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**Effect of the method and volume of irrigation on yield and fruit quality of yellow fleshed kiwifruit in northern Italy**

M. Quartieri1, M. Toselli1, E. Baldi1, G. Polidori1, M.A. Germani1, M. Noferini2 and E.Xylogiannis3

1Department of Agricultural and Food Sciences, Viale Fanin 46, 40127, Bologna, Italy; 2IFarming, Via Selice, 55/a, 40026, Imola, Italy; 3Zespri Fresh Produce Italy Srl, Via delle Margherite 121, 04011 Aprilia, Italy.

***Abstract***

**The aim of the study** **was to evaluate the effect of type of irrigation and of amount of water supplied on vine growth, yield and fruit quality at harvest and after 2 and 4 months of cold storage. The study was carried out in 2019, in northern Italy, on kiwifruit Gold 3® (*A. chinensis* var. *chinensis*) grafted onto micro-propagated Hayward (*A. chinensis* var. *deliciosa*) in 2012, planted at a distance of 4.5 m x 2 m apart. The investigated irrigation systems included: 1) control (T0); 2) drip irrigation with a single line (T1); 3) drip irrigation with double lines (T2); 4) sprinkler (T3); 5) drip irrigation with double lines + sprinkler (T2+T3). Water management in the control treatment was carried out with drip irrigation with a single pipeline according to the advisory service, based on daily evapotranspiration only. In T1, T2, T3, and T2+T3 water was applied according to the soil water content measured by potentiometric probes, located at two depths: 0.20 m and 0.60 m, and two distances from the line of the trees: 0.20 m and 1 m. Irrigation started when soil water content got down below the field capacity (-0.03 MPa) and returned the same amount of water lost the day before and measured by a PAN evaporimeter. Compared to the control, T1 reduced the volume of water applied by 34%, T2 by 3%, while T3 increased the irrigation volume of 14% and T2+T3 by 17%. Sprinkler application induced an excess of water in the interrow, where soil structure was impaired by the frequent passes of machines, reducing soil permeability. No effect of treatments on vine yield was observed, however fruit soluble solid concentration and fruit dry matter at harvest was increased by T2 compared to the other treatments. A similar response was also found after 2 months of cold storage, but disappeared after 4 months. The incidence of storage break down (SBD) was higher in fruits of the control and T3 (22% and 40% of the fruits, respectively), while T2 and T2+T3 irrigation strategies showed the lowest percentage (5-8%, respectively). Finally, the incidence of SBD was negatively correlated with the fruit dry matter (r=-0.88; P≤0.05).**

**Keywords**: *Actinidia chinensis*, storage break down, wireless sensor network, soil moisture sensor

**INTRODUCTION**

Kiwifruit Gold 3® is an excellent fruit crop in terms of yield and quality, and the interest of Italian fruit growers for yellow flesh varieties has recently increased. Unlike the green fleshed Hayward, the yellow ones have usually a shorter marketing period due to the shorter storability of fruit. Among the fruit characteristics that most affect the storage life and quality of yellow kiwifruit, the dry matter (DM) seems to play an important role. Growers can modify fruit DM content through orchard management practices, such as irrigation. Although high irrigation volumes increase fruit size (Longman et al., 2016), a decrease of fruit DM and quality may be expected. Kiwifruit plants need a constant soil water content, near to field capacity, given that a reduction of soil water availability turns into a reduction of fruit size (Judd et al., 1989). The area of soil surface affected by irrigation, that is the result of the irrigation system and volume of application, may affect fruit growth, final size and DM. Our hypothesis is that often the irrigation of kiwifruit is managed with low accuracy, based only on the evapotranspiration rate without considering soil moisture. The objective of the study was to evaluate the effect of type of irrigation and of amount of water supplied on vine growth, yield and fruit quality at harvest and after 2 and 4 months of cold storage.

