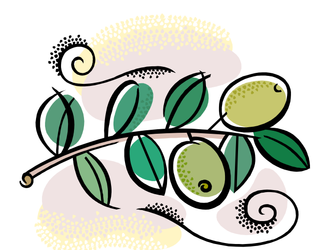
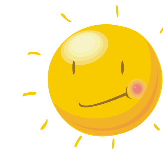
The importance of optimizing Macro-elements fertilization in olive

Arnon Dag, Gilat Research Center
Agricultural Research Organization
(Volcani Institute)
Ministry of Agriculture, Israel



Limiting factors:
water and nutrients

Limiting factor:
Radiation



Close spaced planting

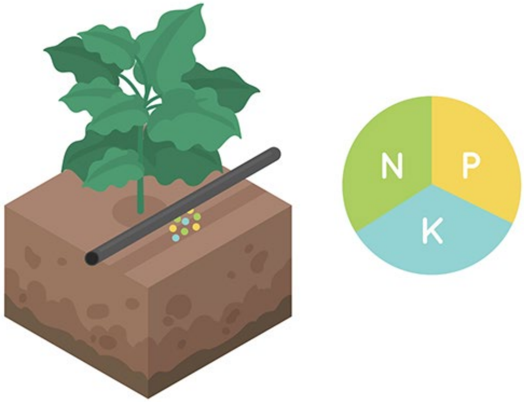
Traditional orchards → Intensive orchards

Table 6.3.2. Comparison of fertilization in rainfed vs. irrigated olive orchards.

	Rainfed	Irrigated
Timing of fertilizer application	Towards the end of winter	During spring/ summer
Formulation of fertilizers	Solids	Liquid forms or dissolved solids
Fertilization efficiency	Low	High
Tree nutrient requirement	Low	High

Dag et al., 2023. Nutrition and Fertilization. In: The Olive Botany and Production. pp 374-414.

Fertigation



‘Precision’ Olive Management

Maximize oil yield and oil quality

Minimized inputs; irrigation, fertilization, labor

Fertilization experiments of olives in Israel

Controlled – Containers

- N, P and K
- P carbohydrate
- K, Na and drought
- Mycorrhizae
- Ca- oil quality

Field

- Treated wastewater
- N, P and K
- Ca, Zn, Fe

Olive productivity

Productivity (fruit number) = Flowering X fruit set

Flowering ⇨ Reproductive buds and flowers per inflorescence

Fruit set ⇨ Flower viability, pollination, fertilization and fruitlet abscission

Fruit Yield * % Oil in fruit = Oil yield

Experimental layout

Treatments

Soil measurements

Drainage measurements

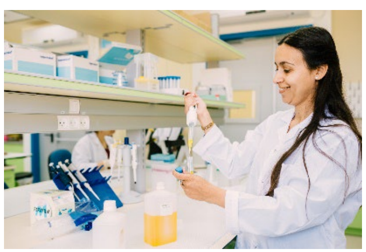
Fig. 6.3.16. Illustration of the diagnostic leaves (youngest fully developed leaves). Leaves should be sampled in July (northern hemisphere) from a non-bearing branch. (Photo: Tali Nachshon Dag)

Plant nutritional status

Productivity

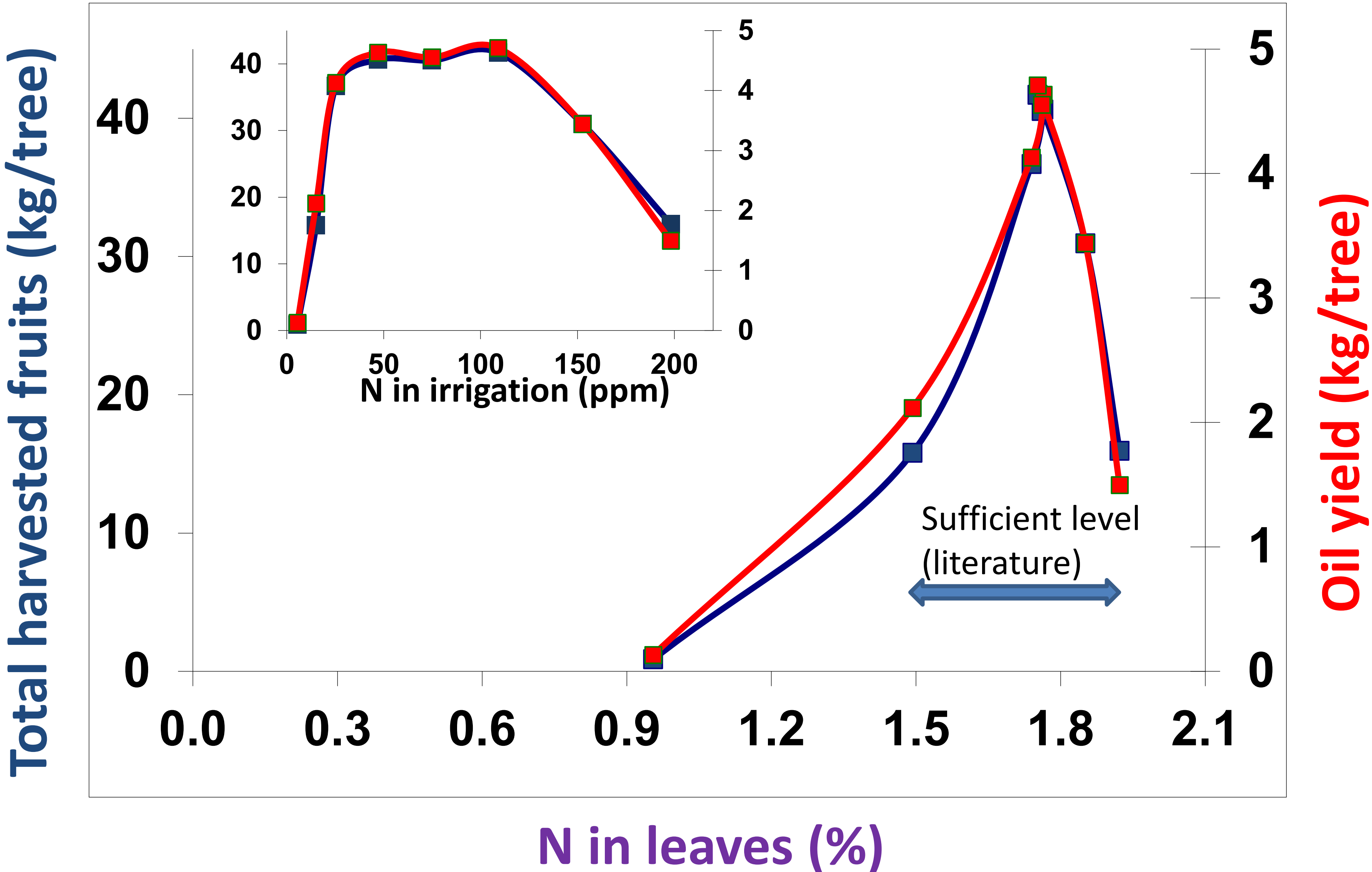
Oil content

Oil quality



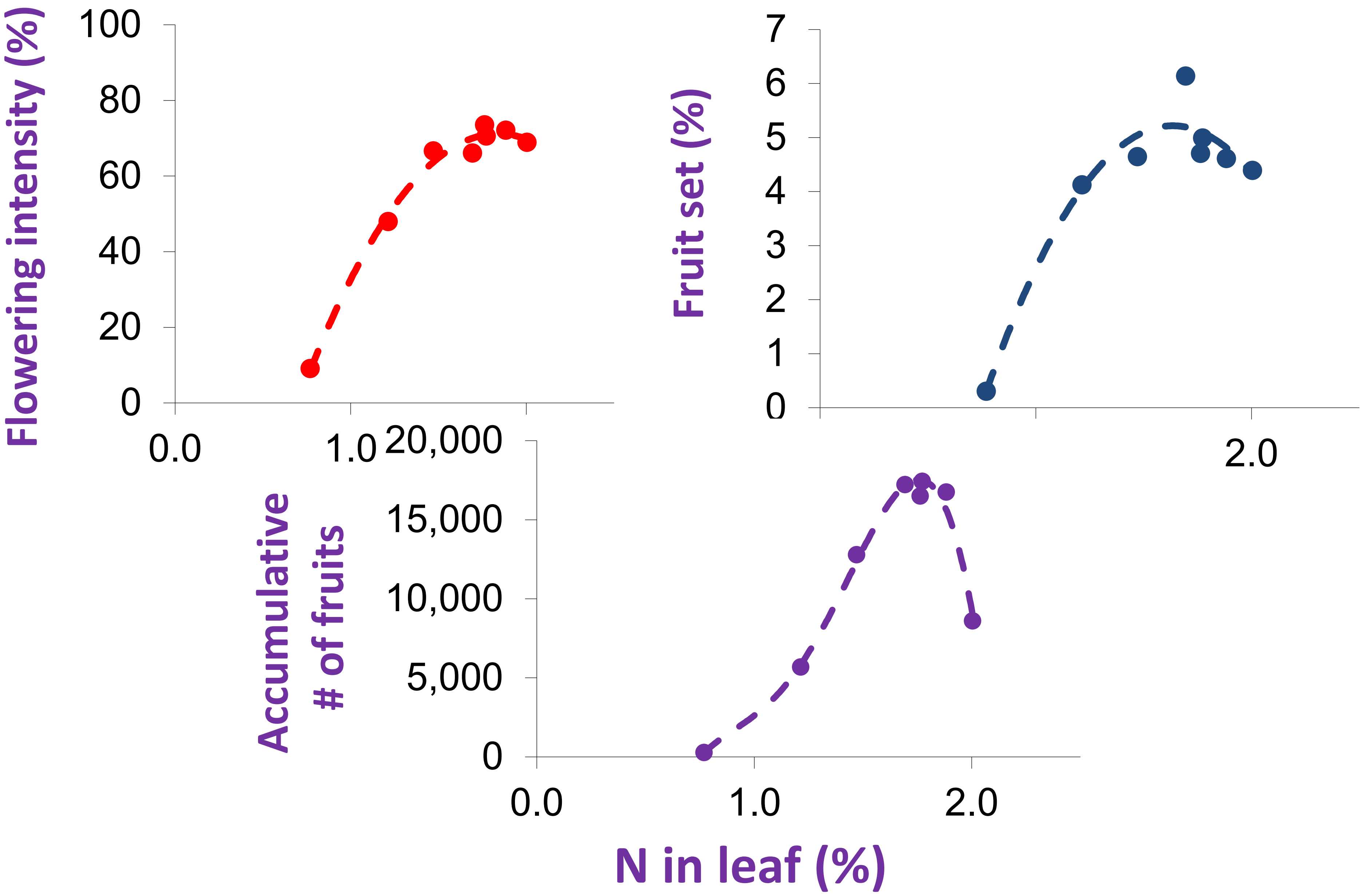
Nitrogen (N)

The effect of nitrogen level in leaves on fruit and oil yield

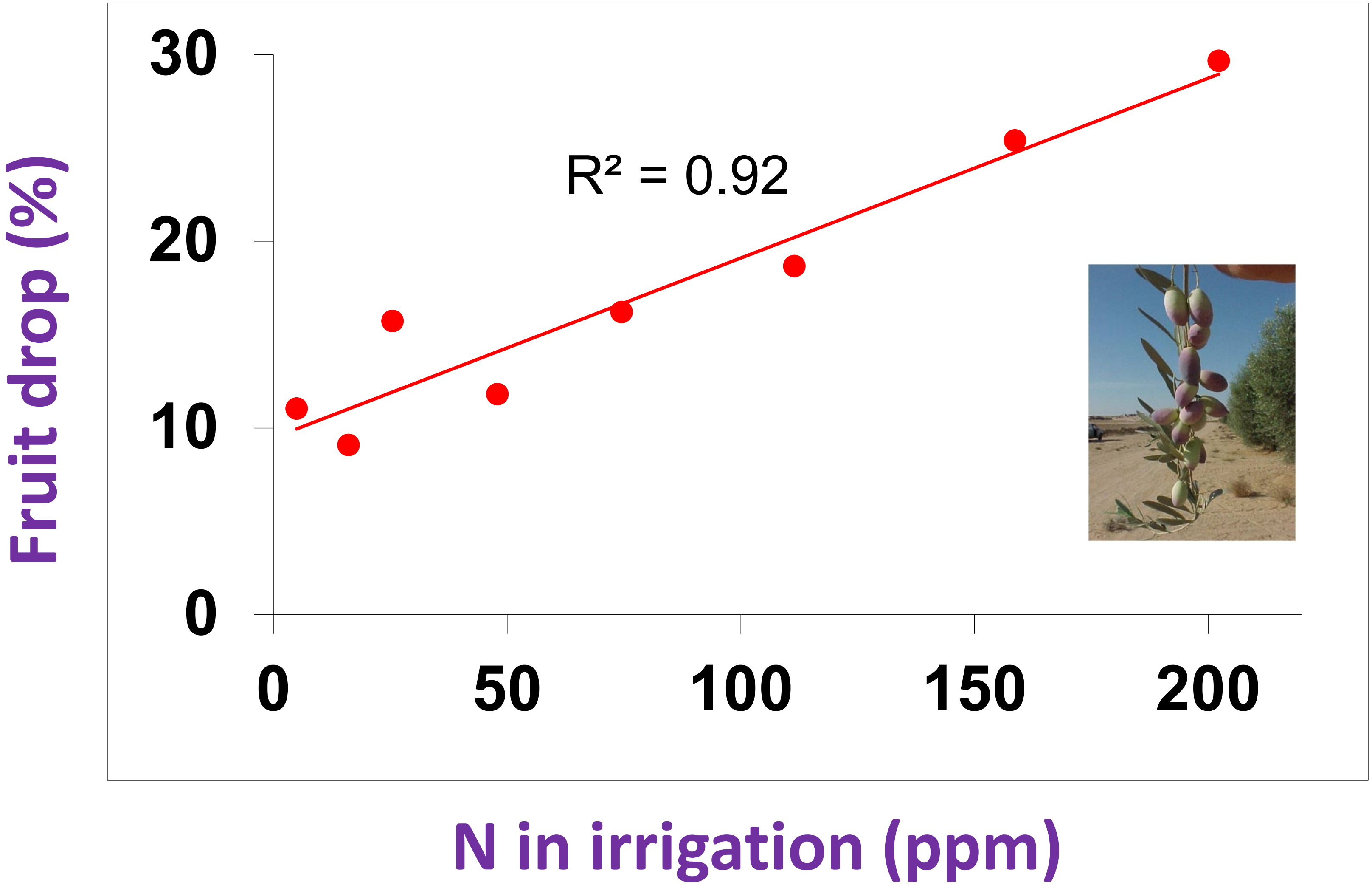


Erel et al., (2013) Scientia Hort.

The correlation between nitrogen level in diagnostic leafs to productivity



The correlation between nitrogen level in Irrigation solution and fruit drop



Field
Exp.

