# Assessment of kiwifruit physiological decline: irrigation and soil management strategy to recover from waterlogging

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***Abstract***

**Kiwifruit plantations reduced by 7,200 ha, equal to 30% of the total production, in Italy in recent years, as a consequence of the spread of kiwifruit vine decline syndrome (KVDS) (Sportelli, 2022). This study aims to investigate the factors involved in the onset of this syndrome as waterlogging, improper irrigation and soil management practices. The experimental trial was conducted in a yellow fleshed kiwifruit orchard ('Zesy002') located in Latina (Italy). Three different plots with different KVDS symptoms severity were identified (CTRL, $KVDS_{moderate}$, $KVDS_{severe}$). In order to evaluate predisposing factors to plant decline, soil characterization (telluric gases,) and water table level were performed. Daily telluric gases concentration ($CO_2$ and $CH_4$) was significantly higher in the $KVDS_{severe}$ plot compared to the CTRL one, confirming that soil hypoxia due to waterlogging conditions is a predisposing factor of vine decline. The irrigation system in the $KVDS_{moderate}$ and $KVDS_{severe}$ plots was modified using two independent drip lines associated with micro-sprinklers, in order to apply an innovative water management based on soil water availability and leaf area index (LAI), that were different from the conventional management. The innovative irrigation was based on the simplified water balance and the irrigation volume applied was corrected considering the soil water content monitored by soil moisture probes at different depth. The seasonal irrigation volume applied for the different plots were 4,002, 3,890 and 4,060 $m^3$ $ha^{-1}$ in the $KVDS_{moderate}$, $KVDS_{severe}$ and CTRL plots, respectively. The results revealed a general optimization in the irrigation management, with a 30% reduction in water use, compared to the average irrigation volume ordinarily applied in the Latina area. In the $KVDS_{severe}$ plot, water table level was monitored along the season revealing a reduction of 30 cm compared to the previous irrigation season, thanks to the application of the innovative irrigation strategy and a drainage system.**

**Keywords:** *Actinidia deliciosa*, vine decline, soil management, water management

## INTRODUCTION

Kiwifruit (*Actinidia* spp.) production and marketing have great importance in Italy, which is the third producing country in the world with a cultivated area of more than 25,000 ha (https://www.fao.org/faostat/en/#home). In recent years, the kiwifruit supply chain has been threatened by the emergence and progressive spread of a rapid and severe decline, determining a decrease in the Italian total kiwifruit production quantity of about 30%, known as "kiwifruit vine decline syndrome" (KVDS).

KVDS has a multi-factorial origin and its causes have not been widely investigated yet. Waterlogging and decreasing soil oxygen concentration, with the consequent establishment of asphyxiation conditions for the root system, have negative effects on vine physiological state and overall on crop production and quality, defining kiwifruit as a susceptible species to low oxygen levels due to water excess (Savé and Serrano, 1986; Hughes and Wilde, 1989; Bardi, 2020). The kiwifruit vine decline has been observed mainly in compacted and waterlogged soils, conditions promoting root asphyxiation, which can even lead to plant death, suggesting waterlogging to be a key factor predisposing the syndrome. The early symptoms of KVDS are observed in the kiwifruit root system, which is characterized by decreased root activity (Donati et al., 2020) and turnover capacity, with consequent disappearance and reduced development of new absorbing feeder roots. Smith et al. (1990) found no new roots for vines waterlogged for more than four days. In the summer period, decline spreads in the epigeal part of the plant canopy and induces an overall decrease in plant growth, affecting physiological performance (Savian et al., 2020).

In particular, in Italian kiwifruit orchards, empirical agronomic and irrigation practices, applied over the years, compromised physical-hydrological, chemical and biological soil properties, leading to current compacted and waterlogged soils. The improvement of soil physical structure through sustainable soil management (e.g., compost application, retention of pruning residues and cover crops) and optimized irrigation strategies is pivotal to reduce water stagnation (Sofo et al., 2022), which induces soil compaction and root asphyxia, promotes the oxygenation of the soil layers interested by root deepening, and finally prevents the propagation of anaerobic pathogens responsible for root rot diseases (Donati et al., 2020; Spigaglia et al., 2020).

