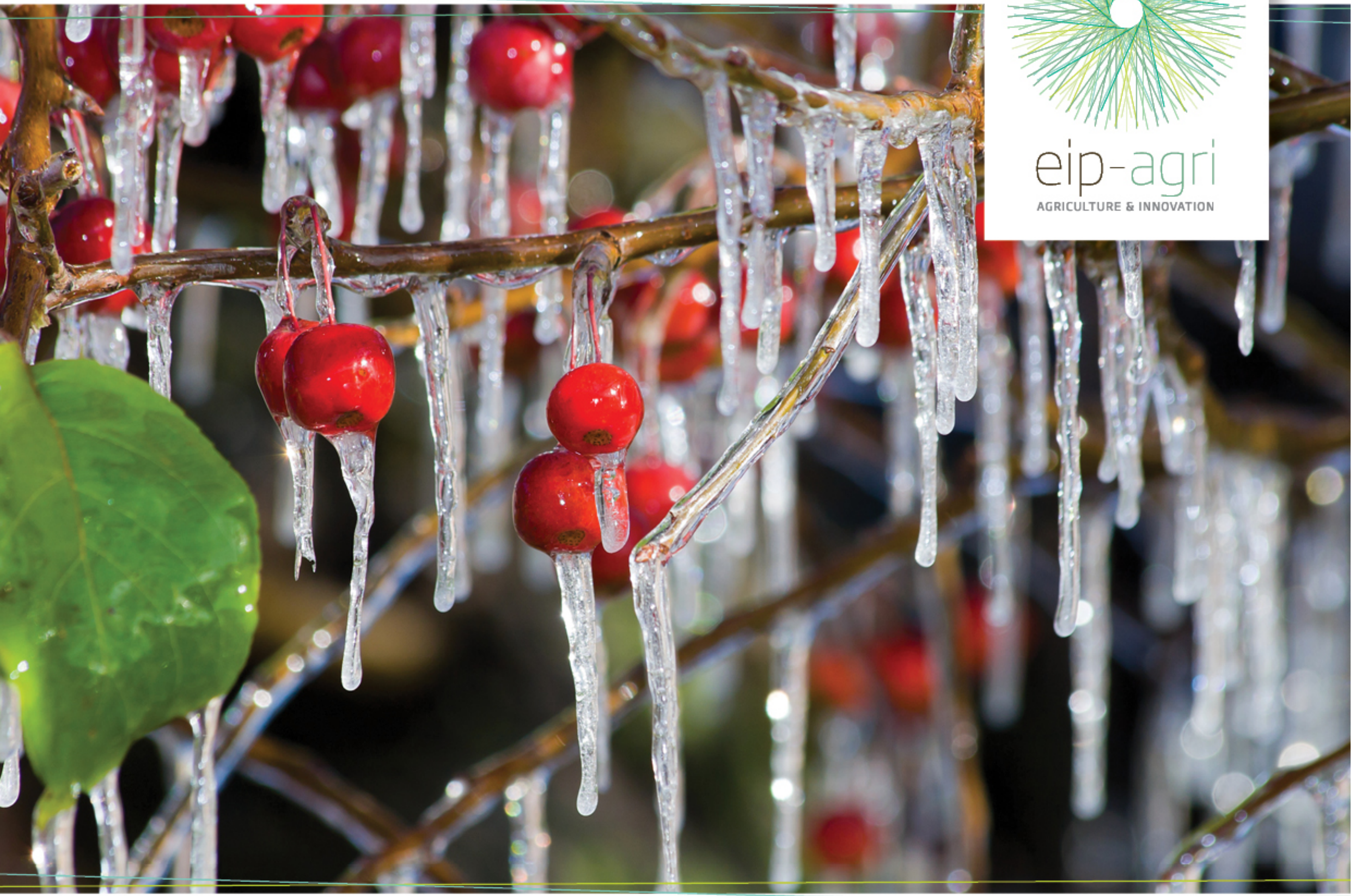

EIP-AGRI Focus Group
Protecting fruit production from frost damage

MINIPAPER 01: Frost protection by above crown sprinkling
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Introduction - Motivation

