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Micrometeorological Observations for the Evaluation of the Selective Inverted Sink against Radiation Frost and the Potential of a New Hybrid System

Ikani Vahid[a], Chokmani Karem[b], Turcotte Caroline[c], Ferland Martin[d], Eve Rainvill[e], Granberg Hardy[a]*

[a]*Université de Sherbrooke –Le Centre d'applications et de recherches en télédétection (CARTEL), Département Géomatique Appliquée, Sherbrooke, Québec, Canada*
[b]*Institut National de la Recherche Scientifique (INRS), Québec, (QC) Canada*
[c]*Ministère de l'Agriculture, des Pêcheries et de l'Alimentation du Québec (MAPAQ), Québec Canada*
[d]*Verger Ferland, 380 Chemin de la Station, Compton(Québec) Canada J0B 1L0*
[e]*Domaine Bergeville, 1030 chemin Sherbrooke, Canton de Hatley (Québec) Canada J0B 2C0*

Abstract

For the radiation frost in agricultural fields, it is difficult to determine a satisfactory solution. To solve this problem, Selective Inverted Sink (SIS) is proposed as a new active frost protection method. However, the interactions of the SIS (also known as tower less wind machine) with some topo climatic effects such as cold air drainage and inversion strength are not well known. Consequently, this study was dedicated to two main objectives: First, different micro- topographic conditions are compared to validate the capability of SIS against the radiation frost. Second, a new hybrid system was proposed to improve the SIS effects. For these two purposes, three meteorological field campaigns were conducted on the fields of a vineyard and an orchard in Quebec, Canada. The air temperature was recorded with a fine spatiotemporal resolution min and spatial resolution in a synchronous mode of operation. In addition, the air temperature and humidity were recorded with mobile measurements and launching balloons to infer the general variations of temperature and specific humidity. Based on the topographic maps and field measurement, the several locations for SIS installation were determined. The high-resolution isotherms maps were used to evaluate the influence of SIS on nocturnal air-cooling. These results did not provide conclusive observational evidence that the SIS has impartial efficiency on nocturnal cooling. Indeed, a minor part of the SIS's exhausted flux was from horizontal direction, essentially due to land surface roughness. In contrast, a major part of the flux was from the upper layer around the SIS, which behaves like a funnel. The wind speed in the funnel's direction was 3 times greater than the wind speed in the horizontal direction. Therefore, the SIS was not able to remove a sufficient amount of cold air pool or stagnant air. To elucidate the second

* Corresponding author. Tel.: +1 819 821-7190.
E-mail address: vahid.ikani@Usherbrooke.ca

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objective, a simple and affordable innovation with reliable testing was performed. A hot water SIS hybrid system (HWSH) was proposed to use the "forced convection" produced by the SIS to disperse a maximum of water vapors into the air in order to decrease the air dryness. In this system, hot water with a temperature of 60° C was deployed under the SIS. The observation during a radiation frost night demonstrated that, although the reference area (35 m away from the HWSH) was affected by frost, hybrid system's location area was not affected. However, there was no significant temperature gradient between two points, but the moist enthalpy calculated at 18 m altitude was higher above the HWSH in comparison to reference point. In conclusion, the main physical notion throughout this study is moist enthalpy, which depicts heat content. Nocturnal cooling rate decreased by increasing the moist enthalpy using HWSH system. This environmentally clean hybrid system has potential to be considered as an alternative to some frost protection methods such as heaters and fires burning. In addition, the importance of fine-scale measurement in agricultural field is highlighted in this study.

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Keywords: Radiation frost, Selective Invers Sink (SIS), enthalpy, nocturnal cooling, cold air drainage