**MATERIALS AND METHODS**

The trial was carried out in the hillside of Brisighella, province of Ravenna (44°13′20″ N,11°46′24″ E, 116 m a.s.l.), in an orchard planted in 2010 as a self-rooting ‘Hayward’ variety (*A. chinensis* var. *deliciosa*), grafted in 2012 with Gold 3® (*A. chinensis* var. *chinensis*). Kiwifruit vines were spaced 2 m along the row and 4.5 m between rows for a total of 1,111 vines ha-1 and trained as pergola system, with 10 canes per vine and 10 buds per cane. The orchard management included fertigation with N, P, K, Mg, Fe at the following rates (in kg ha-1): N: 141, P: 36, K: 147, Mg: 7, Fe: 1 e Mn: 0,5. During the season, the grower sprayed Kriss (Biolchim SpA, Medicina, Italy) twice as a fruit growth promoter. Before full bloom, flowers were thinned by removing the laterals and leaving five fruits per shoot. For each cane, the first and the last shoot were left without flowers. The following five irrigation systems were compared:

1. control treatment (T0), with emitters (4 l h-1) distributed at 0.66 m along the pipe line;
2. drip irrigation with single pipe line (T1), with emitters (4 l h-1) distributed at 0.66 m;
3. drip irrigation with two pipe lines per row (T2), with emitters (2 l h-1) distributed at 0.60 m; the two pipe lines spaced 0.50-m transversally from the tree row;
4. sprinkler irrigation (T3), with emitters (28 l h-1) every 1.5 m along the tree row;
5. combination of treatment 2 and 3 (T2+T3): two pipe lines per row with emitter (2 l h-1) distributed at 0.60 m, and sprinkler (28 l h-1) every 2 m along the tree row.

Each irrigation treatment was set on a single row of 84 vines, with 4 replications. Volume of irrigation for T0 was established according to the evapotranspiration method (Allen et al., 1998) measured by a weather station located in the farm, and modified by the advisory service to replenish the same amount of water lost the day before. Volume of irrigation for T1, T2, T3 and T2+T3 was estimated by both soil probes and evapotranspiration rate. The water was applied when the chalk potentiometer probes (Fig. 1) indicated a soil moisture below field capacity. The strategy of T1, T2, T3 and T2+T3 was to keep soil water potential between -0.03 MPa (field capacity) and -0.1 MPa, in a volume of soil of at least 33% of that explored by roots. The probes were placed on four plots per treatment, at 0.20 m and 1 m in the inter-row and at 2 depths (0.20 m and 0.60 m).



Figure 1. From left to right: data logger box, chalk potentiometer probes and irrigation volume meter (Ifarming).

The control units, sensors and technical assistance was provided by Ifarming srl (<http://www.ifarming.it/>), a company specialized in precision farming technologies. Due to the frequent rainfalls in May (245 mm), the irrigation started in June 2019.

At harvest (October 1, 2019) yield was recorded and fruit (15 fruit per plot) were analyzed for their chemical and physical characteristics, including: size, DM, flesh color and firmness and juice soluble solid concentration (SSC). From each plot, two other 30-fruit-samples were collected and placed into cool curing (5-10°C) for 3 days and then cold-stored (T: 1°C; RH: 98%). After two and four months, 4 samples of each treatment were removed to assess fruit quality and defects as: fruit weight loss, storage break down (SBD), and rots caused by *Botrytis cinerea*, *Phialophora* spp., etc. These measurements were then replicated after 1 and 5 days of shelf life at room (21°C) temperature. Data were submitted to analysis of variance and when treatments showed a statistical effect (P≤0.05), means were separated by the Student Newman Keuls (SNK) test. Correlation analysis was carried out between fruit dry matter concentration and percentage of fruit with SBD symptoms, to determine Pearson coefficient (r).

**RESULTS**

**Environmental data**

Minimum air temperature (9 °C) was recorded at the end of September, while the maximum air temperature (39 °C) was reached between the end of June and the beginning of August. From the beginning of June to the end of September, the amount of rain was about 140 mm, distributed in June (46 mm), July (48 mm) and September (37 mm). The average evapotranspiration rate was 4.16 mm day-1 in June, 3.57 mm day-1 in July, 3.14 mm day-1 in August, and 2.0 mm day-1 in September.

**Volume of irrigation water**

Between 7 June and 30 September 2019, 190 mm of water (Tab. 1) were used in T0, while T1 (single pipeline) received 34% less and T2 3% less water (Tab. 1). The treatments with sprinklers (T3 and T2+T3) provided a greater irrigation volume than T0 (Tab. 1), with an increase of 14% (T3) and 17% (T2+T3).

Table 1. Amount of water distributed during the study in the different treatments.

|  |  |  |
| --- | --- | --- |
| Treatment | Irrigation (mm) | Irrigation +Rainfall (mm) |
| Control (single pipe, T0) | 190 | 330 |
| Single pipe (T1) | 126 | 266 |
| Double pipe (T2) | 184 | 324 |
| Sprinkler (T3) | 216 | 356 |
| Sprinkler+double pipe (T2+T3) | 223 | 363 |

**Soil moisture**

Soil moisture was affected by irrigation strategies. The soil water content of T0 plots was higher near drip emitters, with a constant field capacity (≤-0.03 MPa) for most of the season. However, at 1 m in the inter-row, especially from mid-July, soil water potential was between -0.3 and -0.8 MPa, a condition of drought stress for kiwifruit (data not shown).

