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Effect of Frost and Salts Dissolved after Heavy Rain on the Productivity of Olive Trees under Desert Growing Conditions

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Research Article

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ABSTRACT

Due to the health benefits of olive oil and increasing demand on olive products in Saudi Arabia, cultivation of olive trees started in 1984 in the north-west regions of the country. Tabuk Agriculture Development Co. (TADCO) is one of the leading companies in Saudi Arabia in fruit crops production such as Stone fruits, Grapes, Pears and Olives. Over a period of more than 30 years of growing olives successfully at TADCO, olive trees of 1-4 years were subjected to severe salts toxicity following the sudden rainfall in the seasons 1994, 1997; leaching operations of the salts from the soil and pruning dry branches lead to the recovery of the trees for their normal growth after few months. TADCO reached maximum olive fruits productivity of 2305 M.T. in 2004 season after 20 years from the establishment.

Olive trees suffered frost damage in the winter seasons of 2000, 2007 and 2008, and a combined damage of frost and dissolved salts after heavy rainfall in January 2005. This led to the reduction of trees productivity for fruits by 25.4, 80.3. 39.9, 84.2% in the seasons 2000, 2005, 2007, 2008 respectively, and a reduction on olive oil productivity by 30.2, 85.1, 43.4, 88.9% respectively. Olive trees recovered their growth and productivity after frost damage in 2000, 2005 and 2007, but after the severe damage in 2008 the olive trees were unhealthy with low productivity and infested with neiroun insects which enforced TADCO to remove the damaged trees in 2009 to protect the remaining healthy trees. The productivity of olive trees was improved in 2011 which reached 2728 M.T. from 36.4% less number of olive trees. Cultivars Ayvalik, Jordan and Verdale were found relatively tolerant to frost in comparison to the cultivars Picual, Coratina, Improved Nebali, Surani, Frantioi and Manzanilla.

INTRODUCTION

The olive (*Olea europaea*) is an evergreen plant grown mainly in the Mediterranean basin for the production of both oil and table olives. Generally, olive cultivation is successful in the areas lie between latitudes 30° and 45° in the northern and southern hemisphere [1]. In the last two decades and due to high demand for olive products, cultivation of olive trees expanded in Australia, China, India, Latin America [2], and also in other countries like Egypt, Saudi Arabia & South Africa. The newly cultivated areas which do not have typical Mediterranean climates and located at subtropical latitudes may encounter production problems.

The olive tree grows successfully in areas with hot temperate climate in summer and temperate-low temperature in winter. A dormancy period of about two months with average temperature lower than 10°C is conducive to flower bud differentiation. During the dormancy period, the tree tolerates short periods of frost of - 6°C [3]; when winter temperature drop below -7°C, the aerial parts of olive tree can be damaged leading to yield reduction and in extreme cases kill the plants [4]. Olive tree grows well in different types of soil as long as it is deep, well aerated and free from waterlogging [5,6]. Under waterlogged conditions damage through lack of oxygen and fungal diseases increases sharply [3]. The olive tree is moderately tolerant to soil salinity [7,8] provided electric conductivity of the soil (EC) does not exceed 8 mmhos/cm, but EC of 4.5 mhos/cm or less is preferred [3].

Cultivation of olive trees started in the semi-Mediterranean areas of the North West of Saudi Arabia in 1984 mainly at Al-

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Jouf, Tabuk and Hael regions. Over the following years, cultivated areas increased rapidly and especially after the introduction of super high density planting in 2007 season adapting the mechanized cultivation method. There were around 15 million olive trees in Al-Jouf region [9]: five million of the total were super high density planting cultivars, and the estimated olive oil production in Al-Jouf was around 3000-4000 M.T extracted from 30,000-40,000 olive fruits. Due to the ability of olive trees to yield in poor soil with fewer requirements for nutrients, most of the early olive planting in different projects was carried out in non-cultivated areas around field crops pivots, main roads as part of the landscape in the farms or in areas which were not suitable for fruit trees production.

Over the period of more than 30 years of growing olive trees successfully at Tabuk Agricultural Development Co. (TADCO), there were sudden extreme drop in the temperature in the winter months of 2000, 2007 and 2008 seasons which affected the productivity of the olive trees. In addition, dissolved salts after heavy rainfall occurred at the early years of the project and in January 2005 caused significant damage on the trees. The aim of this study was to investigate the effect of frost and salts dissolved after heavy rainfall on the survival and productivity of different olive cultivars grown at TADCO farm and develop practical solutions to this problem.

MATERIALS AND METHODS

TADCO began planting olive trees in 1984 at the leading company roads until 1986 and then expanded the olive area in the other orchards. In 2003, the total number of planted trees reached 107193 in an area of 380.8 Ha **(Table 1)**. The coordinates of olive orchards are:

Latitude: 28° 43' 77" N, Longitude: 36° 16' 21" E, Altitude: 777.45 M.

Table 1. Number of trees, date of planting and area of olive trees at TADCO orchards in 2003 season.

Location	TADCO Roads	Orchard (3)	Orchard (4)	Orchard (6)	Total
Number of Trees	10283	18983	48056	29871	107193
Trees Spacing	6 X 6 meter	7.3 X 7.3; 7.3 X 4.8; 6 X 6 M.	6 X 6 meter	6 X 5 meter	------
Area (Ha.)	27.6	94.00	172.3	86.9	380.8
Date of Planting	1984-1986	1991	1992-1993	1998	

TADCO selected planting different olive cultivars commercially spread in the Mediterranean basin countries such as Spain, Italy, Jordan, Syria and Turkey as shown in **Table 2**. These cultivars are mainly for olive oil production, but some cultivars are double purpose i.e. for table processing and oil production like Improved Nebali, Jordan, Picual & Manzanilla. This selection allowed TADCO for different dates of harvest based on cultivars maturity: Jordan cultivar is early maturing in September followed by Frantioi late September and October, then Ayvalik and Surani after mid of October, then Picual in November, then improved Nebali mid of November to early December, then Verdale in December and Coratina matures in middle of December. Also, the selection of different cultivars allowed TADCO to alleviate the seasonal variation of olive fruits bearing and get reasonable quality & productivity/year.

Table 2. Number of trees of different commercial olive cultivars grown at TADCO orchards in 2003 season.

Cultivar	Jordan	Improved Nebali	Surani	Ayvalik	Frantioi	Coratina	Picual	Manzanilla	Gordal*	Verdale
Country of Origin	Jordan	Jordan	Syria	Turkey	Italy	Italy	Spain	Spain	Spain	France
Number of Trees In 2003	4879	31959	16008	7363	17330	7532	17985	3446	319	1173

*Gordal is a table cultivar

Soil, roots, and leaf samples were collected frequently and sent to TADCO laboratory for chemical and biological analysis to check the level of salts and nutrients in the soil and leaves samples. Also soil samples were collected shortly after heavy rainfall from salt damaged olive trees to check salinity problems.

To monitor soil salinity and nutrition level in the soil: we selected and marked 20 trees within one block in each Orchard. These trees were monitored annually; soil cores were taken by soil auger from each of the 20 trees, collected in a bucket and from that a sub-sample 1-2 kg was withdrawn and this was considered a representative sample to that block. Separate soil samples were collected from the following locations: Top soil (0-30 cm) at center wetting front at dripper, sub-soil (30-50 cm) at center of the wetting front at dripper, outside (approx. 50 cm) of the front away from the dripper at depth 30 cm and 50 cm. Then, we

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dispatched the samples to the laboratory on the same day of sampling with proper labeling and record in the log book. Dry the samples and sieve it through 2 mm sieve discarding small gravel but not soil crumbs.

To monitor the nutritional status of olive trees, we follow a certain path in one selected block at each orchard as X or W or Z direction when we collect the leaves samples. We had chosen and marked around 20 trees/block/cultivar from the chosen path, collect (50-100) leaves per sample from the mid-shoot leaves at the midseason. Put the leaves sample inside polyethylene bag in a cold field box or in the shade, write the name of the cultivar, location, date of sampling, and name of collector. Send the samples to the laboratory, record in the log book & keep the samples in the lab at 20°C for a few hours until it was processed. Wash the leaves sample with deionized water, drain excessed water and put it into an oven at 65-85°C for overnight. Grind the sample using fine grinder, leave it inside close polyethylene bag until analysis.

For the determination of casual pathogens on roots and shoots samples, we inoculated the damaged tissue under aseptic techniques on PDA, NA media and incubated at 30°C for few days, mount the grown fungus on blue lactophenol stain into microscopic slide with cover slip and inspected under the microscope. For the detection of Verticillium fungus, a Glucose-mineral salt medium was utilized [10] and the incubator was set to operate day and night temperature below 20°C to satisfy the optimum fungus conditions. The components of this media were: Glucose 60 gram, KH_2PO_4: 1 gram, $MgSO_4.7H_2O$: 0.5 gram, $MnSO_4.H_2O$: 0.5 mg, KNO_3: 2 gram, Na_2HPO_4 : 0.5 gram, $ZnSO_4.7H_2O$: 0.5 mg, $CuSO_4.5H_2O$: 0.16 mg, Ammonium Molybdate: 7.2 microgram, Agar 20 gram, Water 1000 ml. We incubate the petri dishes for 7-10 days and then we prepare slides and examine under the microscope. For the detection of nematodes in the soil: soil & feeding roots samples were collected frequently during summer time, roots were examined for the presence of root-knot galls or lesions and the nematode juveniles were extracted from the soil using centrifugal-floatation technique and expressed as number of nematodes per liter of soil [11].

