FOLIAR APPLICATION OF UREA AS ALTERNATIVE NITROGEN NUTRITIONAL DELIVERY SCHEME FOR KONSERVOLIA AND KALAMON COMMERCIAL OLIVE ORCHARDS

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Abstract

Konservolia and Kalamon olive orchards were tested for their vegetative and fruit growth after foliar urea applications served as nitrogen nutritional delivery scheme. Five urea aerial fertilizations (8-65 kg/m^3/ha) from January to September with summer aerial supplement of buffered KNO_3 replaced regular fertilization program for the above-mentioned olive orchards. Despite of different stem growth rates due to seasonal effect on tree physiology, throughout the experimental period no major changes in biomass productivity were observed for both varieties. Final size Konservolia fruits did not differ among conventional and foliar urea treatments. Although Kalamon olive fruits including pit data, differ in size among fertilization strategies with bigger size observed in foliar urea treated areas; their flesh firmness was found to be significantly lower to fruits received from soil fertilized orchards. Both varieties produced olives with increased pit weight and size and lower fruit flesh firmness when trees treated with urea. Konservolia decreases its fruit flesh/pit ratio as opposed to Kalamon where treated trees increased the weight of their commercial fruit flesh. Data suggest that each of tested olive varieties respond differently in foliar application of urea as a replacement of soil fertilization strategies. Results for Konservolia reveal that urea foliar applications can be approached as safe, conservative tactic nutritional replacement to soil fertilization for the orchard trees. For Kalamon variety, aerial treatments positively affect fruit size, increased pit size and flesh/pit ratio providing potentially faster harvest maturity times. This alternative nitrogen fertilization delivery strategy for Kalamon olive orchards can be considered as viable approach to restrict groundwater nitrate leaching and atmospheric pollution from previous fertilization conventional plans and increase fruit biomass for olive oil and olive waste byproducts useful in circular economy.

Keywords: *olive culture, urea, foliar fertilization, olive fruit characterization*

1. INTRODUCTION

Olive tree (*Olea europaea*) consists competitive key farming element in Mediterranean agricultural landscape. Apart of it aesthetic, historical presence and monumental value serves high nutritive standards in human diet. Kalamon and Konservolia olive cultivars were considered as dynamic basis of world table olives and olive oil production Olive cv. Konservolia and Kalamon are dominant as farmer's choice in Mediterranean region with distinctive differences in stomatal density and leaf CO_2 assimilation rates with the latter one variety to perform better (Hagidimitriou and Pontikis 2005). In relation to Mediterranean basin, these two varieties are widely cultivated providing contribution to gross olive culture of 9 million hectares in the area (Fraga et al.2020). Both varieties can adapt and perform well with drought in semi-arid climates and be tolerant in arid ones (Arji 2018; Loupassaki et al. 2002; Shirzad 2018).

Foliar applications on olive trees were performed mainly for crop protection and hormonal balancing as a possible route to alleviate alternative bearing consequences (Abd El-Naby et al. 2012; El-Wafa et al. 2021; Iannotta et al. 2002; Moula et al. 2020). Due to the fact that climate evolves into potential deficiency extremes affecting soil fertility and tree canopy vigor, experimentation moved into fulfilling physiological, immunological and nutritional requirements of olive trees via non-previously known routes such as microbial fertilizers and biostimulants (Dias et al. 2022). Microelements (B, Zn, Fe), aminoacids and organic acids foliar delivery schemes, where correctional deficiency conditions was not an occurring situation, has been applied in olive trees with positive fruit and growth effects (Başar and Gürel 2016; Nargesi et al. 2022; Saadati et al. 2013). Major aerial macroelement applications N, P, K, Ca, Mg, S on olive trees are also investigated; results are dependent of each olive tree varietal physiology (Dabbaghi et al. 2019; Hagagg et al. 2020; Marcelić et al. 2022; Regni and Proietti 2019; Saykhul et al. 2014; Thanaa et al. 2017).