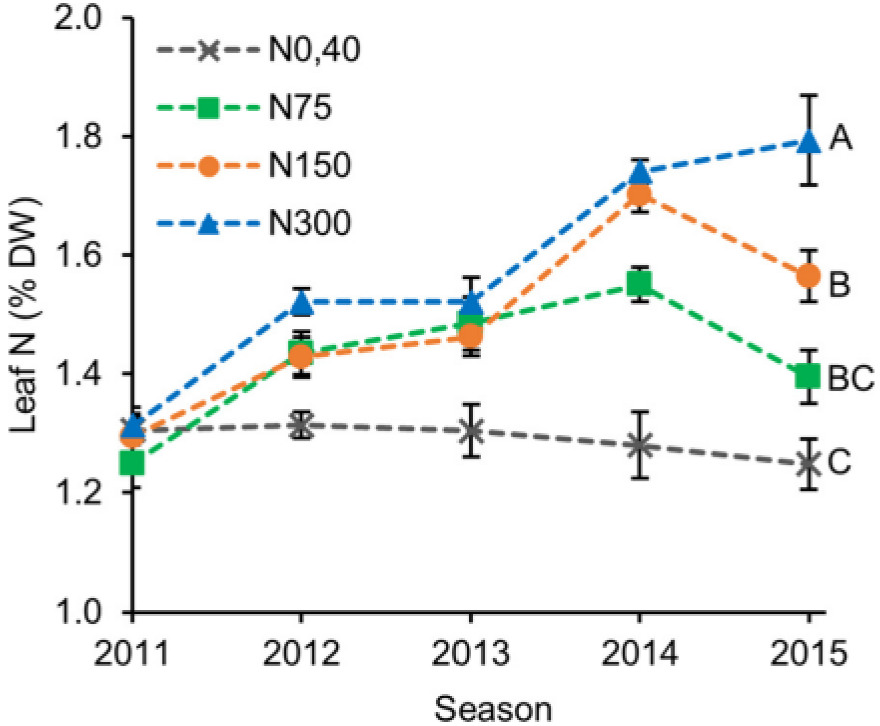
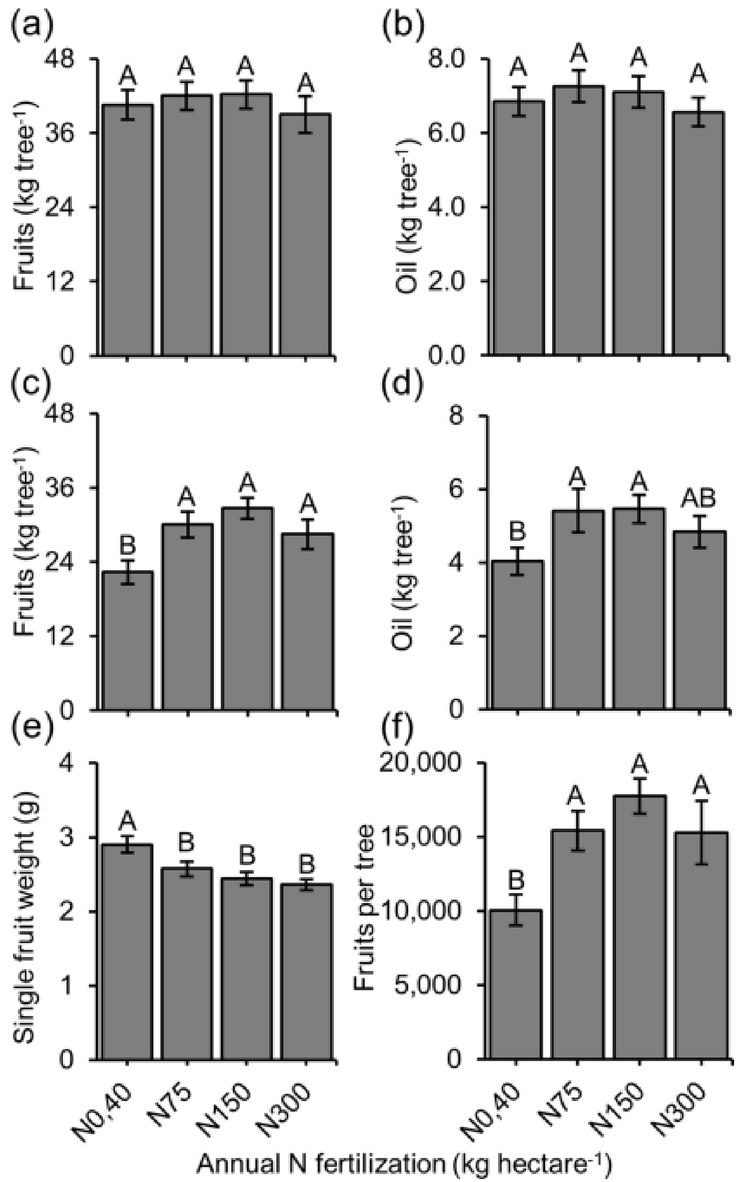


Fig. 1. Effect of N fertilization on leaf N concentration. Experiment plots were fertilized with annual amounts of 0 (40 in 2015–2016 seasons), 70, 150 or 300 kg N hectare^{-1}. Leaf N concentration was determined as percentage of leaf dry weight (DW) sampled during July. Numbers are mean values of 14 replicates (trees) ± standard error of the mean (bars). Different letters indicate a statistical significant difference between N levels in July 2015 according to Tukey-Kramer HSD test ($P \leq 0.05$).

Haberman, A., Dag, A., Shtern, N., Zipori, I., Erel, R., Ben-Gal, A., & Yermiyahu, U. (2019). Significance of proper nitrogen fertilization for olive productivity in intensive cultivation. *Scientia horticulturae*, *246*, 710-717.

Field Exp.



2011-12

2013-16

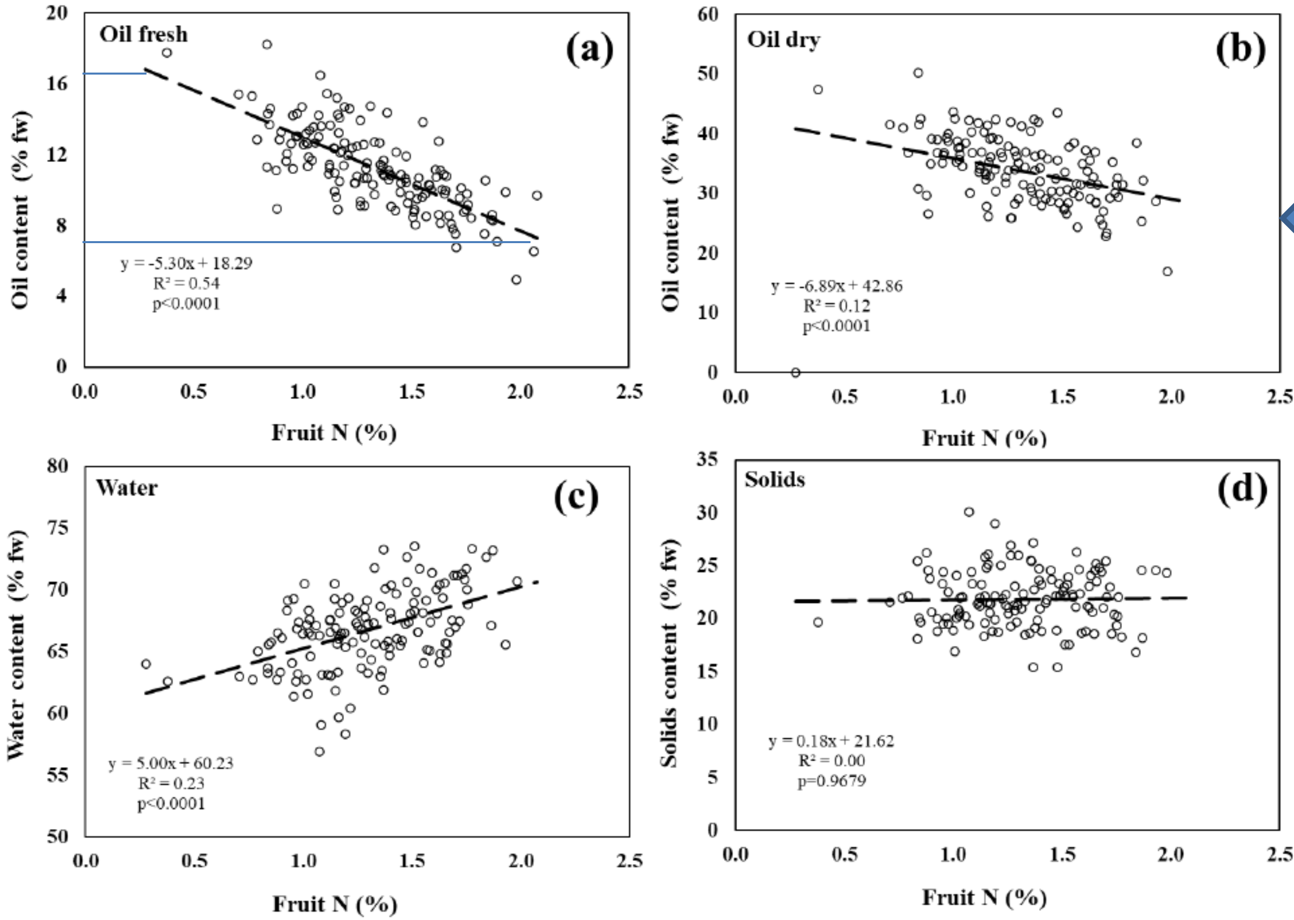
Fig. 3. Effect of N fertilization on yields. Experiment plots were fertilized with annual amounts of 0 (40 in 2015–2016 seasons), 70, 150 or 300 kg N hectare^{-1}. Mean annual fruit (a, c) and estimated oil (b, d) yield, in 2011–2012 (first two seasons of the experiment; a–b) and 2013–2016 (c–d) seasons. (e) Average single fruit weight, in 2013–2016 seasons. (f) Estimated annual number of fruit per tree for 2013–2016 seasons. Numbers are mean values of 14 replicates (trees) ± standard error of the mean (bars). Different letters indicate a statistical significant difference according to Hsu's MCB test ($P \leq 0.05$).

Haberman, A., Dag, A., Shtern, N., Zipori, I., Erel, R., Ben-Gal, A., & Yermiyahu, U. (2019). Significance of proper nitrogen fertilization for olive productivity in intensive cultivation. Scientia Horticulturae, 246, 710-717.

Figure 3. Olive fruit composition in the controlled experiment. (a) % oil by fresh weight, (b) % oil by dry weight, (c) water content, and (d) solids content as a function of fruit N concentration. Linear regressions of oil content (fresh), oil content (dry) and fruit water content are significant (p<0.0001). Solids content are not significantly affected by fruit N. Each symbol represents an individual tree at a given fruit year (2007-2009, n=96).

Containers Exp.

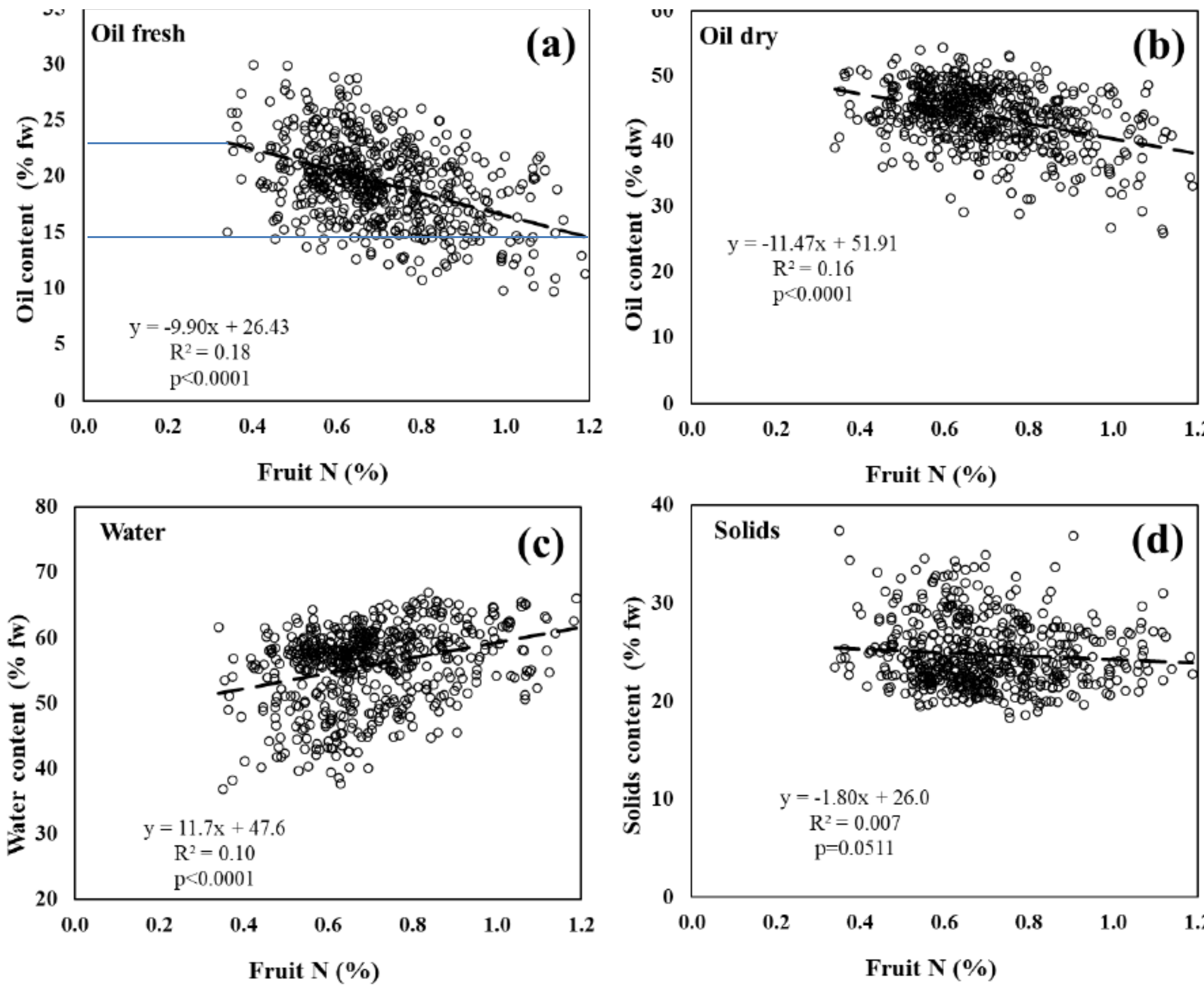
Oil content



Erel et al., (2023) Elevated fruit nitrogen impairs oil biosynthesis in olive. Front. Plant Sci. 14

Figure 4. Olive fruit composition in the field experiment. (a) % oil by fresh weight, (b) % oil by dry weight, (c) water content, and (d) solids content in response to fruit N concentration. Linear regressions of oil content (fresh), oil content (dry) and fruit water content are significant ($p<0.0001$). Solids are not significantly affected by fruit N. Data was collected throughout the experiment, each point represents an individual tree at a given fruit year (2011-2015, n=570).

Field Exp.