The olive production data were collected from the olive press mill operations records over the different years and confirmed by the production dept. & cold stores records. After harvest of 2000 season, we estimated the frost damage on the different cultivars by taking the mean productivity (Control) of olive oil produced in the three seasons (1999+2000+2001) to overcome the seasonal variation of olive bearing. We also estimated the effect of frost and salts after rain on olive trees in 2005, 2007, 2008 by taking the mean productivity (Control) of olive oil of each cultivar for the seasons 2003, 2004 when the trees reached their maximum productivity. Variations on the cultivars productivity were expressed as percentage of the productivity in the control seasons, and the results were presented into column histograms drawing. Statistical analysis for the productivity of olive cultivars using Statistix9 software was utilized to measure the significance of frost and salts damage after rain on olive cultivars.

The visual survey reports of frost damage was recorded in the various sites after few weeks of frost occurrence and stored in the research computer. We frequently shot pictures of the damaged trees in the orchards, and the damaged pictures of roots and shoots samples were saved in the research computer for future study.

To cure olive trees infected with Verticillium, drench treatment of damaged trees was carried out on March 1994 with the systemic fungicide Benomyl 50% at the rate of 20 gram/tree of 1-2 years age, 50 gram/tree of 3-4 years age and 100 gram/tree of 8 years.

Data on the weather had been collected periodically through daily and monthly reports from the company's weather station located near the cold stores at a location overlooking the orchards and is connected with the main TADCO offices through a modem. The daily report contains the data of the previous day: minimum and maximum air temperature, soil temperature at a depth of 20 cm, daily and total chilling hours in the winter months, relative and minimum humidity, wind speed meter/second, precipitation, and evaporation coefficient. The monthly report contains the detailed daily means into three main reports: the first report is dedicated to air and soil temperature at different depths (zero, 20, 50 and 100 cm), and chilling hours; the second report is dedicated to the relative humidity, precipitation rate, evaporation coefficient and the third report dedicated for solar radiation and wind speed. The weather station coordinates were:

Latitude: 28° 43' 87" N, Longitude: 36° 26' 46" E, Altitude: 725.42 M.

RESULTS

Effect of dissolved salts after rain on olive trees

Olive trees, age 1-4 years were observed severely damaged during the early months of 1994 after a heavy rainfall occurred on December 22, 1993 (10.92 mm) and on January 1, 1994 (13.46 mm). Symptoms of damaged trees were sudden leaves defoliation after one week of last rain, and some young trees were killed. Then we observed on the defoliated trees symptoms of limbs dieback. By the mid of February of 1994 new symptoms started to appear on non-defoliated trees: tip burn on the leaves and the branches on one part of the young trees were killed while the other part was green. The cross and slant sections of the damaged branches shown brown discoloration which when we incubated in a moist plastic bag showed after few days fungus growth which was identified as Verticillium. Field survey on the damaged trees was carried out on March 1994 and is represented on **Table 3**. The Olive trees at the orchard (3) and (4) were badly damaged. The cultivars with high salt damage at orchard (3) were in the following order: Picual then Verdale then Gordale then Manzanilla then Improved Nebali with % Damage 92.9, 92.2,

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88.4, 51.5, 0.36 respectively; and at orchard (4), cultivar Picual then Ayvalik then Frontioi then Surani then Jordan with % Damage 45.66, 23.6, 20.26, 3.29, 0.06 respectively. Leaching operation was carried out after one week from the last rain to push the salts away from the root-zone of the trees. A limited number of killed trees were replaced, and most of the trees recovered back on April & May of 1994, and they were in good shape.

Table 3. Damaged olive trees of different cultivars after sudden rainfall on January 1994.

Cultivars	Orchard	Age (Year)	Total Number of Trees	Number of Damaged	% Damaged
Picual	**3**	3 - 4	1248	1159	92.9
Verdale		3 - 4	1855	1710	92.2
Gordale		3 - 4	631	558	88.4
Manzanilla		3 - 4	2156	1110	51.5
Improved Nebali		New	9604	34	0.35
Jordan	**Main Road**	8	4879	3	0.06
Picual		1 - 4	547	129	23.6
Picual	**4**	2 - 4	10569	4826	45..66
Frontioi		1 -1.5	3786	166	4.4
Coratina		1 -1.5	NA	NA	NA
Ayvalik		1 - 2	12617	285	20.26
Surani		1 - 2	17487	576	3.29

Salt damage was observed on olive trees of three years age at the main road after a sudden rainfall occurred on October 17, 1997, of the amount of (5.6 mm) followed by heavy rain on the next day by (21.1 mm). Symptoms of damage were as follows: after a week of heavy rainfall, we observed tip burn on leaves of the average age and old leaves. We also noted the ease removal of active olive leaves by hand from the young shoots; after two weeks we observed total defoliation of leaves and the death of the secondary branches. Survey of the damaged olive trees of the cultivar Improved Nebali had shown the %damaged trees at three locations were in the range of 2.31-22.83% and is represented in **Table 4**.

Table 4. Damaged olive trees of the cultivar Improved Nebali after sudden rainfall on October 1997.

Location	Total Number of trees	Number of Damaged trees	Cultivar	%Damage
Main Road to Cold Store	1472	34	Improved Nebali	2.31
Orchard (3), Blk 32	670	153	Improved Nebali	22.83
Orchard (3), Main Road	2400	102	Improved Nebali	4.25

Data on the soil & tissue analysis of samples taken shortly after heavy rainfall on October 1997 from salt damaged olive trees of Improved Nebali cultivar are shown in **Table 5**. The results had shown very high concentrations of salts in the form of sodium & chloride were accumulated around the trees roots, and it reached above the damaging levels.

Table 5. Analysis of soil samples taken near drippers & away drippers of olive trees affected by dissolved salts after rainfall.

Location	Damage	Dripper	Depth	pH	Ec	Calcium	Magnesium	Sodium	Chloride	Bicarbonate
Main Road, Cold Stores	Yellow Tree	Near Dripper	30 cm	7.8	1.2	130	16	630	265	152
		Away Dripper	30 cm	8.1	17.9	590	143	3400	1991	152
Silo Road	Damaged Tree	Near Dripper	30 cm	7.4	5.4	680	121	800	575	152
		Away Dripper	30 cm	8.8	88.6	490	288	9979	12921	152
		Near Dripper	60 cm	7.4	1.5	100	17	250	265	152
Silo Road	Yellow Tree	Near Dripper	60 cm	7.5	1.5	70	20	160	221	76
		Away Dripper	60 cm	8.3	69.2	430	353	4420	10089	534
Orchard (4),Blk 3	Yellow Tree	Near Dripper	30 cm	7.5	4.5	630	109	440	708	152
Orchard (4), Blk 3	Damaged Tree	Near Dripper	60 cm	7.4	5.9	680	101	750	973	76
		Away Dripper	60 cm	8.4	145	290	401	15760	47878	457
Acceptable Level				6.5-8.0	< 4.5	< 1600	40-80	< 920	< 532	152 - 457

Analysis results for the plant samples taken from the salt damaged olive trees and healthy trees of the Improved Nebali cultivar are shown in **Table 6**. Results had shown high chloride & sodium content in the tissue which exceeded the acceptable Level.

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Table 6. Analysis of olive leaves and twigs samples of Improved Nebali cultivar collected from the trees affected by dissolved salts after heavy rainfall.

Type of Sample	State of Damage	%Chloride	%Sodium
Olive Leaves	Normal	0.3	0
	Damaged	3.2	1.4
Olive Twigs	Normal	0.42	0
	Damaged	2.5	1.3
Acceptable Level		≤ 0.5	≤ 0.25

Effects of frost on olive trees in 2000 season

A drop in the night temperature to -2.85°C was recorded at TADCO weather station on January 29, 2000 and this caused heavy defoliation to the olive trees of Picual cultivar at the orchard (4) near the main road. The trees resumed sprouted leaves and shoots after few months and recovered their natural growth in the following season. Due to frost damage, the productivity of olive oil in 2000 season of all cultivars was reduced by 30.15%, and we found sharp reduction in the productivity of Coratina, Picual and Manzanilla cultivars by 95.89, 89.78, 81.21 respectively; reduction on the cultivars Jordan and Improved Nebali was 33.87, 20.86% respectively, see **Table 7** and **Figure 1**. However, the productivity of Ayvalik was increased by 129.46%; productivity of Frantioi and Surani cultivars were increased by 23.12 and 2.94% respectively. There was no fruits on Verdale.

Table 7. Effect of frost damage on the productivity of TADCO cultivars (M.T.) in 2000 season.

Season	Jordan	Frantioi	Manzanilla	Surani	Picual	Ayvalik	Improved Nebali	Verdale	Coratina	Total
2000	5.74	9.48	0.96	11.91	3.31	29.67	13.73	0	0.39	75.19
Mean Productivity*	8.68	7.7	5.11	11.56	32.39	12.93	17.35	2.42	9.5	107.64
% Variation	-33.87	23.12	-81.21	2.94	-89.78	129.46	-20.86	100%	-95.89	-30.15%

Mean Productivity* = Productivity of olive oil of each cultivar for the seasons 1999, 2000, 2001.

