Adv. Hort. Sci., 2020 34(2): 213-221 DOI: 10.13128/ahsc-7770

AHS
Advances in Horticultural Science

# Effect of spread and shallow irrigation wetted area and application of organic mulch on citrus decline amelioration

**M.S. Tadayon (*), S.M. Hosseini**
*Soil and Water Research Department, Agricultural Research, Education and Extension Organization (AREEO), Shiraz, Iran.*

*Key words: Citrus* decline, fibrous root, irrigation, orange, root decay.



(*) **Corresponding author:**
m.tadayon@areeo.ac.ir

**Citation:**
TADAYON M.S., HOSSEINI S.M., 2020 - *Effect of spread and shallow irrigation wetted area and application of organic mulch on citrus decline amelioration.* - Adv. Hort. Sci., 34(2): 213-221.



**Data Availability Statement:**
All relevant data are within the paper and its Supporting Information files.

**Competing Interests:**
The authors declare no competing interests.

Received for publication 1 January 2020
Accepted for publication 5 May 2020

**Abstract: Citrus decline threatens the orchards in the southern part of Iran. Roots begin to die-out before citrus decline deterioration. In this study, the effect of expanding the irrigation wetted area and decreasing the irrigation depth, and application of compost as organic mulch on root development and amelioration of citrus decline in Valencia orange trees (*Citrus sinensis* L. Osbeck) was investigated. Experimental factors contained the different percentage of irrigation wetted area and decreasing irrigation effective root depth by drip irrigation system at three levels - W0 (control): 30-40% with 60 cm effective root depth; W1: 50-60% with 45 cm effective root depth; W2: 70-80% with 30 cm effective root depth under tree canopy area and the factor of annual application of compost as organic mulch at two levels - M0 (control): means no application of compost and M1: application of 80 kg compost under tree canopy area with 10 cm thickness as ground cover, after rotating the top soil at 10 cm depth for all treatments. The results showed that, annual application of compost as organic mulch under tree canopy area and expanding the irrigation wetted area with decreasing irrigation effective root depth, significantly improved fibrous root length and density at a lower soil depth and decreased the indices of citrus decline such as root rot percentage, leaf and fruit drop and shoot die back. Also these treatments increased the water productivity and fruit quality of in declining Valencia orange trees.**

## 1. Introduction

Citrus decline, commonly known as 'dieback', 'chlorosis' or neglectosis, is not a specific disease but a syndrome expressing many disorders in the plant. Such syndrome leads to decline in productivity, reduced productive life and poor fruit quality. The symptoms of citrus decline contain root rot and blackening, shoot die back, growth stunt, fruit drop, reduction of canopy, smaller leaf number and size and leaf blotchy mottle (Meena *et al*., 2018). Stress-sensitive trees fail to maintain sufficient carbohydrate availability resulting in the dieback of the stressed tissues (Kreuzwieser and Rennenberg, 2014). Also, the percentage of total soluble solids and fruit juices in healthy trees is more than declined trees (Mauk and Shea, 2002). Declining trees have more water stress and more affected trees tend to have higher percentage leaf and fruit drop rates than healthy appearing trees. Soil condition and water status (water stress and water logging) significantly reduce the citrus fibrous root density and increase the severity of citrus decline (Kozlowski, 1997; Graham *et al.*, 2013; Morgan, 2015; Graham, 2017).

Citrus decline is an issue that threatens the economy of various regions of the world, including southern Iran. There are several factors that affect the incidence of this complication. The most important influential factors on citrus decline are environmental stresses such as soil physicochemical conditions (compaction, high pH, bicarbonate, salinity) and soil nutritional status (Srivastava and Singh, 2009), soil moisture content (water stress and water logging with deficit or over irrigation), and biological stresses including rootstock, nematodes, Greening disease (Huanglongbing), Tristesa virus disease, phytophthora fungal infection and root fusarium (Johnson and Graham, 2015; Graham, 2017; Meena *et al*., 2018; Dewdney *et al*., 2019). According to the USDA, since 2004-2005 total Florida citrus production declined by Greening disease from 169.1 to 94.2 million boxes in 2015-2016, down 44.4% (USDA, 2017).

The ideal environment for citrus root development is a porous, medium-textured, well-drained soil, where water is easily available but not in excess (Dewdney *et al*., 2019). Mulching with organic matter helps retain moisture in the top soil by reducing surface evaporation, as well as moderating soil surface temperatures. It also enhances the decomposition process of soil organic matter and improve the soil aeration and availability of nutrients in the soil (Gong *et al*., 2006; FAO, 2011). Increasing root water uptake efficiency and life span is possible by irrigation management such as time and duration (decrease water stress and water logging), also improving the growth environment and drainage, soil compaction, soil thermal stress, bicarbonate and osmosis stress (Huber and Haneklaus, 2007; Dewdney *et al.*, 2019). Increased root density also increases water uptake (Morgan *et al*., 2006).

In arid and semi-arid regions, the application of drip irrigation system results in root accumulation under emitter (Fernandez *et al*., 1991; Tanasescu and Paltineanu, 2004; Ruiz-Sanchez *et al*., 2005), so the expansion of irrigation wetted area could enhance the fibrous root density under declining condition. Increasing irrigation frequency and decreasing irrigation depth stimulate root length density and increase water uptake and under these conditions, irrigation at the field capacity increases root density by 50% (Kadyampakeni *et al*., 2014 a).