Irreversible increasing costs of nitrogen fertilization in olive orchards coupled with environmental compliance framework lead to implementation of novel ideas concerning fertilization delivery schemes on commercial groves. Moreover, nitrogen overfertilization decreases polyphenol and antioxidant content in olive oil with subsequent changes in gustatory and chemical characteristics (Fernández-Escobar 2006). Urea consists a unique nitrogen fertilizer for olive groves due to its solubility properties, minimal phytotoxicity after foliar applications and compatibility with exogenous administration of growth hormones (Klein and Weinbaum 1985; Medan and Hussein 2018). In the past, foliar application of urea has been used successfully for non-nutritional purposes, such as thinning on var. Nocellara del Belice olive groves achieving 50% reduction of fruit set in 20 days after full bloom (Barattà et al. 1990).

Foliar fertilization of olive trees as an absolute alteration of nitrogen nutritional delivery path for olive groves is poorly investigated as direct replacement technique; herein cv. Konservolia and cv. Kalamon olive trees were characterized for their growth performance, inflorescence on annual shoots and fruit and pit characteristics due to urea foliar applications.

2. MATERIALS AND METHODS

2.1 Study site

The experiment was carried out in fully mature cv. Konservolia and cv. Kalamon olive orchards, located at central Greece (Agricultural area of Sourpi, Magnesia, GR; N39.103917 E22.856865) during years 2021 and 2022. Temperature and precipitation information was obtained according to the climate bulletins of the Hellenic National Meteorological Service Data Center for the full area of Sourpi (http://www.hnms.gr/emy/en/climatology/climatology_month) and local farming meteological network data, collected and analyzed by National Observatory of Athens (https://www.noa.gr/en/, https://www.meteo.gr, https://www.meteofarm.gr/). In Sourpi farming area the annual average temperature, annual maximum temperature, and annual minimum temperature were 16.08◦C, 29.2◦C, and 4.9◦C respectively. The annual average rainfall, is approximate 577mm. The study area has suitable olive tree culture especially for the two tested varieties.

2.2 Plots design

Olive trees were spaced at 5X5m and received in full all appropriated cultural practices related to irrigation, pruning and plant protection from pests and diseases. For each olive variety 6 rows of 5 trees were chosen to be examined for their response due to foliar application of urea, compared to conventionally soil fertilized controls which serve the commercial standard for olive culture [one dose of granular chemical fertilization at the beginning of vegetative growth (1500g/tree N)]. Olive groves in the experimentation area was 30-50 years old and had an history of at least 10 years of non-deficiency in N, P, K, B, Mo, Mg. No macro- or micro- nutritional deficiencies were recorded during experimental fertilization treatments.

Delivery scheme of foliar urea involved 5 aqueous applications from January to Jun [January (40Kg/tn), March (30Kg/tn), Jun (15Kg/tn supplemented with 10Kg/tn buffered KNO_3), Aug (5Kg/tn supplemented with 20Kg/tn buffered KNO_3) and September (5Kg/tn supplemented with 15Kg/tn buffered KNO_3)]. Addition of buffering factor in a fertilizer format [4 Kg $NH_4H_2PO_4$ (12-61-0) per tn of spraying volume] was set to secure acidified environment due to the effect of alkaline presence of KNO_3.

2.3 Evaluated parameters

In each olive tree, two branches of east and west orientation were selected to provide measurements of shoot length and growth rate (time intervals of 30 days) throughout the summer season. One year old shoots (n=18) were selected to measure number of developed inflorescences. Cumulative growth was assessed on total growth of annual shoots during experimentation period.

From both olive varieties when olives reach full grown, mature black stage, fruits were collected (n=30) and characterized for their size using digital micrometric caliper. Fruit dimensional parameters were assessed according to Seyedabadi et al. (2011). Same technique was followed for pit size evaluation. Fruit fresh weight, pit weight and flesh/pit ratio were assessed by analytical balance. Fruit flesh firmness was measured using precision fruit sclerometer (Lutron FR-5120, Korea).

