olive trees of the Arbequina, Arbosana and Picual varieties (200,000 trees of each cultivar) were planted on trellises with a 3.5 × 1.5 m planting frame. The reasons for choosing these three varieties are as follows: i) Picual is the most important variety in Spain, with almost 900,000 ha of cultivation, and it has an early entry into production with easy growth; ii) Arbequina and Arbosana exhibit a high precocity and a low vigor and produce high-quality oil. Furthermore, these varieties show good adaptation to superintensive cultivation with drip irrigation.

The fertigation was done with drippers. In 2016, the trees were irrigated with a dose of 3,000–4,000 m$^3$ ha$^{-1}$ year and received N-P-K-Ca-Mg fertilizer units of 150–50–150–30–40 FU ha$^{-1}$ with micronutrient supplements. Four to eight phytosanitary treatments were performed annually against repilo (*Cycloconium oleaginea*) flies (*Bactrocera oleae*), glyphodes and/or scales (*Saissetia oloae*). The olive fruit production oscillated between 8,000 and 10,000 kg ha$^{-1}$.

*Experimental Procedure*

To measure the indices of SR, DRIS, and CND, leaf samples were collected every 15 days during the months of July, August, September, November and December of 2016. On each sampling date, 1 sample was taken per genotype (Arbequina, Arbosana and Picual), which consisted of 15 repetitions of 50 leaves from the central part of budding that year (5 leaves tree$^{-1}$). To compare the diagnostic methods, Arbequina leaves were harvested in the same quantities as previously mentioned from trees located in a plot near the experimental plot with similar characteristics.

*Plant Mineral Analysis*

The plant samples were dried in an oven set at 65 °C for 48 h before the analysis. Afterwards, the mineral elements of the plant were extracted with deionized water, and the concentrations of Cl, N, Ca, Mg, K and P were measured. The concentration of chlorides was measured with a Corning 926 chlororimeter (Sherwood, United Kingdom). The concentration of N was measured utilizing a Thermo-Finnigan 1112 EA elemental analyzer (Thermo-Finnigan, Milan, Italy). The leaf concentrations of potassium (K), magnesium (Mg), calcium (Ca) and phosphorus (P) were determined through inductively coupled plasma optical emission spectrophotometry (ICP-OES, Iris Intrepid II, Thermo Electron Corporation, Franklin, MA, EE. UU.) after acid digestion with nitric acid ($HNO_3$):hydrogen peroxide ($H_2O_2$) (5:3, v/v) in a microwave that reached 200 °C in 20 min, which was then maintained for 2 h (Mars Xpress, CEM Corporation, Matthews, NC, EE. UU.).

*Nutritional Parameters*

The SRs and the DRIS, M-DRIS and CND indices were calculated with the data from the leaf analysis. The detailed mathematical procedures can be found in Hallmark and Beverly (1991) and Parent and Dafir (1992). The SR represents an amplification of the approximation to the critical level, with this level corresponding to 90–100% of the maximum of the concentrations and performances vs nutrient contents. The basic SR divides the concentrations of nutrients into 3 categories of diagnosis: deficient, sufficient and high. For the DRIS index, the mean nutrient ratios presented were selected from each pair of inversely related ratios (P:K, K:P) showing the lowest standard deviation (SD). With the DRIS index, the calculations are continuous. Zero is the optimum value; researchers have utilized an equilibrium range of -10 to +10. This not only identifies the nutrients in disequilibrium but also the order of which the others could follow. DRIS also calculates the global value, which is the sum of the absolute values of the nutrient indices $NBI_{DRIS}$. The greater the $NBI_{DRIS}$ determined for a specific plant is, the greater the degree of global disequilibrium. For the M-DRIS norm, the dry matter index (Dmi) was taken into account. For M-DRIS, only elements with index values more negative than the dry matter index (Dmi) were considered potentially limiting. The CND indices normally plot between ±1. Last, we calculated the nutrient balance index from CND, $NBI_{CND}$, which interprets the global nutritional equilibrium of the sample. This is calculated by adding the squares of the 5 indices of the macronutrients and finding the square root of this number.

*Statistical Analysis*

There were fifteen replicates for each genotype per harvest date (i.e., 3 ×15). All measured parameters were analyzed statistically using SPSS Version 20.0 software (SPSS Statistical Package, Chicago, IL, USA).