In citrus decline new root growth did not stop, but the root survival time was reduced from 9 to 12 months to 4 months and the root decay and dieback were increased (Dewdney *et al*., 2019). Citrus decline cause water stress and under such condition root growth is preferable to shoot growth (Hsiao and Xu, 2000). Root development dependent on soil aeration and moisture as two fundamental parameters for root healthiness, growth and distribution. Root growth in sandy and loamy soils with higher organic matter content is stronger, and increment in soil clay content has a negative relationship with the density of citrus roots (Koudounas, 1994) and the slope of clay content in soil profile is directly related to the effect of citrus decline deterioration (Srivastava and Singh, 2009). In citrus, the highest fibrous length densities were observed in the humid part of the soil at a depth of 0 to 15 cm with higher root activity until 2 m horizontal distance from the trunk (Alves *et al*., 2012). The rate of soil water depletion is directly related to the abundance of fibrous roots and in general pattern of water uptake in citrus fruits indicates that water is drained by surface roots with higher amounts of available soil water (Noling, 2003).

Lack of soil aeration and excessive soil moisture causes more severe damage than lack of moisture in declining trees, due to stop breathing and the breakdown of root cells. There is also the growth of anaerobic microenvironments and the production of substances such as nitrite that is toxic for the roots. Centralize wetted area and excessive irrigation results in water logging, oxygen deficiency and root fungal infestationin the root zone (Johnson and Graham, 2015). Deficit irrigation and soil water stress stimulates longitudinal and singular growth without lateral roots and repeated moisture stress causes thicker fibrous roots in citrus that could decrease the water uptake efficiency by the citrus roots (Castle, 1978). Increment of soil aeration and soil moisture distribution and retention could provide the better condition for root development and amelioration of citrus decline. So in this experiment, the effects of spreading irrigation wetted area and decreasing irrigation depth, and annual application of compost as organic mulch on root development and diminishing of citrus decline indices in Valencia orange was investigated.

## 2. Materials and Methods

The experiment was conducted in a commercial orchard (28°38’13.12” N, 54°40’29.69” E and altitude 1138 m) of Darab region,with very hot and dry climate (Table 1), located in south west of Fars province in Iran, over three consecutive years 2016 to 2018. Ninty-six uniform 12-year-old Valencia orange trees (*Citrus sinensis* L. Osbeck), on lime (*Citrus aurantifolia*) rootstock with citrus decline symptoms (sparse foliage, chlorotic leaves, twig drying, premature leaf fall, reduced productivity and fruit size and die-back canopy complication) were selected based on canopy diameter and labeled based on experimental plan. The distance between the trees was 4×5 m and irrigated by drip irrigation system with a loop contained 6 emitters (4 liters per hour).

Before the application of experimental treatments, a composite soil sample were taken from 0-30 and 30-60 cm depths in Oct. 2014 (Table 2). Soil samples characteristics were determined at analytical laboratory of Soil and Water Research Department, Fars Agricultural and Natural Resources Research and Education Center, Zarghan, Iran. The soil of the experimental field site was calcareous with high pH, high total neutralizing value, and low amount of organic carbon, available P and Mn (Table 2). The fertilizer application was conducted based on soil test and contained fertigation of ammonium sulfate (21-0-0-24S, 450 g tree$^{-1}$), potassium sulfate (0-0-53+17S, 150 g tree$^{-1}$) and triple superphosphate (450 g tree$^{-1}$), manganese sulfate (32Mn, 18S, 250 g tree$^{-1}$) and iron chelate (200 g tree$^{-1}$ sequestrene 138-Fe EDDHA 6%, 150 g tree$^{-1}$).

A Factorial (3×2) experiment was conducted in a randomized complete block design with four replications and each plot with four declining trees over three years. Experimental factors contained the different percentage of irrigation wetted area and decreasing irrigation effective root depth by drip irrigation system at three levels as follows:
- W0 (control)= 30-40% with 60 cm effective root depth;
- W1= 50-60% with 45 cm effective root depth;
- W2= 70-80% with 30 cm effective root depth under tree canopy area.

Also, the factor of annual application of compost as organic mulch at two levels:
- M0 (control)= means no application of compost;
- M1= application of 80 kg compost with 10 cm thickness as ground cover under tree canopy area.

Table 1 - Long-term mean of climatic elements of the study area (Darab) synoptic meteorological station statistical period (1997-2018)