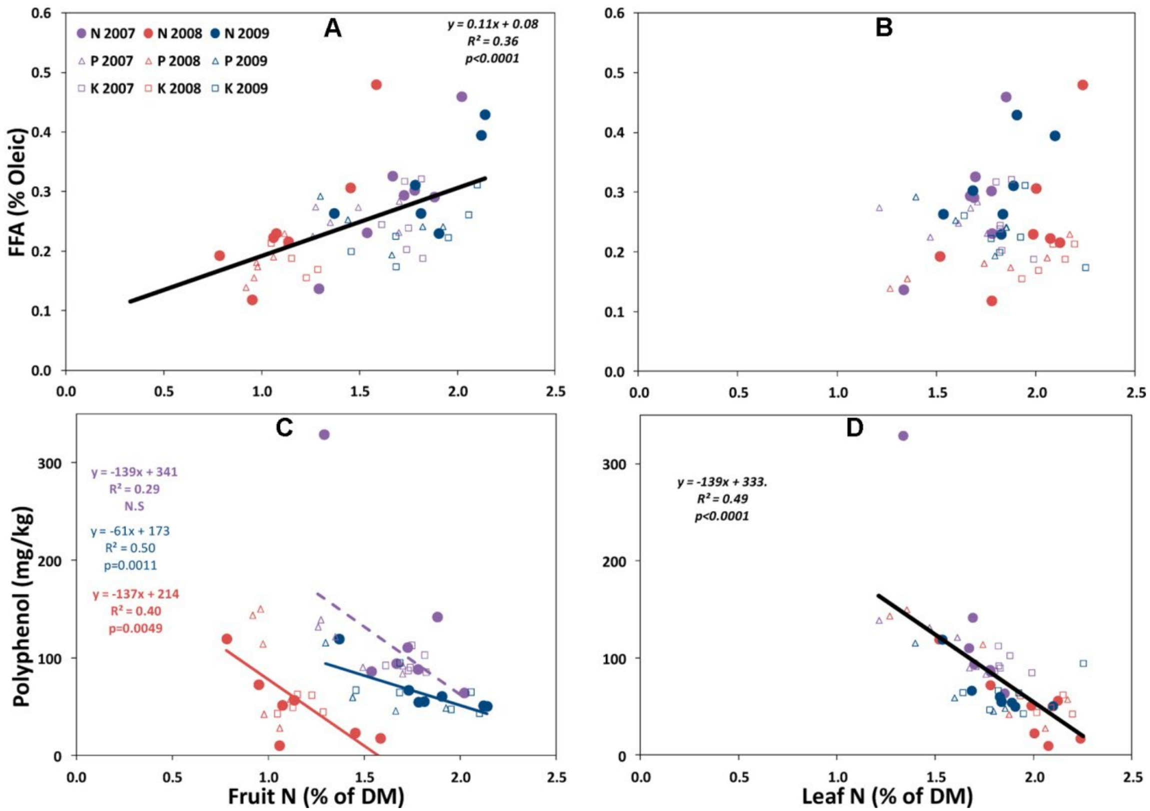


Erel et al., (2023) Elevated fruit nitrogen impairs oil biosynthesis in olive. Front. Plant Sci. 14

These results agree with those reported for oilseed crops for which a trade-off between oil and protein was proposed as the governing mechanism for the negative response to elevated N levels.

The effect of <u>nitrogen availability</u> on oil quality parameters

Containers Exp.

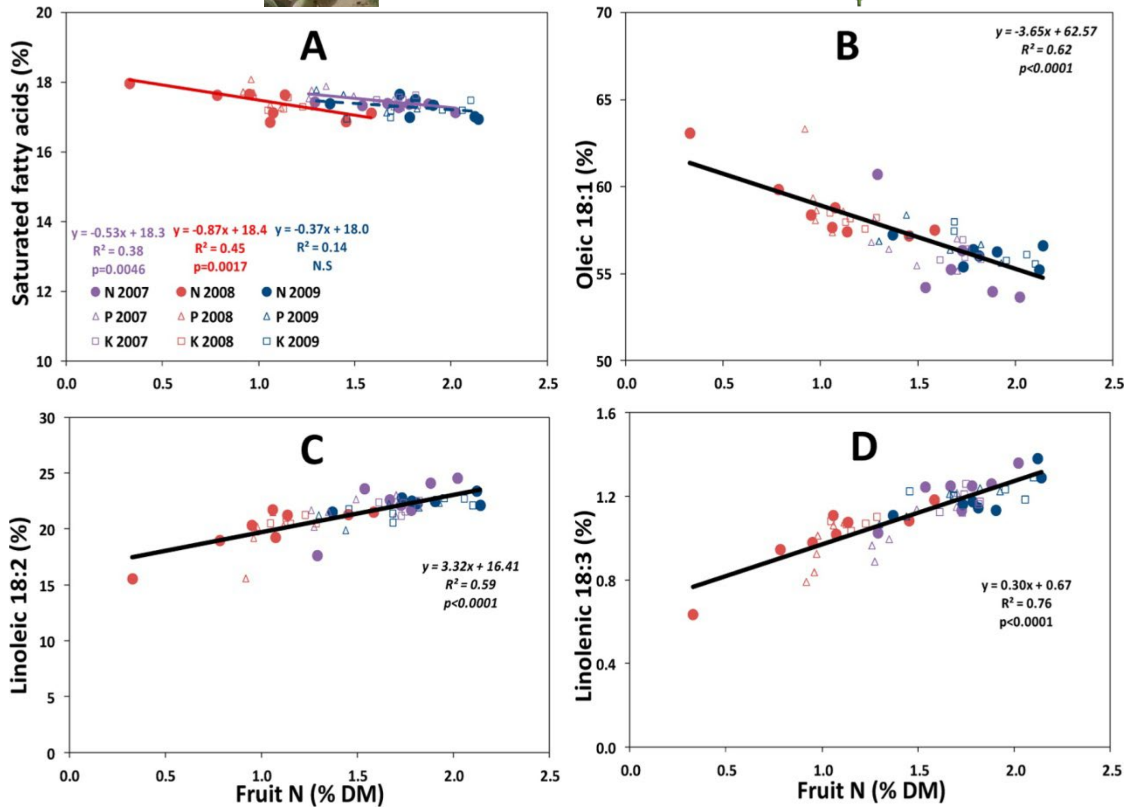


Average free fatty acid (a and b) and polyphenol (c and d) concentration as a function of N concentration in fruit flesh (a and c) and in leaves (b and d) for the three studied years: 2007 (purple), 2008 (red), and 2009 (blue) and the three manipulated treatments: N (●), P (▲), and K (■). Each point represents an average of six replicates in 2007 and three replicates in 2008 and 2009.

Published in: Ran Erel; Zohar Kerem; Alon Ben-Gal; Arnon Dag; Amnon Schwartz; Isaac Zipori; Loai Basheer; Uri Yermiyahu; *J. Agric. Food Chem.* **2013,** 61, 11261-11272.

The effect of nitrogen availability on oil fatty acids profile

Containers Exp.

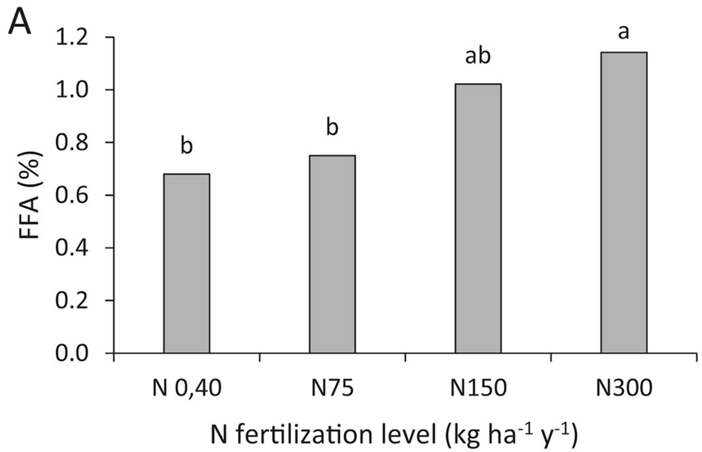


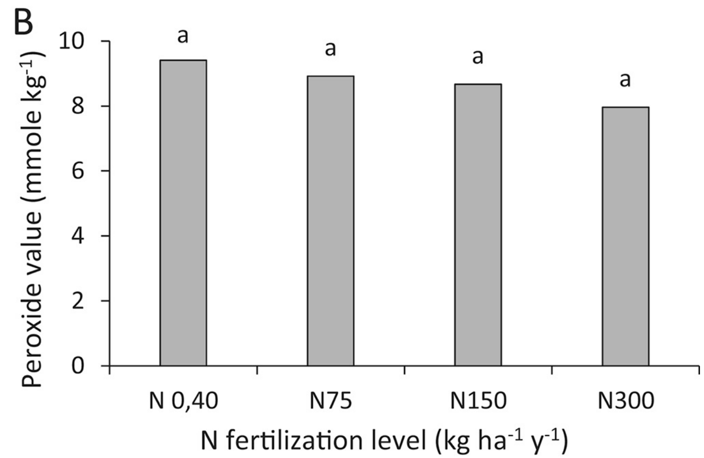
Fatty acid composition as a function of N concentration in fruit flesh for the three studied years: 2007 (purple), 2008 (red), and 2009 (blue) and the three manipulated treatments: N (●), P (▲), and K (■). Each point represents an average of six replicates in 2007 and three replicates in 2008 and 2009. The statistical parameters of the model are presented in Table 4.

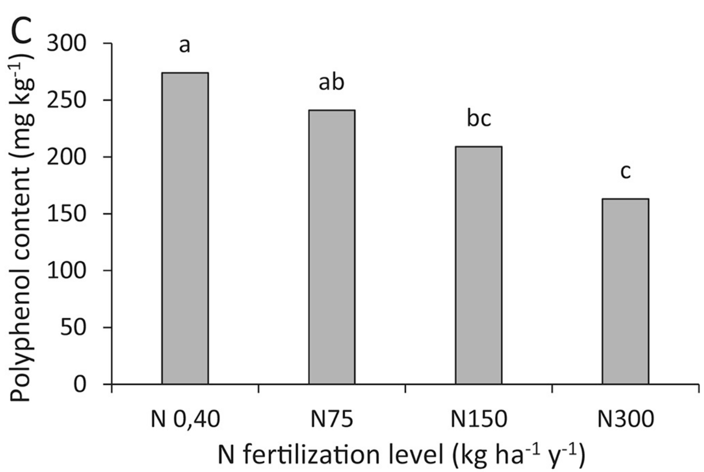
Published in: Ran Erel; Zohar Kerem; Alon Ben-Gal; Arnon Dag; Amnon Schwartz; Isaac Zipori; Loai Basheer; Uri Yermiyahu; *J. Agric. Food Chem.* **2013,** 61, 11261-11272.

The effect of nitrogen availability on oil quality parameters, 6-year average, field study (Negba)

Field Exp.



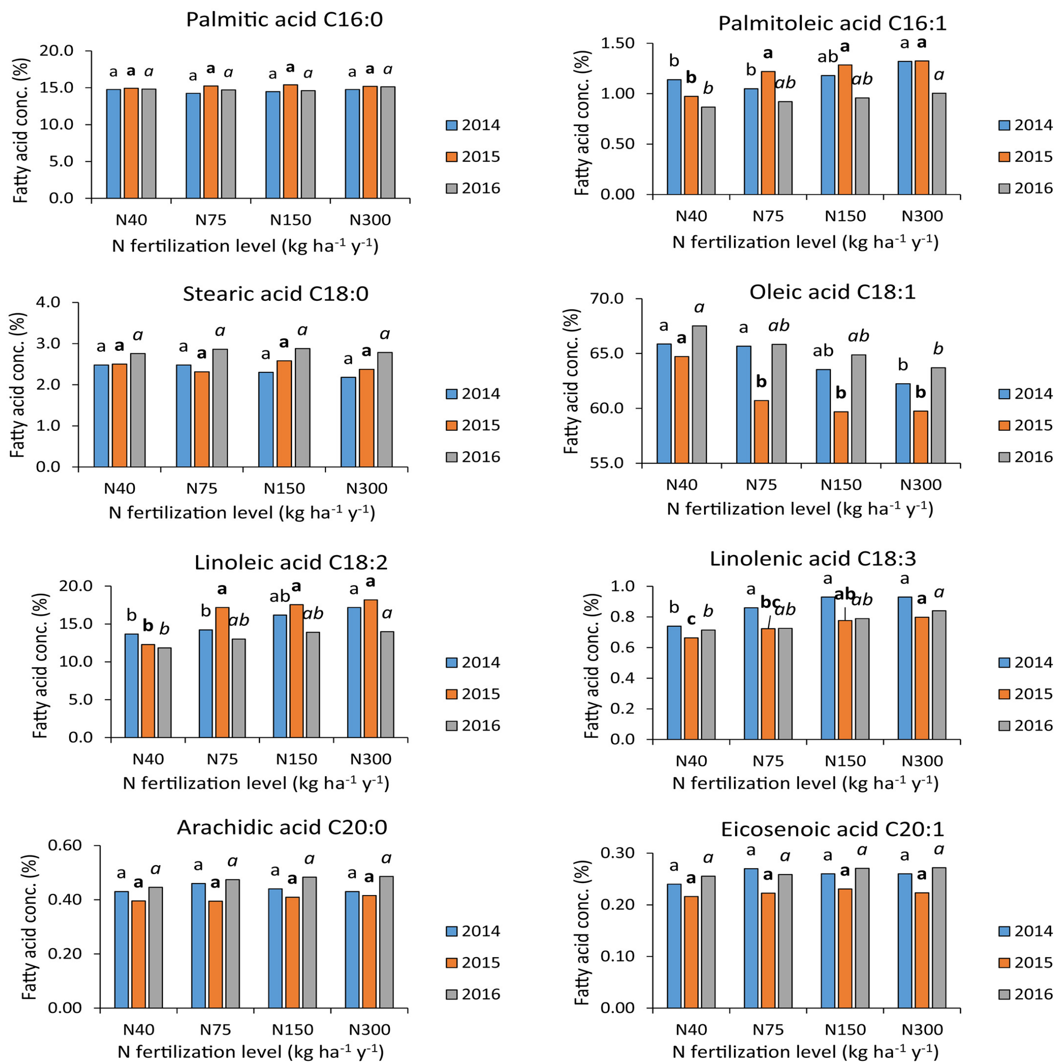




Zipori et al. (2023). J. Sci. Food Agric. 48-56.

