EIP-AGRI Focus Group Protecting fruit production from frost damage

MINIPAPER 03: Affordable real-time online frost detection data

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1 Intro

All around the world fruit farmers have been encountering below zero temperatures at the end of winter and early spring, when plants are less hardy. Despite the temperature increase associated with global warming, this phenomenon has occurred more frequently over the past ten years, and it is now becoming a serious issue for the global fruit production industry. This is due to changes of the time of phenological events conjugated with increasing climate variability.

Several methods have been identified to protect against frost and protect plants. However, for the success of any endeavour, the availability of accurate information is crucial. So, farmers urgently need the following information before activating a frost prevention system:

- Forecast weather situation
- Accurate real-time information about temperature and other parameters in their fruit orchards

A general forecast is needed to prepare for prevention methods that could be used, depending on the type and the severity of frost. In addition, accurate information during a frost night is needed for the correct timing and controlling of these methods.

This mini-paper is about the possibilities of and the requirements for a reliable and affordable frost detection system.

2 Current situation

Current problems that have so far been identified on general forecast include the fact that measurements are sparse and not site specific, mainly because the current networks of weather stations are too widespread.

Some of the problems that have so far been identified on site specific measurements are the lack of real-time data (every 1 minute) as well as the limited places and heights of the measurements that are not adequate for all crops.

Because of the price issue, a lot of farmers depend on general weather forecasts. In order to obtain local measurements, farmers might personally go outside to check temperatures using classic thermometers on different locations around their orchards. This can be inaccurate and very time consuming.

The overall investment of purchasing and installing a reliable weather station varies around € 3.500 to € 4.000 per station. For one station, this price is acceptable, given the long-life expectancy of the hardware when properly maintained (note however that maintenance in rural areas can be very time-consuming and thus expensive), and the immense value the station can bring to the owner. It helps detecting favourable conditions for pest and diseases occurrence, weather forecast along the entire year, and it helps to better understand the influence of climate change. Moreover, the station can justify weather events for insurance issues, alerts for conditions of heat damage (leaf scalding, sunburn of fruits) and in case of irrigated farms, it helps calculate evapotranspiration rate, which in turn will help to irrigate more efficiently saving water, which is more and more becoming a precious and scarce resource.

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Figure 1 – iMetos weather Station (Pessl Instruments)

However, in general, farmers have only one station on one location, with temperature measurement at standard height (1,25m to 2m), which is clearly not enough for an accurate frost forecast. Adding more sensors at different heights to one station and/or adding more stations increases the representation of the measurements over an entire orchard. Adding more of these expensive fully equipped weather stations solely for monitoring frost is an expensive investment. One solution is not to buy more of these expensive weather stations, but instead to have more individual (smaller) measuring devices that only register temperature and relative humidity.

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3 Proposed solution

The ideal frost detection system offers a number of crucial functionalities, each of which are described in this chapter. The total solution should come at a reasonable price for the average fruit farmer. The ideal solution is simple, affordable, reliable, accurate, real-time and online.

3.1 Possible measurements

3.1.1 Weather situation

In order to choose a suitable frost protection method and correctly operate it, farmers are depending on a reliable forecast of the general weather situation. Regarding frost, two main kinds of frost can be differentiated: Radiation frost or wind frost. Mixed events can also occur. Chapter 3.2.5 on inversion provides more information about these types of frost.

It should be possible to obtain the information about the expected kind of frost from the weather services, though the forecast can be tricky, depending on the circumstances. In any case, this forecast cannot be done on a farm scale but can be improved by an increased number of weather stations. It should be considered, that the position of the weather station in the topography plays a major role for the quality of the forecast.

3.1.2 Temperature and relative humidity

Usually, dry-bulb temperature is measured. In fact, for the implementation of some frost protection methods and for assessment of the severity of frost damage, the wet-bulb temperature is also required. The difference between dry- and wet-bulb temperature depends upon air relative humidity (RH). At 100% RH dry-bulb and wet-bulb temperature are equal. Under drier conditions, the wet-bulb temperature is below the dry-bulb temperature. Therefore, the measurement of dry-bulb temperature is insufficient regarding frost protection and frost risk estimation.

Over the past few decades classic analogue temperature sensors like the PT100, PT1000 and thermocouple have been the popular and accurate ways to automatically measure temperature. However, more recently, digital sensors have been gaining market share mainly because of their low price and relatively easy technical integration, as opposed to analogue sensors which require an analogue-digital conversion before integration with digital modules. Some of the best-known examples of digital sensors are the **DS18B20** by Maxim Integrated (temperature) and the **HIH-series** by Honeywell (temperature and RH).