Increasingly extreme events resulting from climate change (e.g., autumn-winter heavy rainfall events), improper irrigation volumes, with consequent alterations of soil physico-chemical conditions in conventionally managed kiwifruit orchards, and peculiar physiological and anatomical kiwifruit traits may be at the base of the worsening and spread of the KVDS, both in the already affected and unaffected sites throughout Italy.

Therefore, an optimized management of the water resource is needed for assuring an optimal plant water status, avoiding water deficit or excess and the related plant disorders. The optimization of the irrigation volumes leads to increase in yield, improved fruit quality and overall production per area, as it occurred in recent years in southern Italy (Fernández, 2017).

In the present study, a kiwifruit orchard affected by KVDS, was characterized for the predisposing factors (soil gases' content and soil water status). Different plots were associated to different symptoms severity in kiwifruit vines. The application of irrigation management based on a simplified water balance could be supplemented with soil water content monitored by sensors, and the scheduled irrigation volume could be adjusted throughout the season to maintain soil moisture levels above the critical threshold. The drainage system aimed to reduce water accumulation (irrigation water and rainfall) along the season was installed.

## MATERIALS AND METHODS

### Experimental site description

The experimental kiwifruit orchard is located in Sermoneta (Lazio region), Italy (41°33'30.72"N, 12°57'18.51"E) and was characterized for its pedo-climatic conditions. The cultivated variety is *Actinidia chinensis* 'Zesy002', a yellow-fleshed kiwifruit, grafted onto D1 rootstocks (*Actinidia deliciosa*) in 2013. The planting density is 3×5 m, respectively, on row and inter-row for a total of 1,000 plants ha$^{-1}$, irrigated with a double drip system and sprinkler system. The site is divided into three areas, CTRL, $KVDS_{moderate}$ and $KVDS_{severe}$, which were identified according to visual symptoms of KVDS (Figure 1).

Meteorological data were collected from the Cisterna - Doganella di Ninfa weather station, located approximately 3 km from the experimental site. Historical meteorological data from the period 2004-2020 were analysed to determine the water deficit requirements.

### Soil gases and water table monitoring

A LI-7810 $CH_4$-$CO_2$-$H_2O$ Trace Gas Analyzer (LI-COR Biosciences; Lincoln, NE, USA) operating at a reduced flow rate was used for analysing soil gases. On July 20, 2021 measurements of soil $CO_2$ and $CH_4$ were taken in the CTRL and $KVDS_{severe}$ plots to define daily and hourly trends, using specific probes installed at 20 cm soil depth (withdrawal length of 76 mm; Swagelokattack 1/4', including pipe of connection and support for withdrawal, and closing faucet). Water table monitoring was assessed by soil excavations (2 m length, 1 m width, 1.5 m depth m) and piezometers installed at 150 cm soil depth. Measurements were assessed once per month.