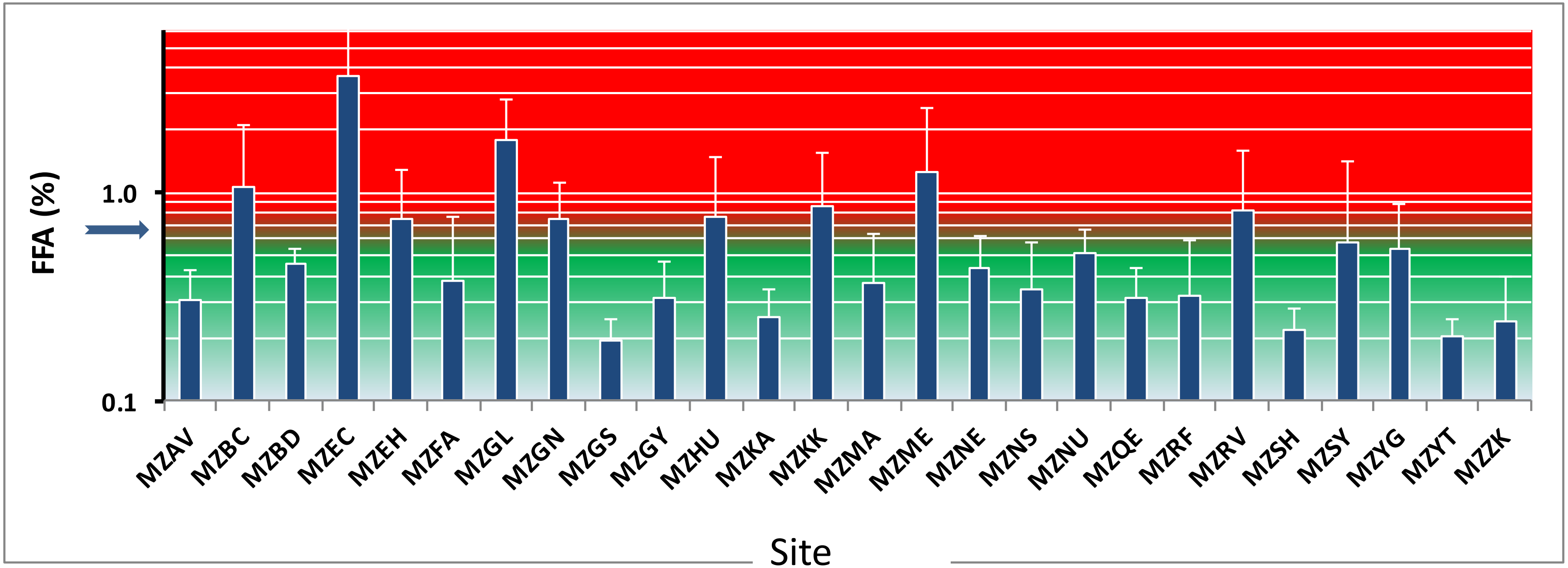
The effect of nitrogen availability on oil quality parameters, 6-year average, field study (Negba)

Field Exp.



Zipori et al. (2023). J. Sci. Food Agric. 48-56.

Free Fatty Acids content in Barnea Olive Oil , 2011



Bustan et al. (2014). Scientia Hort. 176: 11-21.

Table 3. Relationships between yield, fruit- and oil-quality parameters and olive oil acidity. The survey database was divided into two categories of olive oil acidity, below and above the FFA threshold of 0.6%. In 2011 and 2012, 753 and 587 trees were sampled, 197 and 184 of which belonged to the high-acidity group.

Harvest season	**2011**			**2012**		
Category of oil acidity	**Low**	**High**		**Low**	**High**	
Yield level (1–5)	3.7	2.1	***	3.5	2.3	**
Fruit weight (g per fruit)	2.40	3.27	**	2.91	3.66	**
Fruit ripening index (0–7)	2.87	4.10	**	2.70	3.19	*
Fruit oil content (% of FW)	18.2	19.2	NS	16.9	19.9	*
Fruit oil content ($g\,g\,DW^{-1}$)	0.431	0.445	NS	0.404	0.448	*
Fruit water content (% of FW)	57.6	57.1	NS	58.6	55.3	NS
Incidence of *B. oleae* (%)	5.8	9.0	NS	1.5	1.4	NS
Incidence of fungal pathogens (%)	28.8	40.8	**	34.0	57.1	**
Fruit N conc. (%)	0.65	0.77	*	0.78	0.87	**
Fruit P conc. (%)	0.079	0.097	*	0.082	0.099	**
Fruit K conc. (%)	1.41	1.50	NS	1.43	1.46	NS
FFA (%)	0.32	1.89	***	0.30	1.57	***
Peroxide ($meq.kg^{-1}$)	11.6	13.5	*	11.2	12.9	*
Polyphenols ($mg\,kg^{-1}$)	258	155	**	286	167	*

* $P < 0.05$
** $P < 0.01$
***$P < 0.001$

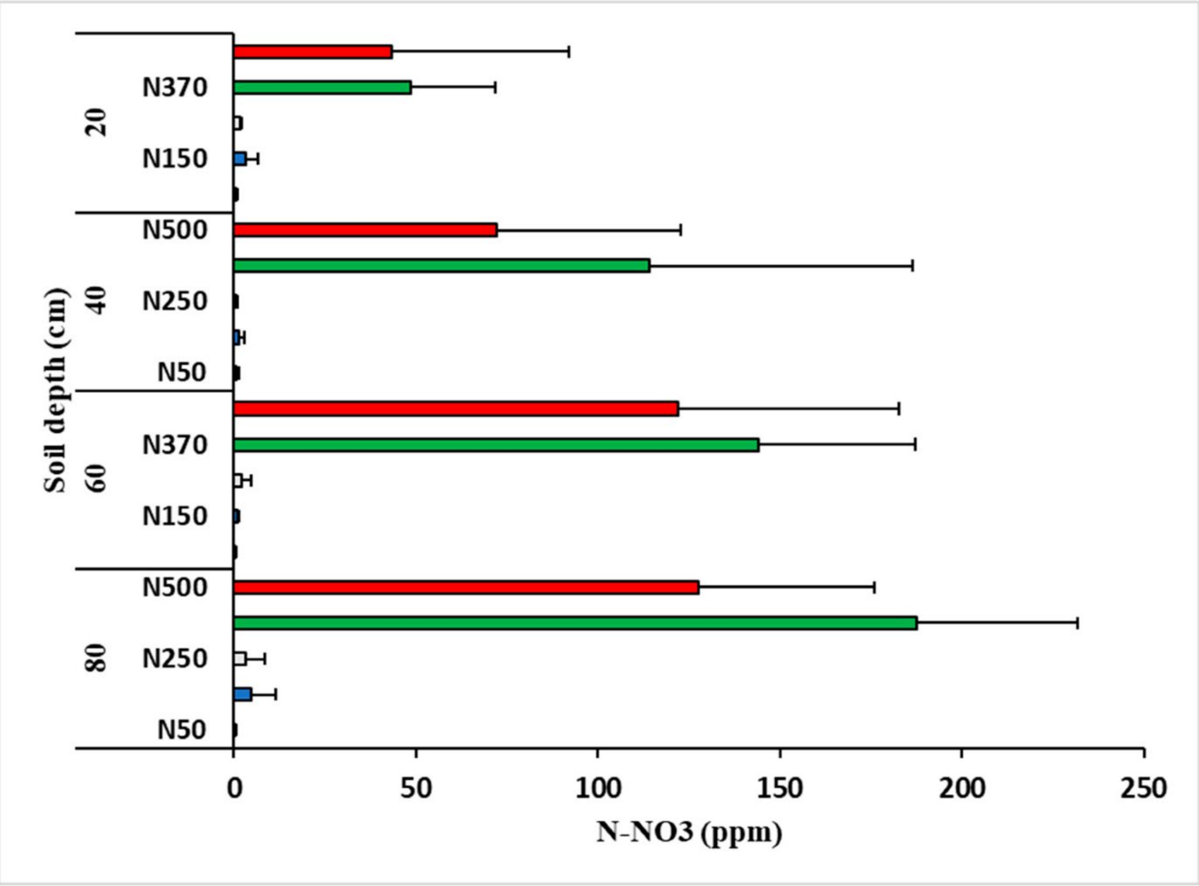
Bustan et al. (2014). Scientia Hort. 176: 11-21.

Jones and Hartley (1999) suggested a protein/phenol competition model. The model's mechanism is derived from biosynthetic pathways of proteins and phenols which share phenylalanine as a common precursor. A high mineral N level induces the biosynthesis of proteins and hence consumes the limiting precursor. A low N level permits more phenylalanine for the synthesis of secondary metabolites, i.e., polyphenol.

Jones, C. G.; Hartley, S. E. A protein competition model of phenolic allocation Oikos 1999, 27– 44

Adequate nitrogen is essential for olive oil production in intensive orchards, however, increased N rates negatively affect oil quantity and quality.

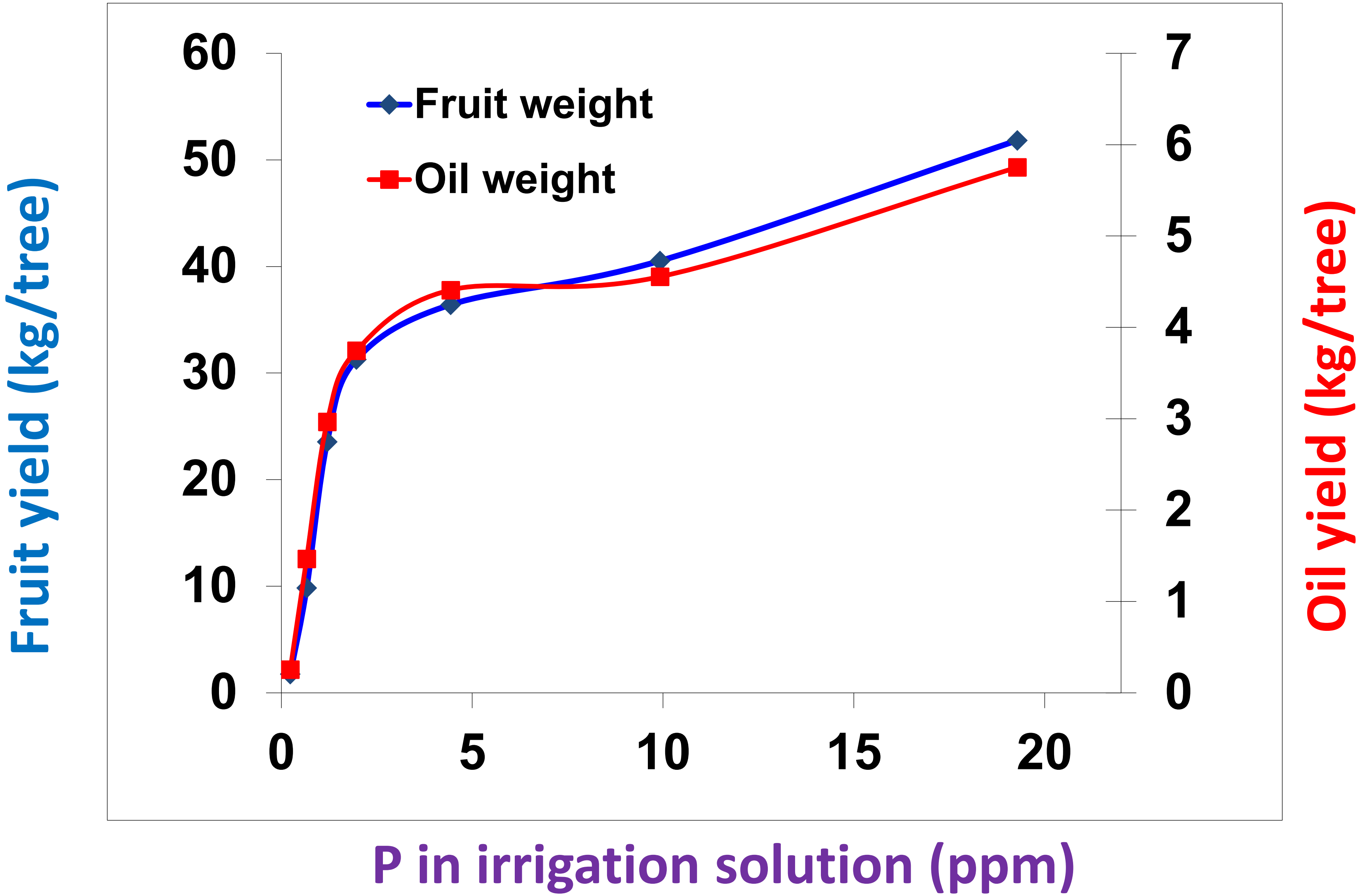
Figure 4. Jojoba; Soil nitrate (N-NO_3) measured on 14 September 2020 after annual fertilization was completed in all treatments. Values are means of five plots per treatment ± SE.



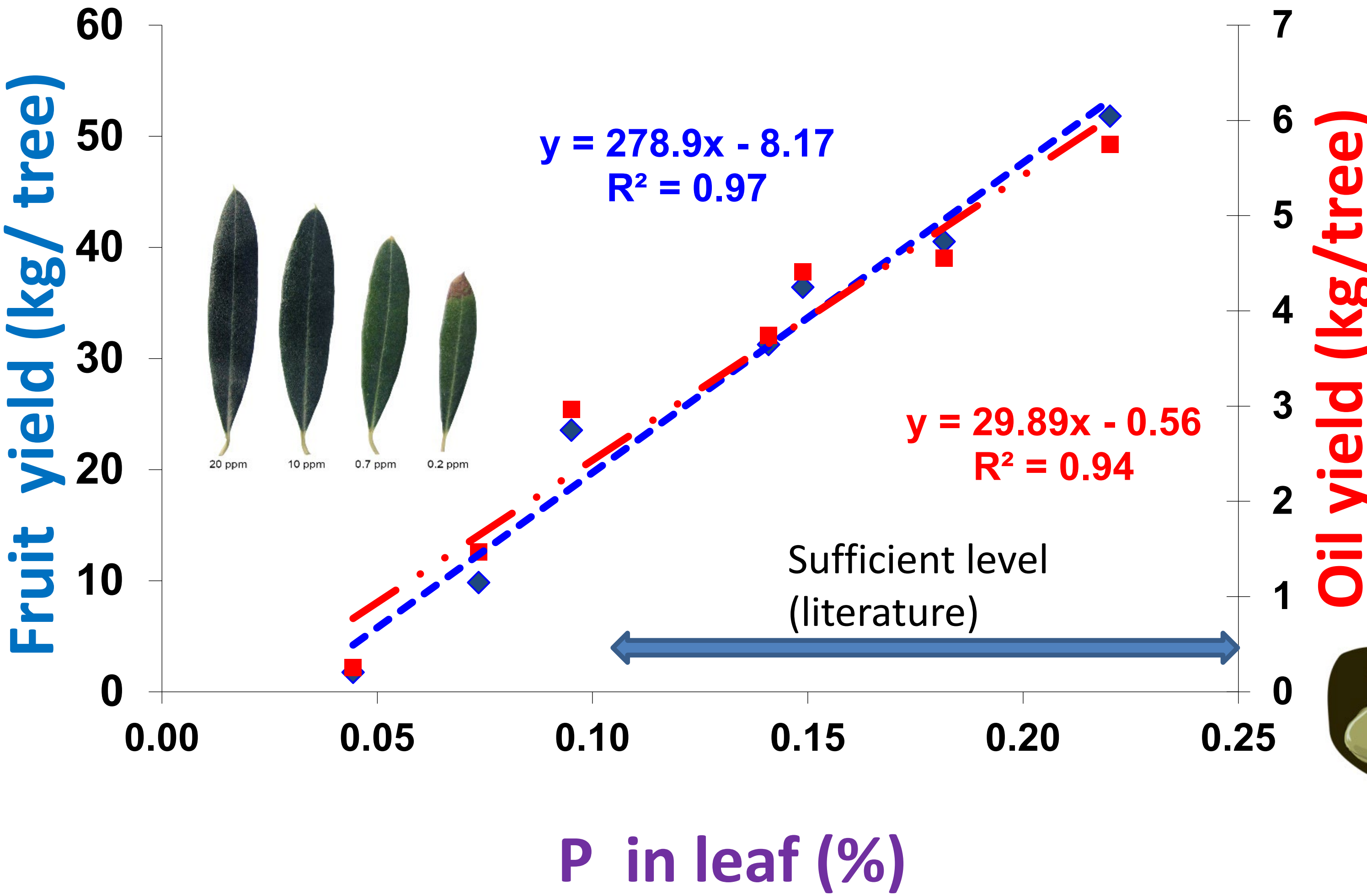
Dag, A., Badichi, S., Ben-Gal, A., Perry, A., Tel-Zur, N., Ron, Y., ... & Yermiyahu, U. (2023). Optimizing nitrogen application for jojoba under intensive cultivation. *Plants*, *12*(17), 3132.