3.1.3 Dew point and wet-bulb temperature

Dew point and wet-bulb temperatures can be calculated based on direct measurements of temperature and RH.

Dew point corresponds to the temperature at which the condensation of water vapor, occurs, which could be in the form of dew, fog or ice. It can be measured directly using a dew point hygrometer, but due to its complexity this measure is frequently obtained indirectly, by correlating the air's RH and temperature.

Relatively affordable sensors can easily be applied to measure and forecast dew point, however to have those values calculated in real time and online there is the need to have a data logger to compute and send it to the end user.

Regarding wet-bulb temperature, it can also be indirectly calculated as a function of air temperature, RH and air pressure (taken as a constant for a given altitude). It is also relatively easy to measure directly with a proper device.

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3.1.4 Wind and other parameters

The above-mentioned parameters are minimum information needed for accurate frost detection. However, one can add other sensors in order to increase accuracy such as the speed and direction of wind. The image below shows how wind affects the other variables.

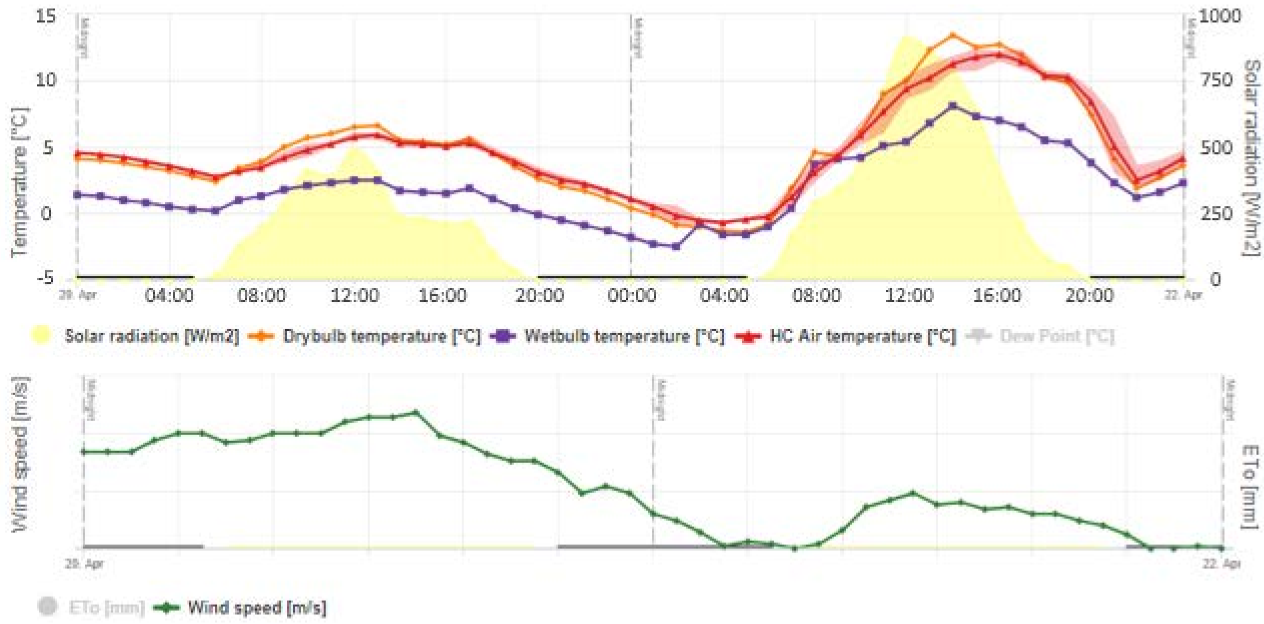

Figure 2 – Information retrieved from weather station sensors (FieldClimate).

Wind is more important with regards to frost protection than it is for frost detection. The actual wind speed as well as the forecast for wind speed is relevant because it influences the efficiency or the method of choice. For example, frost irrigation is only effective until wind speeds of 3 m/s, higher wind speed increases cooling by evaporation and affects the uniformity of the pluviometry provided by the sprinklers. Heating solutions, like frost candles, do work in case of wind, but there are more candles needed under windy conditions. So, this information is important for the farmer to be able to react: more candles can be placed or frost irrigation will not be started when increasing wind speeds are expected.

However, not for every grower and protection method detailed wind speed information is essential. In general, one measurement point per site or farm (depending on the situation), of wind speed is adequate.

As with any other additional weather sensor, the question needs to be raised whether the added cost can be justified to the customer. A possible solution could be to allow customers to purchase the system with only the sensors of their choice.