| | Temperature (°C) | | | | | Relative humidity (%) | | | Precipitation (mm) | | | Evapo. (mm) (montly sum) | Sunny day (montly sum) | No. day frost | Max wind (m s$^{-1}$) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Min | Max | Ave. | Abs. Min | Abs. Max | Min | Max | Ave. | Amount | No. rainy | Max daily | | | | Direc. degree | Velo. m/s |
| April | 11.5 | 26.4 | 19.0 | 3.8 | 34.7 | 26 | 70 | 48 | 32.50 | 6 | 43.70 | 182.0 | 276.0 | 0 | 253 | 13 |
| May | 16.7 | 33.6 | 25.2 | 9.4 | 41.6 | 16 | 51 | 34 | 6.46 | 2 | 24.80 | 286.6 | 331.4 | 0 | 240 | 15 |
| June | 21.6 | 39.3 | 30.4 | 15.6 | 44.4 | 11 | 37 | 24 | 1.10 | 1 | 9.60 | 382.8 | 356.6 | 0 | 200 | 14 |
| July | 25.5 | 41.7 | 33.6 | 15.4 | 46.5 | 12 | 38 | 25 | 0.92 | 1 | 5.80 | 428.3 | 341.3 | 0 | 171 | 15 |
| August | 26.2 | 40.9 | 33.6 | 19.2 | 45.2 | 14 | 40 | 27 | 5.76 | 2 | 20.50 | 422.3 | 339.8 | 0 | 207 | 16 |
| September | 21.9 | 38.5 | 30.2 | 16.2 | 42.6 | 14 | 44 | 29 | 0.82 | 1 | 4.70 | 336.0 | 327.5 | 0 | 180 | 10 |
| October | 16.0 | 33.6 | 24.8 | 7.6 | 38.8 | 16 | 48 | 32 | 0.32 | 1 | 2.60 | 228.4 | 308.0 | 0 | 226 | 10 |
| November | 10.4 | 26.5 | 18.5 | 2.0 | 33.5 | 22 | 62 | 42 | 8.48 | 2 | 50.20 | 138.2 | 269.6 | 0 | 249 | 8 |
| December | 5.7 | 20.1 | 12.9 | -2.2 | 30.0 | 32 | 76 | 54 | 40.25 | 5 | 51.80 | 79.1 | 234.9 | 0 | 207 | 7 |
| January | 3.8 | 17.0 | 10.4 | -2.6 | 25.6 | 36 | 81 | 58 | 64.77 | 6 | 65.40 | 64.4 | 226.1 | 3 | 205 | 8 |
| February | 5.0 | 17.7 | 11.3 | -2.6 | 25.8 | 35 | 81 | 58 | 49.88 | 6 | 68.20 | 79.3 | 238.4 | 1 | 240 | 10 |
| March | 8.0 | 21.8 | 14.9 | 0.2 | 31.6 | 30 | 74 | 52 | 37.26 | 7 | 63.00 | 116.7 | 241.1 | 0 | 238 | 12 |

Table 2 - Soil characteristics in the experimental orchard

| Soil depth | Bulk density (g cm$^{-3}$) | Field capacity (%) | Wilting point (%) | EC (dS.m$^{-1}$) | pH | TNV (%) | OC (%) | P (mg kg$^{-1}$) | K (mg kg$^{-1}$) | Zn (mg kg$^{-1}$) | Mn (mg kg$^{-1}$) | Cu (mg kg$^{-1}$) | Soil texture |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0-30 | 1.25 | 19.5 | 10.3 | 1.32 | 8.15 | 35.2 | 0.76 | 7.3 | 264.5 | 0.76 | 3.12 | 0.57 | Sandy loam |
| 30-60 | 1.28 | 19.3 | 10.4 | 1.36 | 8.16 | 37.7 | 0.62 | 7.2 | 252.4 | 0.62 | 3.19 | 0.56 | Sandy loam |

Compost applied 50 cm away from the trunk of the tree and over the soil surface, after rotating the soil at 10 cm depth for all treatments in March of each year. The physico-chemical properties of the applied compost contained organic carbon (22%), total nitrogen content (1.5%), C/N ratio (15), $P_2O_5$ (0.8%), $K_2O$ (0.7%), electrical conductivity (6.4 dS. $m^{-1}$), pH (7.6), moisture content (12%), density (380 $kg.m^{-3}$), particle diameter (6 mm). The amount of irrigation wetted area was adjusted by increasing the number of emitters (6, 9 and 12 per loop with 4 liters per hour discharge) and the irrigation interval was determined by placing tensiometers (Irrometer Tensiometer Model SR Manual Gauge 12 in) deep down at three irrigations effective root depth (60, 45 and 30 cm, respectively) according to the irrigation experimental factor. Each year in February, the composite soil sample were taken from 0-10 cm and the percentage of soil organic matter, porosity and bulk density (g $cm^{-3}$) were determined. The amount of organic matter was measured by weight loss of oven-dried (105°C) soil sample after loss on ignition at 400°C. To determine the porosity of the samples, divide the pore space volume by the total volume and multiply the result by 100. Soil bulk density was determined by the weight of dry soil divided by the total soil volume. The amount of consumed irrigation water was measured by contours in each treatment. Over the three seasons, the indices of citrus decline were determined on tagged main branches on each tree quadrates. At the late spring, new flush lengths and the percentage of shoot dieback were measured. Leaf and fruit drop percentage were determined by counting their number at two separate time (after June drops and pre-harvest time). Leaf samples (contain 100 leaves) were collected during July-August from fully expanded new flush sub-terminal leaves from non-fruiting from tagged branches. Total chlorophyll content was determined by the method worked out by Lichtenthaler (1987). Leaf fresh weight ($W_f$) were recorded quickly using an analytical balance (Mettler Toledo AL104, Switzerland). Then, they were dried at 120°C in a circulation oven for 20 minutes, and the temperature dropped to 80°C until the constant weight (dry weight, $W_d$) was reached. Then the leaf relative water content (RWC) was calculated as:

$$\text{Leaf relative water content (\%)} = [(Wf - Wd)/Wf] \times 100$$

Individualleaf areas (LA) were determined by Licor leaf area meter, and sample were dried and specific leaf weights, SLW (mg $cm^{-2}$) were measured as:

$$\text{Specific leaf weight (mg cm}^{-2}\text{)} = Wd/\text{LA}$$

Root sampling was carried out under emitters from depth of 30, 45 and 60 cm soil depth, based on the effective root depth considered in the irrigation experimental factor, by auger (diameter 9 cm and height 25 cm), in Early-August (Alves *et al*., 2012). After washing the root samples, length, weight and number of fibrous root with less than 0.2 cm diameter was determined by digital ruler and weight scale, and length density (cm $cm^{-3}$), density (mg $cm^{-3}$) and the percentage of decayed fibrous root were determined in the soil sample volume harvested by auger (1589.6 $cm^3$) (Alves *et al.*, 2012).