Phosphorous (P)

The correlation between phosphorous level in Irrigation solution and fruit and oil yield

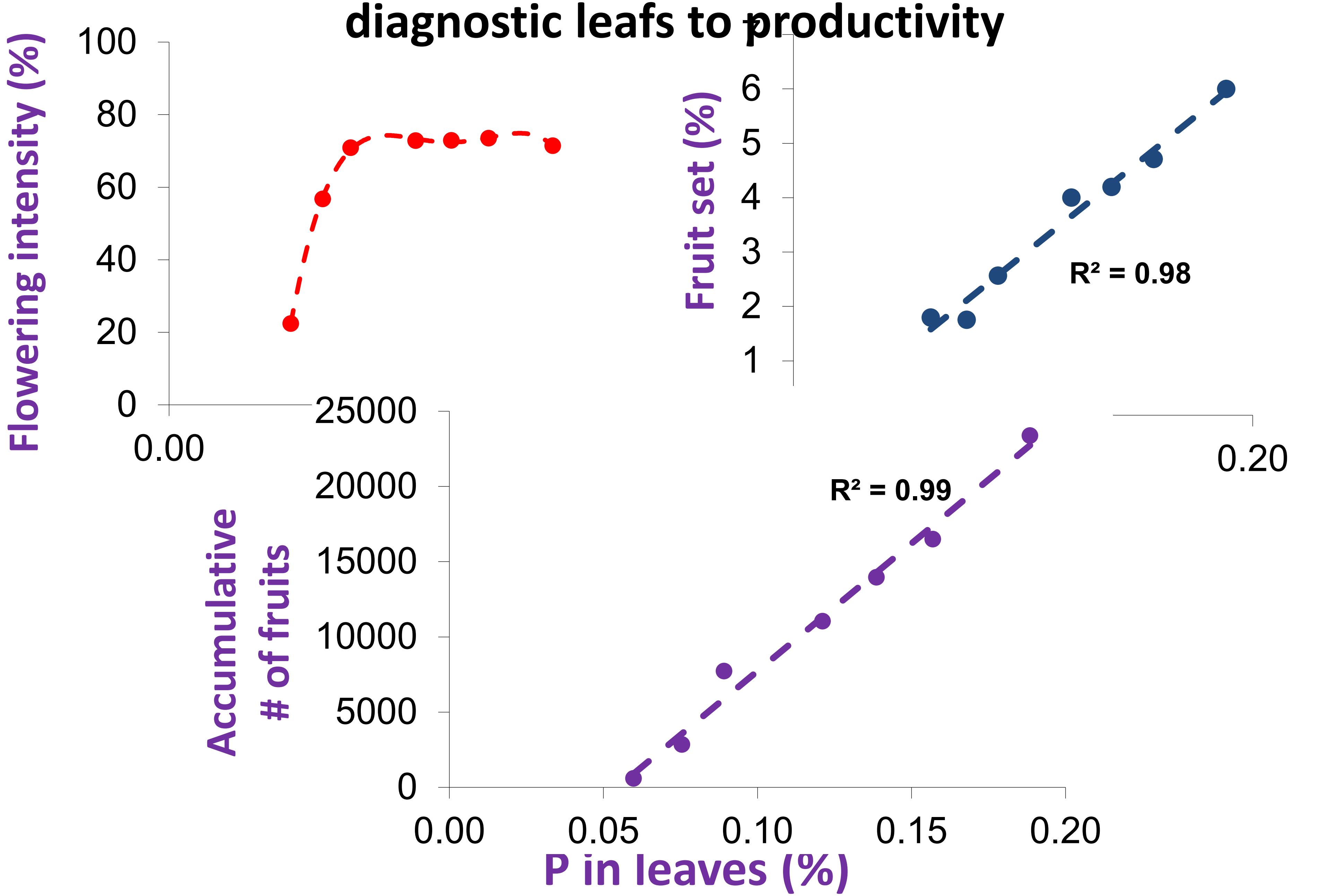


The correlation between phosphorous level in diagnostic leaves and fruit and oil yield

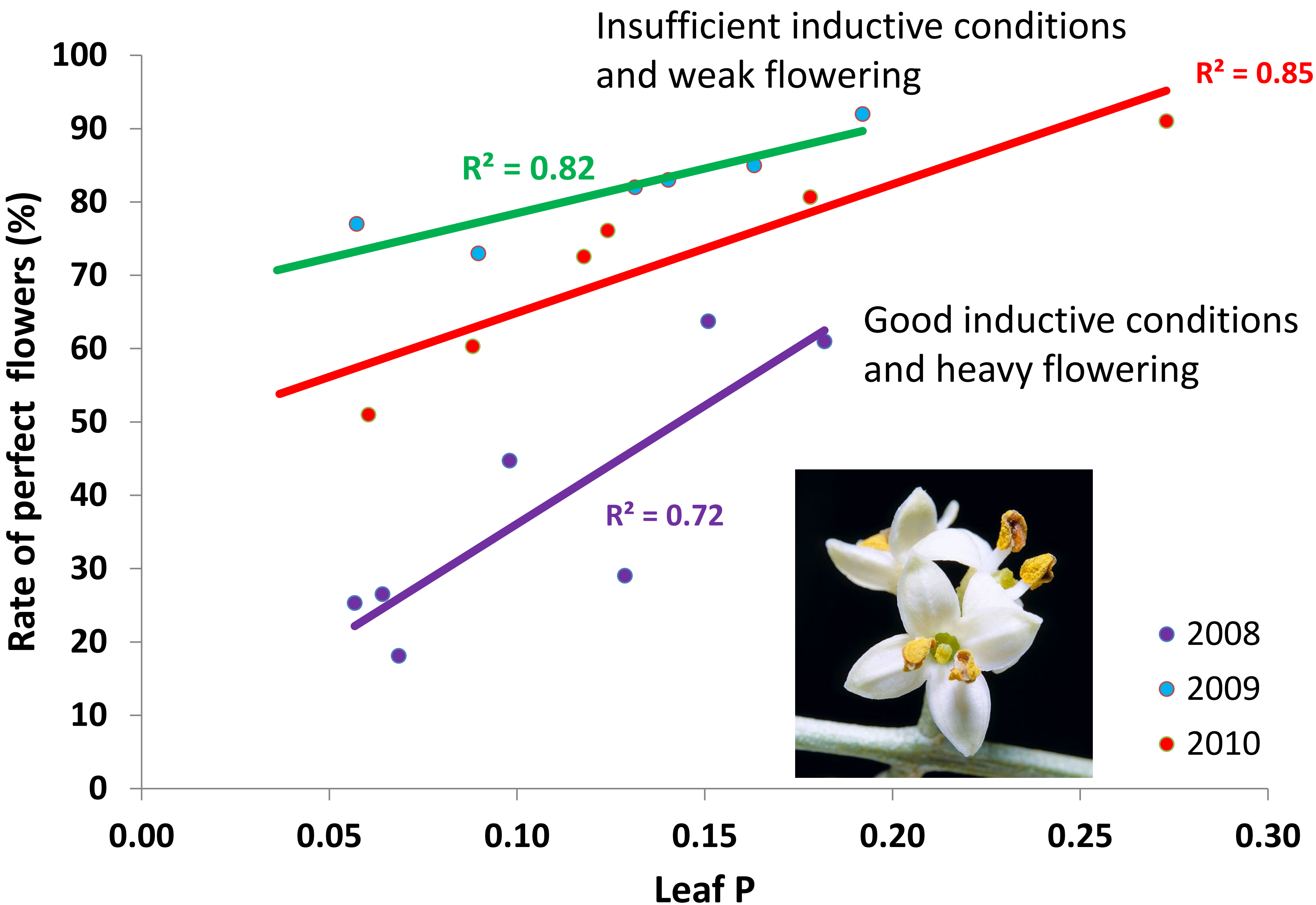


Erel et al., (2013) Scientia Hort.

The correlation between phosphorous level in diagnostic leafs to productivity



The effect of leaf phosphorous on perfect flowers ratio



Averages ± standard deviation of: phosphorus (P) concentration in irrigation solution, and corresponding P leaf concentration measured during the flowering periods, percentage of buds evolved into inflorescences, flowers to fruits, and total number of fruit per tree, all for each of the two years of study.

	Solution P (mg l^{-1})	Leaf P (g $100g^{-1}$)		Reproductive bud break (%)				Flowers per inflorescence				Perfect flowers (%)				Fruit set (%)				Fruit $tree^{-1}$			
		May-12	May-13	2012		2013		2012		2013		2012		2013		2012		2013		2012		2013	
P1	0.1 ± 0.1	0.04 ± 0.00	No data	1.5	C	No data		13.5	C	No data		45.3	B	No data		2.6	B	No data		2	B	No data	
P2	1.0 ± 0.1	0.06 ± 0.00	0.06 ± 0.01	11.8	B	10.4	A	18.6	B	17.6	B	51.4	B	88.8	B	3.5	B	1.6	B	360	B	695	B
P3	10.3 ± 0.5	0.13 ± 0.02	0.12 ± 0.01	33.9	A	15.3	A	19.9	AB	20.3	A	77.4	A	90.4	AB	8.0	A	4.4	A	5,563	A	2,776	A
P4	26.3 ± 0.9	0.16 ± 0.03	0.16 ± 0.02	32.5	A	12.7	A	20.7	A	20.2	A	81.6	A	93.3	A	8.2	A	4.3	A	4,889	A	2,718	A

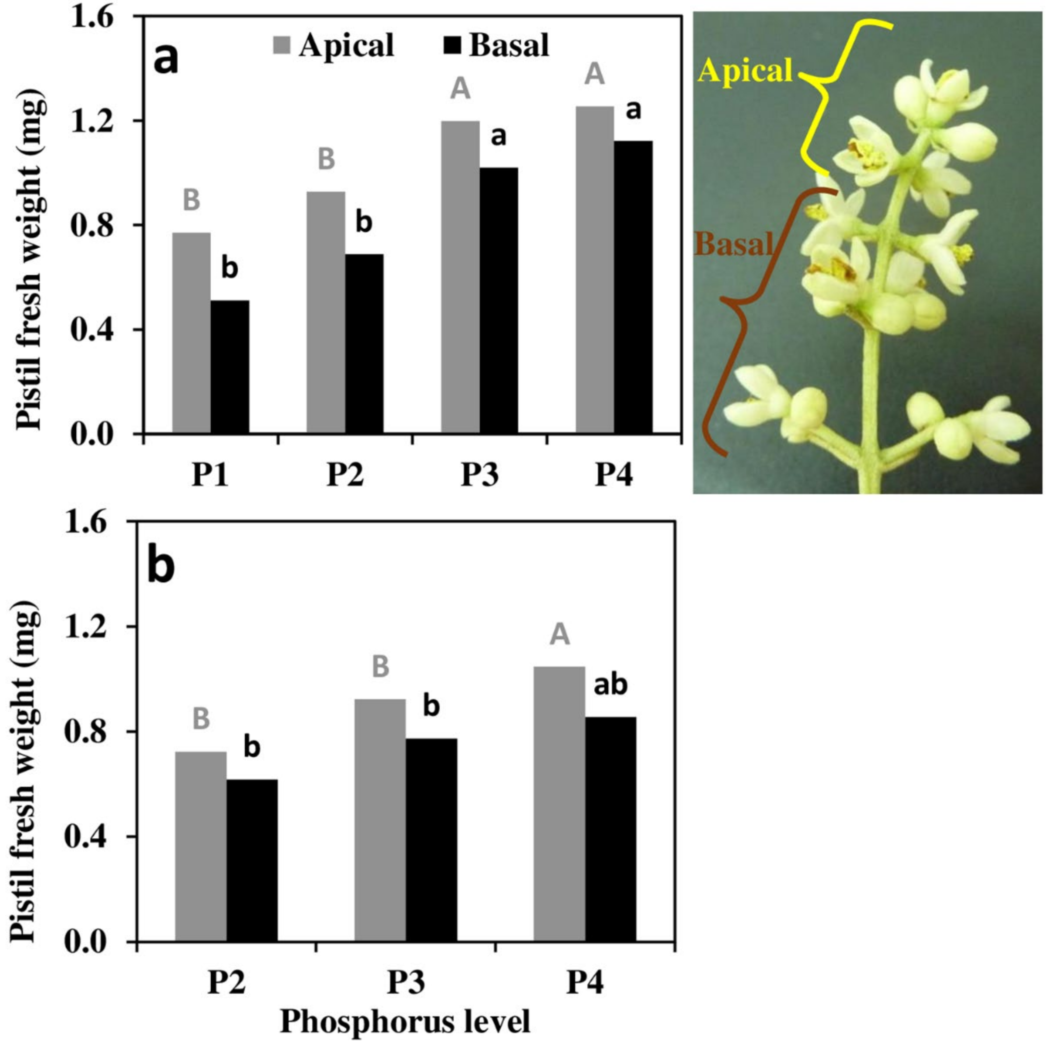
doi:10.1371/journal.pone.0167591.t001

Erel, R., Yermiyahu, U., Yasuor, H., Cohen Chamus, D., Schwartz, A., Ben-Gal, A., & Dag, A. (2016). Phosphorous nutritional level, carbohydrate reserves and flower quality in olives. *PloS one*, *11*(12), e0167591.

Pistil fresh weight as affected by P level.