On the one hand, all existing active frost protection systems have several limitations and drawbacks that farmers need to know to be able to make the best choice for their particular fruit crop, orchard(s) and local weather conditions. However, from all the existing techniques above crown sprinkling of water during frost is the only method that offers effective protection until -7°C, but it also suffers from several constraints. On the other hand, in the past 20 years or more no new frost protection systems have been developed, while the risk of frost events has increased in recent years due to climate change and more specifically, sudden steep increases and decreases in temperature that can occur very early in the season. Hence, the aim of this focus paper is twofold. First, provide the current state of the art of above crown sprinkling and what improvements have been done. And second, identify the research and development gaps as well as opportunities not only for further improvements of above crown sprinkling but also for new, alternative frost protection systems.

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State of the art

Many active frost protection systems exist including different types of burners, hot air machines, wind machines, below crown sprinkling, above crown sprinkling, etc. All these methods are effective to a variable degree depending on the local weather conditions with the temperature being the most important parameter but relative humidity, wind direction and speed, altitude, etc. cannot be neglected when evaluating the effectiveness of a particular frost protection system. However, above crown sprinkling is the only method that offers full protection of the flower buds/flowers during spring frost as low as -7°C and hence, is generally recognized as the most effective frost protection system.

Advantages of above crown sprinkling

- Above crown sprinkling is suitable for pome fruit, is widely used and for over 50 years of good experience are available. The system is also suitable for peach, some plums, apricots and even cherries but depending on the fruit region it is more or less being applied in stone fruit. Diseases due to sprinkling of large amounts of water (see below) can prevent the general acceptance of above crown sprinkling is stone fruit.
- Easy to use and low operational cost. Only one person is needed to start the system and maintain it. However, investment costs depend on the availability of water and the cost of the storage of water. When deep drilling is required to reach good quality groundwater and powerful pump(s) are needed and/or a large water collection pond(s) has to be installed investment costs can become high. Luckily, the more rainwater can be collected the cheaper the system becomes.
- Can also be used for cooling and thus, can sometimes delay flowering time if spring is extremely dry and warm. Provided water availability is sufficient the sprinkling system can be used for cooling during summer to decrease heat stress of the trees and protect the fruits against sunburn limiting yield loss and maintaining high fruit quality.
- Can also be used for irrigation, but the water consumption is relatively high since a lot of water will evaporate before it benefits the trees. An additional drip irrigation can be easily attached, which will greatly reduce the water consumption and enhance the water use efficiency.
- In some cases, e.g. in organic production the above crown sprinkling system can also be used for spraying, if there is an approval for suitable products like lime sulfur. Between 3000 and 4500 l/ha are applied per treatment, but it is important to rinse the system properly and apply tractor sprayer treatments as well. Hence, maintenance efforts are slightly higher when using the system for spraying, too.

Limitations and drawbacks of above crown sprinkling

Water related

- High water consumption of 30-40 m^3/ha/h and hence, a large water supply is needed. To overcome a longer period of frost on average a water supply of three nights of eight hours each or 720-960 m^3/ha or 7200-9600 m^3/10 ha are needed. The latter requires a water storage facility of approximately 50 m x 30 m in size and 6 m deep unless groundwater can be directly used without storage.
- Water availability is bound to sufficient storage volume. Cost effective storage of water is a critical issue.

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- Rain water collection is accepted by authorities and public opinion. Naturally, availability and volume depend on the amount of rain/snowfall during winter which is limited for instance in Southern Europe.
- Groundwater is often needed: only best water quality, usually potable water, low preparation cost (filters etc.) is suitable for above crown sprinkling but is in competition with many other purposes (drinking water), which is a critical point in public acceptance. In many regions including fruit production regions, it is very difficult to get an official permit to pump up groundwater for agricultural purposes and/or high taxes have to be paid for the use of groundwater. A thorough knowledge of the legislation in the different European countries is helpful.
- Alternatively, surface water might be used but it is difficult to get access and depends on national law. In addition, there is competition with power plants and other users.
- On the long term the use of the large amounts of water are not sustainable.