3.2 Required features and characteristics

3.2.1 Affordability

One of the main requirements for the ideal frost detection module is affordability. One measurement per orchard is not enough, so farmers will need to purchase several devices for measurements on different heights and locations. Therefore, the cost of a device needs to be low enough to justify the investment. Moreover, most of these internet-connected systems usually charge a service cost per year or per month, so this has to be kept in mind.

Some temperature sensors on the market are very cheap (cents of euro), but for these sensors it is important to investigate the accuracy and calibration. The **DS18B20** by Maxim Integrated and the **HIH-series** by Honeywell, mentioned above, are known to be highly accurate and reasonably priced. The chips inside these

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sensors cost only a few euros, and fully assembled waterproof units cost less than €50. They feature an accuracy of 0.5°C and a resolution of less than 0.1°C.

Digital monitoring devices such as the **Crodeon Reporter** (Belgium) cost less than € 1.100 and can connect up to 6 different sensors. This kind of next-generation products offer more flexibility than the classic and more expensive fully equipped weather stations usually do.

3.2.2 Real-time measurements

When temperatures are about to go below zero, it is crucial for farmers to have access to continuously updated information. This means that measurements should be transmitted to the internet in real-time, giving the user information about the past few minutes, not hours. The measurement interval can be 5 minutes at maximum, but preferably less.

Monitoring devices will often be installed in fruit orchards in remote locations. In this case, it makes sense to transmit the measured values wirelessly to the internet. It is important to choose the right kind of wireless technology, to maintain a continuous and real-time data stream.

- **High bandwidth - short range**: On of the most used wireless standards is Wi-Fi, which features a high bandwidth. However, Wi-Fi has a very limited range (e.g. 30-40m) and is therefore *not* suited for remote applications.
- **Low bandwidth - long range:** Some of the upcoming wireless technologies include **LoRa**, **Sigfox**, **NB-IoT** and **Cat-M**. These standards are very popular in Internet of Things applications, because of their low power consumption and long range. However, these technologies offer a very limited bandwidth of just a few kB per day, and are therefore *not* suited for real-time communication.
- **High bandwidth - long range**: A third option are the well-known GSM-based wireless standards, such as GPRS, 3G and 4G. These offer a high enough bandwidth to allow real-time communication and have good coverage in rural and remote areas.

When the bandwidth of the network is limited, one possible solution is to only send the data when a certain threshold is crossed. This allows for real-time information, but offers no deeper insight in the evolution of measurements over the past minutes or hours.

3.2.3 Notifications

As an autonomously operating system, a frost detection device should be able to send out warnings to farmers to inform them of the situation. Two different kinds of warnings can be identified in this context.

The first kind of warning should be sent out when the measured values drop below a certain minimum threshold. This informs the user that temperatures are low and that risk of frost is real. Ideally, the user has the ability to modify the threshold remotely, as he/she might want to be warned sooner or later depending on the location of the device and the risk of frost as announced in weather forecasts.

A second, more complex kind of warning could be sent out in advance, when measured values are *expected* to soon drop below the threshold. This requires an algorithm that compares measurements with historic data in order to determine the risk of frost for the upcoming hours. Weather forecasts from in-farm weather stations could be a reliable source of "expected" information. There are services that correlate the forecast from common providers (e.g. **Meteoblue**) with the real data from farm sensors, making the system more accurate along the time in the forecasting of weather conditions.

A kind of "citizen science" approach was implemented in Austria for the forecast of scab: farmers have a Web App on the smart mobile device and can add the actual situation in their orchard: i.e. "leaves are wet" although the forecast tool reports "leaves are dry" (**https://obstwarndienst.lko.at/1251/Schorf**). The forecast is then adapted to the real situation and the plant health situation is re-calculated and therefore better fitting to reality. Similar to this, for frost warning it might be useful to think about possible additions by the customer.

Several well-known communication channels could be used to send out the warning message. SMS is probably the easiest and most used option. Email is a powerful alternative, although email warnings tend to often go unnoticed among the many emails that people receive on a daily basis. Since the rise of smart mobile devices, a third option called Web Push Notifications has become popular. Although more affordable than SMS – push notifications are free to send and receive – this option is not universally available because an updated version of the browser needs to be installed on the smartphone of the farmer. As long as some farmers still use basic phones without internet connection, SMS remains the only universal option.

3.2.4 Decision support

A decision support system (DSS) can be helpful to integrate different kinds of information sources, in order to give farmers the most accurate information as possible.

