An innovative and multidisciplinary approach to face kiwifruit vine decline syndrome (KVDS)

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Abstract

In the last three years, the spread of the so-called kiwifruit vine decline syndrome (KVDS) in Italy also involved SunGold (G3) production. Preliminary indications from the research financed by Zespri pointed out water excess, stagnation, soil compaction or soil structure disruption associated with hypoxia or hyper oxidation as a potential cause in the emergence of KVDS. To face and contain the spreading of the problem, Zespri is coordinating five projects, considering plants as an integrated system with soil and atmosphere, and where microbial communities play a key role in modulating and translating environmental factors, with a "one health" approach. The approach of these new projects is clearly oriented, other than on research, toward extension and communication. Thanks to the wide network of Zespri teams, technicians and growers that Zespri is involving in this "task force" approach, we are supporting growers and the rest of the industry with the "learning by doing" strategy. Using soil science as the base for the agronomic management, we're investigating and validating processes capable of creating stable soil biological porosity, decreasing soil compaction and hypoxia, increasing soil microbiome diversity, improve water and nutrient management and consequently increasing fruit yield and quality. The implementation of novel management and monitoring strategies can improve kiwifruit growth, vine productivity and reduce KVDS symptoms in impacted vineyards, contributing to the socio-economic sustainability of farms, and increasing the ecosystem services, according to a sustainable, integrated, modern and multifactorial concept of kiwifruit growing.

Keywords: KVDS, kiwifruit, one health, soil structure, water logging, orchard management, microbiome, ecosystem services

INTRODUCTION

During the last ten years a phenomenon classified as kiwifruit vine decline syndrome (KVDS) has heavily impacted the Italian Kiwifruit Industry. A reduction of more than 8,000 ha of kiwifruit in Italy (around 30% of the total cultivated area) occurred, especially on Hayward but also on yellow-flesh varieties. In general, it is known that KVDS is occurring under water excess and stagnation conditions due to increased, concentrated rainfall events and/or excess irrigation volumes in poorly drained soils. Soil compaction and hypoxia seems to have a priming effect in the emergence of KVDS. Heavy soils are the most susceptible to different levels of compaction, clay/silt content and water content, with higher values being highly associated to KVDS.

The decline process starts with the inhibition of root functions under non favorable root growing conditions (compaction, water logging, lack of oxygen), the underground root blockage is usually unnoticed by the growers who continue managing the vines as in healthy conditions. Aiming to keep similar crop load and productivity from previous seasons creates an uneven ratio between the inhibited root system growth and the canopy, causing an even higher damage to the root growth processes. Initially, the impact is noticed on the fruit and

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canopy growth with a reduction of vigour and fruit size. If actions are not taken, in the coming season the vines are in a situation where the root system has a severe lack of carbohydrate content and turnover, while a major vine decline manifests once the canopy is established, the fruit is set and the transpiration rates increase during the first hot days of the season, as the root system is unable to support the canopy and fruit growth. Such a complex phenomenon cannot be managed and resolved with an univocal agronomic approach, similar for all the growers. A complex and well-coordinated approach is needed.

The Task Force approach

In 2020, the SunGold (G3) Supplier Group has made an official request to Zespri to lead and coordinate the response to KVDS, creating a Task Force (TF) to manage projects and communication around this problem. The Task Force is composed by Zespri teams (Innovation, Grower Liaison, OPC, Post Harvest), technicians from the main OP (Agrintesa, Apofruit, OP Kiwisole, Salvi), representative growers, and scientists involved in the different projects (UNIBAS, UNIBO, i.ter, Vitaceres, CREA-DC). The group activity pointed out two main actions: research coordination and collaboration around the communication within and outside the group. The approach of the Task Force is to study every single situation matching all the disciplines together, even the ones where apparently the causes may not be referable to the factors commonly associated with the KVDS (Table 1).

Table 1. The complete view of the five projects crossing each other on a geographical approach to represent different soil regions and climatic area.