1. Introduction

There are no perfect solutions for frost in the agricultural field and the problem is much more complex than it may appear at first. Passive methods under severe frost conditions are often inadequate to protect crops (Ribeiro et al., 2006). In addition, different active protection methods may reduce the frost damages but their applications are not well known and the influence of microclimate furthermore complicates the situation. Selective Inverted Sink (SIS) system, also known as tower less wind machine, is a new active frost protection system. SIS system has been increasingly adopted worldwide due to its low investment costs and it is currently operating in several countries such as the USA and Canada. Based on the literature review, we find some paradox analysis about SIS efficiency. For example, on one hand Splenger (2015) indicated that SIS will pull cool air from the ground of the most frost prone areas and direct it upward into the stratosphere (18 km height). On the other hand, Batancy (2012) indicated that based smoke tracking of the airflow SIS that the air reached 25 m height, and then tended to slowly settle back towards the ground. Another recent experiment was performed in an experimental peach orchard by Vardar and Taskin (2014). They showed the temperature difference between the two points of lower and higher elevation areas was reduced when the SIS was operating in the orchard. However, there was no information about the meteorological conditions during the onset of SIS and analysis did not compare the air temperature gradient for the rest of night when the SIS was not operated or before starting SIS. In this field, Yazdanpanah and Stigter (2010) used SIS in an almond orchard. The increase of temperature (0.5 to 2.8°C) due to the SIS operation system is reported. However, the analysis did not compare air temperature patterns for wind machine operation nights to similar nights when the wind machine was not operated, thus the conclusions may not be strongly supported (Batancy, 2012). In addition, as the SIS itself does not generate heat, there is no discussion about the source of this huge energy for increasing close to 2°C in an almond orchard. In fact, the interactions of SIS with some topo-climate effects such as cold air drainage and inversion strength are not well known. As a result, the quantitative relationships of the protection level and the location of the SIS system remain unknown.

Consequently, this study was dedicated to two main objectives: First, to validate the capability of SIS against the radiation frost in different micro-topographic conditions. The second objective is to propose and test a new hybrid system (using SIS mechanism) in order to improve the frost protection method. The specific objective was to determine a proper location for SIS to optimize the SIS efficiency. This study presents an analysis of observational data and micrometeorological temperature maps that were created during the radiation frost in the vineyard and an orchard. The spatial-temporal influence of wind machines on air temperature was evaluated using high resolution isotherms maps. The difference between the present study and the previous study were as follows: an existing dense network of data loggers to study SIS effects at fine spatial temporal resolution; testing the SIS in different topographic locations (each position several times); to onset SIS at different times: for example before sunset, after sunset, before inversion formation, after inversion formation etc., and the nocturnal cooling rate was studied during selected frost nights with the close synoptic conditions such as cloudiness and wind speed.

2. Measurements

The measurements presented in this paper were obtained in three meteorological field campaigns in the southeastern region of the province of Quebec in Canada. The first experiment was made over Le Domain Bergevrille, a commercial wine vineyard (45.27N, 71.95W), in autumn 2013. The second and third experiments were carried out in an orchard (45.23, -71.85) in autumn 2014 and spring 2015. Figure 1 shows the study sites. Both of them are frost prone areas in this region.

2. Description of the data

A regular dense grid temperature data logger (20 m, 50 m for the vineyard and orchard respectively) were installed (Figure 1). Air temperature was recorded with a high time frequency (one minute and five minutes for vineyard and orchard respectively) in a synchronous mode of operation. With this setup small scale variations associated with the cooling process and the disturbance, which are produced by the SIS operation, were covered. In addition, mobile measurement utilizing thermometer infrared and tethered balloons were used. The probe consists of a temperature–humidity sensor. It should be noted that the diameter of Selective Inverted Sink (SIS) which operated in this study is Propeller diameter: 2.39 m and it worked at a speed of 540 rpm.

3. Methodology

The methodology was based on four essential components as follows:

1. Derived thematic map
2. Installation data logger network and SIS test
3. SIS test, Data processing and Cartography
4. Present, installed and tested new hybrid system Hot Water SIS Hybrid (HWSH)

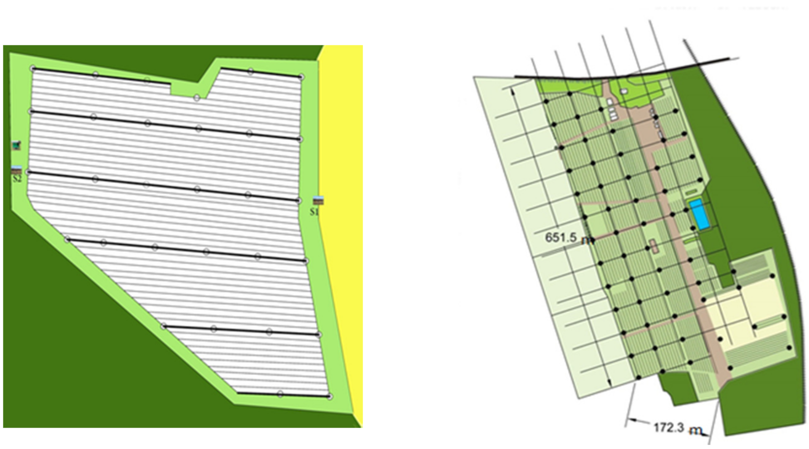

Fig. 1. Study sites and Installation data logger network; left the vineyard (20 m resolution) right Orchard (50 m resolution).

a) Derived the thematic maps:

A digital elevation model (DEM) with a 10 m resolution was used to create a thematic map (the flow accumulation pattern and the major current trace) figure 2. Based on the thematic maps and field observation and farmers experience, different locations for SIS installation were determined.

b) SIS test, Data processing and Cartography of SIS evaluation:

In this part, SIS was installed and tested in different locations. The spatial influence of wind machines on air temperature was evaluated using high-resolution isotherms maps. The analysis of data proceeding and cartographies are presented in the results section.

