Report on MT scientific and technical documentation

Sub-action B1.2

31.03.2023

Contents

Abstract

This deliverable focuses on the scientific basis and the technical aspects of the monitoring tool (MT), developed within the LIFE DRIVE project to help farmers in the evaluation of the soil water storage in vineyards and in the prompt detection of water stress conditions.

The first part of the deliverable presents the overall MT structure, its key components and main functionalities, together with technical details about the weather and soil database and the modelling solutions for water balance estimates.

The second part of the deliverable is entirely devoted to the app PocketDRIVE, which plays a key role in the MT as the interface between the MT and the user. A step-by-step explanation of how to use the app is provided, together with the explanation of the principles at the basis of the app functions. The scientific approaches used to diagnose water stress and to measure key biophysical variables like the leaf are index (LAI) by using a common smartphone are described in detail, providing references to related scientific publications for further information and insights.

The monitoring tool

The MT structure

The monitoring tool is based on three main components (Fig. 1):

- a geo-referenced database with weather and soil data;
- modelling solutions for estimating vineyard water balance;
- the smartphone app PocketDRIVE, specifically developed to allow the user interacting with the MT.

The soil and weather database, as well as the models used for water balance estimates have been fully described in the deliverable of the Action A1, so only a synthetic description is reported here. Please see deliverable A1 for further details.

The weather database is based on the historical European dataset of daily meteorological data of the University of Milan Cassandra Lab, which includes historical and near real time data, the latter constantly updated with a 2-day delay. This database covers the whole European area with an average spatial resolution of about 2 km × 2 km (0.016° × 0.016°), gathering data from the international networks of NOAA-GSOD, METAR and SYNOP and from several Regional Extension and Environmental Services. The near real time data are integrated with a forecasting system with the aim of projecting agroenvironmental simulations for the two weeks ahead.

Concerning the soil database, data from the WISE (World Inventory of Soil Emission potentials; version WISE30sec 1.0 – 30 by 30 arc-seconds) soil database (Batjes, 2016) was used, because (i) it was explicitly developed to provide inputs to run agro-environmental simulation models, and (ii) it allows to achieve the highest consistency between the sources of information for soil physical properties at European level, a key point considering the planned extension of the MT to new contexts during the last year of the project. Data on soil texture percentage sand, silt, clay, organic carbon, skeleton and bulk density data were derived from the WISE database and pedotransfer functions (van Genuchten, 1980) were used to derive, for each soil typological unit, soil water contents at permanent wilting point and field capacity.

The modelling solution for water balance simulation includes approaches for estimating crop evapotranspiration, soil water redistribution, and root uptake. The grapevine maximum evapotranspiration is obtained by applying a dynamic multiplicative factor Kc to the reference crop evapotranspiration (ET0), which is estimated according to the Penman-Monteith model (Allen et al., 1998). To overcome the limits of the simplistic approach proposed in the FAO Paper 56 (Allen et al., 1998), the modelling solution implements a more physiologically-sound approach that dynamically derives Kc values form the phenological development stage of the grape, the latter derived according to a simplified version of the Iphen phenological model for grapevine (Mariani et al., 2013, Cola et al., 2014, Cola et al., 2017). In this way, Kc values are derived as function of the grape phenological stage and related canopy development (Cola et al. 2014), determining the fraction of intercepted incoming global solar radiation (Riou et al.,1989). Moreover, inter-row cover is also considered in order to define the inter-row evapotraspiration. Also, leaf area index (LAI) measurements *in situ* obtained with the app PocketDRIVE (as described in the last chapter of this document) can be used to correct the simulated value of the fraction of intercepted incoming solar radiation and correct the phenological stage of grapevine.