At the harvesting time total fruit yield per trees was determined by the scale. A random sample of 50 fruits per plot was provided to determine fruit diameter (average of two perpendicular diameters), total soluble solids, pH and titratable acidity of the juice. Total soluble solids (Brix) were determined by using hand refractometer (WYT portable model) and juice total acid was measured by titration method with 0.1 N sodium hydroxide until pH meter reads 8.2 (Graham, 2017). Fruit juice percentage was calculated by fruit juice weight divided by fruit total weight. Water productivity (kg $m^{-3}$) was calculated based on the yield of trees to the amount of consumed irrigation water. The data set was auto scaled before analysis. All the parameters for three years were subjected to combine analysis of variance (ANOVA) by MSTAT-C software. Means were compared by Duncan's multiple range test and Pearson correlation were determined by SPSS software.

## 3. Results

The results of the combine analysis of variance (ANOVA) over three consecutive seasonal growths from 2016 to 2018, indicated that there was a significant effect of experimental factors on improvement of citrus decline deterioration indices in Valencia orange (Tables 4-8). Annual application of compost as organic mulch and adding them to 10 cm top soil in the following years had significant effect on the increment of soil organic matter and soil porosity up to 170.45, 13.18% respectively, and decreasing soil bulk density by 11.98% at 10 cm soil depth in comparison with control (without application of compost as mulch) (Table 3).

Annual application of compost as organic mulch significantly increased the fibrous roots length density and fibrous roots density of Valencia orange trees by 34.63 and 38.27% respectively. Also the interac-

Table 3 - Effects of experimental treatments on 10 cm top soil organic matter, porosity and bulk density over three consecutive seasonal growths from 2016 to 2018

| Treatments | Soil organic matter (%) | Soil porosity (%) | Bulk density (g cm-³) |
|---|---|---|---|
| W0M0 | 1.42 ± 0.12 b | 42.05 ± 1.21 b | 1.49 ± 0.04 a |
| W1M0 | 1.24 ± 0.14 b | 41.86 ± 1.32 b | 1.43 ± 0.04 a |
| W2M0 | 1.30 ± 0.10 b | 42.42 ± 1.15 b | 1.42 ± 0.05 a |
| W0M1 | 3.38 ± 0.07 a | 47.08 ± 1.01 a | 1.31 ± 0.06 b |
| W1M1 | 3.84 ± 0.08 a | 48.51 ± 1.02 a | 1.27 ± 0.07 b |
| W2M1 | 3.50 ± 0.07 a | 47.39 ± 0.93 a | 1.24 ± 0.06 b |

Mean separation (± SD) within columns followed by different letters are significantly different at $P≤0.05$ using Duncan's new multiple range tests.

tion between expansion the percentage of irrigation wetted area along with and decreasing irrigation effective root depth with annual application of compost as organic mulch (W1M1 and W2M1), significantly increased the fibrous root density up to 87.09 and 112.9% and decreased the root decay by 43.23 and 46.48% at a lower soil depth respectively in comparison with control (W0M0) (Table 4).

Table 4 - Effects of experimental treatments on root characteristics of declining Valencia orange over three consecutive seasonal growths from 2016 to 2018

| Treatments | Fibrous roots length density (cm cm -³) | Fibrous root density (mg cm-³) | Root decay (%) |
|---|---|---|---|
| W0M0 | 0.043 ± 0.003 d | 0.31 ± 0.08 d | 66.24 ± 6.21 a |
| W1M0 | 0.054 ± 0.002 c | 0.48 ± 0.06 c | 53.72 ± 8.60 b |
| W2M0 | 0.056 ± 0.002 c | 0.49 ± 0.06 c | 54.25 ± 7.32 b |
| W0M1 | 0.066 ± 0.003 b | 0.53 ± 0.04 bc | 48.07 ± 7.56 b |
| W1M1 | 0.065 ± 0.004 b | 0.58 ± 0.04 b | 37.60 ± 8.14 c |
| W2M1 | 0.075 ± 0.003 a | 0.66 ± 0.03 a | 35.45 ± 8.81 c |

Mean separation (± SD) within columns followed by different letters are significantly different at $P≤0.05$ using Duncan's new multiple range tests.

In comparison with control (without compost as mulch), application of compost as organic mulchsignificantly increased the total leaf chlorophyll content and new flushes length up to 36.3 and 29.67% respectively and decreased leaf and fruit drop (Table 5, 6) and shoot dieback by 40.21, 38.18 and 40.59%, respectively (Table 5), in declining Valencia orange trees, respectively. Increment the irrigation wetted area percentageand decreasing the effective root depth for irrigation, significantly increased leaf chlorophyll contentand flush lengthand reduced leaf and fruit drop and shoot dieback. The interaction between the expansionof irrigation wetted area with annual application of compost as organic mulch (W1M1 and W2M1) had the highest impact on the increment of total leaf chlorophyll contentup to 58.62 and 62% and flush length by 75.78 and 80.9% and decreasing leaf drop 56.17 and 71.1%, fruit drop by 44.62 and 63.3% and shoot dieback by 56.3, 76.44%, respectively, in comparison with control (W0M0).

Leaf relative water content, specific leaf weight, fruit diameter and tree yield increased with annual application of compost as organic mulchanddeveloping the irrigation wetted area (Table 6). The interaction between irrigation wettedarea and annual application of compost as organic mulch (W1M1 and W2M1) had the highest impact on the increment of leaf relative water content up to 11.91 and 14.25% and specific leaf weight up to 18.75 and 22.66%, respectively, in comparison with control (W0M0) (Table 6). Also Fruit diameter significantly increased by increment of wetted area and application of mulch by 15.9 and 14.11%, respectively (Table 6).