The trend of the soil moisture of the T1 treatment (the same irrigation system of T0, combined with chalk potentiometer data), showed, between June and mid-July, a soil water potential under the dripline between -0.03 MPa and -0.1 MPa; subsequently, the availability decreased at 0.2-m depth (-0.2 MPa, -0.3 MPa) and also at 0.6-m depth (-0.2 MPa, -0.6 MPa). The sensors at 1 m from the row showed the constant decrease in water potential, reaching -0.9 MPa measured in September (data not shown).

Drip irrigation with double line (T2) allowed a constant moisture in the soil volume along the row (between -0.02 MPa and -0.15 MPa) until mid-August, when soil moisture decreased to -0.1 MPa, -0.4 MPa. In the inter-row, the moisture probes showed a trend similar to T0 and T1, but with less negative water potentials (always > -0.6 MPa) (data not shown).

Sprinkler treatment (T3) resulted in a different soil moisture compared to drip system. Soil water potential was often near field capacity in the row, while in the inter-row a higher moisture (> -0.3 MPa) than other treatments was observed (data not shown). The water content of the inter-row also hindered the movement of tractors in the orchard, with frequent water pooling (Fig. 2).

Finally, in T2+T3 treatment, the trend of water potentials was similar to that described for T2. In the row, at a depth of 0.2 m, water availability was high (> -0.05 MPa) until the end of July, while in August and September it was between – 0.05 MPa and -0.15 MPa. At 0.6-m-depth, the availability of water was adequate until mid-July (> -0.1 MPa) and then decreased to -0.25 MPa, and -0.4 MPa. In the inter-row, however, the water potential was between -0.05 MPa and -0.1 MPa until the end of July, but then decreased to -0.7 MPa at 0.6-m-depth (data not reported).

|  |
| --- |
| Figure 2. Topsoil structure alteration and water pooling due to vehicular traffic, observed in plots irrigated with sprinklers (T3 and T2+T3 treatments). |

**Yield and fruit quality at harvest**

The productivity of vines was unaffected by irrigation treatment (Tab. 2) and ranged from 32 to 39 kg vine-1 (35-44 t ha-1). Hue angle (a measure of flesh yellowing) was higher (greener flesh) in control treatment (T0), while the best yellow color was found in fruits of double line drip irrigation, that showed also the highest SSC and DM at harvest (Tab. 3). No effect of irrigation strategy on fruit firmness was found (Tab. 3).

**Post-harvest fruit quality**

After 2 months of storage and 1 day of shelf life, fruits of double pipeline treatment (T2) showed a lower Hue angle value than T0; T2+T3 treatment induced a fruit firmness similar to T1 and higher than the other treatments; SSC were higher in T2 and T2+T3 than in the other irrigation systems; DM was highest in T2+T3 (Tab. 4). After 5 days of shelf life, compared to the other treatments, fruits of T0 and T1 showed a higher Hue angle, fruits of T2+T3 a higher firmness, fruits of T2 a higher SSC that, however, was not statistically different than T1 and T2+T3; fruits of T0 showed the lowest DM (Tab. 4). The analyses performed after 4 months (Tab. 5) of cold storage confirmed the previous results. After 1 day of shelf life, firmness and SSC were lower in T0 compared to the other treatments; DM was higher in T2+T3 than in the other treatments (Tab. 5); however, after 5 days of shelf life, T0 showed a lower firmness and SSC than all other treatments, while T2 showed the highest percentage of DM (Tab. 5).

The incidence of SBD was particularly high in fruits of T0 and T3 (Tab. 6). In both checks carried out after storage, control and sprinkler treatments showed the highest SBD incidence (22-39% of the fruits, Tab. 6), while T2 and T2+T3 irrigation strategies showed the lowest percentage (5-8%, Tab. 6); however, only in the first check statistical differences were observed. The incidence of SBD disorder was negatively correlated (r=-0.88; P≤0.05) with the fruit dry matter (Fig. 3).