Soil water redistribution is simulated using the cascading approach (also known as tipping bucket model), which is the most widespread method to simulate vertical water movements in agricultural soils. Despite being a relatively simple approach, many authors (e.g., Stöckle et al., 1997; Confalonieri et al., 2010) have demonstrated its reliability when compared to more sophisticated models like those based, e.g., on numerical solutions (e.g., van Dam and Feddes, 2000) of the Richards equation (Richards, 1931), especially when there is a limited availability (or total unavailability) of spatially distributed information of physical soil properties like, e.g., saturated hydraulic conductivity. In such contexts, indeed, the estimate of missing inputs – like, e.g., saturated hydraulic conductivity – using pedotrasfer functions (e.g., van Genuchten, 1980) could lead to uncertainty that propagates in an unpredictable way along the modelling chain. Root water uptake is simulated using a two-step approach derived from the CERES model (Ritchie and Otter, 1985). Potential root water uptake is estimated as a function of maximum evapotranspiration, and then reduced according to the water availability in the different soil layers, the latter derived based on root length density derived according to the van den Berg-Driessen model (van den Berg and Driessen, 2002). In case of availability of specific calibration data, a simplified version of the model STARWARS will be used (Van Beek, 2002) to improve the simulation of the hydrological dynamics as described in detail in the deliverable B2.1.

The app PocketDRIVE, is a key component of the MT, given its role as interface between the MT and the user. By using PocketDRIVE it is possible to easily:

- create a registry of the farm's vineyards, by providing their GPS position as well as information on the cultivar, training system, etc.;
- provide key data for refining the calculation of the daily water balance (i.e., leaf area index of the vineyard and of the inter-row grasses, as well as management events affecting the amount of vegetation like, e.g., green pruning);
- diagnose early water stress by analysing canopy architecture.

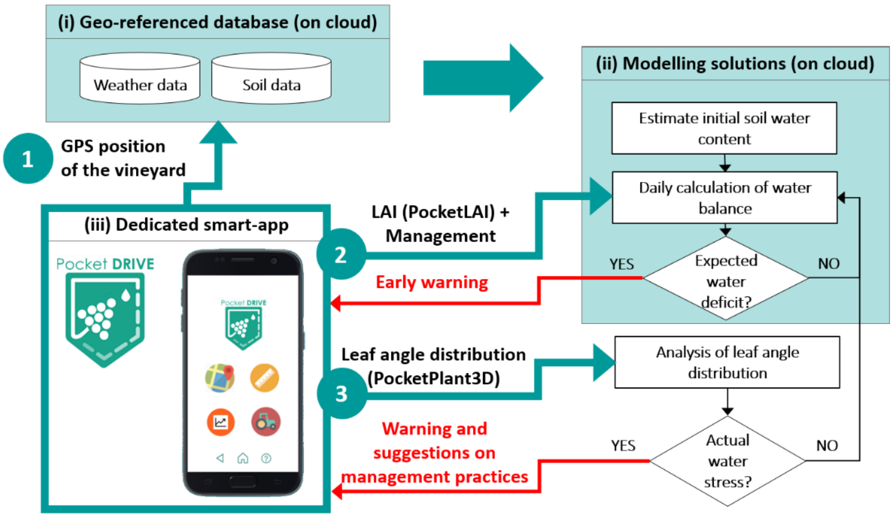

Figure 1. General structure of the monitoring Tool (MT) highlighting the connections between its three key components (georeferenced database, modelling solutions, and the app PocketDRIVE). Numbers in circles represents the three main functionalities provided by the app PocketDRIVE, which allow the user to interact with the MT by both providing (light blue arrows) and receiveing (red arrows) information.

The app PocketDRIVE

The scientific and technical documentation of the app PocketDRIVE is reported here below, together with screen-shot figures to explain how to use the app step-by-step. The chapter is organized in five sections, one for each of the PocketDRIVE main functions.

1. Create the vineyard register

By clincking on the top-left icon of the main screen of PocketDRIVE (Fig. 2a), it is possible to access the screen (Fig. 2b) where the user can enter the following information for each of the vinyards to be registered:

- the name to be used within the MT to identify the vineyard (please avoid blanck spaces in the name),
- the cultivar,
- the training system,
- the inter-row space (units: meter; please use the dot as decimal separator)
- how the inter-row is managed (e.g., bare soil, cover crops, etc)

- the vineyard's GPS coordinates. This information can be provided by clicking on the blue icon at the bottom of the screen. A map tool will open (Fig. 2c). From there, it is possible to center the map on the current device position by clicking on the red gunsight icon on the bottom right. Then use the pencil icon to start highlighting the vineyard area by touching the screen clockwise on the vineyard perimeter; Fig. 2c). If you make mistakes, use the rubber icon (on the bottom left) to delete the points by simply clicking on them.