Pedoclimatic area	Region	I.ter	Vitaceres (Soil fertility)	UNIBAS (Agronomy & soil fertility)	CREA RM	UNIBAS (Agronomy)
Volcanic	Lazio (IT)	Monitoring network	Soil & plant health		Metabarcoding	Soil & plant health
Alluvional plan	Lazio (IT)	Monitoring network	Soil & plant health	Water & soil	Metabarcoding	Soil & plant health
Sand	Lazio (IT)	Monitoring network	Soil & plant health		Metabarcoding	
Travertin	Lazio (IT)	Monitoring network	Soil & plant health		Metabarcoding	
Alluvional plan	Emilia Romagna (IT)	Monitoring network	Soil & plant health			
Volcanic	Calabria	Monitoring network	Soil & plant health			
Riverside plan	France	Monitoring network	Soil fertility			

At the moment, the TF is coordinating five different projects, maintaining a common focus on the general philosophy of the group: plants are an integrated system with soil and atmosphere, and microbial communities play a key role in modulating and translating environmental factors. The concept can be summarized as a “one health” approach.

MATERIALS AND METHODS

Following, a summary of the scientific methods adopted for each project, in reference to the proposal of this paper.

Timeline: from December 2020 to December 2023

1. Water and soil management of G3 in Italy, UNIBAS.

The aim of the project is to define the water needs of the Sun Gold (G3) in Italy and the correct soil management to avoid or recover from KVDS. A special focus has been on a trial

orchard, which can be considered an emblematic case study.

Water management: the precision irrigation approach.

- Irrigation volume based on the plant status: under KVDS, it is very important to classify the plants based on the severity of symptoms and differentiate the irrigation volume according to the LAI – leaf area index (the total area of leaves per unit ground area) (i.e., using drippers with different flow rate in the same line or segregating specific irrigation sectors);
- Optimized irrigation management through the soil water content monitoring the use of commercial soil moisture sensors can help on defining the correction of irrigation volume and is feasible to guarantee an optimized irrigation management and should be widespread;
- Plant sensors: to better define the correct water needs of each plant, the use of plant sensors to estimate the trunk sap flow (TSF) or the steam water potential (SWP) is strategic. Plant & Food Research T Max Sap Flow has been used in the experiment. On the side, 3 different commercial sensors have been evaluated for the future extended use in commercial orchards (Flora Pulse, Croptide, TreeToScope);
- A specific irrigation strategy: using the combination of the classical water balance approach corrected by the soil moisture probes reading, a day-by-day strategy has been defined, favoring the distribution of daily irrigation volume over several times, alternating distribution of irrigation water in different soil volumes to limit the impact of irrigation on soil structure and promote root system oxygenation.

Soil management.

- Trench excavations and deep soil study: in order to detect the potential risks of having soil compaction, waterlogging conditions;
- Installation of a drainage system to reduce the water table level (especially in environments or after events characterized by intense rainfall) and continuous monitoring of the water level along the season with piezometers;
- Adoption of sustainable soil management practices, such as application of organic amendments (e.g., compost or derived products) and cover crops to improve soil structure and functions;
- Use of commercial soil moisture probes installed at different depths to continuously monitor the water content along the soil profile, managing the soil water condition primarily in the first soil layers (0-30 cm), mainly interested by root development and activity, and in the deeper soil layers (up to 60 cm);
- Adjustment of irrigation volumes to keep the soil moisture between the field capacity (FC) and readily available water (RAW) threshold defined as 40% of the total available water (AW) for kiwifruit and provide the right amount of irrigation water;
- Monitoring and measurement to address the soil fertility, microorganism presence and eventual pathogen's role in the KVDS process.

Vine management.

- Root/cane pruning and fruit thinning to achieve a balanced root/canopy ratio.

Timeline: from November 2021 to December 2022

1. Soil map and relative management definition, Zespri and i.Ter.

The aim of this project was the definition of a kiwifruit map based on pedological characteristics of soil and the relations between these traits and the agronomic management. A series of field activities and workshops were organized involving the TF aimed to the definition of a Lazio kiwifruit soil vocation map and to create a booklet on soil management good practices.

