Physical structure and chemical quality of waterlogged soils in an Italian kiwifruit orchard

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Abstract

In the last years, kiwifruit vines have been affected by the kiwifruit vine decline syndrome (KVDS), which is damaging the Italian kiwifruit industry. We hypothesize that soil compaction and asphyxia could have a priming effect in the emergence of KVDS. On this basis, we characterized soils from three areas of a kiwifruit orchard in Latina (Lazio region, Italy): one with vines showing severe symptoms of KVDS (K_{field}), another with vines having intermediate symptoms (I_{field}), and the last with healthy vines (C_{field}) as control. Soils were characterized physically showing a gradient of compaction, clay/silt content and water content, with the highest values in K_{field} and the lowest in C_{field}, while soil chemical properties were not significantly different. The soil gas redox potential after the onset of waterlogging was significantly lower in K_{field} than in the other treatments. This parameter indicates reducing soil conditions and it is negatively correlated to oxygen concentration. Higher CO_2 and CH_4 concentrations, two indicators of anoxic soil conditions, were found in K_{field}, compared to C_{field}. The microscope analysis of the soils showed that K_{field} soils had fewer macropores than C_{field}, whose number is positively correlated to the oxygen content. Implementation of soil and water management strategies could improve kiwifruit roots growth and vine productivity, and also help reduce symptoms of KVDS in impacted vineyards.

Keywords: KVDS, soil aeration, soil compaction, soil macropores, waterlogging

INTRODUCTION

Italy, the third largest kiwifruit producing country in the world, with a total production of 318 kt and an export of 249 kt, has lost 10% of its production in recent years due to the spread of kiwifruit vine decline syndrome (KVDS), which causes severe and rapid decline in vines (Bardi, 2020a). Symptoms similar to KVDS have been observed in different environments and are often associated with impermeable soils because of compaction, waterlogging and root asphyxiation (Smith et al., 1989, 1990). Early KVDS symptoms are root damage and root rot phenomena, which ultimately cause the physiological decline of the whole plant (Ermacora et al., 2020). Kiwifruit is a crop with a high water requirement but it is also extremely sensitive to water stagnation, even transitory, whose deleterious effects can arise if the soil does not rapidly drain excess water, with the consequent establishment of soil anoxic conditions (Reid et al., 1992). Waterlogging is often enhanced by excessive irrigation. Sustainable irrigation management should start from a climate characterization of the area, in particular from the environmental water deficit. Kiwifruit production is of great commercial importance in Italy, but its profitability has been threatened by KVDS. As part of the Zespri Innovation project "Water and Soil Management of Gold3 in Italy", in collaboration with the University of Basilicata (UNIBAS), a preliminary experiment has been performed in 2020 in kiwifruit orchards affected by KVDS in Latina (Lazio region, Italy) (Figure 1). This study of soils aims characterizing the soil content/composition in kiwifruit orchards hit by KVDS, suggesting solutions for mitigating it.

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Figure 1. A kiwifruit orchard affected by kiwifruit vine decline syndrome (KVDS) in the Latina area (Lazio region, Italy). It is possible to see vines with not expanded canopies and wilted and dry leaves.

MATERIALS AND METHODS

Experimental site

The trial was performed in Latina region (Italy) characterized by an average annual ET_0 of 732 mm and an annual rainfall of 1113 mm. In the last three years (2018-2020), the environmental deficit (ET_0-Rainfall) was 288 mm during the growing season (Figure 2). The irrigation volume applied to the kiwifruit orchards was approximately 6,500-7,000 m^3 ha^{-1} $year^{-1}$, which is higher than the effective irrigation requirement of kiwifruit orchards.

For this study, the soils of three areas of a kiwifruit orchard (*Actinidia chinensis* (Planch.) var. *chinensis*, cultivar 'Zesy002') located in Latina were characterized: one with vines showing severe visual symptoms of KVDS (K_{field}), another with vines with intermediate symptoms (I_{field}) and the last with healthy vines (C_{field}). In October 2020, soil physicochemical parameters and soil gases were measured in the three areas.