Sprinkler system related

- The accuracy of the sprinklers is sometimes insufficient. For example, in practice, it has been shown that with a target intensity of 4 mm/h, the actual intensity was 5.04-6.59 mm/h or 659 m^3/ha water was used instead of 400 m^3/ha per night (10 h). Consequently, savings in water usage could amount up to 20% or more.
- At temperatures down to -2°C lower water pressures can be used, which give a lower intensity of rainfall and, thus, saving a considerable amount of water and energy (to 35-40%). However, to achieve this precise steering of the system is needed, but that is often not possible because exact monitoring of the temperature in the orchards at different heights in the trees is not available.
- The sprinklers are sensitive to wind, especially the in-row sprinklers and microsprinklers, but is less a problem for the rotating sprinklers.
- The system is difficult and expensive to install in each orchard when a grower has many spatially distributed but smaller orchards where water is not always easily reached.

Disease related

- Above crown sprinkling can lead to water lodging with a negative impact on soil drainage and risk of anoxia, tree rot and root rot caused by root diseases. Therefore, when planning the orchards, water drainage should be taken into account.
- Although it is often not critical, it is difficult to apply fungicides during the frost protection period.
- Following the use of above crown sprinkling the risk for *Pseudomonas* infection and fungal root diseases increases, which can cause a strong setback in yield and fruit quality for several consecutive years especially in younger trees.

The above crown sprinkling method is currently the most effective method for frost protection (Figure 1), but due to all the above mentioned constrains we are convinced that we need to make the frost protection systems including above crown sprinkling more sustainable and/or develop alternative frost protection systems that are more sustainable. In other words, in the (near) future alternative active frost protection system(s) that are effective (preferably down to -7°C), energy efficient, more sustainable and cost effective (not more expensive than existing systems) are not only desired but needed.

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Figure 1 Anti-frost sprinkler system installed in an Avocado tree orchard in the South of Portugal in Algarve (left). Apple trees undergoing above crown sprinkling during spring frost in Belgium (right).

Available technologies to reduce the water consumption of the above crown sprinkling system

Sprinkler systems that use less water need further evaluation to confirm that they are effective and reliable (e.g., variable-rate sprinklers, targeting the jets).

- Precision or in-row sprinklers can be used: Naandanjain Flipper system (http://www.naandanjain.com/products/micro-sprinklers/micro/flipper/) (Figure 2) that is used in vineyards and has been successfully applied in Belgium in pome fruit and delivers water in the tree row and not on the grass strip. Approximately 15 m3/ha/h water is used and thus, more than 50% less water than conventional sprinkling systems. The system can be used under a hail net or any other cover system provided there is at least 80 cm between top of the trees and the cover system (sprinklers approximately 50 cm above the trees). However, these systems are very sensitive to wind, which can cause the water to fall on the grass strips in between the tree rows. Apart from a wind shield or hedge blocking or tempering the cold North – Northeast wind currently no corrective measure can be taken. Perhaps turning the sprinkler against the wind might be helpful, but that requires careful monitoring of the wind direction and an automatic system to turn the sprinkler in the correct direction always aiming for the trees.