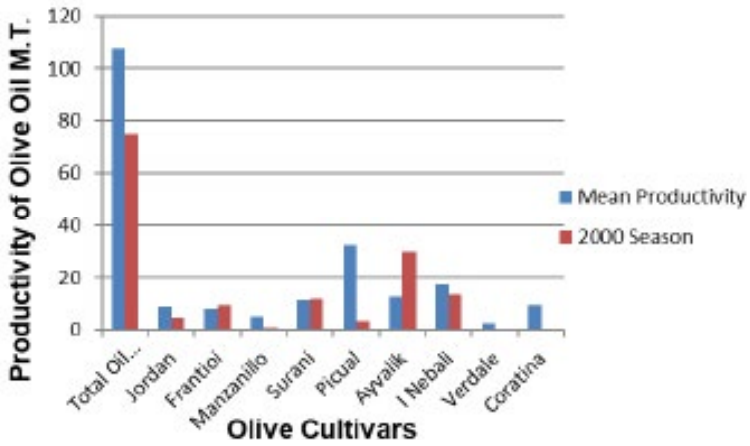

Figure 1. Effect of frost damage on the productivity of olive oil of TADCO cultivars in 2000 season.

Statistical analysis for the productivity of olive cultivars using Staistics9 Software is represented in **Table 8** had shown no significant difference for olive oil productivity kg/tree in 2000 season compared to the mean productivity (Control) of each cultivar for the seasons 1999, 2000, 2001.

Table 8. Effect of frost damage on the productivity of olive cultivars for olive oil kg/tree in 2000 season. Randomized Complete Block AOV table for Olive Oil.

Source	DF	SS	MS	F	P
Years	1	1.0658	1.0658		
Cultivar	8	8.9861	1.1233	1.36	0.3372
Error	8	6.6107	0.8263		
Total	17				

Note: SS are marginal (type III) sums of squares.

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Grand Mean 1.0733 CV 84.69

Tukey's 1 Degree of Freedom Test for Nonadditivity

Source	DF	SS	MS	F	P
Nonadditivity	1	2.5944	2.5944	4.52	0.0710
Remainder	7	4.0163	0.5738		

Relative Efficiency, RCB 1.00

Means of Olive Oil Kg/Tree for each Olive Cultivar

Jordan	Frantioi	Manzanilla	Surani	Picual	Ayvalik	Improved Nebali	Verdale	Coratina
1.48	0.495	0.88	0.745	0.99	2.895	0.485	1.035	0.655

Observations per Mean 2

Standard Error of a Mean 0.6428

Std Error (Diff of 2 Means) 0.9090

Effect of frost and rain on olive trees in 2005

Olive trees mainly at the orchard (4) were subjected to a combined effect of frost occurred in the second week of January 2005, and high soil moisture conditions after heavy rainfall on January 22, 2005, which caused heavy defoliation of leaves, and terminal shoots and twigs dieback. The damage observed on Surani trees which were located in the middle area of this orchard and spread towards the surrounding areas on different cultivars. Symptoms of damage were of three types:

Type I: Damage is characterized by heavy leaves defoliation on some trees. The feeding and supporting roots of these trees were with severe necrotic lesions, and Fusarium fungus was detected on the roots lesions as shown in **(Figure 2a and 2b)**.

Figure 2. a) Heavy leaves defoliation, b) Damaged olive tree roots.

Type II: damaged trees showed brown leaves sticking on damaged trees. Bark split on the twigs of these trees was characterized by longitudinal cracks 1-5 cm, and the bark split was the cause of drying leaves, small shoots and twigs as shown in **(Figure 3a and 3b)**. Few Surani trees demonstrated dark brown exudates at the tree trunk and cross-section of the trunk showed dark brown circle in the wood centre **(Figure 3c and 3d)**.

Type III: some trees showed the two types of damage i.e. brown leaves, bark split & leaves defoliation.

Figure 3. Symptoms of frost damage on olive trees in January 2005.

a) Bark split on twigs b) Tree with dry brown leaves c) Tree with brown exudates d) Cross section on Surani Trunk.

Analysis of soil samples collected from the orchard (3) and orchard (4) on January 2005 before the start of frost & rain had shown a high level of chloride in the soil and high Ec outside dripper area of block 20 at the orchard (3), a detailed analysis is presented in **Tables 9** and **10**.

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Table 9. Analysis of soil samples taken from orchard (3) on January 1, 2005.

Particular Analysis	Blk 20, Near Dripper	Blk 20, Near Dripper	Blk 20, Outside Dripper	Blk 20, Outside Dripper	Acceptable Level
Depth (cm)	**25**	**50-75**	**25**	**50-75**	
pH (0-14)	7.23	7.37	7.52	7.32	6.5 - 8.0
Ec (mS/cm)	4.5	2.88	8.35	8.06	< 4.5
Calcium, ppm	1116	1080	1032	1127	1000 - 1600
Magnesium, ppm	220	215	222	225	40 - 80
Potassium, ppm	290	211	335	281	100 - 175
Sodium, ppm	240	267	355	332	460 - 920
Chloride, ppm	851	681	1872	1957	355 - 532
Phosphorus, ppm	15	9	10	8	10- 20
Bicarbonate, ppm	458	153	458	305	152 - 457

Table 10. Analysis of soil samples taken from orchard (4) on January 10, 2005.

Particular Analysis	Blk 1, Near Dripper	Blk 1, Near Dripper	Blk 1, Outside Dripper	Blk 1, Outside Dripper	Acceptable Levels
Depth (cm)	**30**	**50**	**30**	**50**	
pH (0-14)	7.35	7.26	7.74	7.37	6.5 - 8.0
Ec (mS/cm)	0.96	1.74	2.37	0.89	< 4.5
Calcium, ppm	185	281	279	305	1000 - 1600
Magnesium, ppm	105	124	123	115	40 - 80
Potassium, ppm	77	80	81	93	100 - 175
Sodium, ppm	93	108	140	108	460 - 920
Chloride, ppm	340	510	681	425	355 - 532
Phosphorus, ppm	5	7	8	9	10- 20
Bicarbonate, ppm	305	305	153	153	152 - 457

Tissue analysis on Surani damaged trees at the orchard (4) shown relatively high chloride level which exceeded the toxic level 0.5%, besides the trees were under stress due to nutrients deficiency of nitrogen, calcium, manganese & copper as shown in **Table 11**.

Table 11. Analysis of leaves samples taken from the damaged Surani at Blk 9 of orchard (4) on February 16, 2005.

Element Analysis	Green Leaves	Dried Leaves	Twigs Tips	Sufficient Levels
% Nitrogen	0.87	0.91	1.33	1.5 - 2.5
% Phosphorus	0.16	0.15	0.23	0.1 - 0.3
% Potassium	1.17	1.29	1.52	0.9 - 1.2
% Sodium	0.06	0.08	0.05	< 0.25
% Chloride	**0.62**	**0.56**	**0.56**	**< 0.5**
% Calcium	0.57	0.64	0.85	> 1.0
% Magnesium	0.23	0.2	0.28	> 0.2
Iron, ppm	214	327	245	> 30
Zinc, ppm	76	98	88	> 25
Manganese, ppm	19	26	19	> 25
Copper, ppm	4.8	11.9	7.1	> 5

Examination of the feeding & supporting roots of the damaged trees at the orchard (4) shown some supporting roots are dead with black color, while the young feeding roots are with brown color and the cortex is easily peeled as shown in **Figure 4a and 4b**. We encountered Fusarium wilt disease on the damaged roots associated with the moist conditions after the heavy rain. After two months of the frost damage, a new type of drying started to appear on the trees at other areas of olives and main roads on cultivar Improved Nebali. Most of the damaged trees showed drying on one or two branches on the side of each tree with brown leaves sticking to these branches **(Figure 5a)**, and some trees showed dry out on all parts of the tree with brown leaves sticking on the tree branches **(Figure 5b)**.

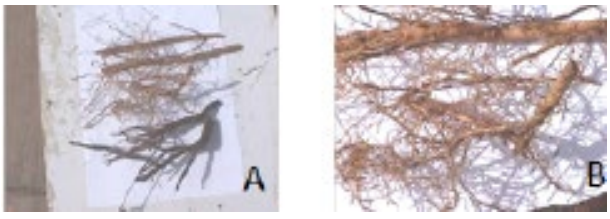

Figure 4. a) Damaged and dead supporting roots b) Damaged feeding roots.

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Figure 5. Symptoms of Verticillium wilt disease on two trees of Improved Nebali cultivar (5a, 5b).

The bark color of the damaged branches changed from green to blue-green and scrapping the cortex of these damaged branches showed brown discoloration **(Figure 6a)**; also scrapping the cortex of the supporting roots showed light brown discoloration **(Figure 6b)**.

Figure 6. a) Discoloration of damaged branches b) Discoloration of damaged roots.

Cross sections of the roots from the damaged part of the tree showed brown discoloration in the phloem and in the wood vessels, and some sections showed brown phloem **(Figure 7a)**.