2.4 Statistical analysis

Data were analyzed using the 95% confidence limits overlap protocol (Sokal and Rohlf, 1969). Graphic data are presented as means ± standard error of the mean. An α level of 0.05 was chosen. A minimum of five replicates containing 30 samples were used for each value or otherwise it is stated. Prism 8.0 (GraphPad) was used for data analysis.

3. RESULTS

Foliar application of urea affected positively cv. Kalamon olive fruit weight ($P < 0.001$); however urea delivery scheme did not affected fruit weight and size in cv. Konservolia ($P = 0.901$) (Table 1). Dimentional data of cv. Kalamon fruit reflect increase in size due to urea treatments [length, width, thickness ($P < 0.001$)], (Table1). Flesh firmness of olive fruits was lowered by urea treatments in both varieties [cv. Kalamon, $P<0.001$; cv. Konservolia, $P<0.001$], (Table 3).

Olive fruit pit weight was increased for both varieties under urea delivery scheme in comparison to conventional fertilization regime [cv. Kalamon, $P < 0.001$; cv. Konservolia, $P= 0.012$] (Table 2). All dimensional parameters of cv. Kalamon pit affected by urea treatements and increased [length, width an thickness ($P < 0.001$)]. In contrast, higher pit weights of cv. Konservolia fruits found to be correlated only to width dimensional increase (width 1, $P<0.001$), leaving unaffected pit length size ($P= 0.154$) (Table 2).

Table 1. Dimensional and weight effect of urea foliar application on cv. Kalamon and cv. Konservolia mature, black stage olives. Means ± standard error of the mean followed by the same letters for the same olive variety and for the same parameter are not significantly different.

	Fruit Weight (g)	Fruit Length (mm)	Fruit width (mm)	Fruit Thickness (mm)
Kalamon - Control	2.622 ± 0.487^a	22.47 ± 0.16^a	14.06 ± 0.11^a	13.72 ± 0.17^a
Kalamon - Urea treated	3.675 ± 0.111^b	24.81 ± 0.26^b	15.90 ± 0.19^b	15.53 ± 0.19^b
Konservolia - Control	6.006 ± 1.349^a	25.07 ± 0.20^a	19.96 ± 0.16^a	19.54 ± 0.16^a
Konservolia - Urea treated	5.993 ± 1.061^a	25.16 ± 0.17^a	19.71 ± 0.14^a	19.24 ± 0.14^a

Table 2. Pit weight and size effect of urea foliar application on cv. Kalamon and cv. Konservolia mature, black stage olives. Means ± standard error of the mean followed by the same letters for the same olive variety and for the same parameter are not significantly different.

	Pit Weight (g)	Pit Length (mm)	Pit Width (mm)	Pit Thickness (mm)
Kalamon - Control	0.494 ± 0.009^{a}	17.07 ± 0.13^{a}	7.19 ± 0.05^{a}	6.87 ± 0.04^{a}
Kalamon - Urea treated	0.578 ± 0.010^{b}	18.05 ± 0.18^{b}	7.67 ± 0.05^{b}	7.25 ± 0.04^{b}
Konservolia - Control	0.800 ± 0.014^{a}	15.79 ± 0.13^{a}	8.83 ± 0.06^{a}	8.70 ± 0.06^{a}
Konservolia - Urea treated	0.847 ± 0.011^{b}	16.08 ± 0.13^{a}	9.16 ± 0.04^{b}	8.73 ± 0.05^{a}

Table 3. Flesh firmness and flesh/pit ratio effect of urea foliar application on cv. Kalamon and cv. Konservolia mature, black stage olives. Means ± standard error of the mean followed by the same letters for the same olive variety and for the same parameter are not significantly different.

