Smart irrigation system for precision water management: effect on yield and fruit quality of yellow fleshed kiwifruit in northern Italy

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Abstract
The study aimed at evaluating the effect of the type of irrigation system and amount of water supplied on vine yield and kiwifruit quality at harvest and after cold storage. The irrigation systems included a control with a single line (T0; water supplied considering daily evapotranspiration); and two system (single line - T1 and double lines - T2) where water was returned according to soil matric potential. The use of probes reduced water by 44% (T1) and 11% (T2) and increased fruit soluble solid concentration and dry matter at all sampling dates in comparison to control.

Keywords: *Actinidia chinensis*, IoT, soil moisture probes, soluble solid content, soil matric potential

Introduction

Kiwifruit (*Actinidia* spp. Lindl. spp.) originates from China and has naturally evolved in a high humidity area with regular annual rainfall between 1050 and 1950 mm (Buwalda and Smith, 1990). The subsequent worldwide spread of this crop has induced its adaptation to different environmental conditions. Despite this, kiwifruit has high water needs that should be carefully managed in order to produce fruit of optimum yield and quality (Pinto *et al.*, 2021). Kiwifruit Zezy002 (yellow-fleshed kiwi) tends to have a higher crop load and a higher fruit percentage of dry matter (DM) than the green one; however, unlike Hayward (the green kiwi), it has a shorter storability that led to a reduced period of commercialization. Among the fruit properties that mainly affect the storage life and quality of yellow flesh kiwifruit, DM seems to play a key role; consequently, its accumulation during the growing season should be optimized. Irrigation is one of the most important factors influencing DM accumulation; according to recent research (Longman *et al.*, 2016), high irrigation volumes induce an increase in fruit size, but also a decrease in fruit DM and quality. During the growing season, soil moisture should be near to field capacity, excess or lack can cause impaired fruit quality, reduced storage and increased susceptibility to pathogens and post-harvest disorders. In most Italian orchards, water supply is managed by only taking into consideration the evapotranspiration rate without considering the soil moisture thus not always being enough precise. The aim of this study was to evaluate the effect of the type of irrigation system and amount of water supplied on yield and fruit quality at harvest and after cold storage of kiwifruit Zezy002.

Materials and methods

The trial was carried out from 2019 to 2022 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 Zezy002 (*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 pergoletta system, with 10 canes per vine and 10 buds per cane (Quartieri *et al.*, 2022). The data here reported refer to 2021. The orchard management included fertigation according to Integrated Crop Management Guidelines of the Region Emilia-Romagna. 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 investigated irrigation systems included:
1) control (T0), with emitters (4 l h^{-1}) distributed at 0.66 m along the pipe line. Water management was carried out according to the local advisory service, only based on daily evapotranspiration;
2) drip irrigation with a single line (T1), with emitters (4 l h^{-1}) distributed at 0.66 m along the pipe line;
3) drip irrigation with double lines (T2), with emitters (2.3 l h^{-1}) distributed at 0.50 m; the two pipe lines spaced 0.60 m transversally from the row.
In T1 and T2, water was applied taking into consideration the soil water content measured by chalk potentiometric probes located according to a sensor grid covering the soil volume intersected by root growth (Fig. 1). The probe consists in pair of highly corrosion resistant electrodes that are embedded within chalk; electric is applied to the probes to measure the resistance, that is correlated to soil water content.