2012

2013

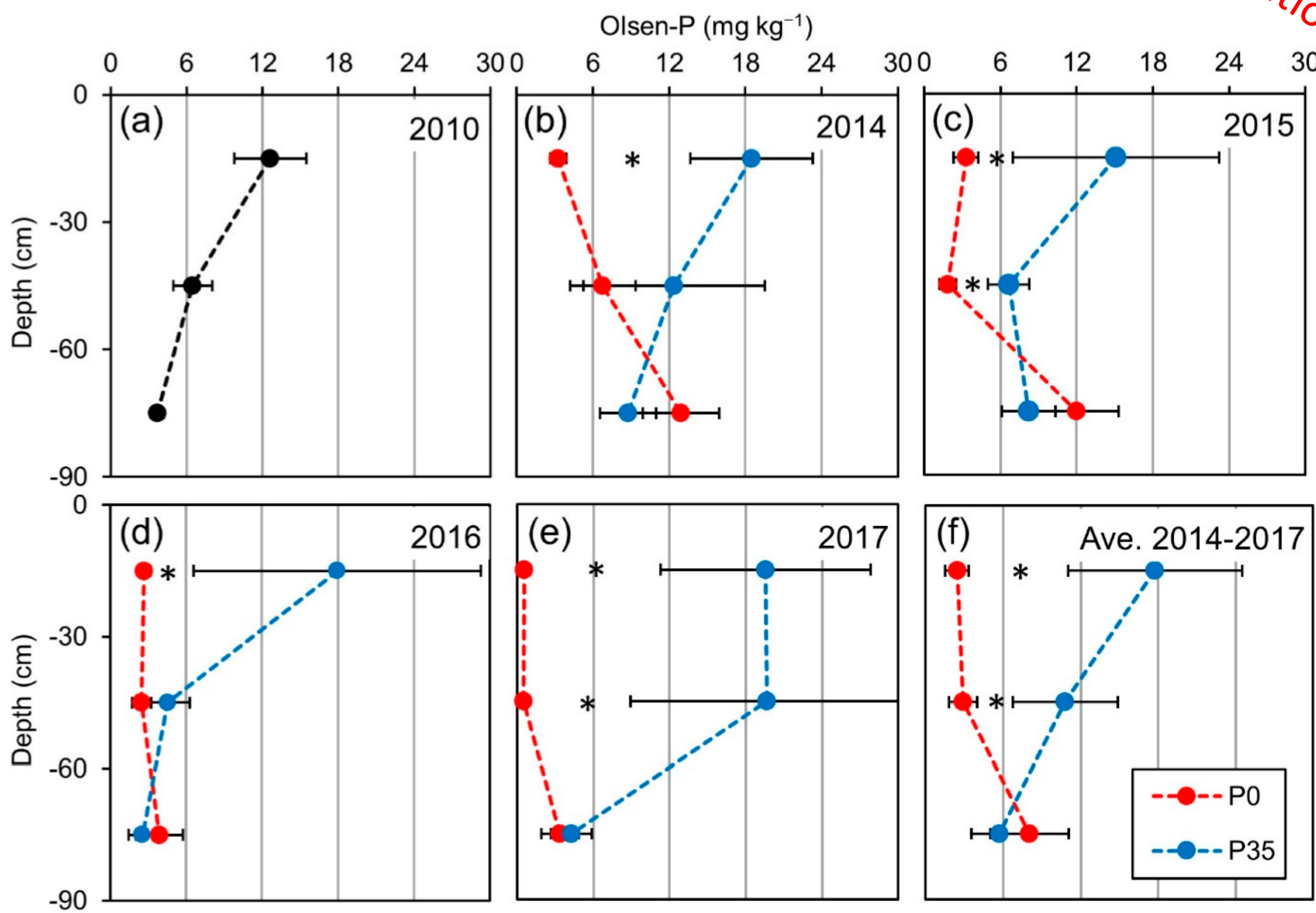


Erel, R., Yermiyahu, U., Yasuor, H., Cohen Chamus, D., Schwartz, A., Ben-Gal, A., & Dag, A. (2016). Phosphorous nutritional level, carbohydrate reserves and flower quality in olives. *PloS one*, *11*(12), e0167591.

Field study

Olsen-P content in soil profile throughout the experiment. Experiment plots were fertilized either with an annual amount of 35 kg P ha^{-1} (P35) or without P (P0).

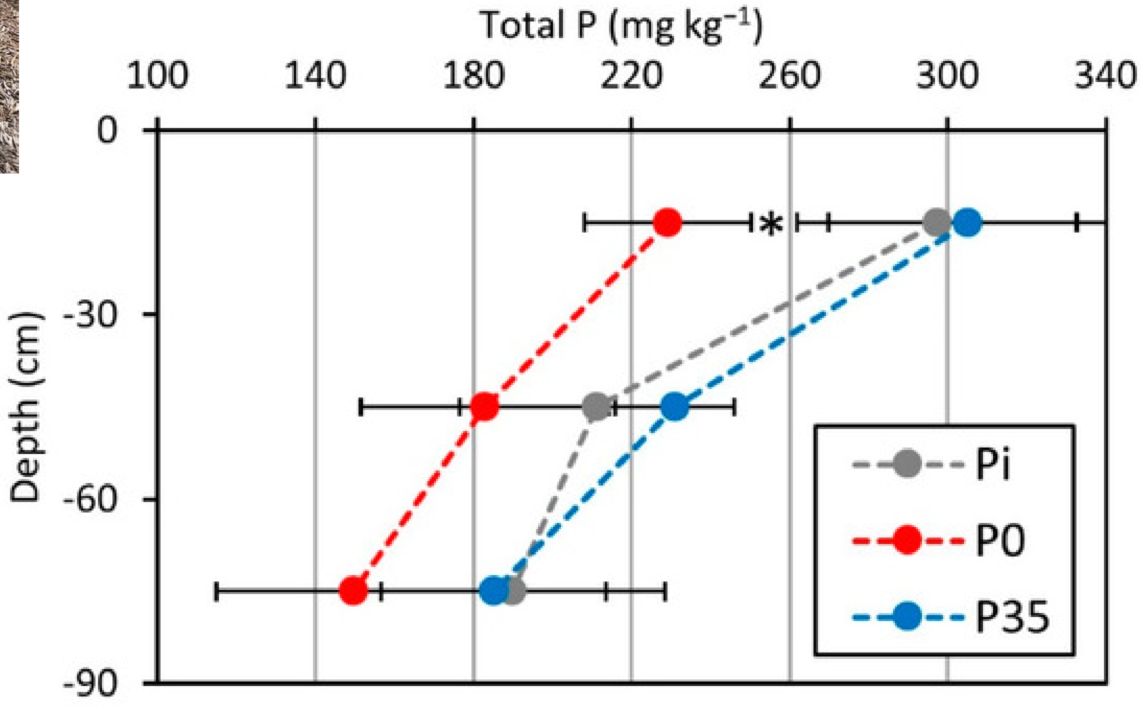
Estimation for plant-available P



[Orchard planted in 2007, treatment initiated at June, 2011]

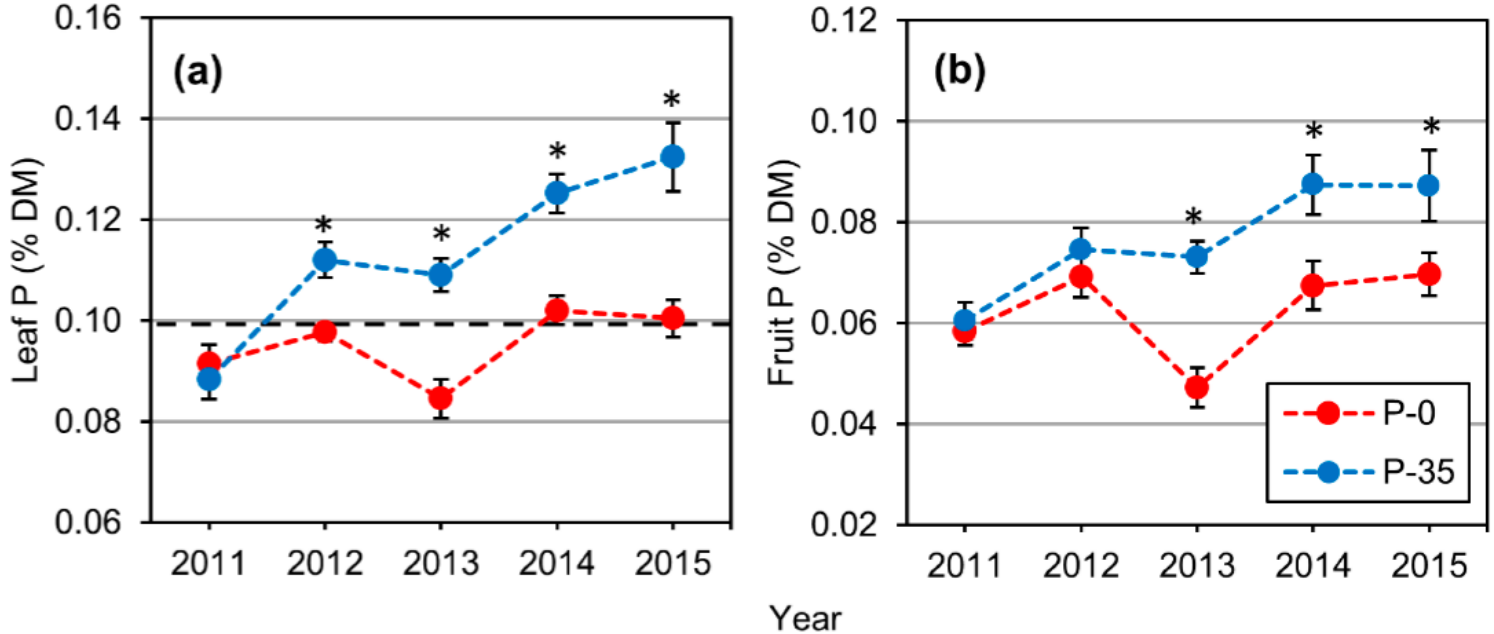
Haberman, A., Dag, A., Erel, R., Zipori, I., Shtern, N., Ben-Gal, A., & Yermiyahu, U. (2021). Long-term impact of phosphorous fertilization on yield and alternate bearing in intensive irrigated olive cultivation. *Plants*, *10*(9), 1821.

The soil total P content was measured for three soil depths (0–30, 30–60, 60–90 cm) in March 2017 after six seasons of differential fertilization or in February 2010 before the experiment (Pi).



Haberman, A., Dag, A., Erel, R., Zipori, I., Shtern, N., Ben-Gal, A., & Yermiyahu, U. (2021). Long-term impact of phosphorous fertilization on yield and alternate bearing in intensive irrigated olive cultivation. *Plants*, *10*(9), 1821.

Phosphorus in leaves and fruit. Experiment plots were fertilized either with an annual amount of 35 kg P ha^{-1} (P35) or without P (P0).



Haberman, A., Dag, A., Erel, R., Zipori, I., Shtern, N., Ben-Gal, A., & Yermiyahu, U. (2021). Long-term impact of phosphorous fertilization on yield and alternate bearing in intensive irrigated olive cultivation. *Plants*, *10*(9), 1821.

Table 1. Phosphorus fertilization impact on vegetative and reproductive development.

P Fertilization	Trunk Circumference Increase	Pruning Weight	Flowering Intensity	Inflorescences Initiation [a]
	2011–2017	2012–2015	2014–2017	2014–2015
($kg\ ha^{-1}\ season^{-1}$)	(%)	($kg\ tree^{-1}\ season^{-1}$)	(index)	(%)
0	69.5 ± 3.0 a	31.1 ± 1.9 a	3.05 ± 0.07 b	36.3 ± 2.4 b
35 [b]	74.3 ± 2.8 a	34.0 ± 2.5 a	3.34 ± 0.11 a	44.5 ± 3.2 a

Numbers are mean values of 14 replicates (trees) ± standard error of the mean. Different letters indicate a statistically significant difference ($p \leq 0.05$). [a] The rate of buds initiating an inflorescence. [b] Values of this level were published previously [37,38]. Seasonal pruning weight, flowering intensity, and inflorescences initiation data are presented in **Tables S1–S3**, respectively.

Haberman, A., Dag, A., Erel, R., Zipori, I., Shtern, N., Ben-Gal, A., & Yermiyahu, U. (2021). Long-term impact of phosphorous fertilization on yield and alternate bearing in intensive irrigated olive cultivation. *Plants*, *10*(9), 1821.

Table 2. Phosphorus fertilization impact on flowering quality traits and fruit set.

P Fertilization	Flowers in an Inflorescence	Perfect Flowers	Pistil Weight	Fruit Set
(kg ha^{-1} season^{-1})	(No.)	(%)	(mg)	(%)
0	16.1 ± 0.3 a	46.9 ± 3.6 b	0.72 ± 0.02 a	4.5 ± 0.4 b
35 [a]	16.2 ± 0.5 a	56.5 ± 3.3 a	0.79 ± 0.04 a	6.7 ± 0.6 a

Data from trees flowering at medium to high intensities (index of 3–5) during the 2014–2017 seasons. Numbers are mean values of 27–28 replicates (trees) ± standard error of the mean. Different letters indicate a statistically significant difference ($p \leq 0.05$). [a] Values of this level were published previously [37,38].

Haberman, A., Dag, A., Erel, R., Zipori, I., Shtern, N., Ben-Gal, A., & Yermiyahu, U. (2021). Long-term impact of phosphorous fertilization on yield and alternate bearing in intensive irrigated olive cultivation. *Plants*, *10*(9), 1821.

Seasonal fruit yields. Experiment plots were fertilized either with an annual amount of 35 P ha^{-1} (P35) or without P (P0). Numbers are mean values of 14 replicates (trees) ± standard error of the mean (bars). Different letters indicate a statistically significant difference between P fertilization levels in the specified season ($p \leq 0.05$).