## Results

*Effect of Sampling Date*

The mean concentrations of macronutrients N, P, K, Ca and Mg for the three cultivars, i.e., Arbequina, Arbosana and Picual, are shown in Table 1. The analysis of variance of the macronutrients for the two week periods from July to December showed the presence of two periods of nutritional stability for the three varieties of olives: a) from the first two weeks of July until the first two weeks of August and b) from the first two week period of October to the latter half of November.

*Effect of Genotype*

Table 2 shows the mean values and standard deviations of the leaf macronutrient contents (%) for each cultivar (Arbequina, Arbosana and Picual) for the two periods of stability established. For both sampling periods, the three olive varieties showed significant differences in each of the macronutrients. In the second period of nutritional stability, the leaf concentrations of N and K were lower than those in the first period, while the opposite phenomenon occurred for P, Ca and Mg.

*Sufficiency Range*

To validate the reference values, 25% of the total plants with high performances were utilized to determine the nutrient levels of the reference population. Table 3 shows the concentration intervals of leaf macronutrients divided into

**Table 1.** Period macronutrient concentration stability (% dry matter) for the set of three cultivars, Arbequina, Arbosana and Picual. For the analysis of variance of the macronutrients, for the two-week periods from July to December, there were fifteen replicates for each genotype (n=710). The table shows two shaded periods: (Jul-1 to Aug-1) and (Oct-1 to Nov-2). In both periods, the greatest stability in the concentration of macronutrients is observed.

| | Average (n=710) | jul-1 | jul-2 | aug-1 | aug-2 | sept-1 | sept-2 | oct-1 | oct-2 | nov-01 | nov-2 | dec-1 | dec-2 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| N | 1.74 | 1.89ab | 1.94a | 1.86b | 1.85b | 1.85b | 1.68cd | 1.62def | 1.67cde | 1.66cde | 1.69c | 1.61ef | 1.57f |
| P | 0.08 | 0.08e | 0.08e | 0.07ef | 0.07f | 0.75e | 0.76e | 0.84d | 0.09cd | 0.09bc | 0.09b | 0.10a | 0.08d |
| K | 0.54 | 0.68a | 0.65a | 0.60ab | 0.57b | 0.56b | 0.49cd | 0.46d | 0.51c | 0.48cd | 0.51c | 0.51c | 0.46d |
| Ca | 1.73 | 1.45h | 1.52gh | 1.57fg | 1.62ef | 1.82b | 1.74cd | 1.94a | 1.98a | 1.93a | 1.79bc | 1.68de | 1.74cd |
| Mg | 0.29 | 0.26f | 0.27e | 0.31ab | 0.29d | 0.32a | 0.33bc | 0.32a | 0.31ab | 0.31ab | 0.30cd | 0.29d | 0.26ef |
| Period of stability | | | | | | | | | | | | | |

Different letters in the same rows indicate significant differences (p=0.05).

**Table 2.** Average and standard deviation (SD) of macronutrient content (%) (n=45) for the Picual, Arbequina and Arbosana varieties for both periods of nutritional stability.

| | Arbequina Average ± SD | Arbosana Average ± SD | Picual Average ± SD |
|---|---|---|---|
| | | July-1st half of August | |
| N | 2.074 ± 0.094 a | 1.668 ± 0.119 c | 1.884 ± 0.088 b |
| P | 0.071 ± 0.005 b | 0.064 ± 0.006 c | 0.087 ± 0.007 a |
| K | 0.700 ± 0.061 a | 0.615 ± 0.055 b | 0.534 ± 0.056 c |
| Ca | 1.636 ± 0.159 b | 1.339 ± 0.090 c | 1.692 ± 0.110 a |
| Mg | 0.271 ± 0.046 b | 0.258 ± 0.010 b | 0.328 ± 0.067 a |
| | | October-November | |
| N | 1.683 ± 0.098 a | 1.483 ± 0.052 b | 1.663 ± 0.107 a |
| P | 0.080 ± 0.006 b | 0.071 ± 0.007 c | 0.117 ± 0.018 a |
| K | 0.520 ± 0.079 a | 0.484 ± 0.096 b | 0.344 ± 0.051 c |
| Ca | 1.742 ± 0.218 c | 1.995 ± 0.222 b | 2.174 ±0.146 a |
| Mg | 0.283 ± 0.026 c | 0.309 ± 0.028 b | 0.353 ± 0.030 a |

Different letters in the same row indicate significant differences ($p \leq 0.05$).