Timeline: from March 2022 to December 2024

1. Metagenomic applied to KVDS, CREA Roma.

As a consequence of the deep study carried out in the Water&Soil project about soil vitality and the microbial community involved in the syndrome, Zespri decided to support a PhD study proposed by CREA-DC and University of Sapienza. The project aims to characterize the microbial community associated with plants and soils affected by KVDS through conventional techniques and metabarcoding analysis, as well as verify the role of pathogens in the phenomenon. The final objective is to understand how to manage the microbial community (and dysbiosis) through good agronomic practices.

Timeline: from March 2023 to March 2026

1. Soil and plant health, UNIBAS and Vitaceres.

The aim of the project is to adopt, in a feasible way, the management concept learned in the Water&Soil project, extending the soil management and the precision irrigation approach to two new orchards. The challenge of this new trial is to translate the ideal practices adopted in the previous project into advice applicable by the growers in "real orchard" situations and adapting them to the specific soil type, orchard story and existing systems. Other than, a special focus will be on the soil health study, exploring analysis, tests and methods to evaluate and score soil structure, fertility and resilience.

2. Orchard Monitoring Network, Zespri and i.Ter.

In continuity with the "soil map and relative management definition" project, a "monitoring network" project has been started. The goal is to involve the TF in a 3-year study on soil health (biological and physical) and vine management of a group of 15 orchards across Italy and France, selected according with their pedological characteristic.

It is a big and ambitious effort to collect all the results coming from all the ongoing and future projects, to share data, cross information and build knowledge using all the projects outcomes.

RESULTS AND DISCUSSION

Sustainable soil management (i.e., compost application and cover crops), innovative orchard management (root and canopy pruning) together with optimized irrigation strategies should be carried out to improve soil structure and microporosity and reduce water logging, soil compaction, root asphyxia while promoting the oxygenation of the soil layers interested by root growth and balance the root/canopy growth.

This general concept has been developed in the KVDS trial orchard, demonstrating, in a three year time frame, that this is true and that the final result is the amelioration of the soil and the canopy recovery of the declining plants.

Water&Soil trial orchard

The Water&Soil trial orchard is a good example, representative of what the holist approach can produce in the long therm.

In September 2020, when the trial began on a portion of the total orchard, looking at the KVDS symptoms, it was possible to classify the orchard this way (Figure 1):

- Severe KVDS area: decline symptoms on canopy, very compromised roots, flooded area, destructured soil, compromised biological fertility;
- Intermediate KVDS: decline symptoms on roots, no symptoms on the canopy, soil beginning destructuring (mainly localized around the drip irrigation area);
- The rest of the orchard around the trial (grower management area) with mild symptoms of decline;
- Block 5: no symptoms at all, selected for a P&F irrigation trial (use of TSP and TDR to determine the correct G3 water balance). A portion of the block began to be managed by UNIBAS, the rest by the grower.