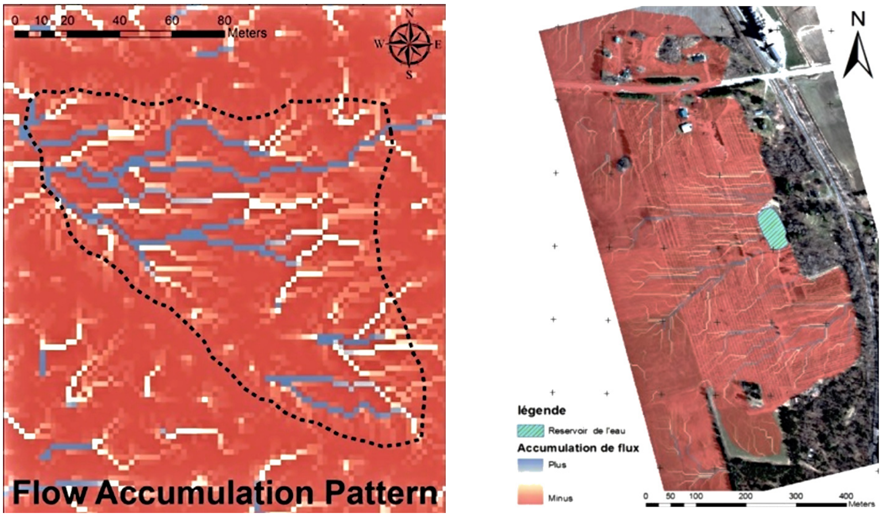

Fig. 2. Map of major current trace and accumulation pattern, left image: the vineyard and right image the orchard.

c) Presented, installed and tested new hybrid system Hot Water SIS Hybrid (HWSH):

The principle of this technique is very simple. The HWSH system was proposed to use the "forced convection" produced by the SIS. Forced convection is due to an external force generated by SIS. The hybrid system uses this force to disperse a maximum of water vapors into the air in order to decrease the air dryness (figure 5, right)

There are various factors like hydrological, meteorological and physical that affect the rate of evaporation from earth's surface. Radiation, vapor pressure, temperature, wind velocity, area of water surface, atmospheric pressure, quality of water and air humidity (Mohan Das and Das Saika,2009). Based on Dalton lows,

$$E = c\,(e_{w} - e_{a}) \qquad (1)$$

(E is the rate of evaporation and e_w, e_a are the vapor pressure in water and air respectively, and c is constant) The evaporation rate varies directly with a difference of vapor pressure between air and water (North, Tatiana, 2010). Toward this end, a mechanism to prepare heated water to 60 in the orchard was installed. Moist enthalpy, which is written as:

$$H = CpT + Lvq \qquad (2)$$

Where Cp is the specific heat of air at constant pressure, T is the air temperature, Lv is the latent heat of vaporization and q is the specific humidity. Recently, Fall et al. (2012) following the Priestley-Taylor method, estimated Lv (J/kg) with the temperature function:

$$Lv = 2.5 - 0.0022 \times T \qquad (3)$$

Such an estimate accounts for the variation of Lv with temperature.

The specific humidity q can be computed from the dew point temperature and surface pressure using:

$$q = \frac{0.62197e}{9 - 0.37803e}, \quad where \quad e = 6.112\exp\left(\frac{17.67T_d}{T_d + 243.5}\right) \qquad (4)$$

where: e is the saturated vapor pressure in hPa, p is the surface pressure in hPa, and T_d is the dew point temperature in °C (Pielke et al.,2006). Temperature and dew point were monitored at 1.5 and 18 m above the ground. Two tethered balloons probes were used for observation during the test HWSW. One of the balloons was close to HWSH locations and another was 35 m far from the one (as a reference point).

4. Results

This component was divided into two sub components as follows. Results are presented in following pictures.