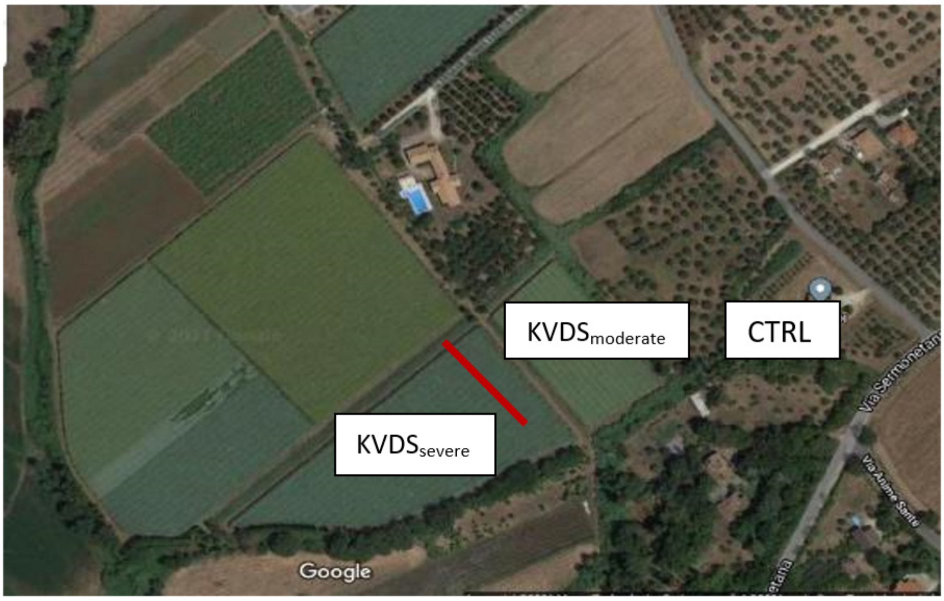



Figure 1. Orthophoto of the experimental site. Source: Google Earth.

**Degree of severity of KVDS on plants in KVDS$_{severe}$ plot**

Within the KVDS$_{severe}$ plot, 193 plants were classified depending on the severity of the dieback symptoms, into three groups whose degree of severity is connected to a colour class, respectively red (severe), yellow (moderate) and green/CTRL (no symptoms).

**LAI monitoring**

The leaf area index was monitored using Fish Eye photography on 9 plants per thesis based on KVDS symptoms severity throughout the growing season. A fisheye lens was used to take hemispherical photos subsequently analysed with Gap Light Analyzer freeware imaging software, to assess gap light transmission and canopy structure.

**Innovative irrigation management**

Irrigation was calculated using a simplified water budget method assuming evapotranspiration losses (ETc) as the crop's water requirement and useful rainfall (ER) as the external supply. The applied formula is: IV = [($ET_c$ - ER)/ime)]×10 ($m^3$ $ha^{-1}$), where IV is the irrigation volume to be supplied ($m^3$ $ha^{-1}$); $ET_c$ is the crop evapotranspiration (mm); ER is the effective rainfall (mm), ime is the irrigation method efficiency, assumed equal to 0.9 for drip irrigation. The $Et_c$ was calculated using the following formula: $Et_c = Et_0 \times K_c$, where $Et_0$ is the reference evapotranspiration, measured by the Doganella Ninfa weather station and $K_c$ is the crop coefficient reported in FAO book no. 66, ranging between 0.5 and 1.1 during the irrigation season (Xiloyannis et al., 2012).

The simplified water balance was referred to the soil volume determined by the formula: Vs = A × d × L ($m^3$ $ha^{-1}$), where Vs = soil volume considered in the water balance; A = soil area wetted by the irrigation system, d = the depth of the soil layer affected by irrigation (50.0 cm) and L = the length of the soil strip wetted by the drip line. Plant water uptake takes place almost entirely from this soil volume wetted by irrigation, where the fine absorbing roots are highly concentrated (Green and Clothier, 1995).

Soil moisture was measured with Drill & Drop probes (Sentek© Technologies) installed up to 90 cm soil depth in order to detect the moisture of eight layers of soil, respectively 0-

5.6-25, 26-35, 36-45,46-55,56-65, 66-75, and 76-85 cm. The daily soil moisture trends were used to correct and adjust the irrigation volumes calculated from the simplified water balance. Once defined the available water (AW) and readily available water (RAW) thresholds, the innovative irrigation strategy integrated the daily soil water balance with soil moisture measurements. The irrigation volumes applied were weekly adjusted in order to maintain soil water contents at 0-30 and 30-60 cm of soil depth at 60-90% of field water capacity (FWC), avoiding drought or waterlogging stress. The optimized irrigation management was also based on the partitioning of irrigation volumes throughout the day, aiming to wet soil up to 15 cm and dry the deeper soil layers. Daily irrigation volumes were applied in one or more applications depending on the environmental variables that affect water use in the orchard and the dimension of the soil wetted by irrigation, according to the environmental water demand.