**Table 3.** Interpretation of the normality ranges for the content of the macronutrients (N, P, K, Ca and Mg %) in the Arbequina, Arbosana and Picual varieties. These were defined as the average ± 4/3 standard deviation for the sampling period in July and the first half of August (n=45).

| | Very low | Low | Normal | High | Very High |
|---|---|---|---|---|---|
| | | | Arbequina | | |
| N | <1.824 | 1.824-1.949 | 1.949-2.199 | 2.199-2.324 | >2.324 |
| P | <0.059 | 0.059-0.065 | 0.065-0.077 | 0.077-0.084 | >0.084 |
| K | <0.537 | 0.537-0.619 | 0.619-0.782 | 0.782-0.863 | >0.863 |
| Ca | <1.212 | 1.212-1.424 | 1.424-1.848 | 1.848-2.060 | >2.060 |
| Mg | <0.148 | 0.148-0.209 | 0.209-0.332 | 0.332-0.393 | >0.393 |
| | | | Arbosana | | |
| N | <1.350 | 1.350-1.509 | 1.509-1.827 | 1.827-1.986 | >1.986 |
| P | <0.046 | 0.046-0.055 | 0.055-0.072 | 0.072-0.081 | >0.081 |
| K | <0.470 | 0.470-0.542 | 0.542-0.688 | 0.688-0.761 | >0.761 |
| Ca | <1.098 | 1.098-1.219 | 1.219-1.460 | 1.460-1.580 | >1.580 |
| Mg | <0.232 | 0.232-0.245 | 0.245-0.271 | 0.271-0.284 | >0.284 |
| | | | Picual | | |
| N | <1.649 | 1.649-1.766 | 1.766-2.001 | 2.001-2.119 | >2.119 |
| P | <0.069 | 0.069-0.078 | 0.078-0.096 | 0.096-0.105 | >0.105 |
| K | <0.384 | 0.384-0.459 | 0.459-0.609 | 0.609-0.684 | >0.684 |
| Ca | <1.398 | 1.398-1.545 | 1.545-1.838 | 1.838-1.985 | >1.985 |
| Mg | <0.149 | 0.149-0.239 | 0.239-0.417 | 0.417-0.507 | >0.507 |

5 classes. As these are homogeneous plots, for the same cultivar and fertigation, the range of normality (sufficiency range) was defined as the average ± 4/3 standard deviation for the sampling period in July and the first half of August (n=45). The 4/3 standard deviation values for each nutrient were also utilized to obtain the other intervals of deficiency and excess in each of the cultivars and macronutrients.

*DRIS norms*

Table 4 shows the standards for the DRIS norms of the relationship between the levels of macronutrients in the evaluated Arbequina, Arbosana and Picual olive trees. For the varieties of Arbequina, Arbosana and Picual, the global DRIS NBI values were 19.7 ± 6.3, 24.3 ± 11.0 and 20.2 ± 8.0, respectively (data not shown).

*CND norms*

Table 5 shows the mean values of the V parameter and the standard deviation of each macronutrient, which will help us identify the CND indices we wish to interpret for each sample. These CND indices will normally be between ±1. As calculations involving decimals tend to be somewhat troublesome, we decided to multiply the result by 10 so that the values are now between ±10. In this manner, an interpretive table can be established that is the same as the one created for the DRIS indices, which were previously mentioned.

The global $NBI_{CND}$ indices of the nutrient balance of Arbequina, Arbosana and Picual were 5.8, 8.3 and 5.6, respectively (data not shown).

## Discussion

Table 1 shows the two periods of stability of the three olive tree varieties: July to the 1st half of August and October-November. The first corresponds to the phenological state of fruit development (2nd half of May – 1st half November), while the second coincides with the end of fruit development and

**Table 4.** Averages and standard deviations (SD) of the reference macronutrient ratios used in the calculation of DRIS indices for the Arbequina, Arbosana and Picual olive varieties for the sampling period in July and the first half of August (n=45).