	Flesh Firmness	Flesh/Pit ratio
Kalamon - Control	2.84 ± 0.06^{a}	4.36 ± 0.08^{a}
Kalamon - Urea treated	2.60 ± 0.06^{b}	5.26 ± 0.10^{b}
Konservolia - Control	6.33 ± 0.25^{a}	6.50 ± 0.11^{a}
Konservolia - Urea treated	5.82 ± 0.22^{b}	6.11 ± 0.12^{b}

Growth rates of new vegetation on olive trees differ due to different fertilization regime for cv. Konservolia olive trees with the highest positive change per month in June (P= 0.007, fig1). This initial growth boost observed in foliar urea treated trees in June and August was also contributed to the new vegetation cumulative growth rates (June – September) in comparison to conventional fertilization program [FC_{cum}: 114.73%; TFcum: 256.1%. *P= 0.022]* (Fig. 1). Olive trees cv. Kalamon under foliar urea delivery scheme provided lower average growth rates to conventional fertilization regime without been - per month - significantly different. Olive cv. Kalamon cumulative growth rates for summer period did not differ among treatments [FCcum: 178.16% TFcum: 120.73%, *P= 0.174*] (Fig. 2).

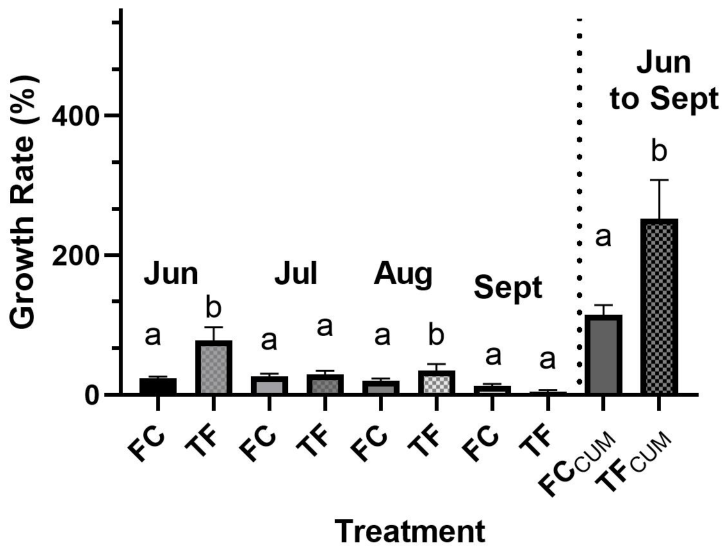

Fig. 1. Cv. Konservolia vegetation growth rates between treated with foliar urea delivery scheme (TF) and fertilized conventionally ones (FC) in a time lapse manner. Cumulative growth of both

fertilization regimes is shown on the side of the graph for fertilized conventionally (FC_{CUM}) and urea foliar treated olive trees (TF_{CUM}). All data represent the means ± standard error, n=18. Letters on bars followed by same letters for the same time period represent a not statistically significant different.