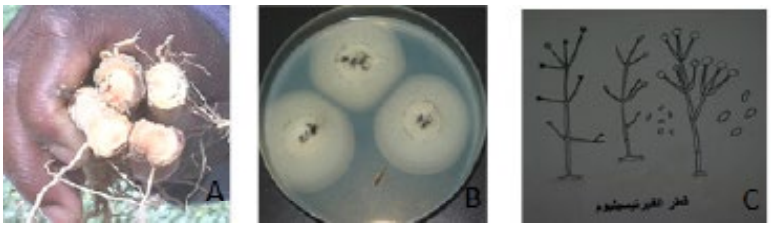

Figure 7. a) Cross section of Improved Nebali olive roots infected with Verticillium wilt disease, 7b) The isolated fungus from the infected tissue and 7c) Drawing of the fungus seen under the microscope.

Inspection of the petri dishes inoculated with the tissue from the damaged branches of olive trees had shown the start growth of a fungus with white colonies on the Glucose-mineral salt medium which turned black later in the centre. When we examined, we found a small microscopic black sclerotia (dormant stage of the fungus), see **Figure 7b**. Microscopic examination of the fungus showed typical Verticillium fungus from three infected trees: Conidiophores slender, branched, at least some of the phialides are branched, conidia ovoid, hyaline, 1 celled, borne singly or in small clusters **(Figure 7c)**.

Damaged trees were pruned; most of the trees improved in the following season 2006 and produced about two-thirds production of the 2004 season, but the waves of early frosts were repeated in the following seasons and affected the productivity significantly. Due to frost damage & high soil moisture after rain, the olive oil productivity of 2005 season of all cultivars was severely reduced by 85.13% due to the severe reduction in the productivity of all cultivar which ranged 62.87-100% of oil, see **Table 12 and Figure 8**; there was no fruits on Verdale.

Table 12. Effect of frost damage and high soil moisture after rain on the productivity of olive oil (M.T.) on TADCO cultivars in 2005 season.

Season	Jordan	Frantioi	Manzanilla	Surani	Picual	Ayvalik	Improved Nebali	Verdale	Coratina	Total
2005	4.32	6.05	0.36	1.89	8.01	1.68	10.26	0.001	2.99	35.56
Mean Productivity*	13.445	16.15	14.63	41.095	50.505	13.6	58.355	9.5	21.825	239.105
% Variation	-67.87	-62.54	-97.54	-95.4	-84.14	-87.65	-82.42	100%	-86.3	-85.13%

Mean Productivity* = Productivity of olive oil of each cultivar for the seasons 2003 & 2004.

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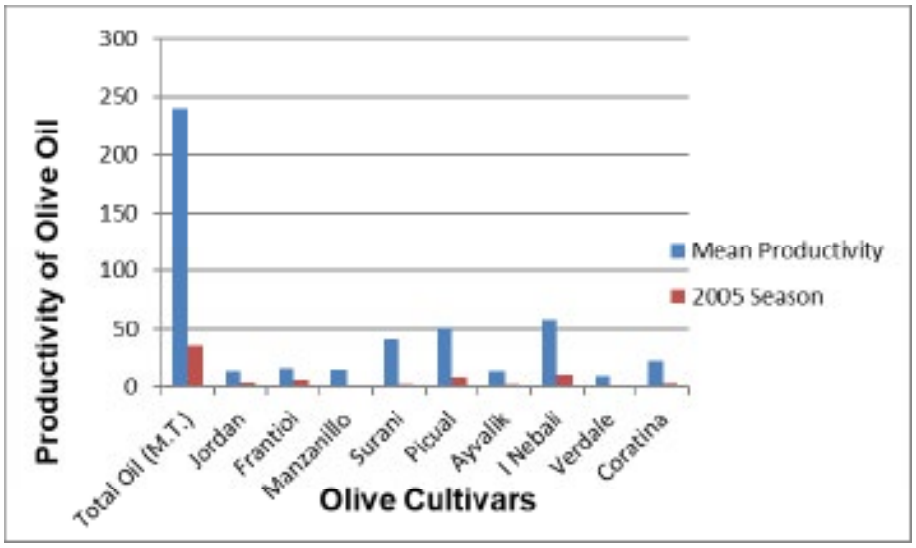

Figure 8. Effect of frost damage and high soil moisture after rain on the productivity of olive oil of TADCO cultivars in 2005 season.

Effect of frost on olive trees in 2007 & 2008 seasons

In the 2006/2007 season, the olive trees at TADCO had been severely damaged by the frost in orchard (3) and orchard (4) which caused blasting of the foliage of the trees, and the frost damage was also observed at TADCO on some trees and shrubs of permanent evergreen trees and ornamental shrubs such as orange, lemon, Washingtonia, Acacia, Dadonia, and Duranta which were not common before. Trees were exposed to freezing temperatures below zero (-2.08 to -2.65 °C) in most of the days of December 2006 when the trees were still active, and on the first half of January 2007 which led to the drying of olive trees in large areas of orchard (3) and orchard (4) in the low sites of those orchards, but slight damage occurred on olive trees at the high sites such as orchard (6), main road and olive trees blocks Near workshops.

The symptoms of frost damage on olive trees started in the early days of January 2007 as follows: redness of the leaves of Jordan cultivar growing at the main road **(Figure 9a)**. Bark split appeared on the 1-2 years young shoots of all cultivars which caused blasted appearance on the olive trees at orchards (3) (4): **(Figure 9b and 9c)**, and Surani trees exhibited wilting foliage appearance at the start of frost **(Figure 9d)**.

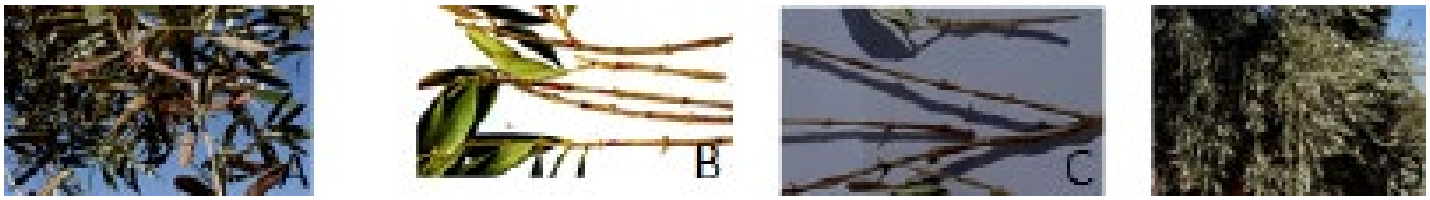

Figure 9. a) Redness of the Jordan leaves b) Bark split of young twigs of Jordan c) Bark split on young twigs of Picual d) Wilting foliage on Surani at the start of frost.

By the end of January 2007, symptoms of frost damage appeared in the middle of orchard (4) as large area of bleached color on the trees tops of different cultivars since the frost scorched the foliage of olive trees **(Figure 10a)**, see the extent of damage in orchard (4) on Jan 31, 2007, in comparison of the same orchard on Nov 10, 2006, twelve weeks before the onset of the frost **(Figure 10b)**. Close inspection of damaged trees at both orchards (3) and (4) showed foliage blasted appearance on most of the trees of the different cultivars **(Figure 11a and 11b)**.

Figure 10. Overview of Orchard 4 in January 31, 2007 (A), and the same Orchard in November 10, 2006 (B) before the frost damage.

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Figure 11. a) blasted olive tree at orchard (3) b) blasted olive tree at orchard (4).

Visual estimation of the effect of frost in 2007 was conducted on February 11, 2007. The frost damage on olive trees varied and the estimation of frost damage on the different cultivars ranged 70-90% on the trees located at the low areas in orchard 4 and 50-70% in a relatively higher location at orchard 3, and 30-50% at other higher areas. There was minimal damage to the trees at orchard 6 with location higher than other orchards and lies nearby of the high way, also no blast damage observed on the olive trees planted at the main roads of the company. Damaged trees were severely pruned and new green shoots appeared in the summer season mixed with blasted leaves, no blooming appeared on the damaged trees.

The productivity of olive oil in 2007 was reduced by 43.41% due to the high reduction in the productivity of most cultivars at orchard (3) and (4). Severe damage occurred on Manzanilla, Surani and Verdale which reached 97.40, 90.02, 62.21% respectively; and on other cultivars it ranged from 13.87-43.41% on Jordan, Picual, Jordan, Improved Nebali, Frantioi and Coratina, while productivity of Ayvalik was increased by 16.69% **Table 13** and **Figure 12**.

Table 13. Effect of frost damage on the productivity of olive oil (M.T.) on TADCO cultivars in 2007 season.

Season	Jordan	Frantioi	Manzanilla	Surani	Picual	Ayvalik	Improved Nebali	Verdale	Coratina	Total
2007	11.58	10.02	0.38	4.1	36.44	15.87	40.02	3.59	13.29	135.3
Mean Productivity*	13.445	16.15	14.63	41.095	50.505	13.6	58.355	9.5	21.825	239.105
% Variation	-13.87	-37.96	-97.4	-90.02	-27.85	16.69	-31.42	-62.21%	-39.11	-43.41%

Mean Productivity* = Productivity of olive oil of each cultivar for the seasons 2003 & 2004.