## RESULTS AND DISCUSSION

The climatic data analysed for the period 2004-2020 showed that the average annual rainfall was 1,128 mm and the reference evapotranspiration was about 965 mm, resulting in a negative water deficit of -163 mm year$^{-1}$ (Figure 2).

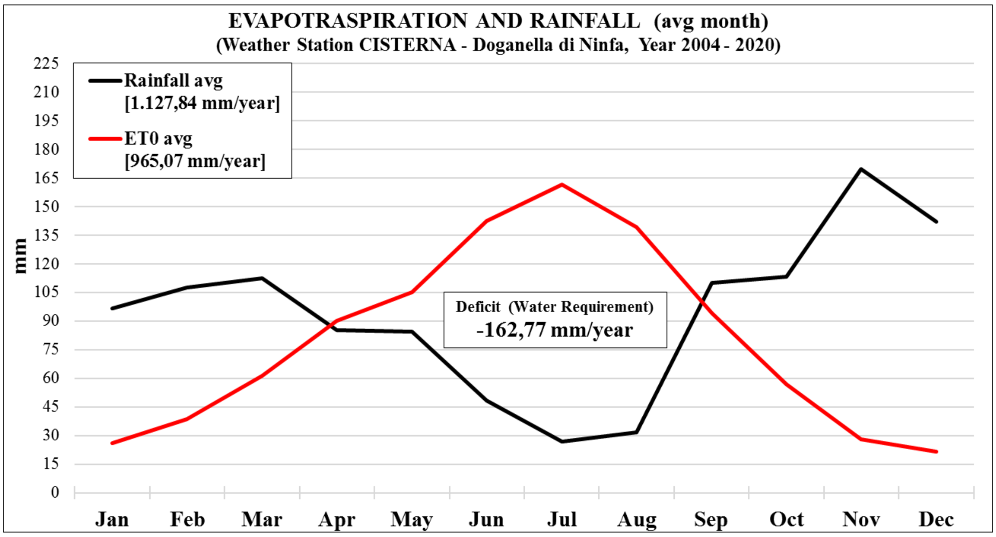



Figure 2. Environmental parameters (avg. 2004-2020) – average per month of $ET_0$ and rainfall (mm day$^{-1}$), total rainfall (mm), total $ET_0$ (mm) and water deficit (m$^3$ ha$^{-1}$).

### Soil gases and water table monitoring

Soil excavations (2 m length, 1 m width, 1.5 m depth m) in the $KVDS_{severe}$ plot revealed an impermeable layer at 100 cm soil depth, a beginning of soil compaction starting from a depth of 40 cm, with adequate root growth only in the first 30 cm of soil (Sofo et al., 2022). Soil macroporosity was reduced in the $KVDS_{severe}$ plot compared to the $KVDS_{moderate}$ and CTRL plots (Sofo et al., 2022). Microscopic analysis revealed damages of root system in plants with severe symptoms, as in D'Ippolito et al. (2022). Measurements of piezometers revealed a water table that is the result of an improper irrigation management, providing excessive irrigation water, and seasonal rainfall events, in particular in the $KVDS_{severe}$ plot (Figure 3).

Daily trends of soil gases, monitored at 20 cm soil depth, show higher levels of $CO_2$ and $CH_4$ in the $KVDS_{severe}$ plot compared to the CTRL (Figure 4). An increase in $CO_2$ and $CH_4$, two indicators of soil hypoxic conditions, and consequent decrease of oxygen concentration in the root zone have deleterious effects on vine growth, inducing its substantial reduction (Smith et al., 1989). Waterlogged soils, characterized by increased hypoxic conditions threaten the root system vitality and functionality, leading to root death and associated damage to leaves (Smith et al., 1990). These are major factors predisposing to kiwifruit physiological decline.