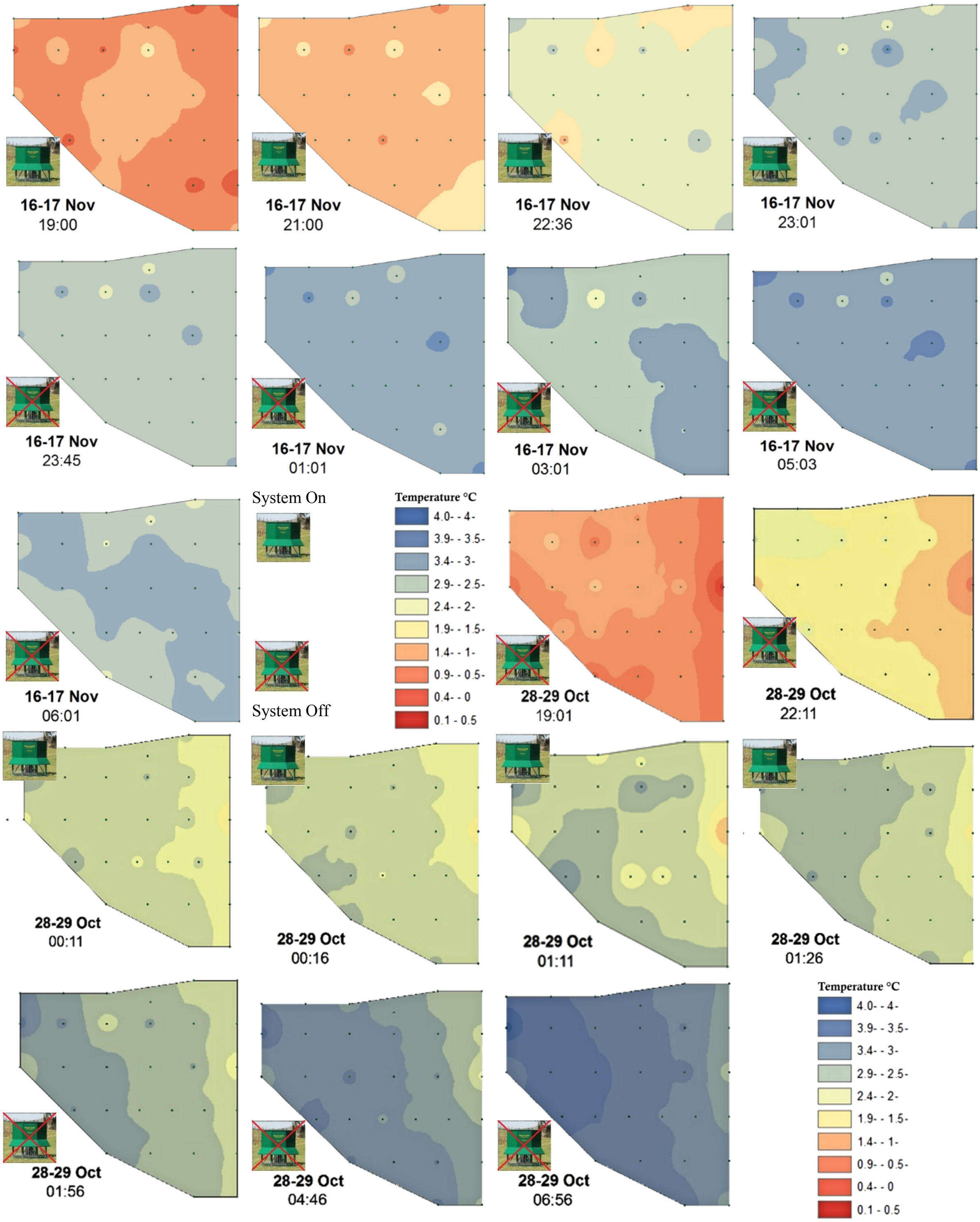

Fig. 3. High-resolution isotherms maps (20m) for 2 SIS location tests at 16, 17 November 2013 and 28, 29 October, (upper and lower image) respectively.

4.1. Presentation of observational evidence of the effect of the SIS on air temperature

The spatial temporal influence of the SIS on air temperature was evaluated by determining isotherms around the SIS in the farms (before, during and after the SIS operation). The figure 3 illustrates the temperature patterns during the frost night. SIS at the micro scale presented for two different positions over the vineyard the strikethrough sign means ‘no operate`, but normal sign means ‘SIS operate’. As the figure shows, there was no evidence in order to find out the effect of SIS on nocturnal cooling rate during the frost night.