The highest yield of Valencia orange trees was belonged to the interaction between irrigation wetted area of 70-80% with 30 cm effective root depth for irrigation and application of compost mulch

Table 5 - Effects of experimental treatments on vegetative growth indices of declining Valencia orange over three consecutive seasonal growths from 2016 to 2018

| Treatments | Total leaf chlorophyll content (mg g-¹ FW) | Flush length (cm) | Leaf drop (%) | Shoot dieback (%) |
|---|---|---|---|---|
| W0M0 | 0.29 ± 0.03 d | 24.82 ± 2.31 d | 35.30 ± 1.12 a | 35.70 ± 2.11 a |
| W1M0 | 0.34 ± 0.02 c | 35.53 ± 3.78 c | 27.63 ± 1.53 b | 29.62 ± 3.10 b |
| W2M0 | 0.36 ± 0.01 c | 38.35 ± 3.81 b | 21.30 ± 1.71 c | 17.60 ± 2.27 d |
| W0M1 | 0.42 ± 0.03 b | 39.47 ± 3.15 b | 24.70 ± 1.92 bc | 25.25 ± 2.15 c |
| W1M1 | 0.46 ± 0.02 a | 43.63 ± 2.80 a | 15.45 ± 1.65 d | 15.60 ± 2.84 d |
| W2M1 | 0.47 ± 0.02 a | 44.90 ± 2.66 a | 10.20± 1.86 e | 8.41 ± 1.90 e |

Mean separation (± SD) within columns followed by different letters are significantly different at $P≤0.05$ using Duncan's new multiple range tests.

(Table 7). Annual application of compost as organic mulch had significant effect on the reduction of consumed irrigation water by 17.39% in comparison with control (without mulch). The interaction between irrigation wetted area and annual application of compost as organic mulch (W1M1 and W2M1) had the highest impact on the increment of water productivity up to 53.06 and 49.79% respectively, in comparison with control (W0M0), and there was no significant difference between them (Table 7). Expansion of irrigation wetted area and decrease effective root depth for irrigation under the condition of compost mulch applicationhad the greatest effect on water productivity in Valencia orange.

Annual application of compost as organic mulch significantlyincreased the fruit juice content by 11.98%, total soluble solids (Brix) by 10.96%, Brix/Titratable acidity ratio by 24.52% in declining Valencia orange trees. Fruit acidity was significantly reduced by annual application of mulch. Increment of irrigation wetted area percentage significantly, increased fruit juice and brix/titratable acidity ratio. The interaction between increased irrigation wetted area with mulch application (W1M1 and W2M1), resulted in the highest increase in fruit juice percentage by 35.43 and 34%, total soluble solidsby 23 and 26.36% and brix/titratable acidity ratio by 49.6 and 57.6%, respectively in comparison with control (W0M0) (Table 8).

Table 6 - Effects of experimental treatments on the leaf relative water content, specific leaf weight, fruit drop and fruit diameter of declining Valencia orange over three consecutive seasonal growths from 2016 to 2018

| Treatments | Leaf relative water content (%) | specific leaf weight (mg cm-²) | Fruit drop (%) | Fruit diameter cm) |
|---|---|---|---|---|
| W0M0 | 83.50 ± 5.30 d | 3.84 ± 0.12 d | 31.15 ± 1.10 a | 7.23 ± 0.10d |
| W1M0 | 89.64 ± 5.24 c | 4.12 ± 0.08 c | 25.12 ± 1.32 b | 7.58 ± 0.08 c |
| W2M0 | 91.25 ± 4.22 bc | 4.36 ± 0.07 bc | 21.84 ± 1.25 bc | 8.20 ± 0.07 b |
| W0M1 | 88.36 ± 5.75 c | 4.04 ± 0.09 cd | 19.61 ± 1.74 c | 7.71 ± 0.08 c |
| W1M1 | 93.45 ± 4.12 ab | 4.56 ± 0.06 ab | 17.25 ± 2.11 c | 8.38 ± 0.06 a |
| W2M1 | 95.48 ± 4.53 a | 4.71 ± 0.06 a | 11.43 ± 2.73 d | 8.25 ± 0.07 ab |

Mean separation (± SD) within columns followed by different letters are significantly different at $P \leq 0.05$ using Duncan's new multiple range tests.

Table 7 - Effects of experimental treatments on the leaf characteristics, fruit quantity and water productivity of declining Valencia orange over three consecutive seasonal growths from 2016 to 2018

| Treatments | Total tree yield (kg) | Consumed irrigation water ($m^3$ $ha^{-1}$ $year^{-1}$) | Water productivity (kg $m^{-3}$) |
|---|---|---|---|
| W0M0 | 62.33 ± 2.14 e | 11625.28 ± 136.58 c | 2.45 ± 0.11 c |
| W1M0 | 71.05 ± 2.71 d | 13857.14 ± 122.61 b | 2.39 ± 0.16 c |
| W2M0 | 83.10± 1.50 c | 14631.67 ± 121.25 a | 2.66 ± 0.14 bc |
| W0M1 | 68.47 ± 2.43 d | 10363.64 ±136.84 d | 3.01 ± 0.12 b |
| W1M1 | 89.40± 1.37 b | 10904.76 ± 132.70 d | 3.75 ± 0.11 a |
| W2M1 | 94.40± 1.15 a | 11869.57 ± 126.39 c | 3.67 ± 0.12 a |

Mean separation (± SD) within columns followed by different letters are significantly different at $P \leq 0.05$ using Duncan's new multiple range tests.