Such information needs to be entered just once during the app configuration. Nevertheless, it is always possible to delete a vineyard from the registry or modify the information associated to it (e.g., change the inter-row management system) by using the dedicated icons on the bottom of the registration screen (Fig. 2b).
Once the vineyard is registered, a text file (.csv) with all the information is automatically created and sent to the MT. All these data are indeed needed to retrieve geo-referenced soil and weather data for estimating the vineyard's water balance.

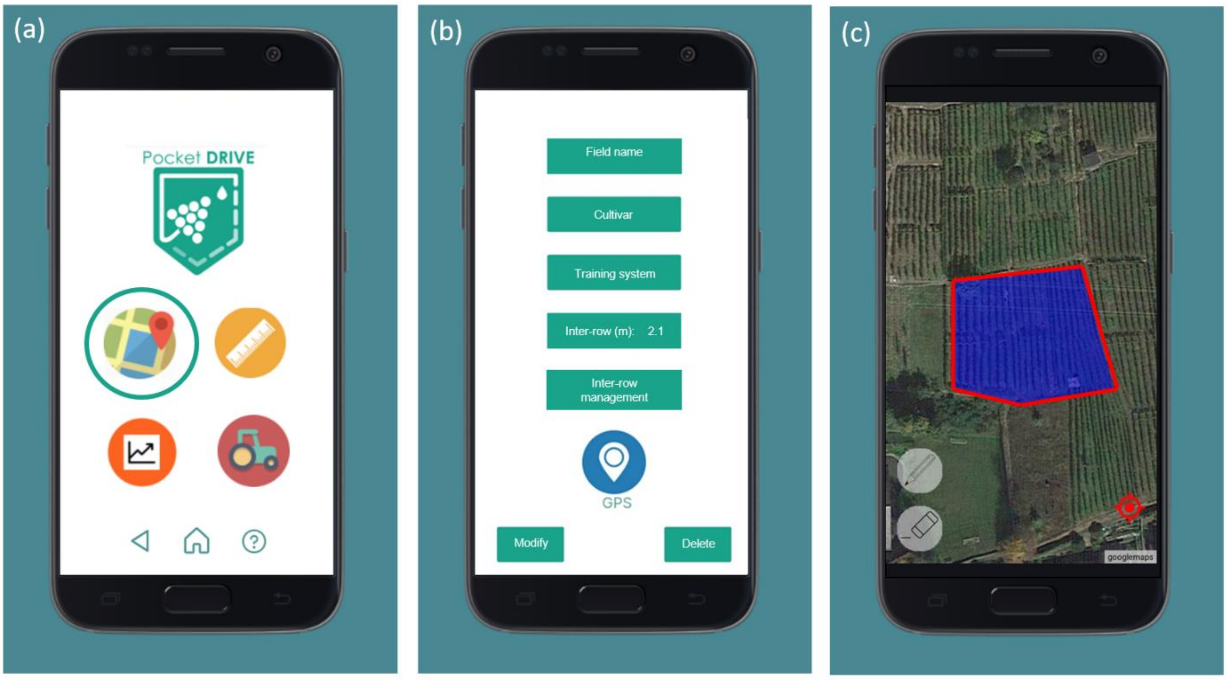

Figure 2. Screenshots showing how to create a vineyard in the app. Icon to access this functionality (a); information that needs to be specified (b); definition of the vineyard GPS position by simply drawing its borders on the map (c).