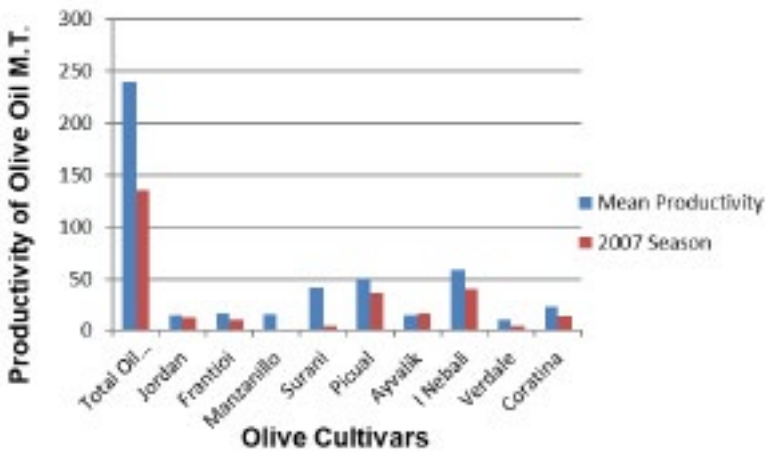

Figure 12. Effect of the frost damage on the productivity of olive oil of TADCO cultivars in 2007 season.

In the 2007/2008 season, the trees suffered the worst frost damage at TADCO as the trees experienced the coldest January month in the history of the company. The temperature dropped at night to low levels of freezing temperatures ranging -3.8°C to -5.7°C in the period January 12-17, 2008 and the damage extended to large areas of the olive trees at orchards (3) and (4). Frost damaged olive trees exhibited a complete blasted appearance of dry foliage on the trees of the different cultivars. Bark split appeared on the twigs and young shoots on these trees, and the bark split was the cause of drying leaves and small twigs due to dehydration followed by dry leaves defoliation as shown in **Figure 13**.

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Figure 13. Frost damage at orchard 3 and 4 in 2008: a) young Jordan cultivar, b) old trees of Picual, c) old tree of Improved Nebali.

The productivity of olive oil in 2008 season was severely reduced by 88.85% due to the very high reduction in the productivity of all cultivars at orchard (3) and (4) which ranged 64.82-100% of oil, see **Figure 14** and **Table 14**; almost no fruits were harvested from Frantioi, Surani and Ayvalik. Damaged trees were severely pruned and new green shoots appeared mixed with blasted leaves, no blooming appeared on the damaged trees.

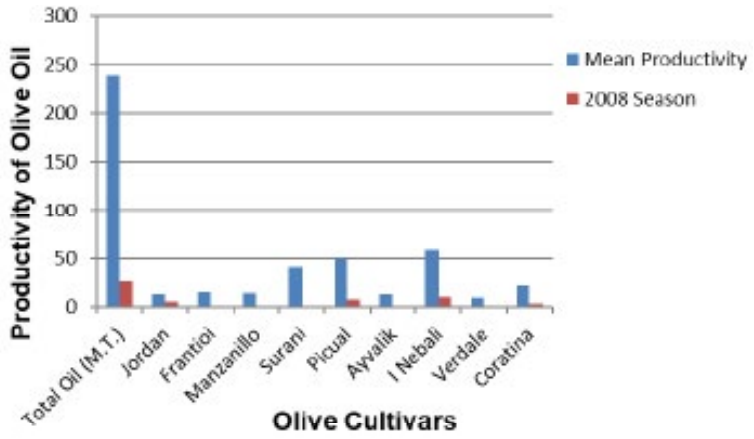

Figure 14. Effect of the frost damage on the productivity of olive oil of TADCO cultivars in 2008 season.

Table 14. Effect of frost damage on the productivity of olive oil (M.T.) on TADCO cultivars in 2008 season.

Season	Jordan	Frantioi	Manzanilla	Surani	Picual	Ayvalik	Improved Nebali	Verdale	Coratina	Total
2008	4.73	0.000	0.645	0.000	7.31	0.000	9.89	1..29	2.79	26.66
Mean Productivity*	13.445	16.15	14.63	41.095	50.505	13.6	58.355	9.5	21.825	239.105
% Variation	-64.82	-100%	-95.59	-100%	-85.53	-100%	-83.05	-8642%	-87.22	-88.85%

Mean Productivity* = Productivity of olive oil of each cultivar for the seasons 2003 & 2004.

Overall evaluation of olive productivity under the effect of frost and dissolved salts after rain

Overall evaluation for the effect of frost and dissolved salts after rain on the productivity of the different olive cultivars at TADCO from 1997 to 2010 is represented in **Table 15** and **Figure 15**. Results had shown a continuous increase in fruits productivity of olive cultivars from 347 M.T in 1997 to 2305 M.T in 2004 season. There was 25.4% reduction on fruits productivity in 2000 season due to frost damage. Also, there was a sharp reduction in the fruits productivity of olive cultivars by 80.27% in 2005 season due to a combined effect of frost and high soil moisture after rain on January 22, 2005. The third reduction of 39.96% in fruits productivity of olive cultivars in 2007 season was due to the onset of early frost in December 2006 and January 2007. The last frost damage occurred on January 22, 2008, caused a severe reduction on the productivity of olive fruits by 84.2% and led to chronic damage on olive trees mainly at the orchard (4) followed by orchard (3).

Table 15. Effect of frost and dissolved salts after rain on the fruits production (M.T.) of the different olive cultivars at TADCO over the period 1997 – 2010.

Season	Year 1997	Year 1998	Year 1999	Year 2000	Year 2001	Year 2002	Year 2003	Year 2004	Year 2005	Year 2006	Year 2007	Year 2008	Year 2009	Year 2010
Fruit Production	347	362.8	876.6	574	857	1476	1526	2305	378	1431	1150	302.6	1165	346
% Variation*				-25.4					-80.27%		-39.96%	- 84.2		

Mean Productivity for 2000 control = 769.2 M.T.; and for other seasons = 1915.5 M.T.

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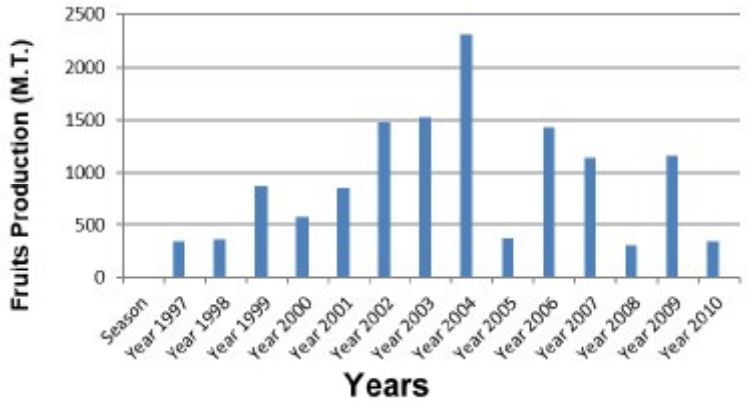

Figure 15. Effect of the frost and dissolved salts after heavy rain on the productivity of olive cultivars at TADCO in 2008 season.

Data on the productivity of olive oil of the different cultivars over the period 1999 - 2009 is presented in **Table 16**. Results had shown a continuous increase in olive oil productivity of the various cultivars from 136.5 M.T in 1999 to 296.8 M.T in 2004 season. However, due to frost damage in the seasons 2000, 2007, 2008 and the combined damage of frost with rain in 2005 season, there was a drop in the productivity of olive oil in 2000 season to 75.2 M.T. Another sharp drop in productivity of olive oil to 35.56 M.T. in 2005 and the third drop on olive oil productivity in 2007 season to 135.3 M.T. Freezing damage in 2008 caused very severe decline in productivity of olive oil to 26.66 M.T. which correspond to 88.85% **(Table 14)**; in 2000 and 2007 %reduction was high and reached 30.15 and 43.41% respectively **(Tables 7 and 13)**. Reduction in olive oil productivity due to the combined effect of frost and salts after rain in 2005 season was very high and reached 85.13% **(Table 12)**.

Data in **Table 16** had also shown the majority of olive oil produced at TADCO was from Picual and Improved Nebali cultivars with 367.99, 360.74 M.T. respectively followed by Coratina, Surani and Jordan with 158.71, 157.3, 113.89 M.T. respectively, then the rest of olive oil production was from Ayvalik then Frantioi then Manzanilla and Verdale with 107.28. 101.85, 72.41, 37.16 M.T. respectively.

Table 16. Effect of frost and dissolved salts after rain on olive oil productivity of the different olive cultivars (M.T.) at TADCO over the period 1999 – 2009.

Varieties	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	Total	# of Trees
Jordan	10.09	5.74	10.21	14.35	4.73	22.16	4.32	14.01	11.58	4.73	11.97	113.89	4879
Frantioi	10.53	9.48	3.11	19.12	25.68	6.62	6.05	8.56	10.02		2.68	101.85	17330
Manzanilla	7.41	0.96	6.97	6.18	3.05	26.21	0.36	19.93	0.38	0.65	0.31	72.41	3446
Surani	12.41	11.91	10.38	24.6	57.52	24.67	1.89	4.33	4.1		5.49	157.3	16008
Picual	52.11	3.31	41.75	58.55	33.48	67.53	8.01	34.3	36.44	7.31	25.2	367.99	17985
Ayvalik	6.77	29.67	2.35	21.52	24.49	2.71	1.68	2.22	15.87			107.28	7363
I. Nebali	7.41	13.73	30.91	38.93	13.21	103.5	10.26	53.1	40.02	9.89	39.78	360.74	31959
Verdale	7.12		0.16	4.39	1.24	17.76		0.96	3.59	1.29	0.65	37.16	1173
Coratina	22.71	0.39	5.4	12.24	17.95	25.7	2.99	13.54	13.29	2.79	4.23	158.71	7532
Total	136.5	75.2	111.2	199.9	180.5	296.8	35.56	159.1	135.3	26.66	117.8		107675

To measure the significant effect of frost and dissolved salts after rain on olive oil productivity, we calculated the olive oil produced Kg/tree of each cultivar in the 2005, 2007, 2008 seasons and the mean productivity of (2003 + 2004) seasons from **Table 16** as shown in **Table 17**.