| Pairs | Arbequina | | | Arbosana | | | Picual | |
|---|---|---|---|---|---|---|---|---|
| | Average | SD | | Average | SD | | Average | SD |
| N*P | 0.1479 | 0.0114 | N/P | 26.2668 | 17.3551 | N/P | 21.8102 | 1.2294 |
| N*K | 1.4500 | 0.1192 | K/N | 0.3691 | 0.0246 | N/K | 3.5584 | 0.3491 |
| N/Ca | 1.2765 | 0.1047 | N*Ca | 2.2303 | 0.1731 | N/Ca | 1.1155 | 0.0428 |
| N/Mg | 7.8337 | 1.0968 | Mg/N | 0.1556 | 0.0124 | N/Mg | 5.9662 | 1.1348 |
| P/K | 0.1024 | 0.0088 | K/P | 9.6692 | 0.5632 | P/K | 0.1632 | 0.0140 |
| P*Ca | 0.1165 | 0.0120 | P*Ca | 0.0854 | 0.0097 | Ca/P | 19.5891 | 1.4496 |
| P/Mg | 0.2705 | 0.0455 | Mg/P | 4.0825 | 0.3751 | P*Mg | 0.0284 | 0.0058 |
| K*Ca | 1.1382 | 0.0746 | Ca/K | 2.1914 | 0.2143 | Ca/K | 3.1973 | 0.3572 |
| K*Mg | 0.1874 | 0.0197 | Mg/K | 0.4223 | 0.0324 | K*Mg | 0.1729 | 0.0263 |
| Ca/Mg | 6.1383 | 0.7410 | Mg/Ca | 0.1933 | 0.0083 | Ca/Mg | 5.3433 | 0.9711 |

**Table 5.** CND norms of the V ratio for the Arbequina, Arbosana and Picual olive varieties for the sampling period in July and the first half of August (n=45).

| | Arbequina | | Arbosana | | Picual | |
|---|---|---|---|---|---|---|
| | Average | SD | Average | SD | Average | SD |
| $V_N$ | 0.4876 | 0.0477 | 0,3821 | 0,0697 | 0,3877 | 0,0613 |
| $V_P$ | -2.8850 | 0.0845 | -2,8840 | 0,0846 | -2,6929 | 0,1022 |
| $V_K$ | -0.6005 | 0.1473 | -0,6168 | 0,0676 | -0,8760 | 0,1387 |
| $V_{Ca}$ | 0.2437 | 0.1036 | 0,1628 | 0,0903 | 0,2781 | 0,0874 |
| $V_{Mg}$ | -1.5593 | 0.1799 | -1,4818 | 0,0503 | -1,3863 | 0,2665 |
| $V_{Rd}$ | 4.3135 | 0.0457 | 4,4378 | 0,0570 | 4,3128 | 0,0031 |
| G | 1.2757 | 0.0550 | 1,2757 | 0,0550 | 1,2852 | 0,0762 |

SD: Standard Deviations

The V parameter for each of the macronutrients was calculated from the book "Fertirrigación. Cultivos hortícolas, frutales y ornamentals" (Cadahia, 2005).

the start of winter lethargy (Fernandez, 2014). For the Picual variety under an irrigation regime and non intensive cultivation, two periods of nutritional stability for macro- and micronutrients were obtained for the same intervals (Nieto *et al*., 2017). The first period coincided with July, which is generally utilized for nutritional diagnosis. On the other hand, in the 1970s, the period of winter lethargy was considered adequate for taking samples. Nevertheless, winter sampling is not advisable, as the change curves of well-fed trees and those with deficiencies tend to converge as the annual cycle progresses (Chapman, 1966). Thus, July could be considered an adequate sampling time for Arbequina, Arbosana and Picual under superintensive cultivation. If needed, sampling in October-November would also be valid.

Table 2 shows that the varieties Arbequina, Arbosana and Picual exhibited notable differences in their macronutrient profiles within both periods of nutritional stability. The varieties studied differed slightly in vigor and fruit maturation period (Diez *et al*., 2016). Thus, the plants of the cultivar Arbosana exhibited low vigor, while those from Arbequina exhibited medium vigor. The results of Table 2 show the N, P, P and K values of Arbosana that were lower than those for Arbequina during both periods of nutritional stability. The differences in the level of nutrients could be related to differences in the vigor of both varieties, which could have been maintained in superintensive cultivation since their planting in 2004. Recent long-term studies (14 years) have shown that Arbequina continues to be highly productive under superintensive cultivation, contradicting the results of shorter-term studies (7–8 years), which have shown a decrease in production due to, among other factors, the elevated vigor of the plant and the subsequent competition for water and nutrients from the soil (Diez *et al.,* 2016). The two periods analyzed corresponded to the phenological state of fruit development; however, the maturation period of the fruit produced by the Arbosana variety was late and occurred three weeks after that of the Arbequina olive tree (November). The second period of nutritional stability corresponded to the end of fruit development, which could be associated with the smaller leaf concentrations of N and K with respect to the first period at the start of olive fruit development. With respect to the SR of July, the concentrations of N and K in the October-November periods were very low in Arbequina and Arbosana, which could indicate the greater and more vigorous consumption of leaf nutrients. On the other hand, these data demonstrate the need to adjust the leaf sampling periods to obtain an accurate nutritional diagnosis. The leaf macronutrient concentrations in the Picual variety differed from those found for these periods under nonintensive cultivation with irrigation, with a density of 156–169 trees $ha^{-1}$ (Nieto *et al*., 2017). In the present study and for the first period, at the start of fruit maturation, superintensive cultivation obtained leaf N concentrations that were higher than those measured under nonintensive cultivation; however, during the second period, at the end of fruit development, the opposite trend was observed. These differences could be related to the optimal production of superintensive cultivation with respect to nonintensive cultivation.