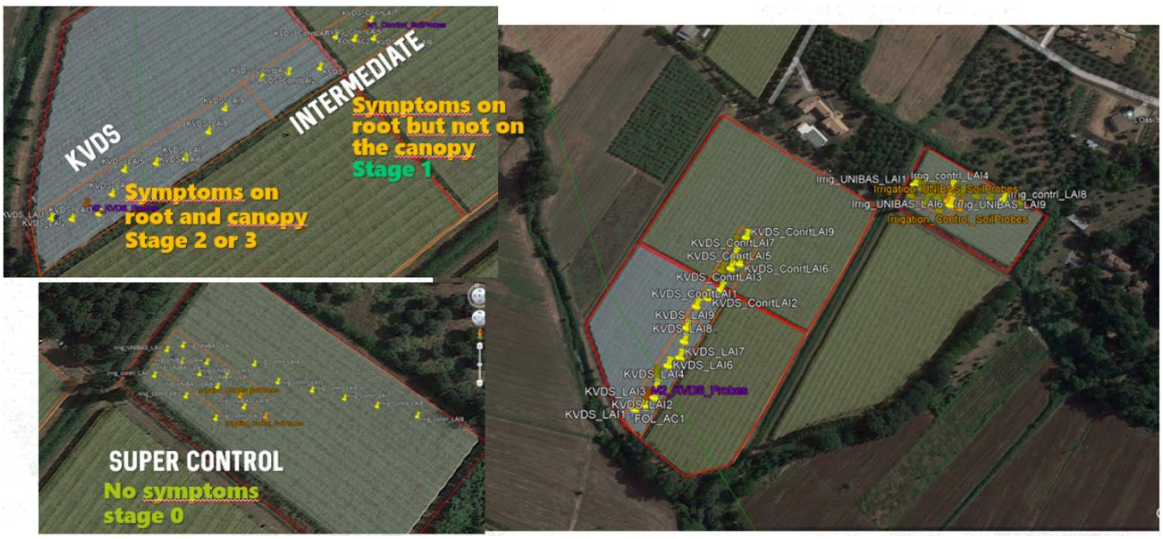

Figure 1. Trial orchard classification map in December 2020.

At the end of 2023, after three years of management, the portion of the orchard interested by the trial can be classified as following (Figures 2-5):

- Severe KVDS area has been divided into two subzones:
  - Zone with severe KVDS: plants recovered, root system regenerated, but the soil is still very compromised due to the initial situation (serious);
  - Zone with intermediate KVDS: plants have recovered and returned to productivity but not yet at 100%, they need another year to reach maximum efficiency;
- Intermediate KVDS area: fully recovered and productive;
- Irrigation trial (block 5):
  - Grower management: drastic and sudden decline, evidently due to an error in irrigation management;
  - Trial sector: no symptoms at all.

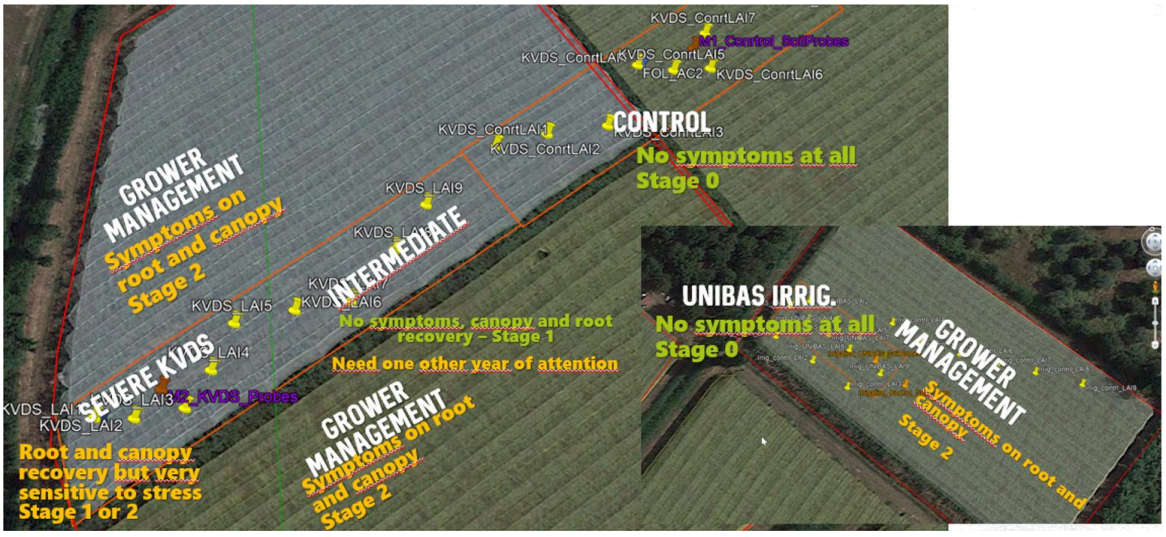

Figure 2. Trial orchard classification map in November 2023.