Physical soil changes

Soil texture was determined on fractions smaller than 2 mm according to Pansu and Gautheyrou (2006). Soil macroporosity analysis was performed by transmitted light microscopy on soil subsamples embedded in epoxy resin (Durcupan™; Sigma-Aldrich, St. Louis, MI, USA) following the method of Sotta and Fujiwara (2017).

Chemical soil analyses

The soil samples were dried at 105°C for 24 h, placed in a desiccator and subsequently sieved through a 2-mm stainless steel sieve. The fraction smaller than 2 mm was used for soil chemical analyses. Soil pH was measured with a glass electrode (model Basic 20; Crison Instruments SA, Barcelona, Spain) in distilled water, using a 1:2.5 suspension from ground to liquid phase ratio. Soil redox potential was determined by potentiometric determination using a 1:2.5 suspension from ground to liquid phase ratio and reading after 5 h. Soil organic carbon (SOC) was measured by the Walkley-Black method at 170°C with potassium dichromate ($K_2Cr_2O_7$) in the presence of sulfuric acid (H_2SO_4), and the excess of $K_2Cr_2O_7$ was measured by titration of the Möhr salt, while soil total nitrogen (STN) was measured by the Kjeldahl method (Pansu and Gautheyrou, 2006).

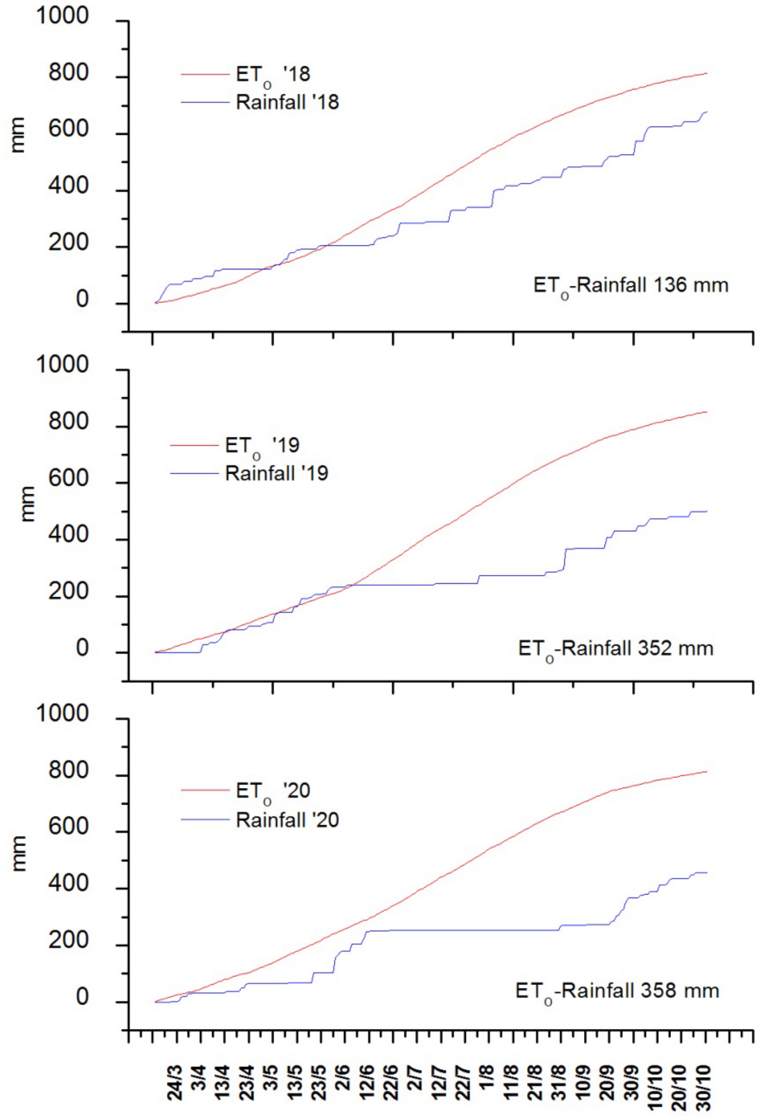

Figure 2. Cumulative evapotranspiration (ET_0) and rainfall during three years 2018-2020 in the irrigation season in the experimental site in Latina area (Italy).