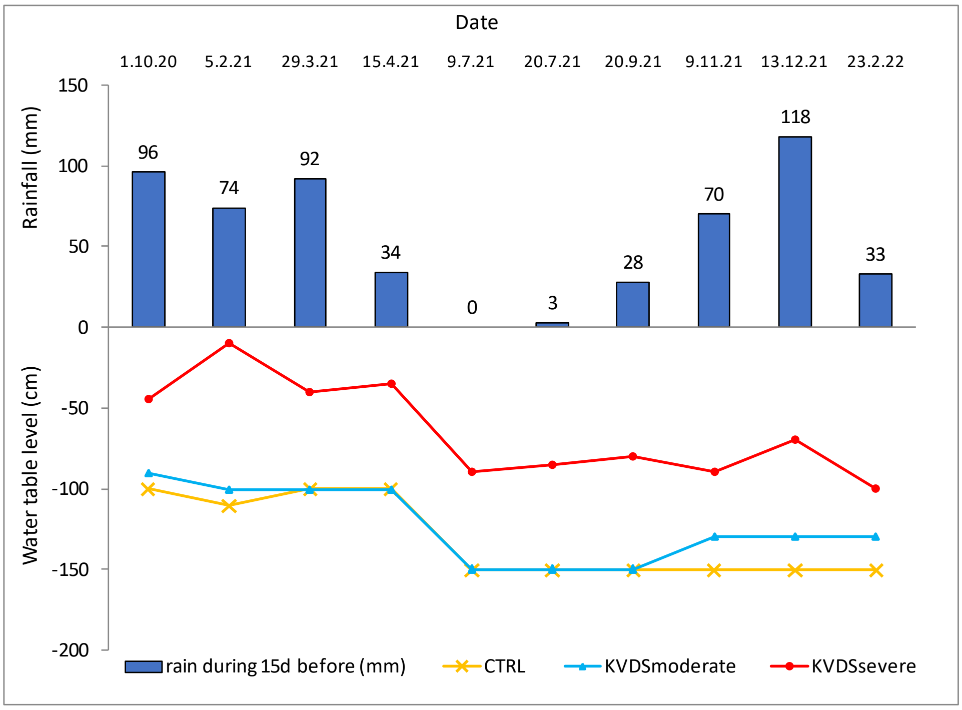



Figure 3. Water table level measured by piezometers installed at 150 cm soil depth in CTRL (yellow line), $KVDS_{moderate}$ (blue line) and $KVDS_{severe}$ (red line) plot. Rainfall events (mm) are represented by histograms.