2. Estimate leaf area index

Concerning the second functionality (providing data for refining the calculation of the daily water balance, Fig. 1), by using the top-right icon (Fig. 3a) the user can access the function to provide the MT with estimates of the leaf area index (LAI) of both the vineyard and the inter-row grasses (Fig 3b). PocketDRIVE implements the approach developed by Confalonieri et al. (2013) to estimate leaf area index by using the camera and accelerometer of common smartphones. This approach has been widely tested on different crops (Campos-Taberner et al., 2016, Francone et al., 2014) including adaptation to vineyards (Orlando et al., 2016).
As described in detail in Confalonieri et al. (2013) and Orlando et al. (2016) the acquisition of the LAI measurements is quick and suitable for operational contexts. Basically, the user has to click at the center of the screen to activate the measuring mode (Fig.3c). PocketLAI automatically takes images of the canopy at a view angle of 57.5° while the user is rotating the device along its main axis. The gap fraction is derived using a fully automatic segmentation algorithm specifically developed to detect the sky pixels according to their chromatic values in a Hue- Saturation-Brightness (HSB) color space. The 57.5° angle – detected by using the device accelerometer – is used because it has been proved that gap fraction estimates at this angle are basically not affected by the leaf inclination angles (Baret et al. 2010).
The LAI value is then retrieved according to the light transmittance model described by Baret et al. (2010) and, in case of vertical canopies, by using also the inter-row distance (Orlando et al., 2016) that is provided by the user when registering the vineyard (Fig 2).

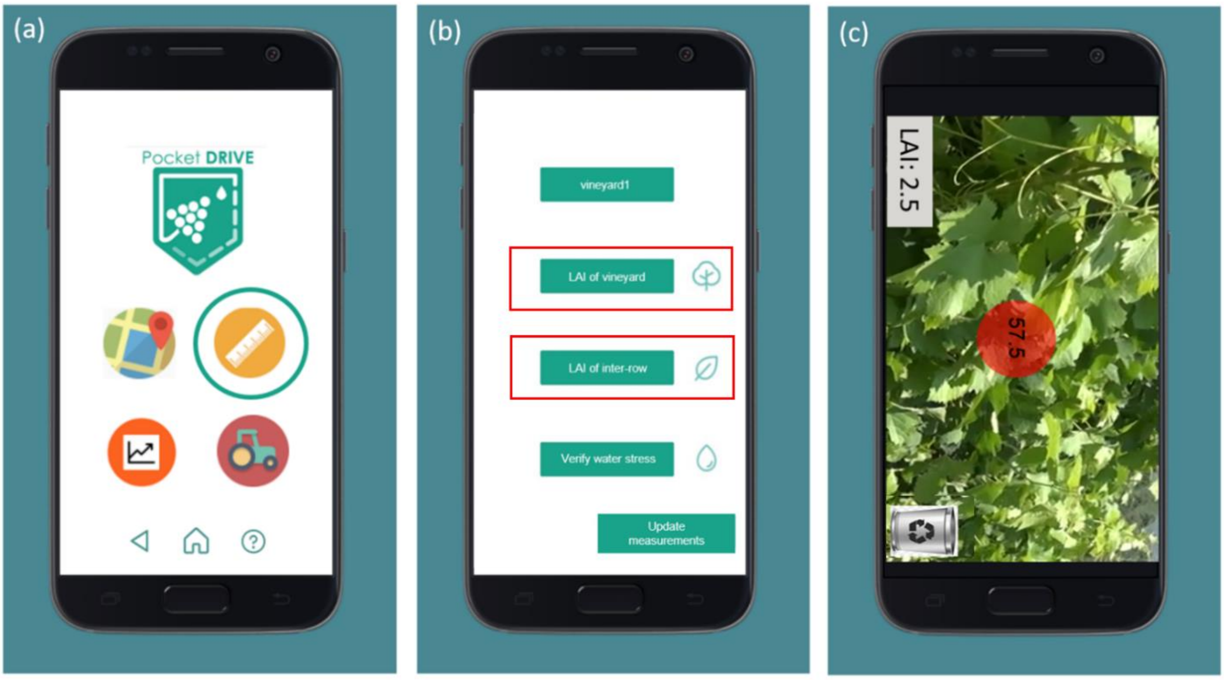

Figure 3. Screenshots of PocketDRIVE showing how to collect estimates of leaf area index (LAI) of the vineyard. Icon to access this function (a); screen where it is possible to specify the vineyard in which the measurement are being collected and the kind of measurement (i.e., LAI of the vineyard and/or LAI of the inter-row grasses) (b); measuring mode for LAI estimates (c). The inclination of the device is shown in the red circle in the middle, with the app automatically acquiring images at 57.5° while the device is rotated along its main axis.