Analysis of soil gases

For the analysis of soil gases, LI-7810 CH_4/CO_2/H_2O Trace Gas Analyzer (LI-COR Biosciences; Lincoln, NE, USA) operating at reduced flow rate was used. The measurements of soil CO_2 and CH_4 were taken at different soil depths (20, 40, 70 and 90 cm) in the three areas, using specific iron probes (withdrawal length of 76 mm; swagelock attack 1/4', including pipe of connection and support for withdrawal, and closing faucet).

Statistical analysis

The statistical analysis of the data was performed using Sigmastat 3.1 SPSS Inc. software (SPSS Inc., Quarry Bay, Hong Kong). The means of all the measured parameters were treated by one-way analysis of variance (ANOVA) with the orchard area (K_{field}, I_{field} and C_{field}) as a factor. Means were separated according to Fisher's LSD test at $p \leq 0.05$. Three independent biological replicates for each treatment (n=3) were considered.

RESULTS AND DISCUSSION

Physicochemical analysis of the soil and water content

In September 2020, soil excavations (2×1 m trenches) revealed an impermeable layer at 1 m depth of the soil, a beginning of soil compaction starting from a depth of 40 cm, with adequate root growth only in the first 30 cm of soil. In K_{field}, the groundwater surface in the trenches was detected at a depth of 40-50 cm (Figure 3) mainly due to excessive irrigation. It was also found that occurrence of seasonal rainfall events, from October to February, increased soil waterlogging (Figure 4).

Figure 3. Ground water level (about 50 cm depth) in October 2020 at the end of irrigation season in a hole perforated at 30 cm from the kiwifruit vine trunk affected by kiwifruit vine decline syndrome (KVDS) (K_{field}) (left); excavation trenches between vines in the same kiwifruit orchard (K_{field}) show the same level of groundwater (right).

Figure 4. Winter period in the kiwifruit orchard affected by kiwifruit vine decline syndrome (KVDS) (left); water stagnation of the soil; trench full of water within the row (December 2020) (right).

Clay content showed the highest values in K_{field} (43 and 44% at 0-30 and 30-60 cm depth, respectively), while they were lowest in C_{field} (39 and 40% at 0-30 and 30-60 cm depth, respectively). This was accompanied by a higher soil compaction in K_{field}, as shown by the fewer macropores (Figure 5), the number of which is directly related to soil oxygen content (Smith et al., 1989).

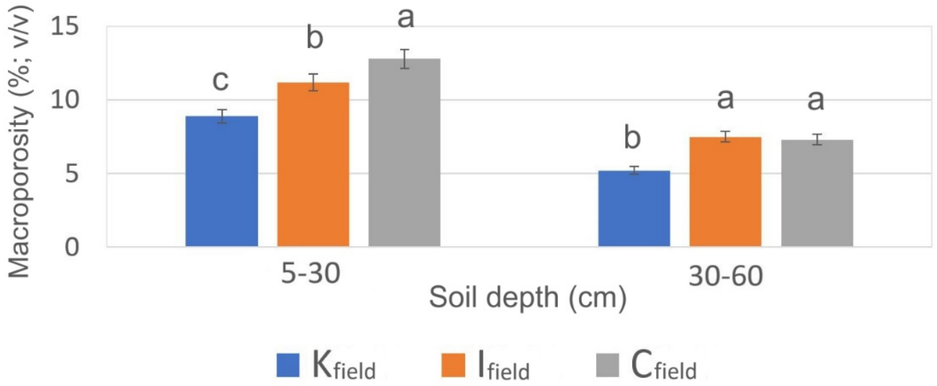

Figure 5. Soil macroporosity measured at different soil depths in the three sites. Each value represents the mean (±SD) from three soil samples (n=3). The values with different letters are statistically different ($p \leq 0.05$) within soil depths.

The soil redox potential is a parameter indicating the reducing conditions of the soil and it is negatively correlated to the soil oxygen concentration (Husson, 2013). In waterlogged soils, we observed that soil redox potential was significantly lower ($p \leq 0.05$) in K_{field} (286 and 339 mV at 5-30 and 30-50 cm soil depth, respectively) than in C_{field} (327 and 393 mV at 5-30 and 30-50 cm soil depth, respectively). Soil pH was significantly lower in C_{field} than the other treatments; SOC was higher in K_{field} than C_{field} at 5-30 cm, while STN was higher in K_{field} (Table 1).