One of the simplest frost warning systems available in the market is composed of a wet and dry temperature sensor and a datalogger (iMetos EcoD3 ICE). Farmers can define in the system's dashboard the threshold of temperature on which the system should send an SMS and/or email, because depending on the crop's physiological stage, frost damage occurs at different temperature ranges.

Figure 3 – iMetos EcoD3 ICE from Pessl Instruments.

From the system described above, the SMS could be sent directly to the farmer or to an irrigation controller, forcing it to start running the system for frost protection (sprinklers). Other conditions such as wind speed could also be monitored to avoid starting the system in windy conditions. In practice, this won't always stop the grower from starting his/her sprinklers, but a variety of (automated) options could nevertheless be helpful.

3.2.5 Inversion

In order to decide whether inversion can be exploited, it is crucial to first measure temperature at different heights. The type of frost (radiation vs advection) will determine the quality of the inversion layer.

- **Radiation frosts** are common occurrences. They are characterized by a clear sky, calm or very little wind, temperature inversion, low dew-point temperatures and air temperatures that typically fall below 0°C during the night but are above 0°C during the day. Radiation of heat from the ground into the air commonly causes temperature inversions, but cold air drainage can also cause an inversion to intensify.

- **Advection frost** is the result of a large cold air mass moving into an area replacing warmer air that was there previously. This causes air temperature to drop even with the wind blowing. It can result in a moderate to severe frost. Temperature inversions usually do not form during an advection frost due to wind mixing air and preventing cold air forming at ground level.

The following table provides a structured overview of the differences between these types of frost.

	Advection	**Radiation**
Wind conditions	Windy	Clear, calm
Inversion	No inversion	Inversion possible
Temperature during day	temperature can be below 0°C during the day	temperature is above 0°C during the day

An inversion layer, best associated with a radiation frost, is closer to the ground when temperature increases rapidly with height. The opposite is the case when the temperature increases slowly with height. Inversion height is also influenced by dew point temperatures, cloud cover and fog.

Depending on the culture, the height of measurement (especially for temperature measurement) should be carefully chosen. In case of an inversion situation, temperature on the ground will be lower than above until the ceiling of the inversion. A good idea is to measure the inversion strength, which is generally defined as the difference of temperature at 15 m height and at 1.5 m above the ground. This measurement is very useful for the decision whether or not to start wind machine operation.

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4 Conclusion

Farmers in frost prone regions need frost detection information. The importance of measuring temperature and air humidity (RH, dew point or wet-bulb temperature) in multiple locations within the area of the endangered crop is paramount.

Efficiently monitoring these parameters can be done by using an affordable monitoring system with a flexible combination of sensors. These sensors need a high accuracy and resolution and the device needs a reliable internet connection, such as GPRS or 3G/4G. Warnings to the owner could be sent by SMS or email.

Using fully equipped weather stations for this purpose can be a solution, although these are no longer affordable when multiple measurements are required on several heights and locations in one orchard. As mentioned in the chapter 3.2.1, modern digital monitoring devices can provide an affordable alternative to the classic weather stations when a flexible combination of sensors is required.

The cost of operating frost protection solutions such as irrigation systems or heat candles is massive. Therefore, a farmer cannot afford to rely on inaccurate manual measurements for deciding to use or not use the protection system. Today frost detection in fruit orchards is more important and relevant than ever before.

5 Ideas for innovations

Following this mini-paper, the following topics have come up as future ideas for innovations.

5.1 Forecasting temperature

Explore the possibilities of testing and integrating existing models for simple prediction of temperature evolution based on real-time measurements and historical data.

5.2 Modelling of air flow

To determine in hilly areas the order in which temperatures in specific regions evolve, air flow could be monitored and modelled. This would allow for prediction of frost in certain areas based on such a model, after calibration and validation on historical data. This might also be interesting in non-hilly areas.

5.3 Automated activation

Several methods exist today for protecting orchards against frost. Each of these systems require manual intervention in order to start working. Some of the most known examples are irrigation systems, wind machines or solid fuel candles. A very interesting idea would be to connect the online monitoring device to the frost protection system, allowing the owner to activate the system by clicking a button on his smartphone. Even more advanced would be to fully automate this process, where the candles or irrigation systems are activated autonomously when temperature drops below a certain threshold. Note, however, that owners will probably want to be in control of this activation given the high cost of heat candles, or implementation of the other methods.

Further research needs coming from practice, ideas for EIP AGRI operational groups and other proposals for innovation can be found at the final report of the focus group, available at the FG webpage **https://ec.europa.eu/eip/agriculture/en/focus-groups/protecting-fruit-production-frost-damage**

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