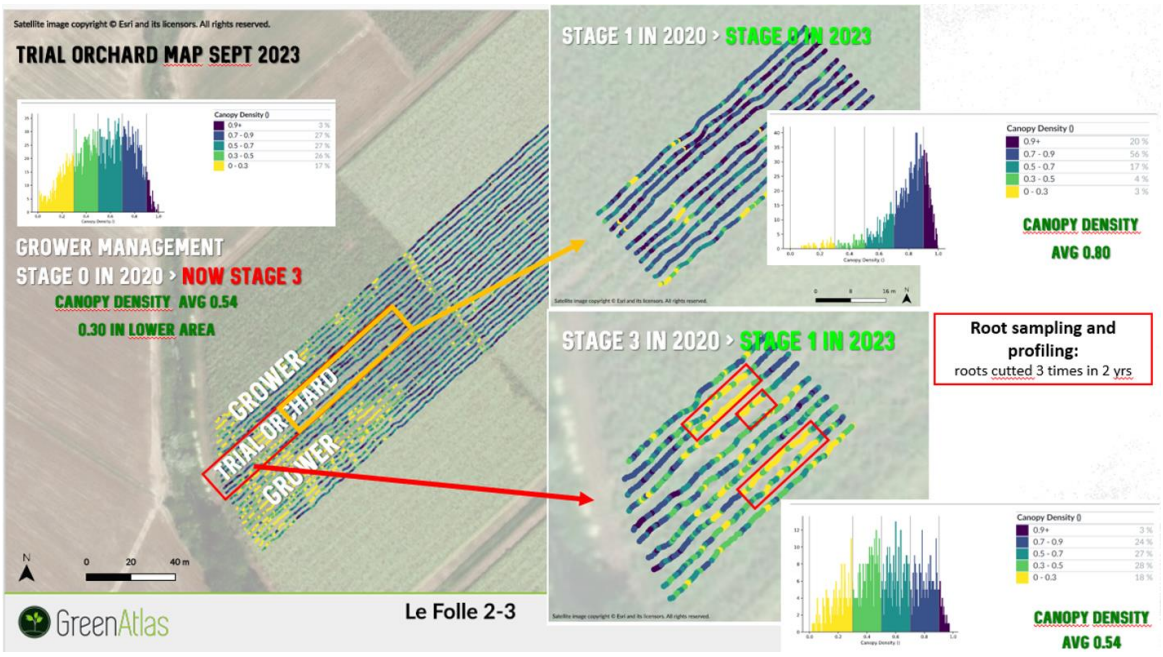

Figure 3. Trial orchard canopy density map, September 2023. Assessed by Gea Smart using Green Atlas technology. The canopy density map show that the low vigour plants (KVDS symptoms) are common and spread in the Grower management, while in the trial management the situation is much better. In the 2020 stage 3 area, plants that have been root pruned for sampling 3 times in 2 years show (obviously) a lower vigour not connected to the management.