Table 2. Effect of irrigation on number of fruits and yield at harvest (October 1, 2019).

|  |  |  |  |
| --- | --- | --- | --- |
| Treatment | Fruits | Yield | |
| number vine-1 | kg vine-1 | t ha-1 |
| T0 | 366 | 39.4 | 43.7 |
| T1 | 306 | 34.7 | 38.5 |
| T2 | 318 | 34.2 | 38.0 |
| T3 | 342 | 37.0 | 41.0 |
| T2+T3 | 281 | 31.8 | 35.3 |
| *Significance* | *ns* | *ns* | *ns* |

ns = effect not significant.

Table 3. Effect of irrigation treatment on flesh color (FC) and firmness (FF), juice soluble solid concentration (SSC) and fruit dry matter (DM) as measured at harvest (October 1, 2019).

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Treatment | FC (Hue angle) | FC (kg) | SSC (°Brix) | DM (%) |
| T0 | 101.8 a | 6.38 | 9.9 c | 18.5 b |
| T1 | 100.9 b | 6.37 | 10.4 bc | 19.2 b |
| T2 | 99.4 c | 6.44 | 12.5 a | 19.9 a |
| T3 | 100.3 bc | 6.58 | 10.7 b | 18.7 b |
| T2+T3 | 100.1 bc | 6.59 | 11.1 b | 18.9 b |
| *Significance* | *\*\*\** | *ns* | *\*\*\** | *\*\*\** |

ns and \*\*\* = effect not significant and significant at P < 0.001, respectively. Within column, values followed by the same letter are not statistically different (SNK test, P=0.05).

Table 4. Effect of irrigation treatment on flesh color (FC) and firmness (FF), juice soluble solid concentration (SSC) and fruit dry matter (DM) as measured after two months of storage at 1 °C, followed by 1 and 5 days of shelf life.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Treatment | +1 day at 21°C | | | | +5 days at 21°C | | | |
|  | FC  (Hue angle) | FF  (kg) | SSC (°Brix) | DM  (%) | FC  (Hue angle) | FF  (kg) | SSC  (°Brix) | DM  (%) |
| T0 | 99.4 a | 1.76 bc | 15.5 b | 17.0 d | 99.8 a | 0.47 d | 16.2 c | 17.7 b |
| T1 | 99.2 ab | 2.00 ab | 15.6 b | 18.0 c | 99.7 a | 0.53 cd | 17.6 ab | 19.0 a |
| T2 | 98.4 b | 1.87 b | 16.3 a | 18.6 b | 98.0 b | 0.59 bc | 18.0 a | 19.4 a |
| T3 | 99.1 ab | 1.59 c | 15.6 b | 18.0 c | 98.6 b | 0.63 b | 17.3 b | 18.9 a |
| T2+T3 | 98.8 ab | 2.15 a | 16.2 a | 19.1 a | 98.3 b | 0.74 a | 17.8 ab | 18.8 a |
| *Significance* | *\** | *\*\*\** | *\*\*\** | *\*\*\** | *\*\*\** | *\*\*\** | *\*\*\** | *\*\*\** |

\* and \*\*\* = effect significant at P < 0.05 and P < 0.001, respectively. Within column, values followed by the same letter are not statistically different (SNK test, P=0.05).

Tab. 5. Effect of irrigation treatment on flesh color (FC) and firmness (FF), juice soluble solid concentration (SSC) and fruit dry matter (DM) as measured after four months of storage at 1 °C, followed by 1 and 5 days of shelf life.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Treatment | +1 day at 21°C | | | | +5 days at 21°C | | | |
|  | FC  (Hue angle) | FF  (kg) | SSC  (°Brix) | DM  (%) | FC  (Hue angle) | FF  (kg) | SSC  (°Brix) | DM  (%) |
|  |
| T0 | 104.9 a | 0.62 b | 15.7 c | 17.6 b | 102.2 | 0.33 b | 15.4 b | 16.9 c |
| T1 | 104.0 b | 0.80 a | 16.6 ab | 17.8 b | 102.1 | 0.45 a | 16.8 a | 18.6 b |
| T2 | 104.4 ab | 0.72 a | 16.2 b | 17.7 b | 102.4 | 0.53 a | 17.2 a | 19.3 a |
| T3 | 103.9 b | 0.76 a | 16.4 ab | 17.7 b | 101.1 | 0.46 a | 16.5 a | 17.3 c |
| T2+T3 | 103.8 b | 0.80 a | 16.7 a | 18.5 a | 100.9 | 0.52 a | 17.2 a | 17.6 c |
| *Significance* | *\*\** | *\*\*\** | *\*\*\** | *\*\*\** | *ns* | *\*\*\** | *\*\*\** | *\*\*\** |

ns, \*\* and \*\*\* = effect not significant, significant at P < 0.01 and P < 0.001, respectively. Within column, values followed by the same letter are not statistically different (SNK test, P=0.05).