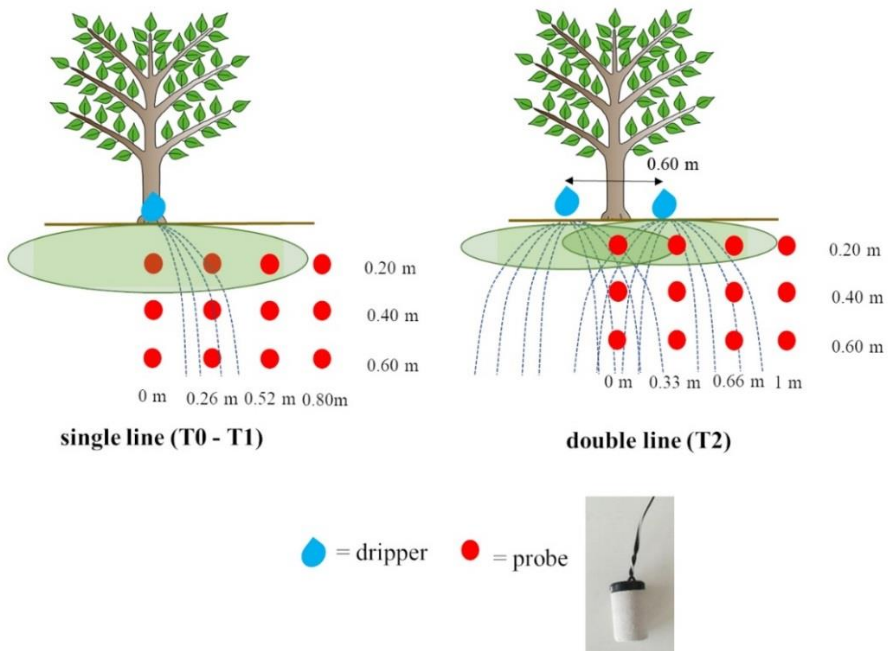

Figure 1. Schematic representation of probes positioning in single (left) and double pipeline (right).

Each irrigation system occupied a single row of the orchard and the grid of probes was replicated twice along each row. Irrigation started when soil matric potential dropped below 100 kPa in more than 50% of the volume of soil monitored by probes that is also the space mainly explored by the root system (Fig. 2) and was aimed at returning the same amount of water lost the day before and estimated by evapotranspiration (ET). The volume of soil explored by roots was considered 0.6 m depth and 1 m wide and long as the tree row. Evaporation was determined by a class A Pan evaporimeter with values supplied by local advisory sensor; ET was determined by multiplying transpiration for a crop coefficient (Allen *et al.*, 1998) equal to one (Silva *et al.*, 2006).

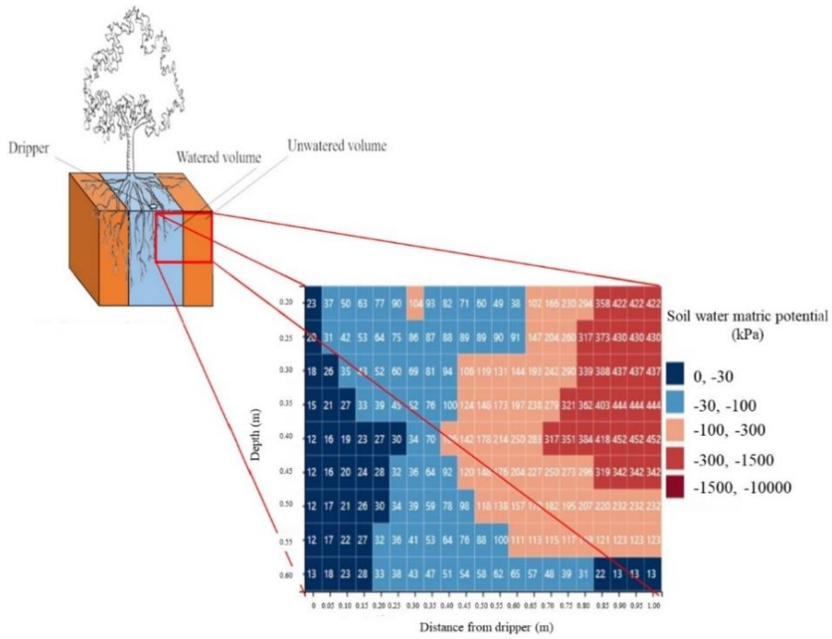

Figure 2. Schematic representation of the soil profile in relation to the values of matric potential in a single line configuration.

Environmental data were recorded by a meteorological station located in the farm; during the period of investigation the average temperature was 21.7°C while the total rain (from May to mid-October) was 359 mm (Figure 3). The control units, sensors and technical assistance for probes and meteorological data were provided by Ifarming srl (Imola, Bo, Italy), a company specializing in precision farming technologies. During the vegetative season, fruit growth was periodically measured with a Bluetooth digital caliper (Wel Caliper, BTCAL 6, Willowbank Electronics Ltd, Napler, New Zealand) on 200 fruits for each treatment (100 for each plot located in the row). Stem water potential was measured with a pump-up pressure chamber (PMS Instrument Company, Albany, OR, USA) to determine plant water status as a function of soil water availability (Turner, 1988). At harvest (October 13th) yield was recorded and fruits (15 for each of the 4 vines of each treatment) were analyzed for their chemical and physical characteristics, including: size, dry matter, flesh color (colorimeter, Minolta, Konica Minolta Inc., Japan), firmness (digital penetrometer, FTA 53220, Güss, Strand, South Africa) and juice solid soluble content (SSC; digital refractometer, PR-1, Atago Tokio, Japan). From each vine, other two 25-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 from cold storage and fruit quality determined after 1 and 3 days of shelf-life (fruits maintained at a constant temperature of 20-22°C).