Table 8 - Effects of experimental treatments on the fruit quality indices of declining Valencia orange over three consecutive seasonal growths from 2016 to 2018

| Treatments | Fruit juice (%) | Titratable acidity (g $100^{-1}$ ml) | Total soluble solids (Brix) | Brix/Titratable acidity ratio |
|---|---|---|---|---|
| W0M0 | 42.64 ± 2.02 d | 1.16 ± 0.01 a | 9.56 ± 0.61 d | 8.94 ± 0.22 f |
| W1M0 | 48.80 ± 1.81 c | 0.94 ± 0.03 b | 11.13 ± 0.35 c | 10.26 ± 0.19 e |
| W2M0 | 53.71 ± 1.60 b | 0.95 ± 0.02 b | 11.87 ± 0.24 b | 11.87 ± 0.17 c |
| W0M1 | 47.65 ± 2.17 c | 0.82 ± 0.02 c | 12.29 ± 0.73 a | 11.23 ± 0.18 d |
| W1M1 | 57.75 ± 1.61 a | 0.74 ± 0.03 d | 11.76 ± 0.40 b | 13.37 ± 0.15 b |
| W2M1 | 57.14 ± 1.55 a | 0.84 ± 0.03 c | 12.08 ± 0.37 b | 14.09 ± 0.14 a |

Mean separation (± SD) within columns followed by different letters are significantly different at $P \leq 0.05$ using Duncan's new multiple range tests.

Results showed that fibrous root density had a significant negative correlation with leaf drops (r= -0.791) and shoot dieback (r= -0.612) (Table 9). Also fibrous root density had positive and significant correlation with flush length (r= 0.624), leaf water content (r= 0.732) and specific leaf weight (r= 0.631). The root decay percentage had significant negative correlation with leaf chlorophyll content (r= -0.643), flush length (r= -0.632), leaf water content (r= -0.603), leaf specific weight (r= -0.638), yield (r= -0.691), water productivity (r= -0.602), and Brix/TA (r= -0.684). Also there was a positive and significant correlation between the percentage of root decay with leaf drops (r= 0.784), shoot dieback (r= 0.692), and fruit drops (r= 0.704) (Table 9). Specific leaf weight had positive and significant correlation with leaf chlorophyll content (r= 0.482) (Table 9). There was a negative correlation between fruit drops and relative water content of leaves (r= -0.774). Tree water productivity had a positive and significant correlation with the leaf chlorophyll content (r= 0.612), leaf relative water content (r= 0.766), and specific leaf weight (r= 0.677) (Table 9).

## 4. Discussion and Conclusions

Citrus decline was directly related to root decay and decreasing of fibrous root density and root expansion in Valencia orange trees. Tree performance is a function of how the root system is distributed over a large volume of soil to absorb water and nutrients (Lehmann, 2003). In arid and semi-arid regions, the highest density of fibrous roots in the drip irrigation system is located under the emitters and soil wetted area (Ciancio and Mukerji, 2008; Alves *et al.*, 2012). The rate of water adsorption by the tree is reduced when the soil oxygen level is low (Levy, 1998; Boman *et al.*, 1999) and the most influential soil condition on citrus decline are soil moisture condition (Meena *et al.*, 2018), and soil compaction (Srivastava and Singh, 2009). Root development is related to the hydrophilicity of roots, soil aerationand distribution of soil moisture (Ruiz-Sanchez *et al.*, 2005).

Our results showed that Application of compost as organic mulch and rotating them with 10 cm topsoil improved soil physical properties such as soil organic matter, porosity and bulk density which could provide the best conditions for root development. This treatment could increase the soil aeration and soil moisture retention at topsoil, as two key factors for root health and growth (Boman and Parsons, 2002; Nelson *et al.*, 2008; Johnson and Graham, 2015). Meanwhile, it could reduce surface evaporation, moderate soil surface temperatures and provide the best condition for root development for declining Valencia orange trees. Application of organic mulches on Eureka lemon (*Citrus limon* Burm) significantly increased the soil moisture status in various soil

Table 9 - Pearson correlation coefficients between the means of citrus decline indices of Valencia orange over three consecutive seasonal growths from 2016 to 2018

| | Chlorophyll content | Flush length | Leaf drop | Shoot dieback | LRWC [1] | SLW [2] | Fruit drop | Fruit diameter | Yield | Water productivity | Brix/TA. | Fibrous roots density | Fibrous roots length density | Root decay |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Chlorophyll content | 1.00 | | | | | | | | | | | | | |
| Flush length | 0.64 ** | 1.00 | | | | | | | | | | | | |
| Leaf drop | -0.51 * | -0.64 ** | 1.00 | | | | | | | | | | | |
| Shoot dieback | -0.55 * | -0.74 ** | 0.78 ** | 1.00 | | | | | | | | | | |
| LRWC | 0.54 * | 0.64 ** | -0.77 ** | -0.75 ** | 1.00 | | | | | | | | | |
| Fruit drop | -0.66 ** | -0.25 NS | 0.67 ** | 0.64 ** | -0.71 ** | -0.69 ** | 1.00 | | | | | | | |
| Fruit diameter | 0.43 * | 0.49 * | -0.52 * | -0.51 * | 0.52 * | 0.53 * | -0.53 * | 1.00 | | | | | | |
| Yield | 0.59 ** | 0.65 ** | -0.76 ** | -0.67 ** | 0.66 ** | 0.60 ** | 0.26 NS | 0.75 ** | 1.00 | | | | | |
| Water productivity | 0.61 ** | 0.50 * | -0.75 ** | -0.65 ** | 0.77 ** | 0.68 ** | -0.75 ** | 0.78 ** | 0.78 ** | 1.00 | | | | |
| Brix/T.A. | 0.63 ** | 0.52 * | -0.70 ** | -0.68 ** | 0.15 NS | 0.57 ** | -0.66 ** | 0.13 NS | 0.57 ** | 0.46 * | 1.00 | | | |
| Fibrous roots density | 0.71 ** | 0.62 ** | -0.79 ** | -0.61 ** | 0.73 ** | 0.63 ** | -0.71 ** | 0.64 ** | 0.70 ** | 0.71 ** | 0.62 ** | 1.00 | | |
| Fibrous roots length density | 0.58 * | 0.48 * | -0.59 ** | -0.54 * | 0.68 ** | 0.59 ** | -0.54 * | 0.61 ** | 0.62 ** | 0.59 ** | 0.52 * | 0.78 ** | 1.00 | |
| Root decay | -0.64 ** | 0.63 ** | 0.78 ** | 0.69 ** | -0.60 ** | -0.64 ** | 0.70 ** | -0.66 ** | -0.69 ** | -0.60 ** | -0.68 ** | -0.64 ** | -0.71 ** | 1.00 |