Tab. 6. Effect of irrigation treatment on fruit storage break down (SBD) incidence after two and four months of cold storage.

|  |  |  |
| --- | --- | --- |
| Treatment | SBD incidence (%) | |
|  | 2 months | 4 months |
| T0 | 33.3 a | 39.2 |
| T1 | 15.0 ab | 14.2 |
| T2 | 5.0 b | 5.8 |
| T3 | 25.0 ab | 21.7 |
| T2+T3 | 6.7 b | 8.3 |
| *Significance* | *\** | *ns* |

ns, \* = effect not significant and significant at P < 0.05, respectively. Within column, values followed by the same letter are not statistically different (SNK test, P=0.05).

♦SBD after 2 months of cold storage

♦SBD after 4 months of cold storage

Figure 3. Relationship between storage break down (SBD) incidence and fruit dry matter observed during 2 and 4 months of storage at 1 °C (r=-0.88; *P≤0.05*).

**DISCUSSION**

In our experimental conditions, the introduction of soil moisture probes allowed us to reduce the volume of irrigation applied by 34% (T1), without compromising the yield of Gold3®. This means that the irrigation rate adopted by the farmer was in excess of vine requirement. The climate of the area is temperate with rains in summer, mainly as showers that provide a consistent amount of water for a short time. This means vine growth is not-totally dependent on irrigation.

The double pipeline irrigation system did not reduce the amount of water applied compared to normal farm management, but increased it compared to the single line treatment. This contradictory response can be explained by considering the soil management and the position of the probes. Soil was managed with raised beds, approximately 0.5 m higher than the average soil level, and the probes were placed right on the top of the bed. Consequently, the water from the emitters moved downhill according to the bed slope, wetting a volume of soil larger than a single pipeline, but probably not completely detected by the probes. On the other hand, the larger volume of soil affected by the irrigation system did not promote a higher yield, confirming previous results on the ability of trees to adapt to change of their root system water status (Poni et al., 1992). In particular, kiwifruit vines were reported to take up superficial water if available, but at the same time to adjust rapidly (in a few days) and move their root system from an area of water depletion to an area of water availability (Green and Clothier, 1995).

The sprinkler treatment did not reduce the rate of water application, compared to the farm-managed control, probably for the same reasons described for the double-pipeline system. In other words, the position of the probes placed on the vine rows, was not the optimal to record the effect of a sprinkler that distributed the water in a circle with a radius of approximately 2 m. The presence of beds along the row together with a minimal slope of the soil, in the same direction as the rows, induced an accumulation of moisture further away from where the root density is expected to be the highest. Indeed, according to Green and Clothier (1995) the root system extends radially about 1 m from the trunk and vertically for 0.65 m, forming a bowl-shaped region. In sloping orchards, the sprinkler irrigation system should be evaluated carefully; in fact, in our experimental conditions, a portion of the water supplied in T2+T3 probably moved towards the plots irrigated with the T3 system, with discrepancies in soil moisture and, therefore, in the availability of water for plants. In addition, the use of sprinkler can cause waterlogging and changes in soil structure, that could damage kiwifruit plants (Reid et al, 1988).

Fruit quality was affected by soil moisture at harvest and after storage, the best fruit quality was obtained with the double pipeline, probably because it induced an optimal balance between soil water content (lower than -0.1 MPa, that induced a mild drought stress several weeks before harvest) and volume of soil wetted by irrigation. In plots irrigated with sprinklers, in particular T3, the higher soil moisture reduced the percentage of fruit DM, confirming that fruit storability depends mainly on this parameter (Crisosto et al., 2011; Famiani et al., 2012). Growers that already use irrigation management services can gain additional benefits from the use of probes to monitor soil water availability.

Recently, vine death is occurring in several areas of the Italian kiwifruit industry. An empirical, non-scientifically (technologically) based irrigation management, that in combination with poor soil structure may lead to waterlogging, is one of the probable causes behind this plant decline (McAneney et al., 1989; Reid et al., 1988; Smith et al., 1990). Although in kiwifruit roots the space for air circulation is limited (approx. 2% of root volume), roots need high amount of oxygen (Smith et al., 1989). This combination makes kiwifruit among the species that suffer from soil anoxia more than others (Jackson and Drew, 1984), consequently an optimal water distribution for each soil type is necessary.

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