Table 17. Effect of frost and dissolved salts after rain on olive oil productivity kg/tree of the different olive cultivars.

Olive Cultivars	Mean of (2003 + 2004) Seasons	2005 Season	2007 Season	2008 Season	Total	Mean
Jordan	2.619	0.885	2.373	0.969	6.846	1.712
Frantio	0.932	0.349	0.573	0.000	1.855	0.462
Manzan	4.245	0.104	0.110	0.189	4.648	1.162
Surani	2.567	0.118	0.256	0.000	2.942	0.737
Picual	2.808	0.445	2.026	0.406	5.351	1.425
Ayvalik	1.847	0.228	2.155	0.000	4.231	1.060
I. Nebali	1.826	0.321	1.252	0.309	3.708	0.927
Verdale	8.099	0.000	3.060	1.100	12.26	3.065

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Coratina	2.898	0.397	1.764	1.764	6.823	1.705
Mean	3.0956	0.3178	1.5078	0.5267		

Statistical analysis for the productivity of olive cultivars using Staistics9 Software is represented in **Table 18** had shown very high significant difference for olive oil productivity kg/tree in the frost years compared to the mean productivity of each cultivar in the mean of (2003 + 2004) seasons which were free from frost damage.

Table 18. Effect of frost damage and dissolved salts after rain on olive oil productivity kg/tree of the different olive cultivars.

Randomized Complete Block AOV Table for Olive Oil

Source	DF	SS	MS	F	P
Cultivar	8	18.6543	2.3318	1.99	0.0924
Years	3	43.3318	14.4439	12.31	0.0000
Error	24	28.1592	1.1733		
Total	35				

Note: SS are marginal (type III) sums of squares

Grand Mean 1.3619 CV 79.53

Tukey's 1 Degree of Freedom Test for Nonadditivity

Source	DF	SS	MS	F	P
Nonadditivity	1	14.6205	14.6205	24.84	0.0000
Remainder	23	13.5387	0.5886		

Relative Efficiency, RCB 1.23

Means of Olive for Years

Years	Mean
Control	3.0956
2005	0.3178
2007	1.5078
2008	0.5267

Observations per Mean 9

Standard Error of a Mean 0.3611

Std Error (Diff of 2 Means) 0.5106

Statistical analysis had shown:

- Very high significant damage of frost and dissolved salts after rain on the olive oil productivity in 2005 in comparison to the control seasons:

t value for (3.0956 – 0.3178) / 0.5106 = 5.44*** (DF 24).

- Very high significant damage of frost on the olive oil productivity in 2007 in comparison to the control seasons:

t value for (3.0956 – 1.5078)/0.5106 = 3.11*** (DF 24).

- Very high significant damage of frost on the olive oil productivity in 2008 in comparison to the control seasons:

t value for (3.0956 – 0.5267) / 0.5106 = 5.03*** (DF 24)

The productivity of olive oil per tree of each cultivar in the seasons of frost stress: 2000, 2007 and 2008 were used to evaluate the tolerance of olive cultivars to frost and in comparison, with maximum productivity per tree/year is represented in **Table 19**. The relatively tolerant cultivars for frost were Ayvalik then Jordan then Verdale as per the criteria of Mean Low Productivity (MLP) of olive oil Kg/tree which reached 2.06, 1.51, 1.39 Kg/tree respectively, while the rest of the cultivars were with low frost tolerance as they had low MLP value in the following order: Picual, Coratina, Improved Nebali, Frantioi, then Surani, and Manzanilla which reached 0.87, 0.73, 0.66, 0.38, 0.34, 0.22 Kg/tree respectively.

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Table 19. Effect of the frost and dissolved salts after heavy rain on olive oil productivity Kg/tree of the different olive cultivars at TADCO.

Cultivars	Jordan	Frantioi	Manza-nilla	Surani	Picual	Ayvalik	Improved Nebali	Verdale**	Coratina
Maximum Productivity/ tree*	2.62	0.93	4.25	2.57	2.81	1.85	1.83	2.29	2.9
2000	1.18	0.55	0.28	0.77	0.18	4.03	0.43	–	0.052
2007	2.37	0.58.	0.11	0.26	**2.03**	2.16	1.25	3.06	1.76
2008	0.97	NA	0.19	-	0.41	-	0.31	1.1	0.37
Mean Low Productivity	1.51	0.38	0.22	0.34	0.87	2.06	0.66	1.39	0.73

*Maximum Productivity of any cultivar = Productivity of (2003 + 2004)/Number of trees per cultivar.

**Productivity of Verdale is the Mean of 2000, 2003, 2006, 2007, 2008 productivity.

One M.T. of olive oil = 1085 liter, and one liter of olive oil = 0.92 Kg.

Jordan cultivar with large trees produced on all frost years; Ayvalik was with the highest yield in 2000 season, but it did not bear fruits in 2008. Verdale was with the highest yield in 2007, but it did not bear fruits in 2000 season. Verdale, Jordan and Ayvalik were relatively with high yield in 2007. Both Verdale and Ayvalik beard no fruits on some years during their life cycle.

The status of low productivity of olive trees at the orchard (4) enforced TADCO to remove the damaged trees at this orchard in autumn 2009 due to being not economically feasible as the trees were weak with dry branches and infested with Neiroun insects which threatened the rest of healthy trees **Figure 16a and b**. The number of trees left after 2009 were 68177 trees in an area of 239.118 Ha. with less number of trees by 36.4% and less area of 37.21% of the planted area **Table 20**. This enabled TADCO to improve fruits productivity to 2728 M.T. in 2011 which is likely reduced the cost of production.

Table 20. Number of olive trees and area at TADCO in 2011 season.

Season	Number of Trees	Area (Ha.)	Potential Productivity (M.T.)
2003	107193	380.8	2305
2011	68177	239.118	2728
% Reduction	36.4	37.21	

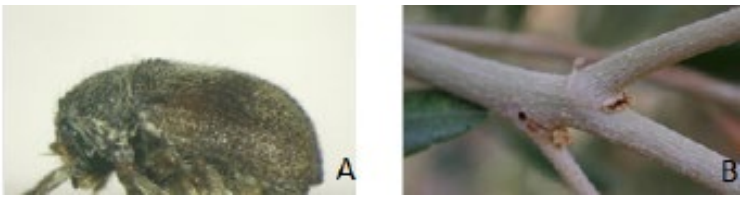

Figure 16. a) Olive Neiroun, Phloeotribus oleae adult figure (Magnified), and b) symptoms of the insect damage as borer at the junction of the twig and small branch.

Tabuk climate

The climate of the Tabuk region is characterized by moderate temperatures in most months of the year, except for the summer period, where the average temperature range between 37 - 40°C in the period from June to the end of August. The temperature drop in winter and the minimum temperature range between 3 - 4°C degrees in the period from December to February as shown in **Figure 17**. The temperature rise in summer months of July and August to a range 42 - 44°C for a few days of the month; in August 20-21, 2010 extreme temperature records reached to a range of 47 - 48.5°C at the orchards area for few hours during the day.

In winter months, the temperature drops below zero for a few days of December, January and February of each year. The lowest temperature recorded at TADCO was (-5.73°C) on the night of January 16, 2008, which caused severe frost damage to olive trees of different cultivars and age, and this level of low temperature probably never happened during the period of the olive project expansion. The temperature dropped to below zero in the winter months of 1997-98, 2000, 2001, 2002 and 2003, and in the period from 2005 to 2009. No drop of the temperature below zero in the seasons of 1996, 1999, 2004 and 2010, as shown in **Figure 18**.

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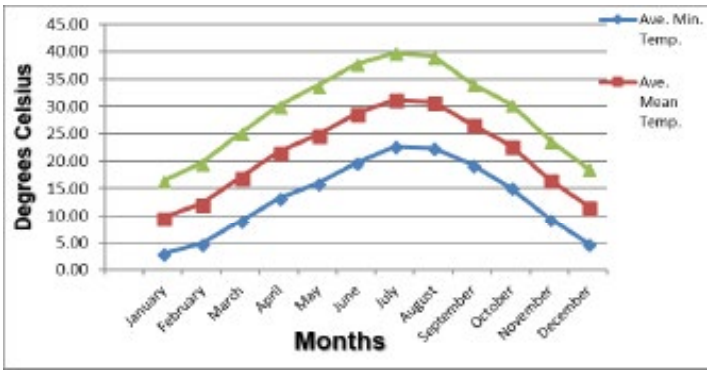

Figure 17. Average monthly minimum, maximum and mean temperature at TADCO for the period 2000 – 2003.