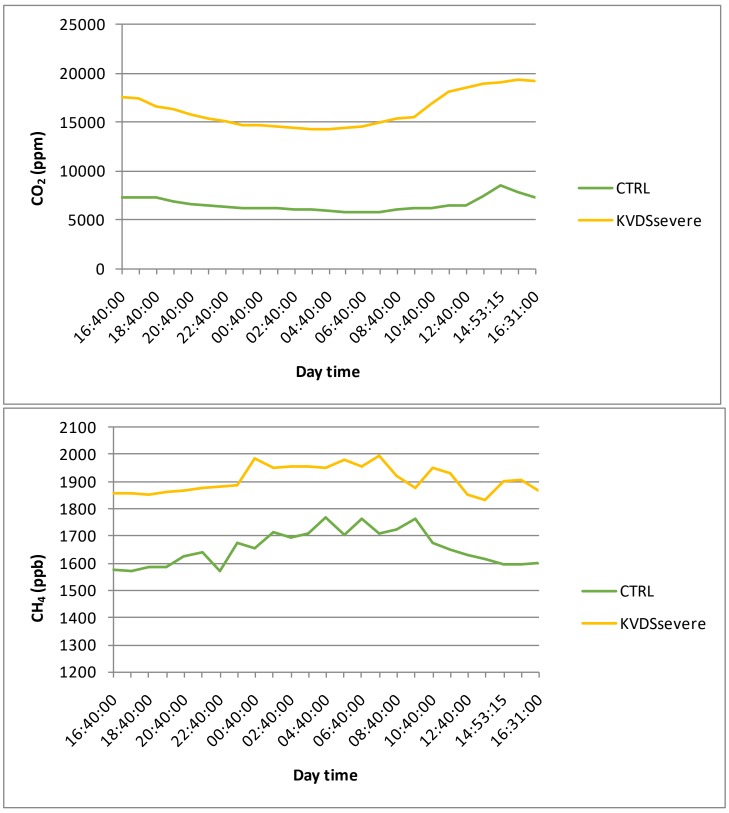



Figure 4. Daily trends of $CO_2$ and $CH_4$ soil gases monitored at 20 cm soil depth in the CTRL and $KVDS_{severe}$ plots on 20 July 2021.

## Innovative irrigation management

The optimized irrigation strategy, by periodically correcting the irrigation volumes through soil moisture monitoring, has led to a substantial reduction in the irrigation volumes administered, allowing, together with the drainage system, to dry the deeper soil layers, lowering the water table level, and maintain an optimal water content in the first 10-15 cm of soil depth. The theoretical volume resulting from the compilation of the water balance, was 4,800 $m^3$ $ha^{-1}$. With the corrections derived from the soil moisture probes, the new volumes provided to the $KVDS_{moderate}$ and $KVDS_{severe}$ plots were respectively of 4,060 and 3,890 $m^3$ $ha^{-1}$ (Figure 5). The irrigation strategy adopted was therefore aimed at consuming water in the deep layers. The drainage system installation and the application of the innovative strategy are shown in Figure 3, which represents the water table that is reduced in $KVDS_{severe}$ plot in 2022.

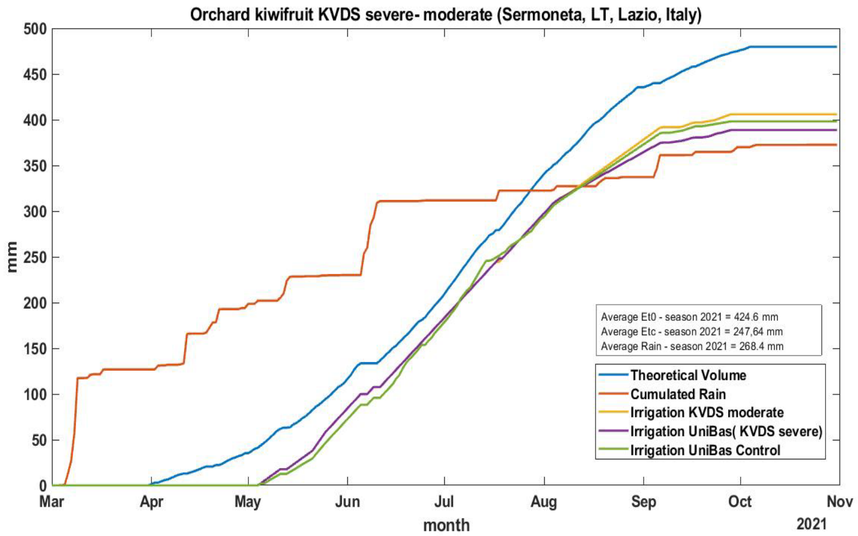



Figure 5. Real and theoretical cumulated water volumes in CTRL, $KVDS_{moderate}$ and $KVDS_{severe}$ plots, with indication of the $ET_c$, $Et_0$ and rain during 2021 irrigation season.

## Degree of severity of KVDS on plants

According to the symptom severity degree plants were classified in the 2021 and 2022 seasons, as shown in Table 1. The classification of plants performed in the 2022 growing season showed an improvement in plant conditions compared with 2021, due to the application of soil and optimized water management strategies. The number of plants classified as green increased considerably in 2022, while the number of plants classified as red decreased, indicating an overall reduction of KVDS symptoms achieved during the 2022 season.