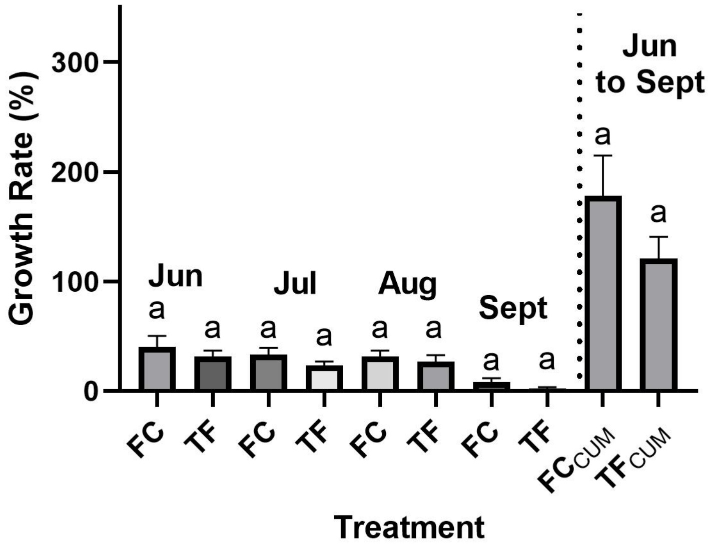

Fig. 2. Cv. Kalamon vegetation growth rates between treated with foliar urea delivery scheme (TF) and fertilized conventionally ones (FC) in a time lapse manner. Cumulative growth of both fertilization regimes is shown on the side of the graph for fertilized conventionally (FC_{CUM}) and urea foliar treated olive trees (TF_{CUM}). All data represent the means ± standard error, n=18. Letters on bars followed by same letters for the same time period represent a not statistically significant different.

Produced annual shoots length appear to be smaller on urea foliar treated olive trees for both varieties [Konservolia $P < 0.001$; Kalamon $P \leq 0.023$] (fig 3,4). Konservolia appears to have statistically different shoot elongation in absolute numbers for all summer months (June – September) (Fig. 3), whereas Kalamon did not appear to be affected by alteration in fertilization treatments in June (Fig. 4). No differences in inflorescence counts were found between treated and conventionally treated olive trees for all cultivars [Konservolia $P = 0.298$; Kalamon $P = 0.243$] (Fig. 5).

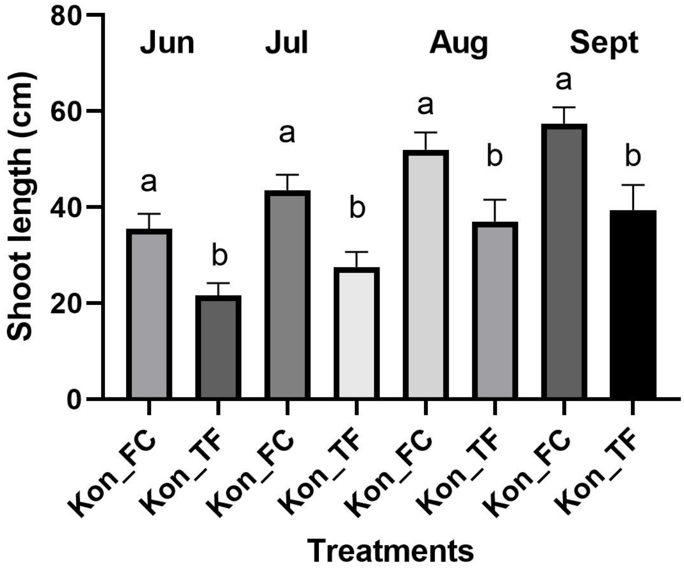

Fig. 3. Olive tree cv. Konservolia annual shoots length treated with foliar urea delivery scheme (TF) and fertilized conventionally ones (FC). All data represent the means ± standard error, n=18. Letters on bars followed by same letters for the same time period represent a not statistically significant different.

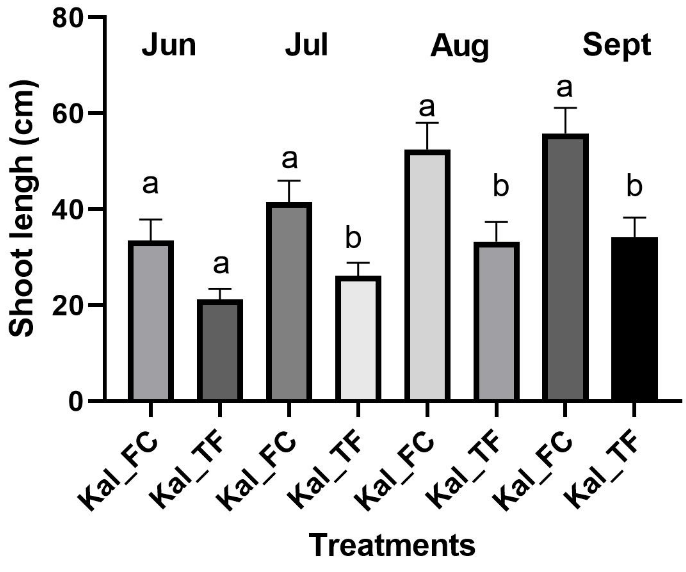

Fig. 4. Olive tree cv. Kalamon annual shoots length treated with foliar urea delivery scheme (TF) and fertilized conventionally ones (FC). All data represent the means ± standard error, n=18. Letters on bars followed by same letters for the same time period represent a not statistically significant different.