Figure 4 shows the results of another observation in an orchard (Verger Ferland). Based on thematic maps results, the tests were done in two positions. For both of the positions, there was no evidence of SIS effect. The Figure is one example of this result. As the Figure shows the SIS was started at 20 h, but after 60 minutes, at 21 o’clock, there was no effective evidence. On the other hand, development lower temperature observed.

In addition, the SIS was tested at the north of the orchard but the result is not better than others. The tests did not provide conclusive observational evidence that the SIS has impartial efficiency on nocturnal cooling.

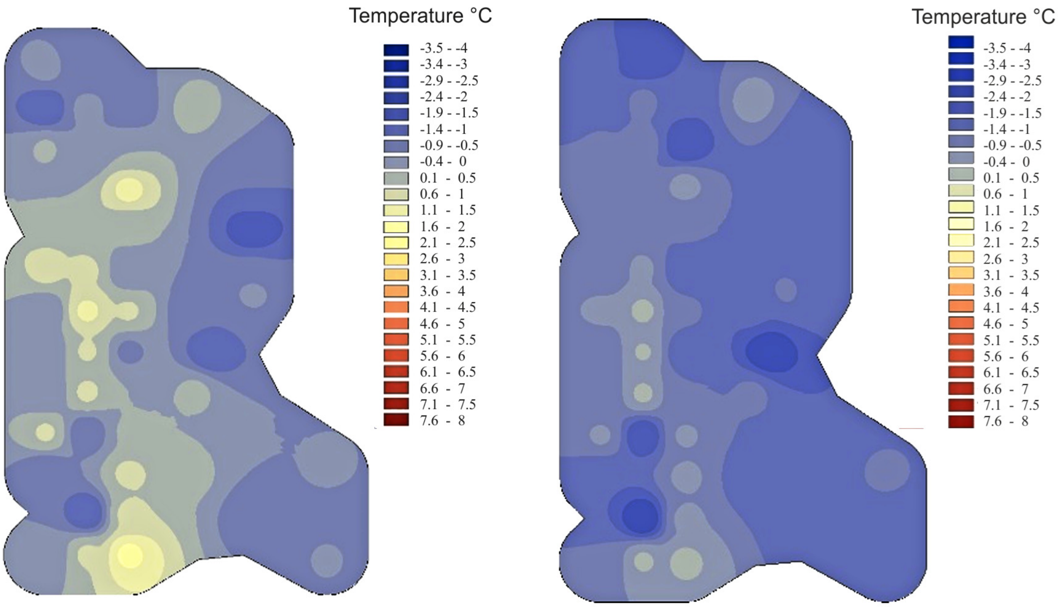

Fig. 4. Comparison starting operation SIS left image with temperature pattern after 60 minutes (right image)-16 November 2013, over orchard.

4.2. Toward the derivation of the airflow produced by SIS

An observation experience of SIS’s airflow patterns was conducted in the orchard. Using smoke during the SIS operation showed that a minor part of the SIS’s exhausted flux was from the horizontal direction. It might be due to the land surface roughness. In contrast, a major part of the flux was from the upper layer around the SIS, which behaved like a funnel (figure 5, left.). The wind speed in the funnel’s direction was 3 times greater than the wind speed in the horizontal direction. From this finding, it can be explained why the SIS was not able to remove a sufficient amount of cold air pool or stagnant air.However, it should be mentioned that the more optimistic result location close to a body of water gives us an idea to develop a hybrid system of hot water and SIS (figure 5 right).

4.3 Presentation of an experimental result of testing the new Hot Water SIS Hybrid (HWSH) system

In order to assess the HWSH, two meteorological field campaign observations were made. One of them in fall 2014 and the other in spring 2015, and both of them gave the same results. In this part, the second experiment was conducted during the night of May 13-14.

The figure 6 shows the moist enthalpy and figure 7 show air temperature (at 18 m) during periods with operation of the SIS. However, there was no significant temperature gradient between two points, but the moist enthalpy calculated at 18m altitude was higher above the HWSH in comparison to reference point. Moist enthalpy includes both temperature and atmospheric moisture contents. In fact, the nocturnal cooling was disturbed by the increase of the moist enthalpy by the HWSH system. Therefore, despite the high potential for radiation frost in the HWSH's area, this area was not affected by frost, while the reference area (with the same architecture) was affected by the frost phenomenon.