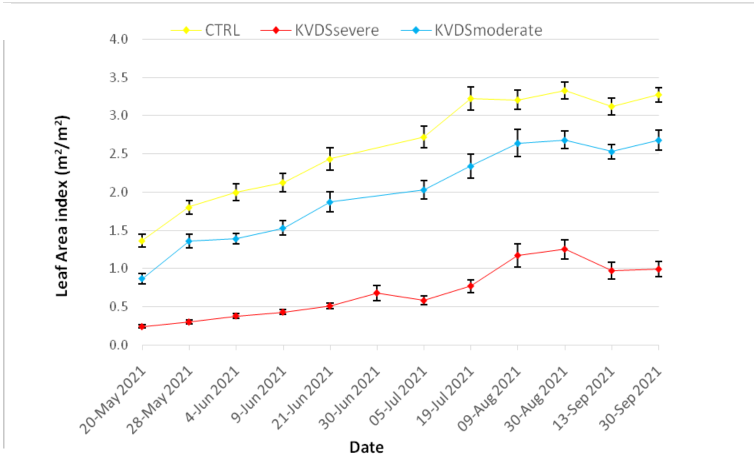
Table 1. Symptom severity index in the $KVSD_{severe}$ plot in the following seasons: 2021 and 2022.

| KVDS symptoms classification | Number of plants | |
|---|---|---|
| | 2021 season | 2022 season |
| KVDS – Red | 20 | 4 |
| KVDS – Yellow | 82 | 37 |
| KVDS – Green | 89 | 149 |
| Dead | 2 | 3 |
| **Total** | **193** | **193** |

## LAI monitoring

The leaf area index shows higher values in the CTRL plot compared to the $KVDS_{moderate}$ and $KVDS_{severe}$ plots. In particular, LAI values depend on the degree of KVDS symptoms severity, showing decreasing LAI values with increasing decline severity (Figure 6). As known from the literature, diseased plants are characterized, at first, by severe decay of fine roots, which is followed by canopy wilting (Donati et al., 2020; Savian et al., 2020), as confirmed by results from LAI monitoring.

A




B

Figure 6. A) leaf area index trends for the three different plots (CTRL, $KVDS_{moderate}$, $KVDS_{severe}$); each point is the mean of nine plants, bars are standard errors. B) fisheye hemispherical photos in CTRL (left), $KVDS_{moderate}$ (centre) and $KVDS_{severe}$ (right) taken on 21 June 2021.

## CONCLUSIONS

In kiwifruit orchards, a situation of soil water excess is difficult to diagnose early, as the processes involved (reduced root growth and soil destructuration) are slow, and visible symptoms on the plant appear when the physiological decline is advanced. For this reason, it is important to implement management actions to prevent and/or promptly remove all the conditions predisposing to vine physiological decline. In particular, developing a precision irrigation strategy that adjusts volumes to the actual plant water need and allows water availability to be synchronized even during the day with plant uptake, can avoid permanent situations of soil water excess, which can trigger those slow processes of soil destructuration making them asphyctic and inhospitable for root system development. The reduction of waterlogging especially in the winter period, as affected by intense rainfall, is possible through the installation of the drainage system and the adoption of the optimized irrigation strategy, which adjusts the irrigation volumes obtained from the water balance according to the actual soil water content constantly monitored by moisture sensors.

The optimization of the irrigation management achieved in the present study lead to a reduction of irrigation volumes of approximately 30%, compared to the average irrigation volume conventionally applied in kiwifruit orchards in the Latina area. In the $KVDS_{severe}$ plot, water table level was monitored along the season revealing a lowering of the level of 30 cm compared to the previous irrigation season, due to the application of the innovative irrigation strategy and the drainage system.

The validation and adoption of irrigation and soil management strategies are therefore pivotal to prevent new kiwifruit orchards from being affected by the KVDS syndrome and recover those already affected, restoring their physiological and productive potential.

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