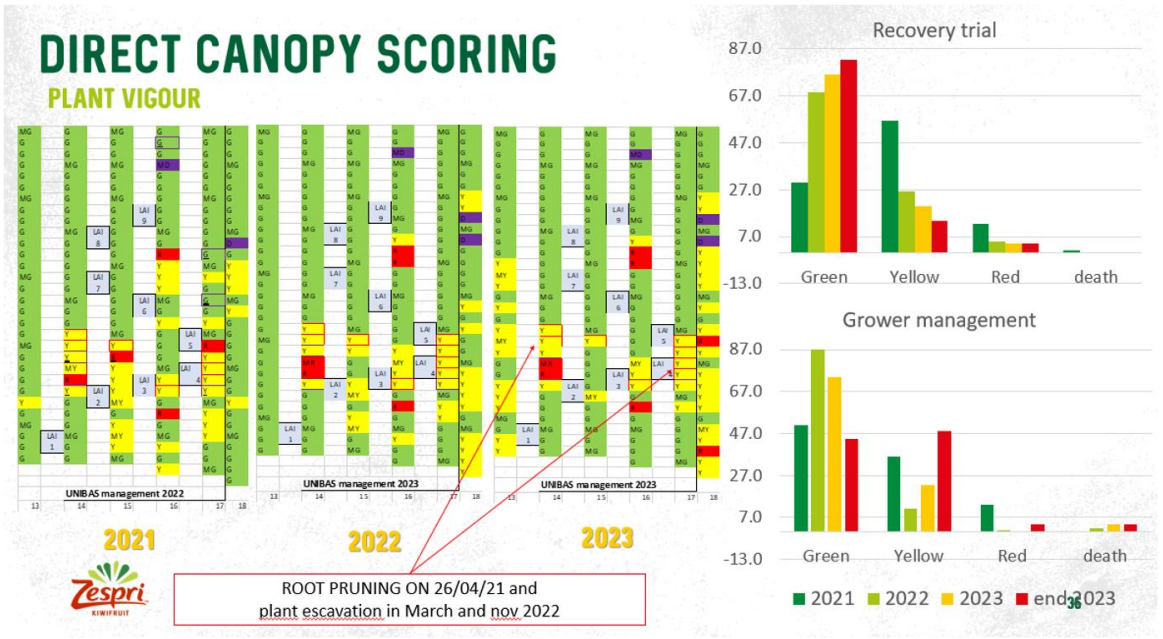

Figure 4. Direct canopy scoring with physical assessment. Red = sever KVDS, yellow = intermediate KVDS, green = no KVDS. The chart shows the difference between the trial management and the grower management: under grower management yellow and red category plants increased during the three years, while under the trial management it decreased.

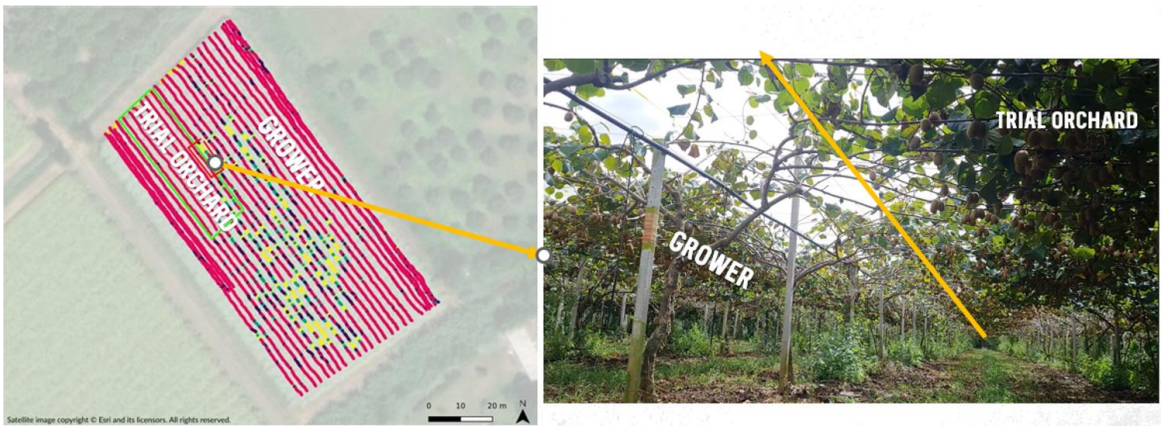

Figure 5. Block 5 in September 2023. It is evident that the portion of the orchard managed during the trial has a much better canopy than the rest of the orchard, managed by the grower. In this block, only irrigation has been managed differently. This demonstrates the relevance of the irrigation management in preventing KVDS.

Finally, the trial demonstrated that restoring optimal soil conditions through precision irrigation and regenerative agriculture allows physiological recovery of declining plants (regeneration of the root system and recovery of the above-ground part) and overcome dysbiosis. Also, in non-KVDS conditions, the correct irrigation and soil health management allows kiwifruit plants to perform well in non-optimal climatic conditions, giving the system more resilience to climate change.