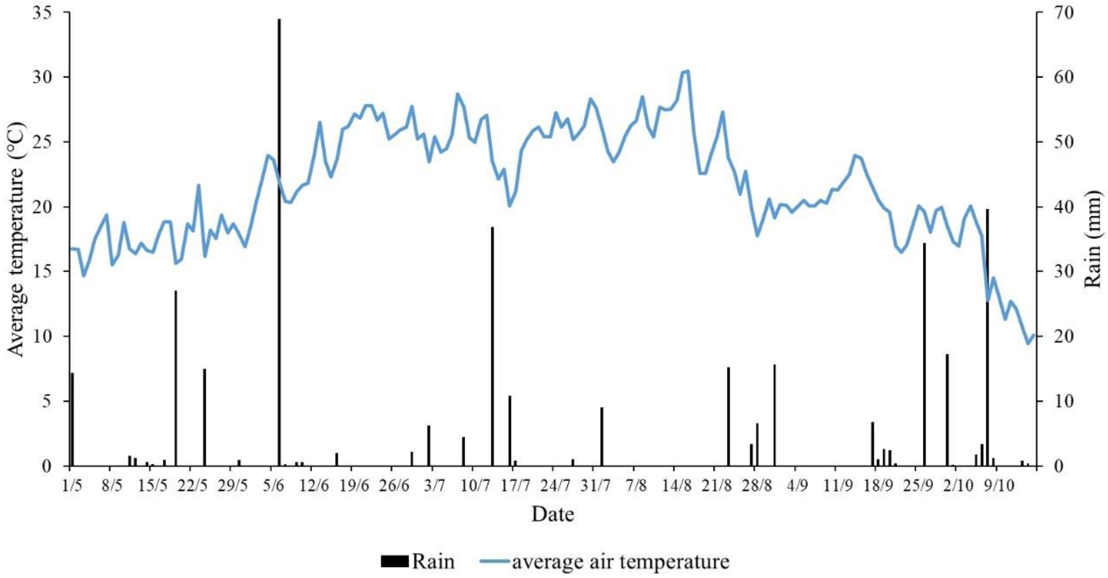

Figure 3. Figure 3. Average temperature and total rain from May 1st and October 15th 2021. Data collected by a meteorological station located in the farm.

Statistical analysis

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.
Fruit quality data after cold storage were analyzed as in a factorial experimental design with irrigation strategy (3 levels: T0, T1 and T2) and shelf-life timing (2 levels: +1 day and + 3 days) as main factors. When the interaction between factors was significant, 2 times standard error of means (SEM) was used as the minimum difference between two means statistically different for P≤0.05.

Results

Between 3 May and 30 September 2021, the quantity of water supplied per hectare with irrigation was 379 mm in T0, 211 in T1 and 338 mm in T2, meaning a water saving of 44% and 11% for T1 and T2, respectively. The reduced supply of water did not impair plant water status; indeed, stem water potential was not influenced by the irrigation strategy (Table 1).

Table 1. Effect of irrigation strategy on stem water potential (MPa) measured at midday.

IRRIGATION STRATEGY	August 11th	August 27th	September 15th
T0	-0.334	-0.292	-0.267
T1	-0.384	-0.283	-0.317
T2	-0.350	-0.317	-0.308
Significance	*n.s.*	*n.s.*	*n.s.*

n.s effect not significant at P≤0.05.

Fruit diameter on August 4th was similar in T1 and T2 and higher than T0; on August 25th the highest values were measured in T1 fruits while T0 and T2 showed similar values, lower than T1 (Figure 4). In mid-September, T2 showed values higher than T1 and T0 that were similar each other; at fruits harvest, no significant differences were observed between treatments (Figure 4).