Table 1. Soil pH, soil organic carbon (SOC) and soil total nitrogen (STN) measured at different soil depths in the three sites. Each value represents the mean from three soil samples (n=3).

Site	Soil depth (cm)	pH	SOC (%: w/w)	STN (%: w/w)
K_{field}	5-30	7.4 a	3.39 a	0.195 a
I_{field}		7.3 a	2.57 c	0.151 c
C_{field}		6.9 b	3.07 b	0.180 b
K_{field}	30-60	7.3 a	2.60 c	0.153 c
I_{field}		7.2 a	2.37 d	0.138 d
C_{field}		6.7 b	2.85 bc	0.161 bc

The values with different letters are statistically different ($p \leq 0.05$) within columns.

Regarding soil gases, the levels of CO_2 and CH_4, two indicators of soil anoxic conditions (Bardi et al., 2020b), were found to be significantly higher at the maximum soil depth in K_{field} (Figure 6). At all the other depths, CO_2 was significantly higher in K_{field} than C_{field}, while CH_4 was not significantly different between the two sites.

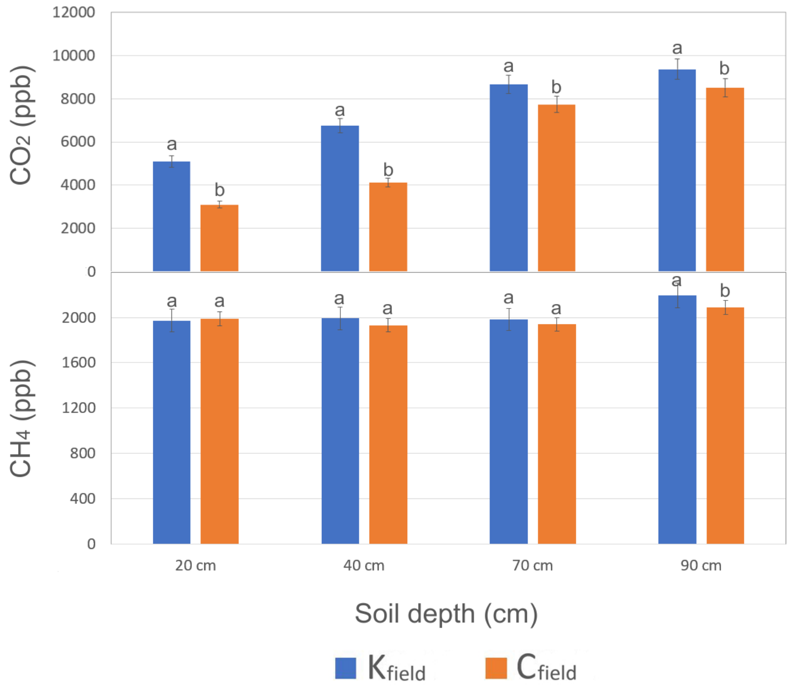

Figure 6. CO_2 and CH_4 concentrations measured at different soil depths. Each value represents the mean (±SD) from three soil samples (n=3). The values with different letters are statistically different ($p \leq 0.05$) within soil depths.

CONCLUSIONS

To improve the physical qualities of the soil and ensure optimal growth of the kiwi roots, an innovative soil and irrigation management is necessary. This should include the application of correct irrigation volume of water in order to prevent the increase of groundwater level, amelioration of soil drainage by excavating trenches full of pebbles, the application of external organic matter up to a depth of 40 cm, and the use of decompacting cover crops. The objective is to reduce soil compaction and provide the oxygen necessary to mitigate the effects of potentially pathogenic microorganisms, many of which proliferate in anaerobic environments (Ermacora et al., 2020). Adequate soil management is also aimed at facilitating the horizontal and vertical movements of soil waters (Xiloyannis et al., 2016). Particularly in kiwifruit, where waterlogged and compacted soils are a serious problem, the results show that soil physico-chemical quality plays a key role not only in terms of fertility and productivity, but is also important in ensuring optimal plant growth and avoiding emergent plant decline syndromes.

ACKNOWLEDGEMENTS

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