Here below a step-by step explanation of how to conduct LAI measurements:

- By clicking on the ruler icon (Figura 3.a) it is possible to access the screen for LAI measurements. From here, select the vineyard where the measurements are being conducted.
- To conduct LAI estimates, click on the “LAI of the vineyard” button. This will automatically activate the camera (Fig. 3.c).
- Hold the device at about about 40 cm from the row and about 20 cm below the lowest bound of the canopy (fig. 4.e), in order to capture images correctly centered on the grape canopies (Fig. 4a). The phone camera should point towards the canopy (please check that the device is not in selfie mode!). Please avoid to have the sun beams directed towards the camera (better to have the sun behind the user) and any obstacle that can bias the LAI estimates (e.g. people or tractors moving in the neighboring row in front of the camera).
- Click on the green circle at the center of the screen to activate the measuring mode (the circle turns red). Start rotating the device upwards along its main axis (Fig. 4.e) until it vibrates to inform the user that it has acquired the measure at the 57.5° inclination angle.
- The LAI value is shown in the bottom left corner of the screen. In case of errors, use the bin icon (on the bottom-right corner of the screen, Fig.3.c) to delete the last LAI measure.
- Move about one step along the row and repeat the procedure to acquire another measure. To achieve robust LAI estimates, five readings for each measuring point within the vineyard are suggested.
- Once the five readings have been completed, go back to the main screen and click on “Update measurements” to save the data on the device (the app saves the mean and the stardard deviation of the five readings) and send them to the MT on cloud. From this point it is possible to make other LAI measurements within the same vineyard (e.g., in case of marked variability in leaf development in different areas of the same field) or close the session. A dedicated message will appear to choose between these two options.

To derive LAI estimates of the inter-row grass, once on the mainscreen (Fig. 3.b) click on “LAI of inter-row” button to access the screen for activating the measuring mode (Fig. 3.c). The measurement protocol is the same described above with the only difference that the device should be placed as closest as possible to the ground and ortogonal to the row direction.

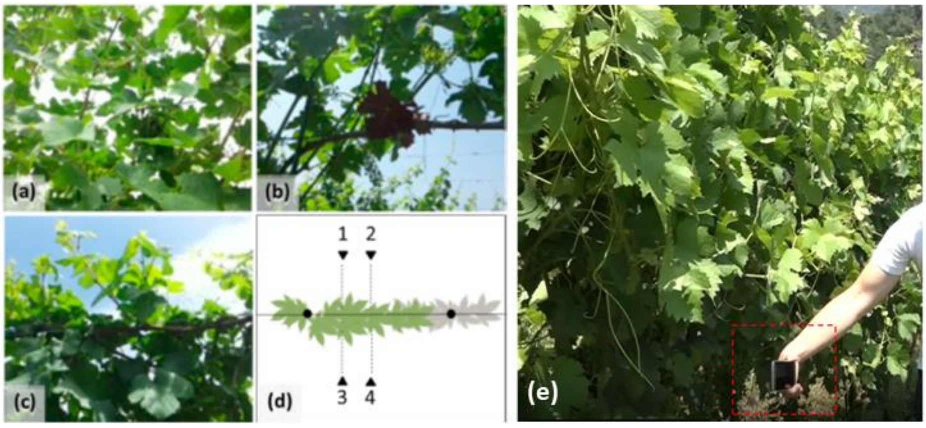

Figure 4. Example of a correct image captured with PocketLAI following the protocol (a); and wrong images that include the space below (b) or above (c) the grape canopy. The protocol for PocketLAI data acquisition in vineyard is described in (d): dark triangles and dotted lines = device orientation; black points vineyard poles; continuous line = vineyard row; green leaves = measured vine; grey leaves = adjacent vine. The correct device position is shown in (e); from that position, the device should be rotated upward until it vibrates to inform the user that it has acquired the measure at the 57.5° inclination angle. Image partly retrieved from Orlando et al. (2016).