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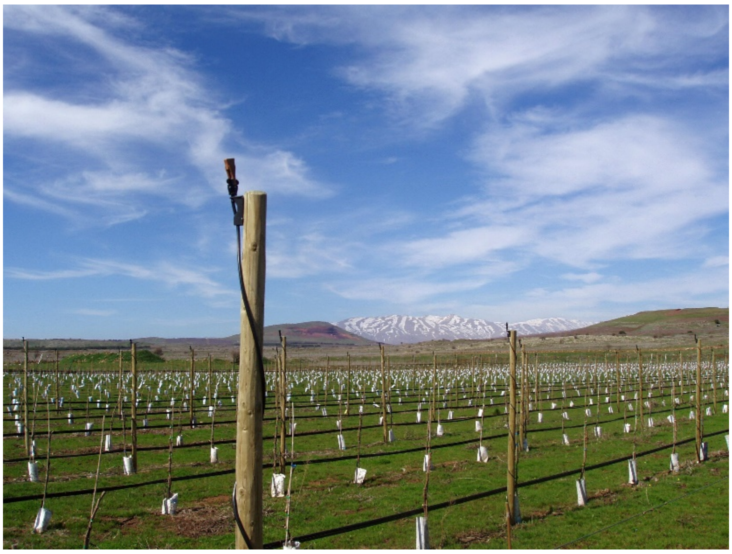

Figure 2 Example of Naandanjain Flipper system installation

- A thorough comparison of less water consuming sprinklers under frost conditions is needed since multiple water saving sprinklers exist but it is not clear which is/are suitable for frost protection? Netafim Pulsar™ with STRIPNET™ head (https://www.netafim.com/en/products-and-solutions/product-offering/Sprinkler-irrigation/) (Figure 3) is a tube with air bag and special valve that gives several pulses per minute and has a 12 l/h overflow and gives a 3.8 mm/h spray intensity in the weaving belt. This sprinkling system represents an additional 40% saving of water. Excel-wobblers use about 20-30% less water, give a very even droplet distribution due to a bigger and more even droplet size than standard sprinklers. They are more energy efficient, since they use less pressure.

Figure 3 Example of Netafim Pulsar system installation.

- Netafim Meganet sprayers (**https://www.netafim.com/en/products-and-solutions/product-offering/Sprinkler-irrigation/**) use a similar technique, but still need higher pressure and need good filters.

- Naandanjain AquaSmart sprinklers (**http://www.naandanjain.com/products/micro-sprinklers/micro/2002-aquasmart/**) (Figure 4) have been successfully used and consume 50% less water than the conventional sprinklers, but are designed for under-tree sprinkling. The risk of dropout is, however, higher due to the small hose diameter, the high number of sprinklers and the high filter system requirements. The system has to be started earlier than conventional sprinklers to prevent freezing of the sprinkler units.

Figure 4 AquaSmart under tree sprinkling system installation.

- Rain Bird® LF™ Series (**https://www.rainbird.eu/products/impact-sprinklers/lf-series**) (Figure 5) low flow sprinklers offer another less water consuming system for above crown application.

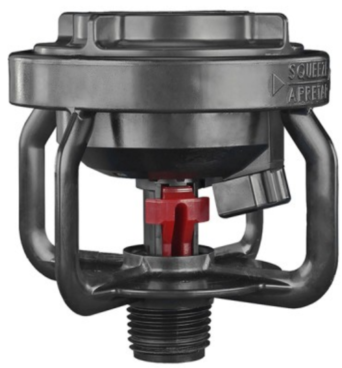

Figure 5 RainBird LF Series equipment (left) and an example of an installation (right).

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Research needs

The three main research needs that were identified by the authors were the following:

1. Development of precise and reliable frost warning systems for farmers. Explore if wind speed is also a parameter which might improve the predictions. This can be complemented with MP04 top 2 research need (improving local predictions);
2. Recycling o the water used in above crown sprinkling systems by drainage tubes in the soil. Installation of the drainage system is easier when done prior to planting and even allows to position drainage tubes under the tree rows. However, capillary raise of the ground water might be affected and should be investigated. In existing orchards drainage could be installed under the grass strip, so it wouldn't be on the way of root pruning. The drainage system would also collect drain water in autumn and winter that can be stored for above crown sprinkling during spring frost and irrigation throughout the season provided the drain water is purified (at least filtered) before reuse.
3. Test below plant sprinkling (in combination with hot air machines) for stone fruit.