In the long term, it is necessary to plan the management of soil fertility, supported by the respective ranges of nutrient availability, to cover the nutritional needs of olive trees. However, it is generally recognized that the sufficiency ranges (SRs) of the studied leaf concentrations are the best seasonal indicators of the nutritional needs of olive trees. Mulvaney *et al.* (2016) proposed some normality ranges based on a compilation of published data, which are recommended by diverse entities in Spain. Nevertheless, these wide nutrient intervals (SR for N, P and K are ± 14, 67 and 33%, respectively) should be taken as general guidelines and are therefore not strictly applicable for all situations. Thus, the concentrations of N of the three varieties tested would be within the SR (1.5–2.0% N) proposed by Mulvaney *et al.* (2016) when there were substantial differences between them.

The use of general SRs can result in diagnoses that deviate from the truth, as the productivity of these new cultivation systems is much greater than traditional cultivations; therefore, the nutritional requirements needed to achieve the optimum cultivar performance is also higher. Table 3 reports the sufficiency ranges, as well as the intervals of deficiency and excess. These intervals are more precise (i.e., Arbequina, SR for N, P and K are ± 6, 9 and 11%, respectively). These ranges were obtained under new superintensive cultivation systems considering three of the most-utilized cultivars, which respond to the demand of the new olive production system. Although the DRIS and CND norms have been published for olive trees of the Picual variety under traditional cultivation with irrigation (Lucena *et al.,* 2002), these norms are not available in the bibliography for superintensive cultivation. These indices are necessary for organizing nutrients related to their disequilibrium and fertilization requirements to avoid extreme nutrient deficiency or excess, aside from providing a correlation that is very good with the CND and good with the DRIS compared to the average correlation with the SR (Lucena *et al*., 2002).

**Conclusion**

The varieties studied exhibited two periods of nutritional stability that were apt for their nutritional diagnosis: (i) July-1st half of August and (ii) October-November. The three olive tree varieties showed significant differences in their macronutrient concentrations for both periods of nutritional stability. As a result, SR, DRIS and CND tables were created for the specific nutritional diagnosis of Arbequina, Arbosana and Picual under superintensive cultivation. The three methods increase the reliability of diagnosis and provide concordant diagnoses. Nevertheless, all the norms should be validated through the analysis of results obtained in practice after their application.

**Resumen**

**M. Giménez, M. Nieves, H. Gimeno, J. Martínez, y J.J. Martínez-Nicolás. 2021. Normas de diagnóstico nutricional para tres cultivares de olivo en huertos de super alta densidad. Int. J. Agric. Nat. Resour. 34-44.** El cultivo del olivo ha evolucionado hacia plantaciones de alta densidad, para aumentar su rentabilidad y satisfacer la demanda mundial de aceite de oliva. Sin embargo, existe una carencia de normas específicas para el diagnóstico nutricional en los nuevos sistemas de cultivo y para las variedades adaptadas a estos sistemas. El objetivo de este estudio es determinar: Rango de Suficiencia, Diagnóstico y Recomendación Sistema Integrado y Normas de Diagnóstico de Composición Nutricional, para Arbequina, Arbosana and Picual cv en los cultivos de olivos de muy alta densidad. Las hojas fueron muestreadas cada quincena, desde julio a diciembre, para árboles de alta productividad, superior a 8.000 kg $ha^{-1}$. Los resultados muestran dos periodos de estabilidad para las tres variedades de olivo: julio-1ª quincena de agosto y octubre-noviembre. Las tres variedades tuvieron diferencias significativas en cada uno de los macronutrientes: N, P, K, Ca y Mg, para ambos periodos. Los tres métodos incrementan la fiabilidad del diagnóstico y dieron diagnósticos concordantes. No obstante, todas las normas deben ser validadas mediante el análisis de los resultados obtenidos en la práctica, tras su aplicación.

**Palabras clave:** Arbequina, arbosana, CND, DRIS, picual, SR.

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