3. Record management events

The estimation of the daily water balance can be refined also by considering management events that affect the amount of vegetation in the vineyard. This includes green pruning of the grapevines, as well as management of the inter-row such as soil tillage, grass cutting, grass smashing, etc. Information about these management events ca be provided to the MT through the PocketDRIVE bottom-right icon (Fig. 5a) that opens a dedicated screen where the type of intervention and the date can be entered (Fig. 5b). The management information is automatically saved and sent to the MT.

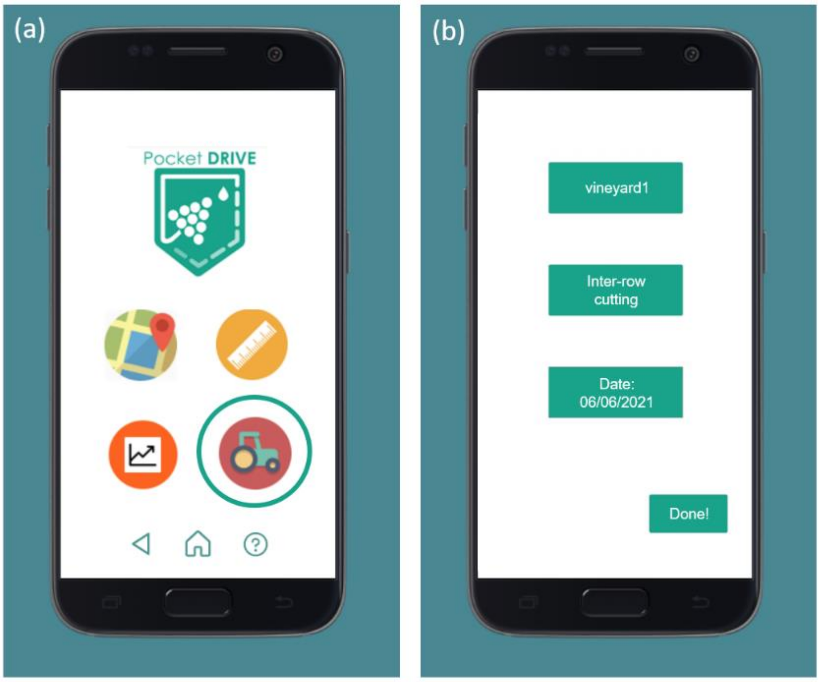

Figure 5. Incon (a) and main screen (b) to register management events.

4. Diagnose water stress

The occurrence of water stress conditions can be verified with the app by measuring variations of canopy architecture that, in turn, are related with drought occurrence. PocketDRIVE implements the app PocketPlant3D (Confalonieri et al., 2017), which uses the magnetometer and accelerometer of the device to derive the leaf orientation towards the north and the inclination of the leaf surfaces with respect to the zenith while the device is moved along the leaf lamina (Fig. 6a, 7a), thus providing the angles of leaf surfaces in a 3D Cartesian space. One measure every 200 ms is automatically acquired.

Leaf angles (θL) are then used by the app to automatically estimate two synthetic indices of canopy architecture: the parameter χ (unitless) of the Campbell's ellipsoidal leaf angle distribution (Campbell, 1990; Eq. 1) and the light extinction coefficient of solar radiation (k; Eq. 2) (Campbell, 1986).

The parameter χ represents the ratio between the horizontal and the vertical semi-axis of an ellipsoid, thus providing a synthetic representation of the degree of erectness of the photosynthetic tissues (Campbell, 1986, 1990). The lower the value of χ, the higher the tendency of the distribution to approximate a prolate spheroid (erectophile canopy).

The parameter χ is estimated as follows:

$$\chi = -3 + \left(\frac{MTA}{9.65}\right)^{-0.6061} \qquad (1)$$

Where MTA is the mean tilt angle (rad), estimated as the complementary of θL because it represents the angle between the normal to the screen and the zenith (Campbell, 1990).