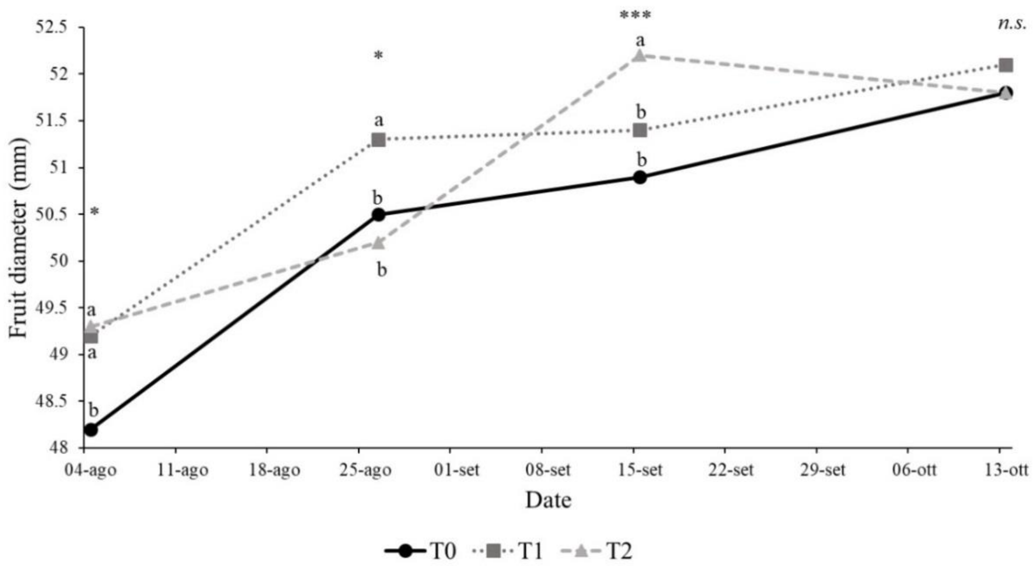

Figure 4. Effect of irrigation strategy on fruit growth during the vegetative season. *n.s.*, *, ***: effect not significant or significant at P≤0.05 and P ≤0.001, respectively. Means followed by the same letter are not statistically different (P ≤ 0.05).

During the entire season, dry matter content was similar in T1 and T2; these two treatments showed higher values than control (Table 2).

Table 2. Effect of irrigation strategy on fruit dry matter (%) during the vegetative season.

IRRIGATION STRATEGY	July 13th	August 11th	August 27th	September 15th	September 29th
T0	9.27 b	12.3 b	15.1 b	16.1 b	17.3 b
T1	10.5 a	13.1 a	16.0 a	17.6 a	18.2 a
T2	10.9 a	13.1 a	16.0 a	17.1 a	18.6 a
Significance	***	***	**	**	**

, *: effect significant at P≤0.01 and P ≤0.001, respectively. Means followed by the same letter are not statistically different (P ≤ 0.05).

The reduction of water did not negatively influence plant yield (Table 3). Fruit firmness was higher in T2 and T0 than T1 (Table 3). Soluble solid content was significantly higher in T1, followed by T2 and T0, while DM was higher in T2 than other strategy; T1 showed higher values than T0 (Table 3). The lightness of fruit pulp was higher in T2 and T0 in comparison to T1; the hue angle (measurement of flesh yellowing) was higher (greener) in T0 followed by T2 and T1 (Table 3). No significant differences were observed for pulp chroma (Table 3).

Table 3. Effect of irrigation strategy on plant yield and main fruit quality parameter and colour at harvest (October 13th).

IRRIGATION STRATEGY	Yield (kg plant^{-1})	Firmness (kg)	SSC (°brix)	DM (%)	L	C	H
T0	38.9	4.07 a	12.7 c	17.2 c	67.9 a	34.6	105 a
T1	35.9	3.15 b	15.3 a	18.4 b	66.3 b	34.4	102 c
T2	37.0	4.05 a	13.7 b	18.8 a	68.6 a	35.9	103 b
Significance	*n.s.*	***	***	***	***	*n.s.*	***

n.s., ***: effect not significant or significant at P ≤0.001, respectively. Means followed by the same letter are not statistically different (P ≤ 0.05). SSC = soluble solid content; DM = dry matter; L = lightness; C = chroma; H = hue angle.

No interaction between irrigation strategy and timing of shelf-life was observed after cold storage; as a consequence, in Table 4, the main effects of treatments are reported. Two months after harvest, fruit firmness was higher in T0 in comparison to T1 and T2 that showed similar values; no significant differences between treatments were observed at 4 months from harvest (Table 4). Two months after harvest, SSC was higher in T1, followed by T2 and T0; in the following sampling data (4 months after harvest), SSC was similar between T1 and T2 and higher than T0 (Table 4). Three days of shelf life induced a decrease of fruit firmness after two and four months of storage; SSC instead decreased at the first date while 4 months after harvest, it was higher after 3 days at room temperature (Table 4).