[1] Leaf relative water content.

[2] Specific leaf weight.

*, ** significant at 5 and 1% statistical levels respectively; NS = not significant.

depths and farmyard manure were found to be more effective in producing maximum growth extension (Kumar *et al.*, 2015). The irrigation wetted area, also affect citrus root system development and distribution (Alves *et al.*, 2012). In our experiment, the expansion of irrigation wetted area and reduction the effective root depth for irrigation with annual application of compost as organic mulchand its rotation in the 10 cm soil depth, increased the fibrous root length and root densityat lower soil depths and decreased root decay in Valencia orange trees. Also, leaf relative water content, specific leaf weight and fruit diameter in Valencia orange significantly increased with developing the irrigation wetted area. Increment of fibrous root length and root density at lower soil depths with decreasing the irrigation depth and consequent improvement of tree water status were in agreement with the results that showed more root distribution in the drip irrigation method was at the depth of 15 cm, with high water uptake efficiency (Kadyampakeni *et al.*, 2014 b). Annual application of compost as organic mulch significantly decreased the consumed irrigation water in Valencia orange trees. Increasing soil organic carbon improve the healthy root system of citrus (Sharma *et al*., 1986). There was a positive and significant correlation between leaf relative water content and leaf chlorophyll content (r= 0.540), and flush lengths (r= 0.643) and a significant negative correlation between leaf water content and leaf drops (r= -0.771), and shoot dieback (r= -0.748) (Table 8). It has been shown that clementine 'Nules' vegetative growth and fruit size was higher with increasing numbers of emitters on the double drip-lines treatments (Abouatallah *et al*., 2012).

We conclude that annual application of compost as organic mulch under tree canopy area and its rotation at 10 cm soil depth at following years and expanding the irrigation wetted area and decreasing the irrigation effective root depth, significantly improved the indices of citrus decline and increased the water productivity and fruit quality in Valencia orange trees.

## Acknowledgements

The authors greatly appreciate Mr. Mojtaba Dadgar who provided the commercial orchard for this experiment and Fars Agricultural Research, Education and Extension center.

## References

ABOUATALLAH A., SALGHI R., EL-FADL A., AFFI N., GHNIZAR Y., ZARROUK A., HAMMOUTI B., 2012 - *Impact assessment of drippers distribution around the tree on soil moisture, roots and fruits growth of* Citrus. - Der Pharma Chemica., 4.5: 1969-1981.

ALVES J. Jr., BANDARANAYAKE W., PARSONS L.R., EVANGELISTA A.W., 2012 - Citrus *root distribution under water stress grown in sandy soil of central Florida.* - Engenharia Agrícola, 32(6): 1109-1115.

BOMAN B., LEVY Y., PARSONS L., 1999 - *Water management*, pp. 72-81. - In: TIMMER L.W., and L.W. DUNCAN (eds.) Citrus *health management.* APS press, Am. Phytopath. Soc., St. Paul. MN, USA, pp. 221

BOMAN B., PARSONS L.R., 2002 - *Evapotranspiration*, pp. 163-174. - In: BOMAN B. (ed.) *Water and Florida citrus: use, regulation, irrigation, systems, and management.* University of Florida Cooperative Extension Service, Institute of Food and Agriculture Sciences.

CASTLE W.S., 1978 - *Citrus root systems: their structure, function, growth, and relationship to tree performance.* - Proc. Inter. Soc. Citriculture, pp. 62-69.

CIANCIO A., MUKERJI K.G., 2008 - *Integrated management of diseases caused by fungi, phytoplasma and bacteria*. Vol. 3. Springer Science & Business Media, pp. 74-75.

DEWDNEY M., EVAN M., JOHNSON G., GRAHAM J.H. Jr., 2019 - *[33 CG022] Brown rot of fruit.* - EDIS, pp. 107971.

FAO, 2011 - *Training manual for (healthy and productive mandarin tree) combating citrus decline problem in Nepal.* - Food And Agriculture Organization of United Nations, Rome, Italy, TCP/NEP/3302(D).

FERNÁNDEZ J.E., MORENO F., CABRERA F., ARRUE J.L., MARTÍN-ARANDA J., 1991 - *Drip irrigation, soil characteristics and the root distribution and root activity of olive trees.* - Plant and Soil, 133(2): 239-251.