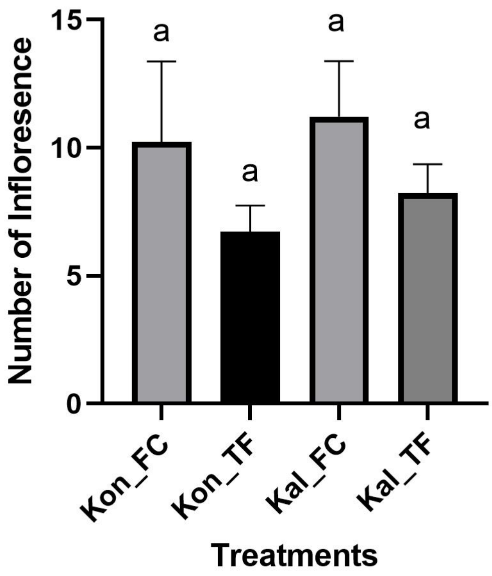

Fig. 5. Number of inflorescences between treated with foliar urea delivery scheme (TF) and fertilized conventionally ones (FC) for cv Konservolia (Kon_) and cv. Kalamon (Kal_). All data represent the means ± standard error, n=18.

4. DISCUSSION

Vegetative growth rates due urea foliar applications did not support cv. Kalamon canopy growth; however, cv. Konservolia was positively affected in comparison to conventionally fertilized trees.

Application of urea on olive trees cv. Mission affected positively leaf N concentration; however, this change wasn't subsequently reflected on annual yield, fruit size and shoot growth (Connell et al. 2002). In terms of increased leaf N concentration after foliar application of urea, similar results were obtained in cv. Picual, Manzanillo, Khodeiri, Dremalali and Sorani olive groves with a flexible nitrogen translocation mechanism to younger leaves and fruits (Al-Aareji and Al-Hamadany 2005; Fernández-Escobar et al. 2011; Sánchez-Zamora and Fernández-Escobar 2002).

Urea application on olive trees appears to be specific on varietal, time and zone climate conditions. In Egypt, winter foliar applications of urea increased cv. Picual yield, leaf mineral content and fruit properties which comes in contrast with obtained data from cv. Manzanillo olive trees in Mexico where urea application did not be proven as valuable to alleviate of low fruit set in high temperatures (Abd El Migeed et al. 2017; Navarro-Ainza et al. 2016).

Foliar application of KNO_3 with urea with supplementation of K_2S investigated as an integration plan to traditional soil fertilization in cv. Carolea olive trees where KNO_3 was found to contribute towards higher fruit fresh, dry weight and flesh to pit ratio without affecting olive oil quality (Inglese et al. 2002). Foliar urea applications of cv. Zard olive trees offer greater yield (kg/tree) and yield efficiency (kg/cm^2) in fruits in comparison to control and nano-chelated nitrogen fertilizer in Iran (Rohi Vishekaii et al. 2021).

Urea application did not affected number of inflorescences; olive trees are not affected on their flowering performance when *O. europaea* trees are not nitrogen deficient (Fernandez-Escobar et al. 2008).

One shot foliar application of 2% urea on cv. Kalamon at full bloom in Egypt led to higher average flesh/pit ratio value (6.22) in comparison to 4% KCl + 2% Urea scheme (6.16) and untreated control (6.06); however combinations of 1% CaCl (21%) + 2% urea, 2% CaCl (21%) + 2% urea and 2%KCl + 2% urea provided lower than control ratios (El-Sharkawy et al. 2014). Herein, urea delivery scheme for cv. Kalamon conferred lower flesh/pit ratio rank (5.26) significantly higher than the untreated control.