Table 4. Effect of irrigation strategy and shelf life timing on fruit firmness and soluble solid content (SSC) after 2 (December 14th) and 4 months (February 16th) of cold storage.

IRRIGATION STRATEGY	Firmness (kg)	SSC (°brix)	Firmness (kg)	SSC (°brix)
	2 months after harvest		4 months after harvest	
T0	0.779 a	15.8 c	0.592	16.2 b
T1	0.666 b	17.3 a	0.587	17.2 a
T2	0.625 b	16.8 b	0.586	17.1 a
Significance	***	***	*n.s.*	***
SHELF-LIFE				
+1 day	0.780	16.8	0.606	16.7
+ 3 days	0.606	16.5	0.572	16.9
Significance	***	*	**	*
*Irrigation*shelf-life*	*n.s.*	*n.s.*	*n.s.*	*n.s.*

n.s., *, **, ***: effect not significant or significant at P≤0.05, P≤0.01 and P ≤0.001, respectively. Means followed by the same letter are not statistically different (P ≤ 0.05).

In the first sampling date, after 1 and 3 days of shelf-life, DM was similar between T1 and T2 that showed values higher than T0 (Table 5). In T0, DM decreased after 3 days of shelf life, while no significant differences were observed between 1 and 3 days at room temperature for T1 and T2 (Table 5). After four months of cold storage and 1 day of shelf life, T1 and T2 showed similar DM higher than T0; after 3 days of shelf life, T1 and T2 showed similar values that were higher than T0 (Table 5). No significant differences, for each irrigation strategy, were observed between +1 and +3 days at room temperature (Table 5).

Table 5. Effect of irrigation strategy and shelf life timing on fruit dry matter (%) after 2 (December 14th) and 4 months (February 16th) of cold storage plus 1 and 3 days of shelf life.

IRRIGATION STRATEGY	2 months after harvest		4 months after harvest	
	+ 1 day	+ 3 days	+ 1 day	+ 3 days
T0	18.2	17.1	17.9	17.9
T1	19.2	19.1	19.1	18.9
T2	18.8	19.1	18.7	19.2
Significance	*2SEM = 0.498*		*2SEM = 0.499*	
*Irrigation*shelf*	***		*	

*, *** = effect significant at P≤0.05 and P ≤0.001. Values differing by 2 standard error of means (SEM) are statistically different.

Discussion

In the present experiment, the use of soil moisture probes led to a decrease of the volume of irrigation by 44% in the single pipe line and 11% in the double, without impairing the yield of Zezy002. This result confirms the preliminary conclusions obtained in 2019 in the same orchard (Quartieri *et al.*, 2022). The double pipeline induced a small decrease of water supplied, even if it was managed according to soil moisture. This could be due to the presence of row beddings that induce water from the emitters to moved more rapidly downhill, according to the bedding slope, than in depth outside the probe detecting zone. Despite the different volume of water, plant water status was not modified meaning that soil moisture was at its optimal level.

Fruit quality was influenced by the irrigation strategy, evidencing an increase of fruit DM as a consequence of water reduction both at harvest and in post-harvest storage, confirming previous reports (Crisosto *et al.*, 2011; Famiani *et al.*, 2012). The increase of DM in fruits could also induce economic benefits to farmers since it is used as a parameter to establish the price. Additional benefits deriving from the use of probes to monitor soil water availability could come from the avoidance of waterlogging that may be one of the possible causes of kiwifruit decay syndrome (Savian *et al.*, 2020; Mejia *et al.*, 2014).

Conclusions

From these results it is evident that the application of water according to soil water content is a valuable solution to reduce water consumption without impairing plants potential yield. The comparison between the use of a single or double line evidenced an increase of water saving when the single line was used. It must be stressed that in these experimental conditions vine row was managed with bedding 0.5 m high and 2-m wide, that allowed water movement towards the interrow. According to the data of the present experiment, the use of probes to monitor soil moisture seemed to have several advantages including fruit quality, economical, phytosanitary and environmental (water saving) benefits. Traditional monitoring systems usually rely on a single sensor or on a column of sensors at different depth; however, this system is not able to properly evaluate soil moisture dynamics in the soil volume colonized by roots. The use of a grid of sensors is able to precisely measure soil moisture profiles, but it is expensive; consequently, future research will use interpolation-based and machine learning approaches to forecast soil water availability with the use of fewer probes, making the strategy more affordable to farmers.

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