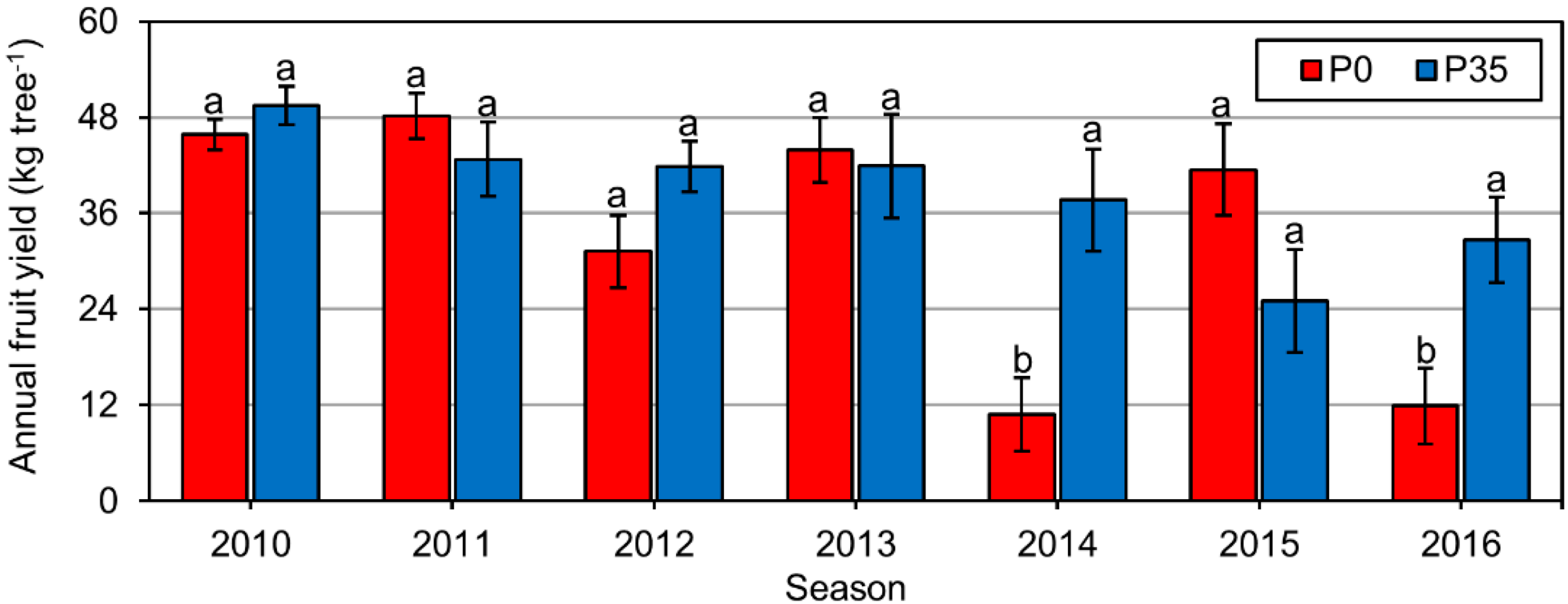


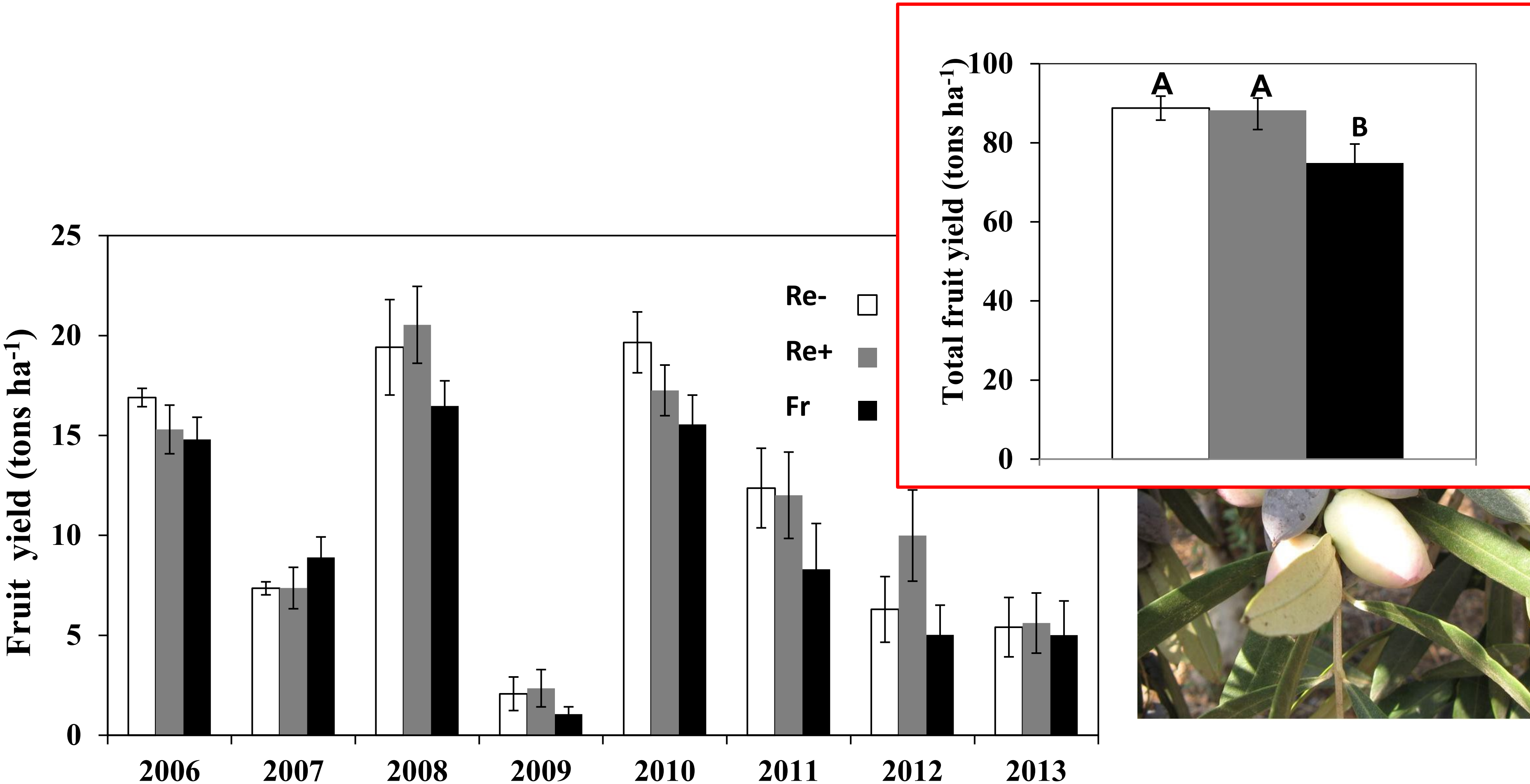
Table 3. Phosphorus fertilization impact on yields.

P Fertilization	Single Fruit Weight	Oil Content	Fruit per Tree	Fruit Yield	Oil Yield
	2013–2016	**2013–2016**	**2013–2016**	**2013–2016**	**2013–2016**
(kg ha^{-1} season^{-1})	(g)	(%)	(No. tree^{-1} season^{-1})	(kg tree^{-1} season^{-1})	(kg tree^{-1} season^{-1})
0	2.66 ± 0.11 a	19.2 ± 0.5 a	14,153 ± 825 b	27.2 ± 1.1 b	4.6 ± 0.2 b
35 [a]	2.42 ± 0.09 a	19.6 ± 0.6 a	19,813 ± 1141 a	34.0 ± 1.6 a	5.6 ± 0.4 a

Numbers are mean values of 14 replicates (trees) ± standard error of the mean. Different letters indicate a statistically significant difference ($p \leq 0.05$). [a] Values of this level were published previously [37,38]. Seasonal single fruit weight, oil content, fruit per tree, fruit yield, and oil yield data are presented in Tables S4–S8, respectively.

Haberman, A., Dag, A., Erel, R., Zipori, I., Shtern, N., Ben-Gal, A., & Yermiyahu, U. (2021). Long-term impact of phosphorous fertilization on yield and alternate bearing in intensive irrigated olive cultivation. *Plants*, *10*(9), 1821.

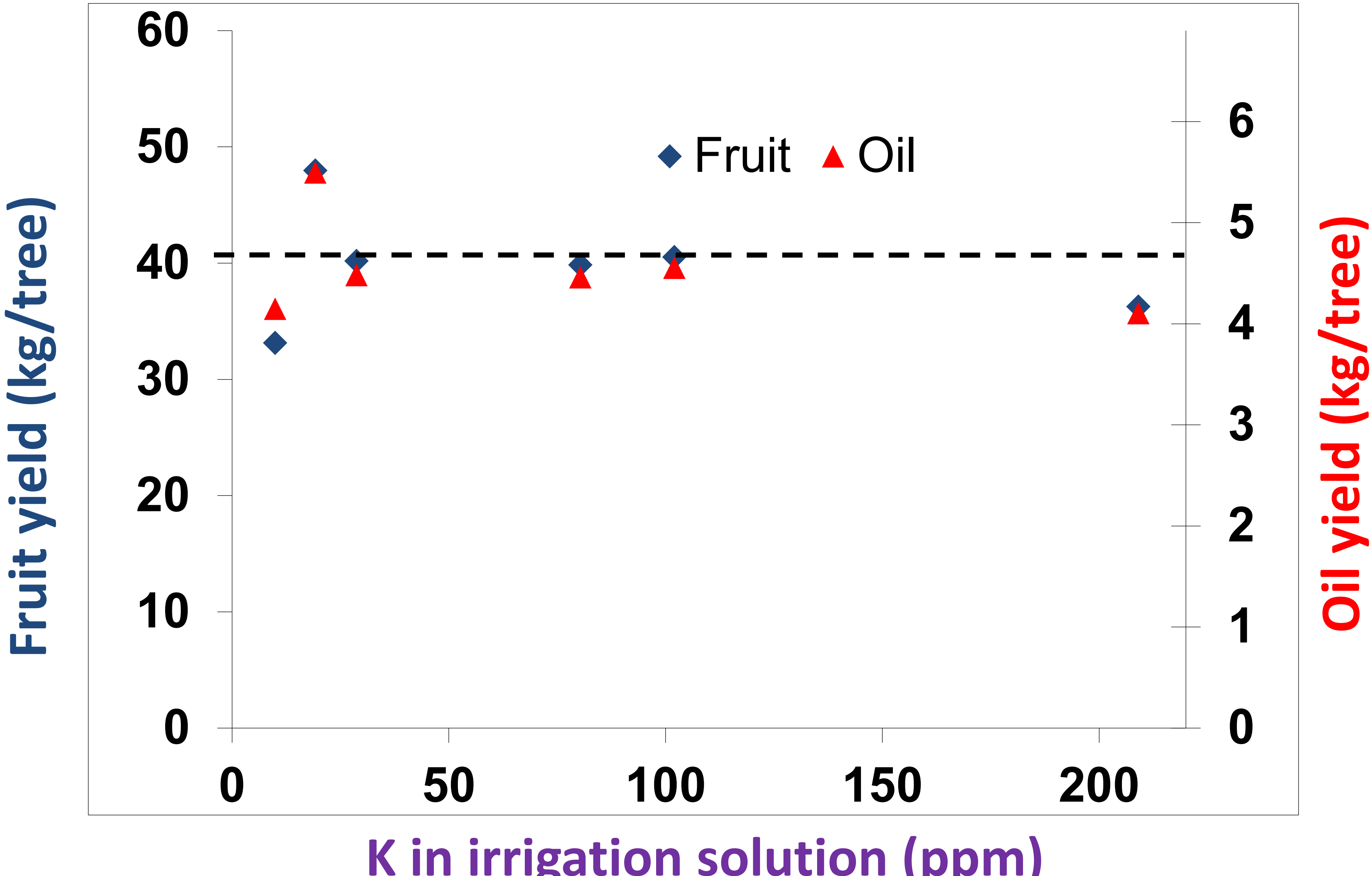
The effect of irrigation with reclaimed wastewater on fruit yield- ‘Barnea’



Erel et al., (2019). *Agric. Water Manag*. 213: 324-335.

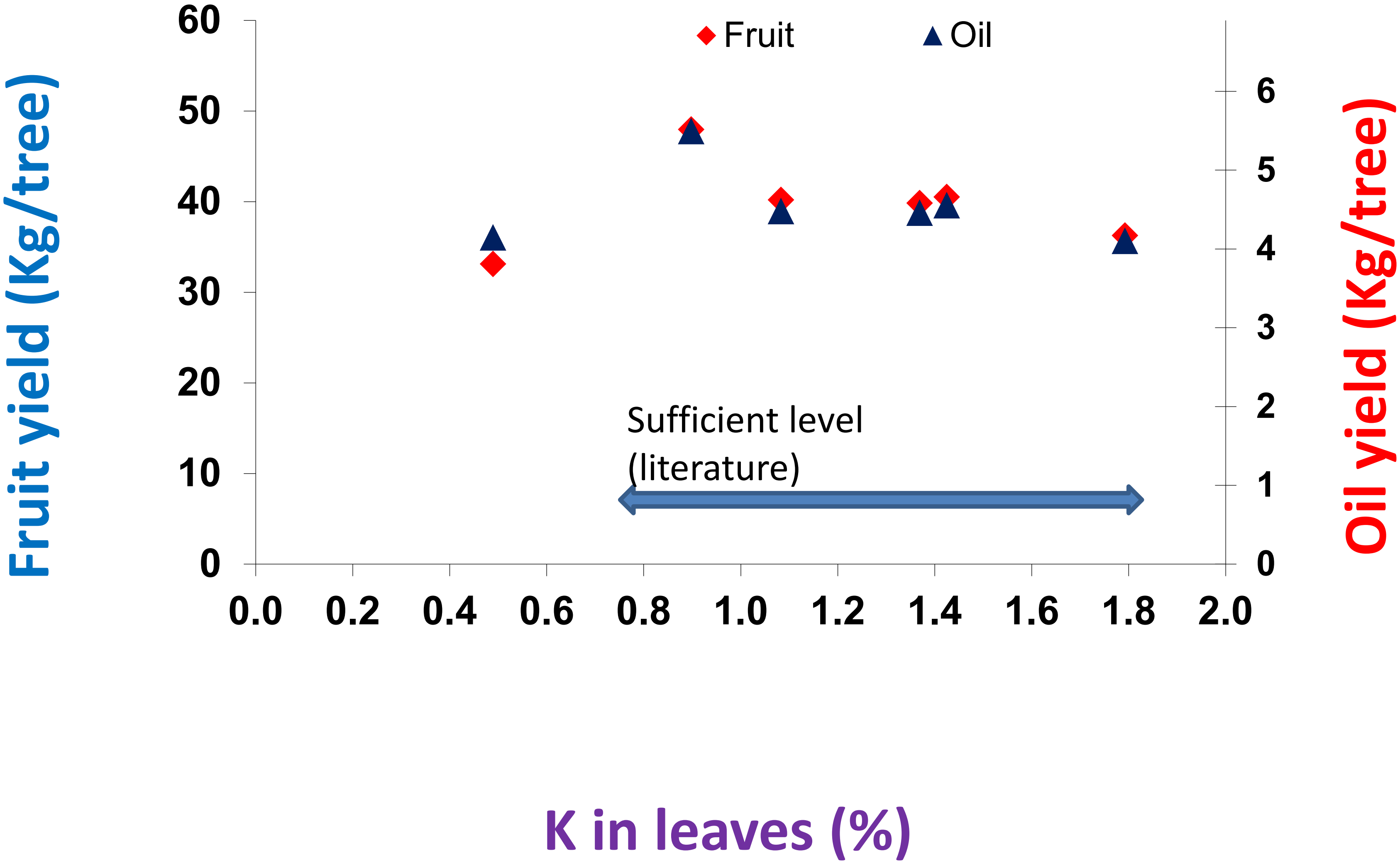
Potassium (K)

The correlation between potassium level in irrigation solution and fruit and oil yield



Erel, R., Yermiyahu, U., Van Opstal, J., Ben-Gal, A., Schwartz, A., & Dag, A. (2013). The importance of olive (*Olea europaea* L.) tree nutritional status on its productivity. *Scientia Horticulturae*, *159*, 8-18.

The correlation between potassium level in diagnostic leaves and fruit and oil yield



Potassium concentrations (% in DM) in the leaves, branches, bark, and roots during an annual cycle of On- and Off-olive trees (‘Barnea’)

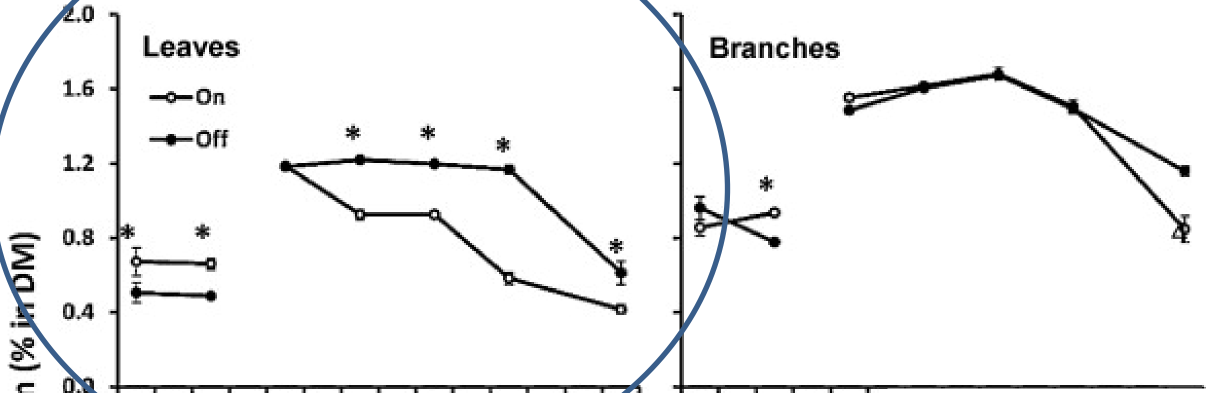


Table 2. Mineral content in fruit of On- and Off-trees at harvest. Different letters within columns indicate statistical significance at $P<0.05$ between years for each element alone.