- The fundamental role of water in triggering the KVDS is confirmed: improper water drainage and wrong irrigation management, in the long run, causes a decline in the root system and soil destructuring;
- Soil health plays a crucial role: destructured soil and water excess causes soil microbiota imbalances (dysbiosis) that need years to be recovered;
- Soil destructuring generates anaerobic and asphyxiating conditions, a microbiota dysbiosis, promoting the proliferation of pathogens and reducing levels of the normally present beneficial populations;
- The fungus isolated from the roots showing symptoms correlated to the syndrome. There is no pathogen causing KVDS but a pool of microorganisms activated in case of soil decline and destructuring;
- Precision irrigation management allows the recovery of intermediate KVDS situations and prevents KVDS in all the intermediate situations;
- All declining plants are recoverable, but in the case of severely compromised soil, replanting is advisable because recovery is very slow and not economically viable.

Soil map and Orchard Monitoring Network

The soil map study included a strong participation by all the Task Force members. After 16 months of orchard visits, pedological study, profile and panel discussions, it has been possible to define a management handbook containing plant, soil and irrigation management specific for each soil region identified with the pedological map.

Also, a geostatistical analysis has shown that most of the KVDS affected orchards in Italy are surprisingly based on volcanic soils. A study conducted with the support of a pedologist, explained that volcanic soils have a -distinctive behavior, due to their geological origin, and tend to lose structure very fast, under heavy rain events. Volcanic soil behavior is more similar to silty soil than to clay soil and their management need to be particularly accurate.

As a conclusion of the work, the handbook has been presented to the growers in a specific event. The proper communication as the participation is a fundamental part of this approach. Giving the concept that all the indication are preliminary and following the concept of the “learning by doing”, a new project has been set: the Orchard Monitoring Network. This

new project is still at the beginning, no data are available at the moment. But, as a preliminary result of this approach, it is evident that a new way of thinking the territory has been set. Every orchard choice, from the row orientation in pre-planting, to the selection of the proper irrigation system to install, pass through a serious analysis of the soil nature. Water retention curves, mineral and soil analysis and soil profile are becoming a strong part of the toolbox of all the technicians involved in the kiwifruit industry.

Metagenomic applied to KVDS

The preliminary data shows that roots and rhizosphere from symptomatic areas/plants exhibit a different microbial profile, direct isolation highlights a higher presence of Oomycetes and fungi. At the same time, in the KVDS sites, the microbial biodiversity is lower than in healthy sites and the development of symptoms on the canopy may remain latent, despite the root system is already compromised canopy.

An early prediction of the KVDS starting point could be determinant also to prevent the dysbiosis and the development of pathogens.

The scoring system for KVDS

As a consequence of the dynamic observed in the KVDS trial orchard, it was clear that all the actions to be undertaken in the orchard need to be based on the base of the roots and plant status. A vine scoring system has developed to allow a quick assessment vine health and indicate appropriate recovery strategies for vines (Tables 2 and 3). Vines are scored in two parts: leaf and canes, and the root system. Each part is scored then the management is determined by the poorest score.

Table 2. Canopy scoring system.

Score	Healthy	Mild	Severe	Extreme
	0	1	2	3
New shoot vigour/ replacement cane	Replacement canes, vigorous growth	Fewer replacement canes, some terminating	Terminated growth	None
Leaf size	Large	Smaller	Small	Dying
Leaf color	Green	Light green	Yellowing	Browning
Cane health	Normal	Some decay at the tips of shoots	Cane dieback or branch wilting	Plant death
Photos				

Table 3. Roots scoring system.

Score	Healthy	Mild	Severe	Extreme
	0	1	2	3
Presence and colour of capillary roots	Lots of white capillary roots	Capillary roots present some browning, no young white fine roots	None present	None present
Evidence of rot on secondary roots	No rot	Some rot marks	Rot present	No secondary roots
Root parenchyma detachment (rats tail)	None	Not significant	Occurring	Occurring on primary roots
Evidence of fungal disease	Not present	Not present	Not present	Primary roots damaged and infected
Photo				

1. Leaf/canes assessment.

Scoring focuses on the common indicators of vine health across the trials including emergence rates/strength of replacement canes, leaf colour and leaf size.