According to TADCO weather records, a temperature below (- 5°C) occurred on the 6th of January and on the 4th of February 1989, where the project was limited in that year to the cultivar Jordan planted at the main road of the company. The olive trees did not suffer serious damage at that time because it is located at a relatively higher location in the orchard. Low temperatures had been measured at TADCO near main offices on different winter months over the years using special devices whose sensors were placed on the surfaces of lawn grass at the early morning and even after sunrise for half an hour or more and recorded temperatures of (-5°C) or less for many times in different seasons.

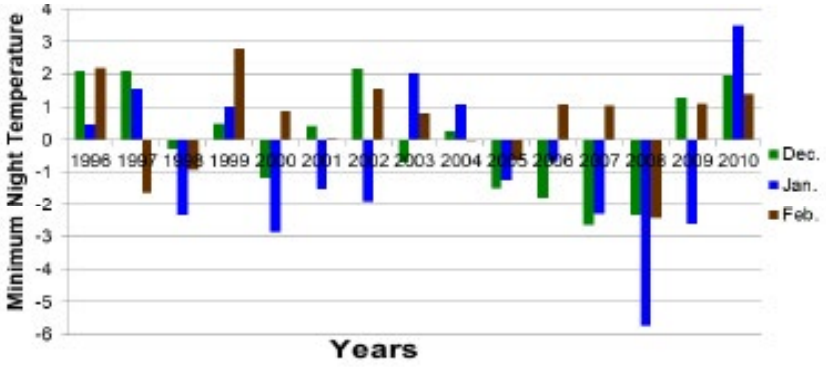

Figure 18. Record of the lowest temperatures at TADCO for the period from 1996 to 2010.

Comparison of the data of the minimum temperatures during the winter months of 2007 season (starting December 1, 2006, until the end of February 2007 with the winter months data of the 2006 season when the low temperature dropped gradually and caused no frost damage on olive trees is presented in **Figure 19**. It had shown an early drop of temperature below zero for 2007 season when the trees are still active as the average minimum temperature was below zero in most of the days for the period December 24, 2006, until Jan 3, 2007. The temperature reached -2.08°C and -2.65°C on December 28 and 29, 2007 respectively and it reached -2.3°C on Jan 3, 2007. The curve of 2007 season had shown that December of the season 2006/2007 was the coldest December in the history of olive orchards and possibly the coldest December in the history of the company. Comparison of the data of the minimum temperatures during the winter months of 2008 season with the minimum winter month's temperatures of the 2006 season is presented in **Figure 20**. It had shown the drop in temperature below zero for 2008 in the period December 22-26, 2007, and then another drop started on January 17, 2008. The temperature drop reached new records of temperatures -3.78°C, -5.3°C, -5.47°C, -5.2°C, -5.73°C, -4.08°C on the period January 12-17, 2008. These freezing temperatures badly damaged the olive trees. The curve of 2008 had shown that January of the season 2007/2008 was the coldest month in the history of olive orchards and possibly the coldest month in the history of the company.

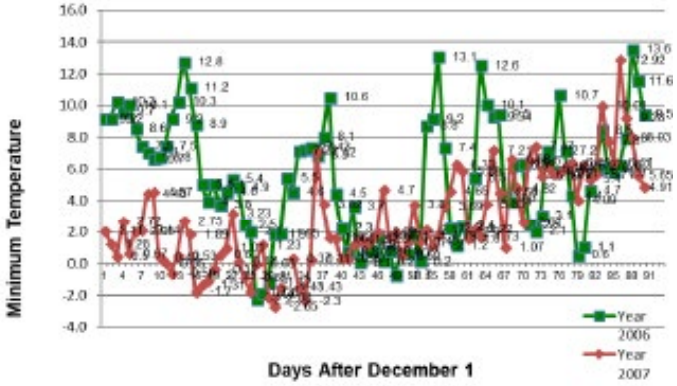

Figure 19. Comparison of the minimum temperatures during the winter months of 2007 season with the minimum temperatures of the winter months of 2006 season.

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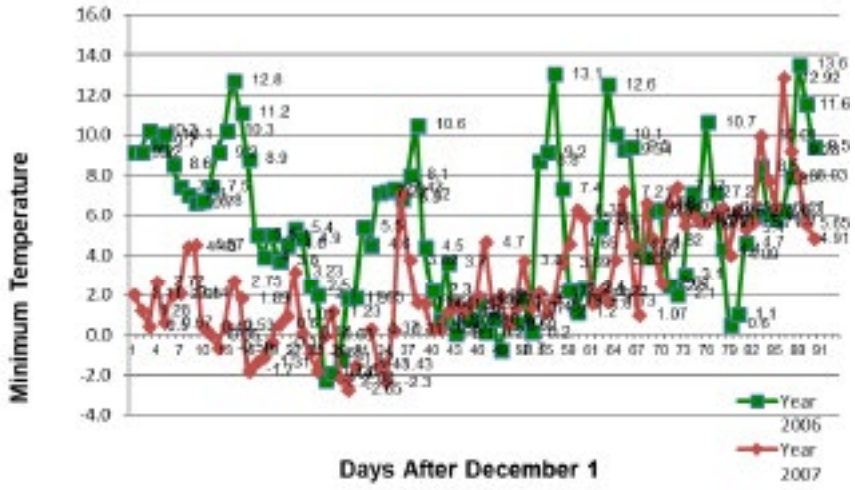

Figure 20. Comparison of the minimum temperatures during the winter months of 2008 season with the minimum temperatures of the winter months of 2006 season.

DISCUSSION

Olive trees were grown in the desert areas with low rainfall during winter to leach the accumulated salts. It is irrigated by the drip irrigation system which leaches the salts away from the vicinity of the roots and provides the tree with the water needed for its growth. The salts were formed as a result of water evaporation in the hot months of the year and accumulate on the soil surface at the edges of the wetting front of the drippers under the canopy of the trees which can be easily seen as a white crust on the soil surface of the trees during the winter months. The source of these salts is irrigation water as well as the soil weathering, and in areas, with regular rain, these salts are dissolved by winter rains. These salts increase in desert areas year after year in the absence of a drainage system, which requires the conduct of seasonal leaching operations to manage this salts problem.

The olive trees age 1-4 years were subjected to severe salt toxicity at the early days of January 1994 after two heavy rainfalls of 10.92 mm in the last week of December 1993 and 13.46 mm on January 1, 1994. Symptoms of damaged trees were heavy leaves defoliation and some young trees were killed, another group of trees showed limbs dieback. By mid of February, the un-defoliated trees exhibited dead branches in one side of the tree while the other side the branches were green. Examination of the roots from the damaged trees showed Verticillium fungus which is favored by cold wet soil after heavy rain and salts leaching operations, and these results agree with the report on Verticillium dahlia in Tunisia [12]. Drench treatment of damaged trees were carried out on March 1994 with the systemic fungicide Benomyl 50% at the rate of 20 gram/tree of 1-2 years age, 50 gram/tree of 3-4 years age and most of the damaged trees recovered back on April and May 1994.

Salt damage was observed on 3-years olive trees of the cultivar Improved Nebali planted at the main roads of TADCO on November 1997 after sudden rainfall of 5.6 mm on October 17, 1997, followed by heavy rain (21.1 mm) on the next day October 18. After one week from the onset of the rain, symptoms of damage were tip leaves burn and after two weeks symptoms of leaves defoliation followed by the kill of secondary branches. Laboratory analysis of soil & plant samples collected from the damaged olive trees shortly after the rainfall showed the high concentration of sodium & chloride salts around the roots. Apparently, the salts dissolved by the heavy rain were leached to the roots zone consequently caused toxicity to the roots. We confirmed this toxicity from the analysis results of the leaves and twigs which showed the high level of sodium (1.4%) and chloride (3.2%) into the damaged leaves and twigs. These results are in agreement with the reports on olive trees salinization when a sudden rainfall >10 mm occurs, it will leach accumulated salts from the dry zone surrounding the roots to the wetted front of the drip irrigation zone under the tree, and this caused the exposure of the roots to a high concentration of soluble salts causing toxicity to the trees after a few days of the rainfall incident and caused leaves defoliation and shoots dieback [13,8].

Olive trees of the different cultivars and age were subjected to frost damage at TADCO on January of 2000, 2005, 2007, 2008 causing economic losses on the olive productivity. A drop in the night temperature to -2.85 °C was recorded at TADCO farms on January 29, 2000 and this caused high leaves defoliation to the olive trees of Picual cultivar at the orchard (4) near the main road. The trees resumed their natural growth in the following season; productivity of 2000 season of all cultivars was reduced by 25.4% for the fruits and 30.15% for olive oil due to the severe reduction on the olive oil productivity of Coratina, Picual and Manzanilla, Jordan cultivars by 95.89, 89.78, 81.21, 33.87% respectively, while the productivity of Frantioi and Surani cultivars were increased by 23.12 and 2.94% respectively, and in Ayvalik cultivar it increased by 129% apparently it is frost tolerant, Verdale cultivar was with no fruits due to alternate bearing phenomena. Apparently, the non-damaged cultivars were dormant during the onset of freezing temperature. The trees resumed their natural growth in the following season, and there was a steady increase in the productivity of the trees of the different cultivars which peaked in the 2004 season. So, the statistical analysis for the

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productivity of olive cultivars using Staistics9 Software had shown no significant difference for olive oil productivity kg/tree in 2000 season compared to the mean productivity of each cultivar for the seasons 1999, 2000, 2001.