	Mineral content (% in dry matter)				
	N	P	K	Ca	Na
On-trees	0.55a	0.069a	1.40a	0.106b	0.044a
Off-trees	0.86b	0.105b	1.51a	0.067a	0.032a

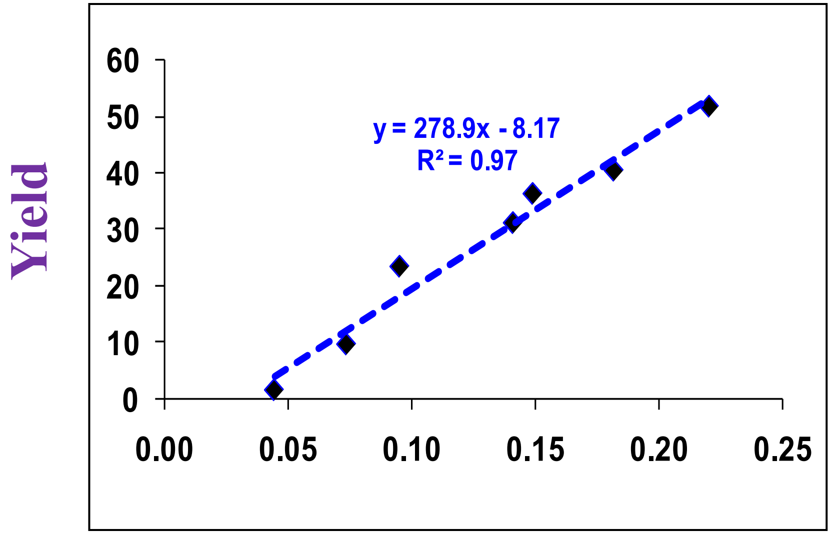
Table 1. Fruit yield (means of eight trees±SE) and harvesting date of Off- and On-trees used for the mineral survey.

	Group I		Group II	
	‘On’ (2005)	‘Off’ (2006)	‘Off’ (2005)	‘On’ (2006)
Fruit yield ($kg tree^{-1}$)	124.5±5.27	30.6±5.57	7.4±5.89	106.4±6.47
Harvesting date	November 2005	17 October 2006	21 October 2005	29 November 2006

Bustan, A., Avni, A., Yermiyahu, U., Ben-Gal, A., Riov, J., Erel, R., ... & Dag, A. (2013). Interactions between fruit load and macroelement concentrations in fertigated olive (Olea europaea L.) trees under arid saline conditions. *Scientia Horticulturae*, *152*, 44-55.

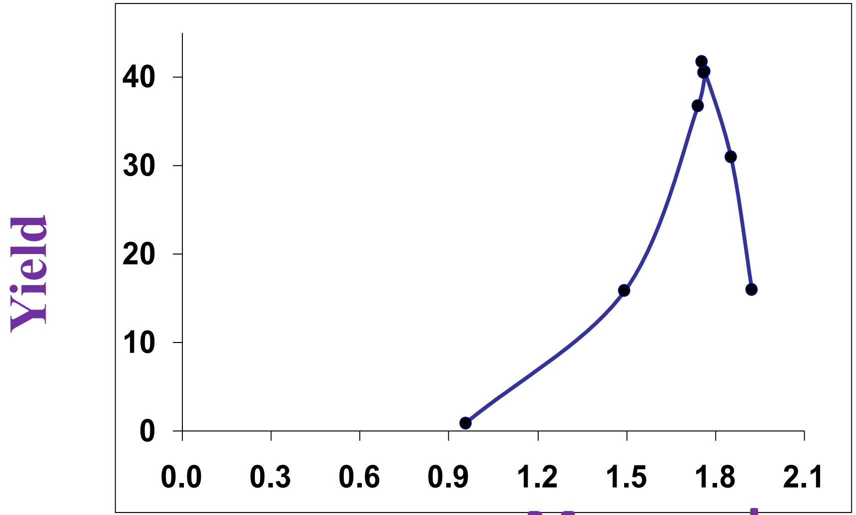
Summary

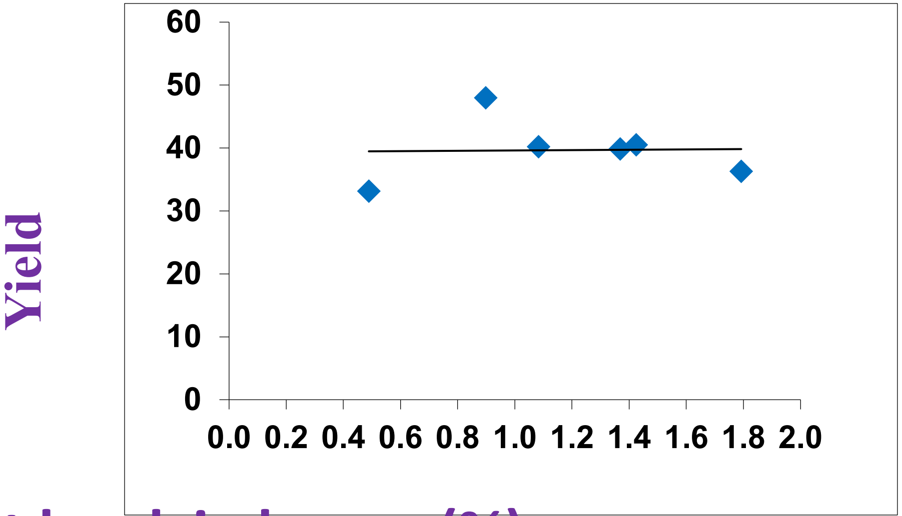
P



N

K





Macro-element level in leaves (%)

Recommended dosages for intensive orchard

Nitrogen; 150 kg/ ha./ year

Phosphorous; 35 kg / ha./ year

Potassium; 200 kg / ha./ year

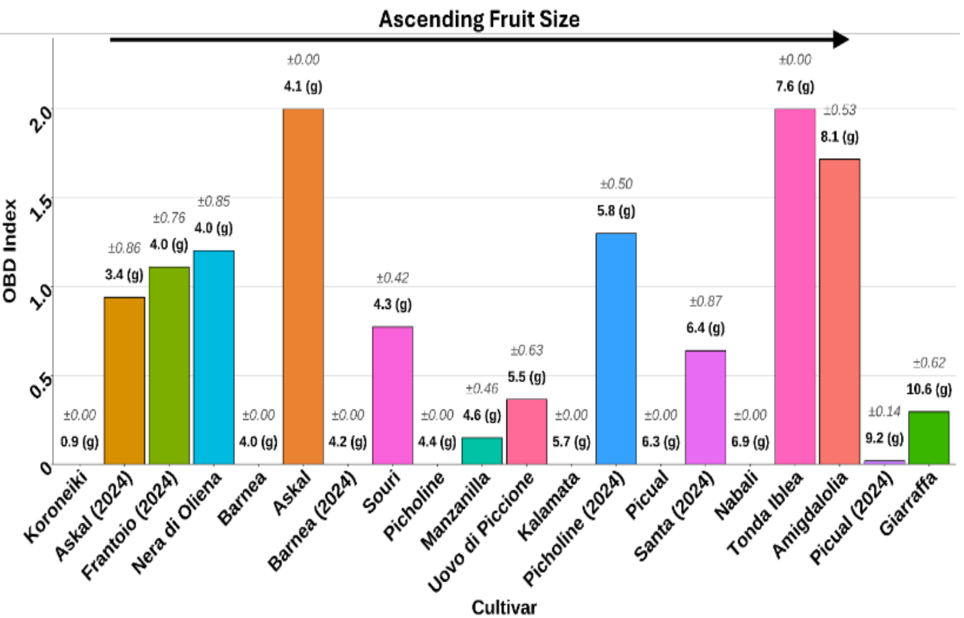
Table 6.3.5. Critical element concentrations in diagnostic leaves sampled in July (northern hemisphere). New suggested standards for modern agro-systems are indicated in ***bold italics***.

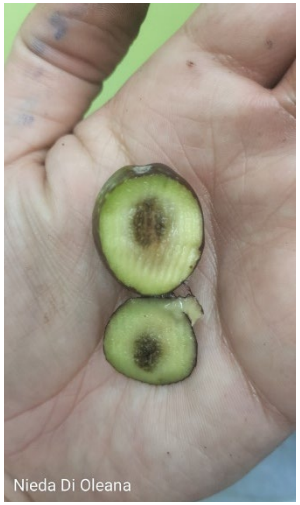
Nutrient		Deficiency	Sufficiency	Over-fertilization/ toxicity	Source
N	%	< 1.4	1.5-2.0		Fernández-Escobar (2010)
			> 1.2-1.3		Fernández-Escobar *et al*. (2009b)
			1.4-1.8	***> 1.9***	Erel *et al*. (2013a); Haberman *et al*. (2019b)
P	%	0.05	0.1-0.3		Fernández-Escobar (2010)
			< 0.13		Zipori *et al*. (2020); Haberman *et al*. (2021)
K	%	0.4	> 0.8		Fernández-Escobar (2010)
			> 0.9		Zipori *et al*. (2020); Haberman *et al*. (2019a)
Ca	%	0.30	> 1.0		Fernández-Escobar (2010)
Mg	%	0.08	> 0.1		Fernández-Escobar (2010)
Na				> 0.2	Fernández-Escobar (2010)
Fe	**mg kg^{-1}**		none		
Mn	**mg kg^{-1}**		> 20		Fernández-Escobar (2010)
Zn	**mg kg^{-1}**		> 10		Fernández-Escobar (2010)
			> 8		Zipori *et al*. (2016)
B	**mg kg^{-1}**	14	19–150	185	Fernández-Escobar (2010)
Cu	**mg kg^{-1}**		> 4		Fernández-Escobar (2010)
Cl	%			> 0.5	Fernández-Escobar (2010)

Dag et al., 2023. Nutrition and Fertilization. In: The Olive Botany and Production. pp 374-414.

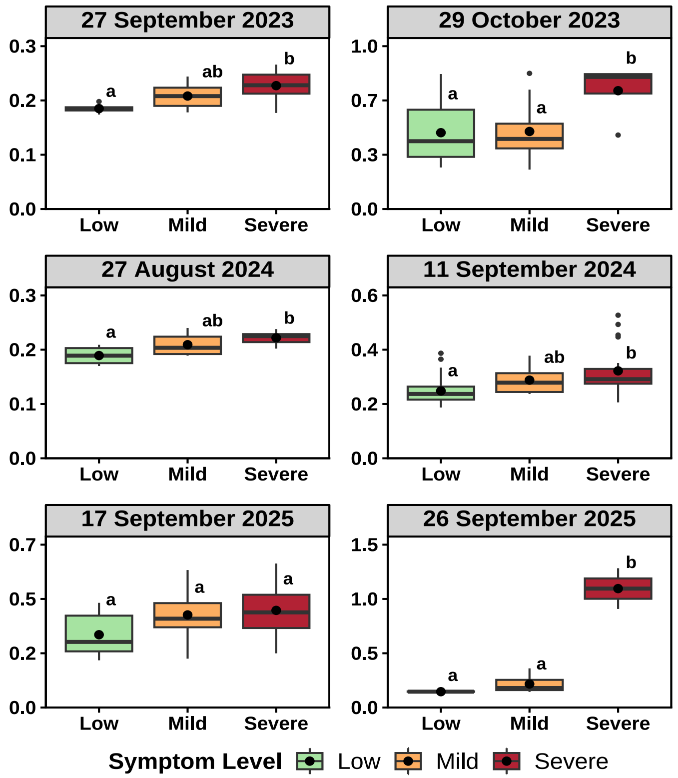
Calcium ??

Varietal Sensitivity to Olive Browning Disorder (Gilat, 2023)

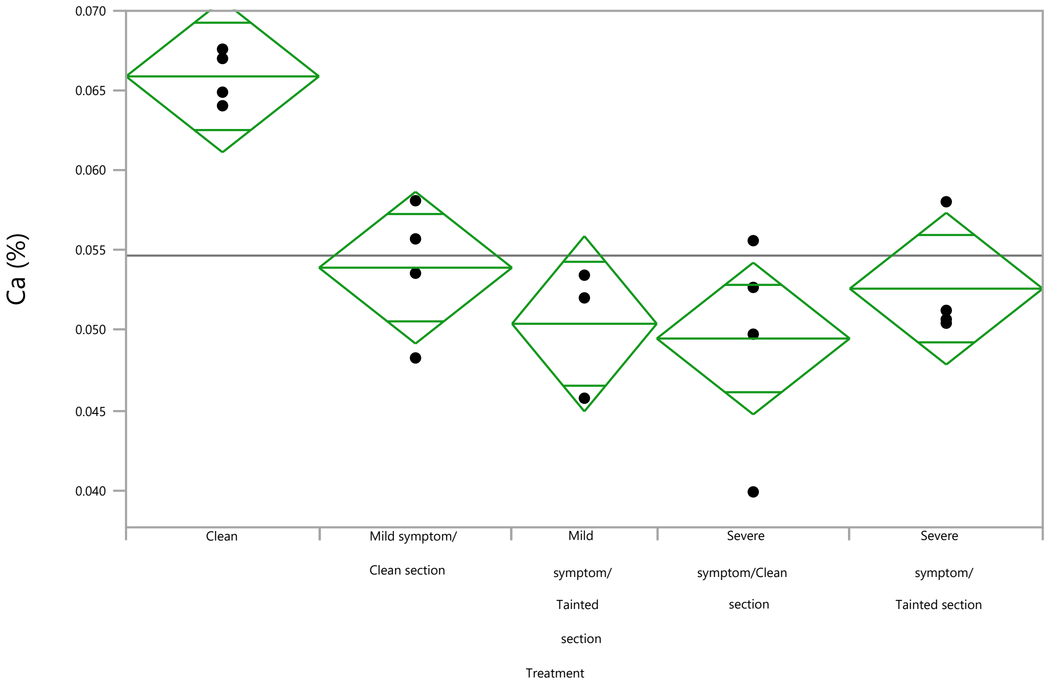


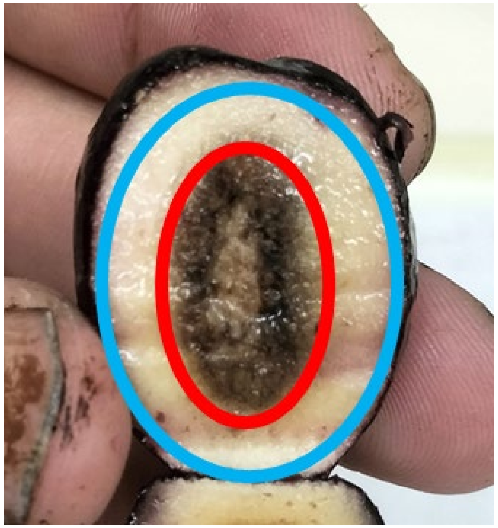


Free Fatty Acid (%) of Oil vs OBD (cv. Askal)



Notable Results – Clean vs Symptomatic Flesh (Olive Variety: Novo)





Collaborators

- Ran Erel, Alon Ben-Gal, Uri Yermiyahu, Isaac Zipori and Amnon Bustn, Amnon Haberman, Zipora Tietel (ARO-Gilat)
- Zohar Kerem, Loai Basher (HUJI)
- Shimon Lavee (ARO, HUJI)

Funding

-Chief Scientist, Ministry of Agriculture, Israel
-Agricultural Research Organization
-MERC


Thank you !