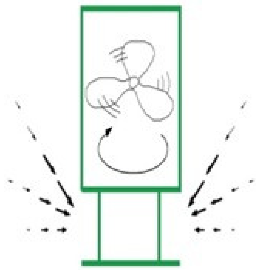

Fig. 5. a) Schematically representation SIS flow pattern, as the figure shows horizontal vector are smaller than the others.

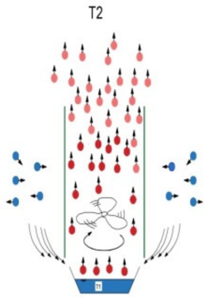

Fig. 5 b) shows new Hot Water SIS Hybrid (HWSH) mechanism.

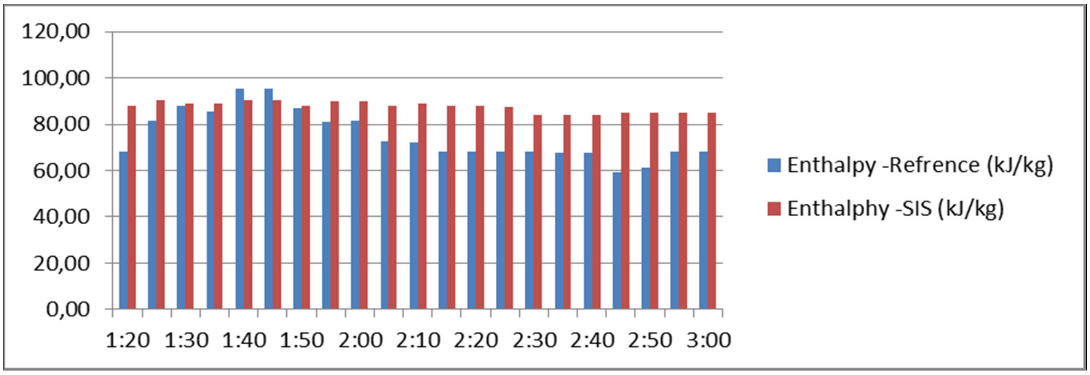

Fig. 6. Enthalpy (at 18m) of two areas, blue indicate reference area enthalpy and red SIS area (14 May 2015, over the orchard).

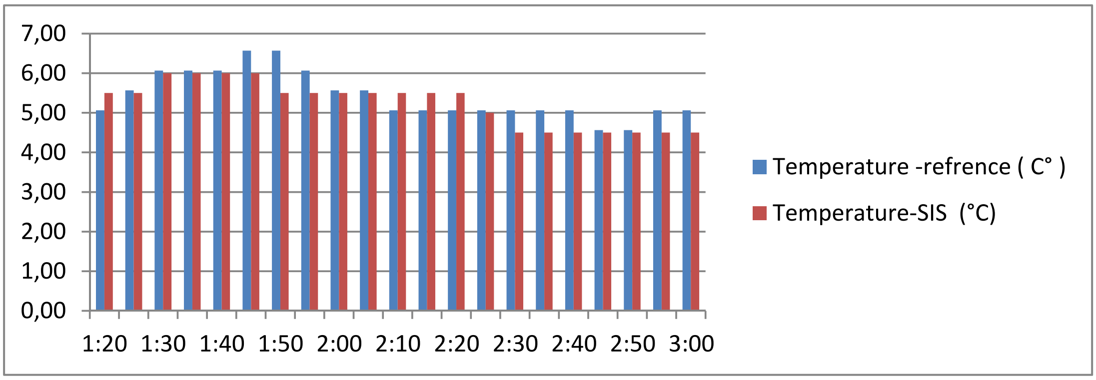

Fig. 7. Temperature (at 18 m) of two areas, color blue indicate reference area and red SIS area (14 May 2015, over the orchard).

5. Conclusion

In general, studies dealing with heat content have suggested that despite its undeniable relevance and popularity, temperature needs to be supplemented with additional metrics in agrometeorological application such as frost. The main physical notion throughout this study is the moist enthalpy, which depicts heat content. Nocturnal cooling rate decreased by increasing the moist enthalpy using the HWSH system. This environmentally clean hybrid system has the potential to be considered as an alternative to some frost protection methods such as heaters and fires burning. In addition, the importance of fine-scale measurement in the agrometeorological field is highlighted in this study. Using high-resolution climatic research keys helps us to understand the microclimates and improve the frost protection systems. Overall, this study provides farmers with useful information to assist them in making the most informed frost protection decision possible. It should be noted that the results of this study may be limited only to this model of SIS (Propeller diameter: 2.39m and speed of 540 rpm) and as such further evaluations of the SIS.

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