The extinction coefficient for solar radiation (k, unitless) was then estimated by using the parameter χ according to Eq. 2 (Campbell, 1986):

$$k = \frac{\sqrt{\chi^2 + tan^2\theta_L}}{A} \qquad (2)$$

Where A was calculated as proposed by (Campbell, 1990):

$$A \approx \chi + 1.774\,(\chi + 1.182)^{-0.733} \qquad (3)$$

In order to use canopy architecture estimates as a proxy of plant water status, relationships between the values of χ and k and physiological variables describing crop water status (stomatal conductance and leaf water potential) were derived during dedicated project's field activities fully described in the deliverable B1.1. An example of such relationship is reported in Fig.6b. Relationships between canopy architecture and stomatal conductance were then used to derive the threshold values of χ and k corresponding to a stomatal conductance of 0.2 mol m^{-2} s^{-1} (threshold for moderate stress) and 0.1 mol m^{-2} s^{-1} (threshold for severe stress). There is indeed a general consensus in the literature that well-watered vines have midday ΨL values of about -7 bar and gs values higher than 0.3 mol·m^{-2} ·s^{-1}, moderately stressed vines have midday ΨL values of about −10 bar and gs values close to 0.2 mol·m^{-2} ·s^{-1}, and severely-stressed vines have ΨL lower than −12 bar and gs lower than 0.1 mol·m^{-2} ·s^{-1} (e.g., Williams and Araujo 2002; Bellvert et al., 2014).

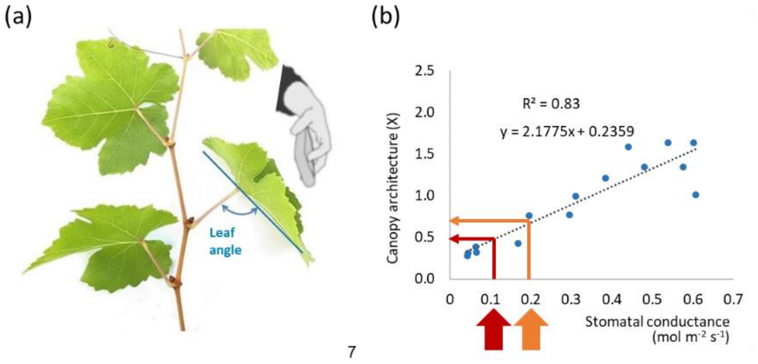

Figure 6. (a) Example of leaf angle acquisition with the app PocketPlant3D in the case of *Vitis vinifera; (b) example of the relationships obtained between canopy architecture (χ parameter of the Campbell's ellipsoidal distribution) and stomatal conductance. Threshold values of stomatal conductance and χ corresponding to moderate and severe water stress are highlighted with orange and red arrows, respectively.*

Results of field trials showed a good agreement between plant water status (stomatal conductance) and canopy architecture, for all the grape varieties considered (Chardonnay, Malvasia, Pinot Blanc, Pinot Noir, Sangiovese, Montepulciano, and Croatina), and without clear differences due to the index of canopy architecture used (parameter χ or light extinction coefficient). All relationships were statistically significant (*p*-value <0.001), with R^2 values that ranged between 0.71 and 0.97 (0.85 on average), thus supporting the use of the app PocketDRIVE as an effective tool to diagnose early water stress under operational contexts.

A step-by-step description of how to verify water stress occurrence with PocketDRIVE follows:

- By clicking on the icon for collecting measurements (Fig 3a) and on that for verifying water stress (Fig. 3b), the user can easily start collecting leaf angles while keeping the device parallel to the leaf main axis (Fig. 6a). To ensure high usability during leaf angles collection, the user can start and stop the recording by simply clicking at the center of the device' screen (Fig 7c). It is also possible to remove measurements in case of error.
- The app automatically counts the number of leaves measured (Fig 7d). Results of field tests conducted during 2021 and 2022 suggested indeed that around ten leaves randomly selected in the middle part of the canopy (Fig. 7b) are enough to provide an accurate evaluation of canopy architecture. Therefore, if less than 10 leaves have been measured the app does not allow to verify water stress and shows instead a message suggesting to collect more data.
- Once the angle collection on at least ten leaves is completed, the user can verify the occurrence of water stress by clicking on the dedicated button ("Verify water stress", Fig. 7c). The app automatically estimates the values of X, makes the comparison with the cultivar-specific threshold values indicating the onsent of water stress (details about calibrated thresholds are provided in the dedicated deliverable B1.1), and returns a quick response in terms of stress level (no/moderate/severe stress).
- After the diagnosis of water stress is completed, go back to the main screen (Fig. 3.b) and click on "Update measurements" to save the data on the device and send it to the MT on cloud.

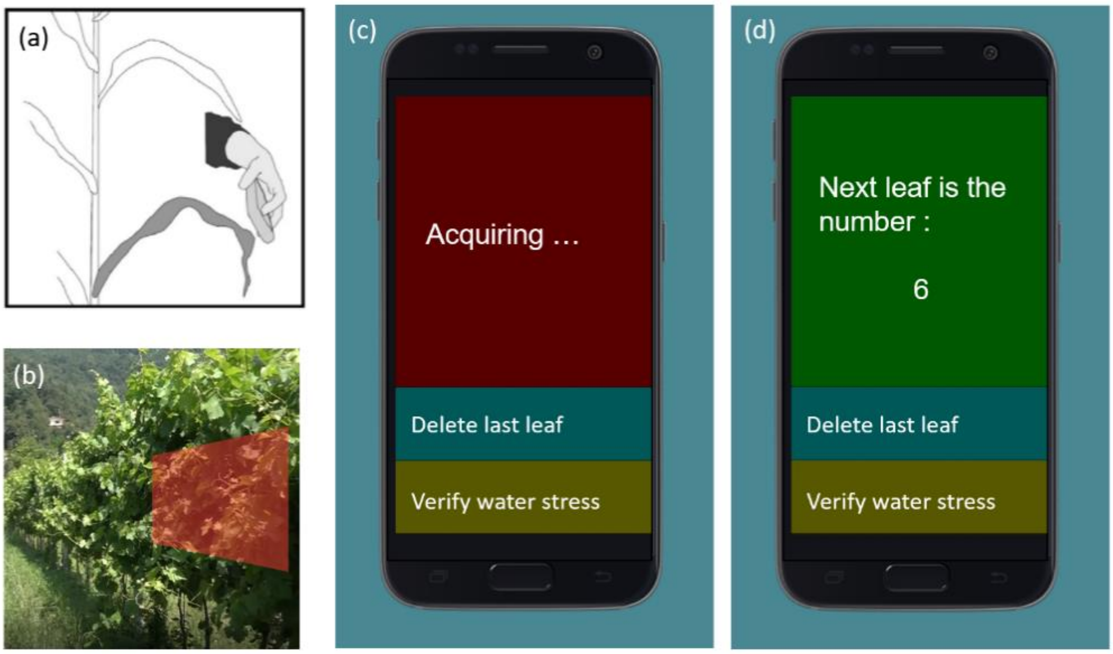

Figure 7. Collection of leaf angles to evaluate canopy architecture and verify water stress occurrence. The device should be kept parallel to the leaf main axis (a). The angle collection should involve leaves in the middle part of the canopy (b) and can be started by clicking on the red button (c). It is possible to delete measurements in case of errors. The app keeps count of the leaves measured (d) because at least 10 leaves are needed to derive reliable estimates of canopy architecture.

5. Look at the data

All the information collected with the app (LAI and canopy architecture measurements, management events) can be accessed and verified by the user through the orange bottom-left icon of the PocketDRIVEmain screen (Fig. 8) along with

- date
- hour of the day
- vineyard ID
- GPS position within the vineyard

For LAI measurement, mean and standard deviation of the readings acquired in the same position are reported as described on the sub-chapter 3.

Figure 8. Icon to access all the data collected with the app PocketDRIVE.

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