GONG D., KANG S., ZHANG L., DU T., YAO L., 2006 - *A two-dimensional model of root water uptake for single apple trees and its verification with sap flow and soil water content measurements.* - Agric. Water Manag., 83(1-2): 119-129.

GRAHAM J., 2017 - *Horticultural factors that contribute to tolerance of citrus to Huanglongbing (HLB).* - Fruticultura 2017 Symposium, October 18, Univ. Florida Citrus Research and Education Center.

GRAHAM J.H., JOHNSON E.G., GOTTWALD T.R., IREY M.S., 2013 - *Presymptomatic fibrous root decline in citrus trees caused by Huanglongbing and potential interaction with* Phytophthora *spp.* - Plant Disease, 97(9): 1195-1199.

HSIAO T.C., XU L.K., 2000 - *Sensitivity of growth of roots versus leaves to water stress: biophysical analysis and relation to water transport.* - J. Exp. Bot., 51(350): 1595-1616.

HUBER D.M., HANEKLAUS S., 2007 - *Managing nutrition to* *control plant disease.* - Landbauforschung Völkenrode, 57(4): 313.

JOHNSON E.G., GRAHAM J.H., 2015 - *Root health in the age of HLB*. - Citrus Ind., 98: 14-18.

KADYAMPAKENI D.M., MORGAN K.T., SCHUMANN A.W., NKEDI-KIZZA P., 2014 a - *Effect of irrigation pattern and timing on root density of young citrus trees infected with Huanglongbing disease*. - HortTechnology, 24(2): 209-221.

KADYAMPAKENI D.M., MORGAN K.T., SCHUMANN A.W., NKEDI-KIZZA P., OBREZA T.A., 2014 b - *Water use in drip-and microsprinkler-irrigated citrus trees.* - Soil Sci. Soc. Amer. J., 78(4): 1351-1361.

KOUDOUNAS C., 1992 - *Soil-citrus relationship studies in Cyprus.* - Inter. Symp. Current Developments in Mediterranean Tropical and Subtropical Fruit Production and Research, 365: 147-150.

KOZLOWSKI T.T., 1997 - *Responses of woody plants to flooding and salinity*. - Tree physiology, 17(7): 490-519.

KREUZWIESER J., RENNENBERG H., 2014 - *Molecular and physiological responses of trees to waterlogging stress.* - Plant, Cell & Environ., 37(10): 2245-2259.

KUMAR V., BHAT A.K., SHARMA V., GUPTA N., SOHAN P., SINGH V.B., 2015 - *Effect of different mulches on soil moisture, growth and yield of Eureka lemon (Citrus limon burm) under rainfed condition.* - Indian J. Dryland Agricultural Research and Development, 30(1): 83-88.

LEHMANN J., 2003 - *Subsoil root activity in tree-based cropping systems*, pp. 319-331. - In: ABE J.J. (ed.) *Roots: The dynamic interface between plants and the earth*. Springer, Dordrecht, Germany, pp. 460.

LEVY Y. 1998 - *Citrus irrigation*, pp. 113-126. - In: EL-OTMANI M., and A. AIT-OUBAHOU (eds.) *Nouveaux acquis de la recherche en agrumiculture.* Inst. Agronomique Veterinaire Hassan II Agadir Morocco.

LICHTENTHALER H.K., 1987 - *Chlorophylls and carotenoids: pigments of photosynthetic biomembranes.* - Methods Enzymol., 148: 350-382.

MAUK P.A., SHEA T., 2002 - *Questions and answers to citrus management*. - University of California, County of Riverside and U.S. Department of Agriculture Cooperating.

MEENA A.K., DUTTA F., MARAK M.C., MEENA R.K., 2018 - *Citrus decline.* - Int. J. Curr. Microbiol. App. Sci., 7(4): 1-9.

MORGAN K.T., 2015 - *Improved citrus nutrient uptake by modification of irrigation water quality, soil water content and soil.* - Soil Water Sci., University of Florida, USA.

MORGAN K.T., OBREZA T.A., SCHOLBERG J.M., PARSONS L.R., WHEATON T.A., 2006 - *Citrus water uptake dynamics on a sandy Florida Entisol.* - Soil Sci. Soc. Amer. J., 70(1): 90-97.

NELSON S.D., UCKOO R.M., ESQUIVEL H., ENCISO J.M., JONES K., 2008 - *Compost effects in "Rio Red" grapefruit production on a heavy textured soil*. - Dynamic Soil, Dynamic Plant, 2: 67-71.

NOLING J.W., 1993 - *Citrus root growth and soil pest management practices*. - University of Florida Cooperative Extension Service, Institute of Food and Agriculture Sciences, EDIS, USA.

RUIZ-SÁNCHEZ M.C., PLANA V., ORTUÑO M.F., TAPIA L.M., ABRISQUETA J.M., 2005 - *Spatial root distribution of apricot trees in different soil tillage practices.* - Plant and Soil, 272(1-2): 211-221.

SHARMA O.N., GUPTA K.R., GUPTA R.K., 1986 - *Soil status of healthy and chlorotic orchards of Jammu*. - Res. Dev. Rep., 3(14): 41-44.

SRIVASTAVA A.K., SINGH S., 2009 - *Citrus decline: Soil fertility and plant nutrition.* - J. Plant Nutr., 32(2): 197-245.

TANASESCU N., PALTINEANU C., 2004 - *Root distribution of apple tree under various irrigation systems within the hilly region of Romania*. - Inter. Agrophysics, 18(2): 175-180.

USDA, 2017 - *Florida Citrus statistics.* - United States Department of Agriculture, FL, USA.