2. Root assessment.

Roots are categorised into 3 types: primary roots which are thick brown structural roots that start at the base of the trunk and tend to grow downwards; secondary roots which branch off the primary roots and are brown; and root hairs – fine white roots that absorb water and nutrients from the soil. Each of these is checked for number, condition, colour, and the presence of rots or fungal infections.

An appropriate scanning and scoring of the vines and roots system as well, is pivotal for a more proactive approach to KVDS management. The simple scoring system and using the management suggestions provide some simple pragmatic guidelines to start the vines' recovering.

Vine management for each of the scoring levels

The assessment of the roots is more critical to the long-term outcome of the plant than the vine leaf and cane assessment. So, if the leaves are a score = 1 and the roots score = 2, use the root score to guide your management plan.

Pruning helps to balance the above ground needs of the vine with the roots ability to provide the nutrients and water required. Winter canopy pruning is the most effective as it reduced the vines needs from the roots from the start of the season. Cutting a vine during the season will trigger the vines natural inclination to produce large amounts of vegetative growth. This vegetative growth doesn't help the plant roots recover and if it is tied down the following year, can result in the vine collapsing at this point.

- Level 0: healthy plant treated normally;
- Level 1: improve soil drainage for heavy soils. Reduce fruiting canopy by between 10

and 25% in winter prune to balance root capability with vine canopy requirements;
- Level 2: improve soil drainage and management (irrigation), root pruning when needed and prune back to 25-50% fruiting canopy in winter. It will take several years to improve this plant and it may be more economic to retain the vine for a year and get a partial crop while a new plant is established nearby;
- Level 3: These vines will die, replace plants but solve the irrigation/drainage issues first. Replant, but not in the same spot or leave at least 12 months before replanting in the same spot.

CONCLUSIONS

What is KVDS? A process more than a syndrome, that can be summarized as following:
- A water imbalance in the soil, due to excess or even localized stagnation causing physiological decline of plants (starting from the roots and reaching the canopy);
- Soil destructuring caused by poor water circulation, asphyxia and degradation of the organic fraction;
- As a consequence, a dysbiosis of the soil microbiome happens causing the loss of its biological and organic fertility with pathogenic microorganisms already present in the soil attacking the root tissues that are weakened due to physiological decline accelerating the process.

The recent years extreme climatic phenomena such as abundant and concentrated rainfall, summertime heat waves and the loss of what are considered good cultivation practices, have accelerated the decline already underway, often causing sudden collapses of plants not equipped with a good root system and healthy soil.

A global and holistic strategy to overcome or manage KVDS

After this first and explorative phase of the Task Force common work, it has been possible to define some key points of a holistic technical strategy to prevent and overcome the KVDS in Italy:
- Prevention plays a key role: monitor and score the orchard condition to define a strategy to adopt and to define if is better to try the recovery or replant;
- Improve precision irrigation to reduce the accumulation of excess water in the soil and to avoid stress from root asphyxiation in all the Italian orchard, regardless of the KVDS phase scored during the monitor phase:
  1. Use a water balance to define the daily quantity to apply, monitor and calibrate it using soil moisture probes;
  2. Define the irrigation volume and strategy also considering the root system status;
  3. Define the strategy considering the hydrological characteristics of the site;
  4. Monitor the irrigation system output installing flow meters on the line;
  5. Automate the systems for a remote control and programming.
- Improve the circulation of rainwater (drainage, slopes, etc.)
- Improve strategy to increase or maintain soil fertility with regenerative agriculture methods: organic matter and/or cover crops, etc.
- When planting or replanting: carefully plan the arrangement of the rows, the slopes and the irrigation system, taking into account the pedological nature of the soil and with the advice of experts. At the same time is important to evaluate practices targeted to improve the soil and plant health supporting the microbiological re-balancing.

ACKNOWLEDGEMENTS

The study was realized within the frame of the ZESPRI INNOVATION project programs GI21020 and GI23343. A special thanks go to all the technicians and the scientists involved in the project, that are still sharing their time and competence with all the group. We also thank the Italian growers for their availability and patience during the trials.