Olive trees at the orchard (3) and orchard (4) were subjected to combined damage under the effect of frost occurred in the second week of January 2005 (-1.2 to -1.78°C) and high soil moisture conditions after heavy rainfall of (10.16 mm) on January 22, 2005. Symptoms of damage varied depending on the orchard location low or high, and it included heavy leaves defoliation, bark split of 1-2 years old shoots and limbs dieback with dry leaves sticking on the trees. Thousands of olive trees were damaged at the orchard (4) four days after rainfall, they were with sudden leaves defoliation on Surani cultivar, and sporadic damage on the olive cultivars at most of the blocks of the orchard (4) with sudden drying of the branches and the leaves were with brown color sticking on the trees. This damage was due to bark split of the small peripheral branches by the freezing effect of frost. The frost damage then appeared at the orchard (3) on Manzanilla, Verdal and Jordan. Few trees of Surani at the orchard (4) showed brown exudations on the main trunk with dark brown wood tissue seen in the crossing section an indication of damaged wood tissue. This frost damage was reflected by a sharp decrease in olive orchards productivity in the 2005 season; the severe damage was probably due to high soil moisture after heavy rainfall and leaching action after rain accompanied with cold soil temperature after frost which caused damage to the olive trees and in addition chloride toxicity. Due to frost damage & high soil moisture after rain, the olive fruits productivity in 2005 season was reduced by 80.3% and in oil by 85.13% due to the severe reduction in the productivity of all cultivars which ranged 62.66-95.40% of oil production.

Orchard (4) is located at a low site, and after 12 years of intensive culturing olive trees were with a dense canopy and tight tree spacing (6 X 6) due to less pruning arrangement which led to the dryness of the branches inside the trees. The orchard rows were with a length of 500-820 meter due to integrated blocks units with no corridors between the blocks to aid ventilation. So, the trees were with poor air ventilation to exchange cold air with normal air when frost arrived. The soil under the trees was with poor permeability due to stratified soil structure and due to shallow dense roots system 30 cm below the soil surface which led to high moisture accumulation around the roots after sudden rainfall of more than 10 mm followed by leaching operation which resulted in a typical waterlogging situation as we observed supporting roots were dead and the cortex of the feeding roots was easily peeled. We frequently encountered root rots fungi such as Fusarium in the samples collected from these trees, and later in June 2005, we confirmed the infection of few olive trees of Improved Nebali at the main roads with Verticillium wilt disease. These results agree with the reports of [5,6] that olive trees grow well in different soils as long as it is well aerated and free from waterlogging. Under waterlogged conditions, damage through lack of oxygen and fungal diseases increases sharply [3].

It was observed in the 2006/2007 season severe frost damage in orchards (3) and (4), trees were exposed to temperatures below zero in most of the days of December 2006 and the first half of January 2007 which caused blast symptoms on the foliage of the trees appeared as large area of bleached color on the trees tops of different cultivars, but little damage was observed at high locations like orchard (6), main roads and blocks near the workshop. Early onset of freezing temperature when the trees are still active and they were not in the state of dormancy was the cause of this severe damage. These results are in agreement of reports of [4,14] that the period of the year when freezing temperature occur might influence cold resistance in evergreen species which is closely related to the hardening process and depends on cold acclimation in terms of exposure to a period of low but non-freezing temperatures that increase the ability to withstand the subsequent freezing temperatures. The productivity of olive fruits in 2007 season was reduced by 39.96% and in oil by 43.41% due to the high reduction in the productivity of most cultivars at the orchard (3) and (4). Severe damage occurred on Surani and Manzanilla which reached 90.02, 97.55% respectively, and on other cultivars it ranged from 13.87–62.21%, while productivity of Ayvalik was increased by 16.69%. Increased productivity of Ayvalik in 2007 indicate the high tolerance of this cultivar to frost. Damaged trees were severely pruned and new green shoots appeared in the summer season mixed with blasted leaves, no blooming appeared on the damaged trees.

In the 2007/2008 season, the trees suffered the worst frost damage as the trees experienced the coldest January month in the history of TADCO. The temperature dropped at night to low levels ranging from -3.8°C to -5.7°C during the period January 12 to 17, 2008, and the damage extended to large areas of the orchards (3) and (4). Frost damaged olive trees exhibited a complete blasted appearance of dry foliage on the trees of the different cultivars: bark split appeared on the shoots of 1-2 years old and the branches on these trees. The bark split was the cause of drying leaves and branches due to dehydration after exposure to freezing temperature followed by dry leaves defoliation. This situation was reflected by a sharp decrease in olive orchards productivity in the 2008 season. The productivity of olive fruits in 2008 season was severely reduced by 84.2% and in olive oil by 88.85% due to the very high reduction in the productivity of all cultivars at orchard (3) and (4) which ranged 64.82-100% of oil and almost no fruits were harvested from Frontioi, Surani and Ayvalik. Damaged trees were severely pruned and new green shoots appeared mixed with blasted leaves, no blooming appeared on the damaged trees. Statistical analysis for the productivity of olive cultivars using Staistics9 Software had shown very high significant difference for olive oil productivity kg/tree in the frost years of 2005, 2007 and 2008 compared to the mean productivity of each cultivar in (2003+2004) seasons which were free from frost damage.

Comparison of the data and curves of the minimum winter months temperatures of 2008 season with the minimum winter months temperatures of the 2006 season, when there was no frost damage had shown drop of low temperature in 2008 season which reached new records of -3.78°C, -5.3°C, -5.47°C, -5.2°C, -5.73°C, -4.08°C on the period January 12-17, 2008. These

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freezing temperatures badly damaged the olive trees, and in January of the 2008 season was the coldest month in the history of the company. The results demonstrate that olive cultivars grown under desert conditions in the north-west of Saudi Arabia have higher threshold temperature for cold hardness than same cultivars grown in Southern Europe countries. Data and curve of 2006 season showed the trees experienced a gradual drop in temperature and reached the lowest temperature (-2.2°C) on the 27th of December 2005, so practically speaking they entered dormancy before the onset of the frost, consequently no frost damage. Data and curve in 2008 season showed the trees experienced a gradual drop in temperature until the second week of January 2008, so they were expected to be in dormancy before the onset of freezing temperatures (-5.2 to -5.73°C) on January 12 which lasted for six days. Reports on frost damage on olive trees in Italy indicated that when winter temperature drop below (-7°C), the aerial parts of olive trees can be damaged leading to yield reduction, and in extreme cases kill the trees [4]. Reports mentioned that the olive trees during dormancy period tolerate short periods of frost of (-6°C) [3]. As per our present weather records on low temperatures in Tabuk area for more than 14 consecutive years which showed frost damage occurred when the freezing temperature reached (-2.85°C) on Jan 29, 2000, but it did not cause economic losses in 2006 when the cold temperature reached (-2.2°C). These results indicate that the threshold temperature for frost damage on olive trees at TADCO is in the range (-2.2 to -2.85°C). We were aware that frost damage is affected by various factors including location of orchard is high or low, age of the tree, health of the tree, type of cultivar, length of exposure to freezing temperature, horticulture practices to prepare the trees to enter dormancy through acclimation by: avoidance of early pruning in the autumn, avoid the application of fertilizers late in the season and in particular nitrogen, reduce irrigation quantity and intervals [15]. However, the weather in the desert area may not allow for full cold hardness due to a sudden rise in day temperature or the onset of early freezing temperatures when the trees are active.

The productivity of olive oil per tree of each cultivar on the frost seasons 2000, 2007 and 2008 was used to evaluate the tolerance of olive cultivars to frost and in comparison, of maximum productivity per tree/year (Mean of 2003 & 2004). Results showed the mean low productivity Kg/tree of the cultivars Ayvalik, Jordan and Verdale reached 2.06, 1.51, 1.39 respectively, an indication of more frost tolerance of these cultivars than other cultivars of Picual, Coratina, Improved Nebali, Frantioi, Surani, and Manzanilla whom were with low productivity of 0.87, 0.73, 0.66, 0.38, 0.34, 0.22 Kg/tree respectively and they were with the lowest frost tolerance. Both Verdale and Ayvalik were tolerant to frost and produced high yield in 2007, but they were not adapted to Tabuk weather as in the years of relatively warm weather in winter they bear little fruits or none, and Ayvalik cultivar did not bear fruits in 2008 in contrary to the previous frost years 2000, 2007 [16-22].

CONCLUSION

New olive projects of the type high-density planting system or super-high-density planting system should give more attention for the site selection of new olive projects by avoiding low sites which act as pockets of freezing temperature, select land from previous cereal crop areas, deep ripping to improve soil structure, leach salts from the soil profile and add organic manure to enhance soil fertility before planting olive trees. In high-density planting system, attention to avoid dense planting and long rows, and allow corridor spacing between the blocks units to aid cold air ventilation during cold weather. Improve the health of the trees through planting olive seedlings free from nematodes & diseases infestations into soil free from infestations, follow the organic farming system where that is possible and use organic manure on traditional farming to improve the soil fertility and trees health. Acclimation of olive trees to raise their winter hardness level is a key for protecting trees from frost damage. Use frost tolerance cultivars with desired oil or fruit quality for table olives. Give more attention to tree shape and pruning.

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