Same researchers reveal that one-time full bloom application of urea on cv. Kalamon increased fruit yield 5,5 Kg per tree in comparison to control; higher values were achieved from applied combinations of foliar urea (2%) with potassium chloride (2-4%) at the same physiological stage.

In this piece of work, fruits from cv. Kalamon trees found to get more weight when air-foliar treated with urea. Comparatively, cv. Kalamon, sprayed once at bloom stage with urea 2% provided fruits in average lighter than the control (5,395g vs 5,555g respectively), with minor differences in dimensional data (fruit length, fruit diameter, fruit shape) (El-Sharkawy et al. 2014). Olive fruit firmness for both tested varieties was lowered under urea treatment, data which are in accordance to foliar urea applications on cv. fuji apple orchards (Fallahi et al. 2002).

According to Olive World Germplasm Bank of CIFA cv. Kalamon exhibits 4,3g average fruit weight, 8,6 flesh/stone ratio and 50,4% oil content (dry matter %); however latest update for Kalamon revealed 4,96g average fruit weight and 9.2 flesh/stone ratio (Del Río and Caballero 2008; Agriopoulou et al. 2021). Similarly, to cv. Kalamon fruit geographic variations, recorded data for cv. Konservolia also demonstrate a spatial variance in terms of fruit size and tissue ratios; fruits produced in Greece reveal 5,95g average fruit weight and 7.6 flesh/stone ratio in contrast to those produced in Iran [5.88g average fruit weight and 4.59 flesh/stone ratio] (Agriopoulou et al. 2021; Taslimpour et al. 2016). Our data reveal: a) production of cv. Kalamon fruits in Greece can be 40% lighter with 50% lower flesh/stone ratio and b) production of cv. Konservolia fruits in Greece can be 21% heavier with up to 30% higher flesh/stone ratio than previously known standards from optimized and fully monitored olive groves suggesting spatial phenotypic plasticity possibly due local relief and microclimate conditions.

Size measurements of olive stone consist a great interest for phenotypic characterization of cultivar fruits, olive breeding, characterization of cultivational practices and functionality of olive pitting machines for food industry using deep learning and artificial intelligence (De Jódar Lázaro et al. 2020). Herein, urea increased olive pit stone size. Foliar application of 7.5g/lt urea and in combination with boric acid (2g/lt B + 5g/lt urea) increased dimensional parameters of cv. Shengeh olive stone (Sayyad-Amin et al. 2013).

Greater weights and sizes in olive stones due to foliar urea application could be useful for new sustainable products development, eliminating orchard waste and using least resources. Died, pyrolyzed activated, grinded and fractionized olive stone provide fundamental basis of materials in packaging, food, pharmaceutical, chemical and electric power industry (Rodríguez et al. 2008; Khwaldia et al. 2022). Increasing biomass olive stone size in a sustainable way (e.g. via foliar spray fertilization) may lower prices as a raw material: a) for industrial applications since it costs double price (80–100 €/t) than olive-tree pruning wastes (30–40 €/t) (Cuevas et al. 2019), and b) for biological denitrification and metal biosorption (Corral-Bobadilla et al. 2021; Salem et al. 2007). Sensory acceptance of roasted olive stones as alternative, non-caffeinated coffee resource rich in phenolic compounds, flavonoids and secoiridoids suggests that up to now valorization of olive pit size is strongly underestimated (Eid et al. 2021).

5. CONCLUSIONS

Foliar applications of urea have a significant effect on growth rates shoot length and fruit dimensional, anatomical and physical data for olive varieties cv. Konservolia and Kalamon. Konservolia variety can accept urea foliar applications as a nutritional replacement; Kalamon variety exhibits increased final fruit pit weight and size which can also feedback third applications to circular economy.

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