Focusing on the above crown sprinkling additional possibilities and research opportunities for improvement of the standard sprinkling systems were foreseen:

Technical opportunities

- Can purified wastewater be used and what are the requirements with regard to purity, and impact on crops (e.g. phytotoxicity)?
- What are the options for management and transport to the orchard in case of the use of more rainwater or purified wastewater?
- Stone fruit (cherry and apricot) compatible systems: how effective are below crown sprinklers – successfully used in plums in the Bodensee region - for frost protection in pome fruit?

Economic opportunity

- An update on the economic cost of the installation, maintenance and operation of the different sprinkling systems in the different European countries is needed and will give the growers a solid basis for choosing the optimal sprinkling system in their orchard(s).

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**

Suggestions for Innovations in frost protection

Considering the broader area of active frost protection systems, we have formulated a number of additional research opportunities that could lead to improved, more sustainable frost protection system(s):

- Testing combinations of different frost protection systems with careful monitoring of temperature and relative humidity: e.g. below crown sprinkling and hot air machine under a hail net (pome fruit) or plastic cover (sweet cherry).
- Can we make use of new energy sources like sun (solar panels, cells), wind, geothermal, residual energy from cooling cells, etc.? In achieving this two main challenges need to be overcome: (1) select the

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source of energy to produce heat including a storage system of energy, and (2) develop a transport system of the stored energy unless it is produced in/near the orchard and build a distribution system of energy in the orchard.

- Availability and quality of orchard specific weather information is important for the decision support to fruit growers. Hence, on site/farm weather monitoring would increase the efficiency of frost protection systems together with the precision that modern weather stations and attached forecast services have today. Then farmers will only start their protection systems upon the local, on site frost conditions that are occurring in real-time. A network of temperature sensors (preferably wet bulb) could also increase the efficiency of protection, since they could differentiate the farm zones with more or less risk of frost occurrence and consequently, the system should be started in the firstly affected zone(s) and not immediately in all zones(s). Sprinklers accuracy could also be continuously monitored online (or visually) with in field rainfall gauges or water counters in each sector, to keep information about real water debit. Of course, these systems relying on zonal information within the orchard are only useful if the sprinkling system is zonally organized.
- Development of low-cost temperature sensors to build a strong network within each farm/region, connected to each other by low-cost wireless systems. That information could be centralized and used to trigger alarms.
- A recent approach opens the possibility for the application of a protective solution via a sprinkler system: cellulose nanocrystals improved the cold hardiness of reproductive buds of grape and sweet cherry by 2 to 4°C following their electrostatic application (Alhamid *et al.*, 2018). Field trials are needed to assess the feasibility of this method.
- A much older and controversial technique is the use of ice-minus bacteria or frost protective bacteria (Love and Lesser, 1989): further studies like the one ongoing in California (https//www.westernfarmpress.com/print/35041) might resolve the issues around this natural/biological fighting method against frost.

Conclusions

- Apart from its ability to fully protect fruit flowers against severe frost damage, the above crown sprinkling system also has several drawbacks with its low sustainability being the one with the most negative impact.
- Reducing the water consumption (up to 50%) by using in row or low volume sprinklers need further testing and improving (e.g. the wind sensitivity of these systems remains a problem), but would greatly lower the environmental impact of the above crown sprinkler system. Combined with a very accurate, real-time monitoring of temperature (and relative humidity) changes additional saving on water consumption is possible by using a lower water pressure at mild freezing temperatures (until -2 °C).
- Zonal steering of the above crown sprinkler system based on zonal weather (temperature and relative humidity) information within the orchard using a sensor network allowing real-time monitoring might further reduce water consumption.
- Precise, up to date overview of the installation, operational and maintenance costs of the above crown sprinkling systems in the different European countries is lacking.
- On the long term and despite additional water saving in the future in the above crown sprinkling method, it is inevitable that (an) alternative, more sustainable frost protection system(s) is (are) needed for preventing frost damage in fruit crops.

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Sprinklers

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