Comparison of different heating systems for spring frost

Introduction:
The heating is a suitable late antifouling measure, especially for crops where other frost stabilization measures are not possible or recommended, eg. B. because the culture is not suitable irrigation (stone fruit) or another Frost defense method.
Several systems are available for heating: Frost candles and frost ovens with different fuels. All systems have in common a relatively high demand for manpower in preparation, implementation and follow-up as well as an additional logistical effort (storage, transport). Depending on the system and materials used, high fuel costs may also be expected. Depending on the fuels, there are relevant effects on air quality, odor pollution and soot and smoke development. The fuels used are either fossil fuels (paraffin, soft wax, petrolatum, peat) or come from renewable sources (wood).

It is desirable to use fuel materials which have a correspondingly good antifreeze effect with high efficiency and, on the other hand, are both inexpensive and environmentally friendly. In addition, the burden on the population due to smoke or odor development must be taken into account. The company OPST developed a self-made frost oven in 2017, which represents an alternative to frost candles.

Test description
In order to compare the efficiency of different fuels in the OPST frost furnace with frost candles, two series of measurements were carried out (June 2018, November 2018). The series of measurements were carried out on both dates in orchards, whereby identical measuring fields were each equipped with one of the antifreeze systems. Between the trial areas a distance was kept, so that a mutual influence was excluded. The measuring fields were equipped with several calibrated temperature sensors at different heights and distance from the heat sources and a reference sensor was mounted outside the surface.
The conditions of the two experimental dates differed from the temperature level (reference temperatures in June: between 13 and 18 ° C, in November: between -2 and 1 ° C), with regard to wind and humidity the measuring nights were comparable (<1m / s, 96% resp 97% RH).

The following heating systems were compared with the same installation density (equivalent to 300 pieces / ha):
June / November: Frost candles "STOPGEL" (6 l soft wax)
June / November: OPST freezer, heated with peat briquettes (20 kg peat briquettes, 1 kg wood chips)
November: OPST freezer, heated with wood briquettes (20 kg wood briquettes)
The heat sources were placed offset in every second lane, with a distance of 5 m. The row spacing of the orchard was 3.25 m.
With the measured values, the temperature profiles and the achieved temperature difference to the ambient temperature could be displayed at different positions. In addition, a mass / energy balance was created for each heating system.

Results
The temperature profiles and the temperature differences achieved showed a clear difference between the three compared heating systems. All systems showed a warm-up phase between ignition to the corresponding heat development. This phase was the longest in the peat briquettes. Only after this heating phase the full performance of the systems (load operation) is achieved. With the wood briquettes in the freezing ovens
The strongest warming (punctually / in phases up to 6 ° C temperature difference) could be achieved, followed by the peat briquettes.
The frost candles could cause the lowest temperature difference (Fig. 1). The red lines (dashed / dotted) show the performance indicators of the heating systems. It can be seen that the performance level of the candles is constant but at a low level.
Numerous figures were calculated from the measured values, which allow a thermodynamic comparison and a comparison to the efficiency of the heating systems. The detailed results will not be presented here, but the conclusions can be found below.
The two experiments showed that the results of the first night of the show could be reproduced on the second night of the show, despite a different temperature level. A conclusion of tests in the positive temperature range on the effectiveness at freezing temperatures is possible under otherwise comparable conditions (eg wind).

In addition to the two series of measurements, OPST conducted numerous practical tests to answer different questions. The most important results were:
- Unsuitable materials are:
o Miscanthus: swells up a lot, produces a lot of ash
o Pinikey pellets lying: heavy smoke

- The use of logs, standing, in the freezer is indeed possible, but the good train burned the logs very quickly and it was a maximum burning time of 3 hours can be achieved

- Different qualities of wood briquettes were tested. In general, the higher the proportion of softwood, the less the briquettes are suitable for use with the freeze stalk. The main factor is the proportion of softwood, the pressing of the briquettes and the

finishing in the oven. As a result of the temperature development, the briquettes swell up and, if they are positioned incorrectly, close the pulling mechanism in the oven. As a result, the material starts to smoke and it can not be achieved sufficient fire and heat development. In addition, it can even lead to dangerous smoke development for the environment. Suitable but not available (because production ceased) would probably be bark briquettes. Pinikey Briquettes standing smoke more than hardwood briquettes, but also burn up to 6 hours.
For the use of hardwood briquettes, the draft control has been adapted to the stove and can be opened completely during operation so that less smoke is produced. The burning time is then up to 6 hours.

Advantages and disadvantages of heating systems and fuel materials
All heating systems require a logistical effort, storage capacity and have a corresponding need for manpower during the frosty nights.
The general advantages of frost oven lie in the reusability of the containers and the flexibility in terms of fuel materials. This is a significant cost savings compared to frost candles possible and it can come to different fuel materials are used. The OPST freeze ovens are available in two versions: black plate and stainless steel. The black iron stoves cost 17 € / pcs. net and have an estimated life of about 5 years, the stainless steel stoves cost 25 € / pcs. net and have an expected life of 20 years.
Frost candles are easier to handle and therefore require less time in preparation. In addition, the deletion of the frost candles and thus a termination of the anti-freeze measure is possible, the remaining candle can be ignited a second time.
Table 1 gives an overview of the tested heating systems and fuel materials.

Average temperature increase and minimum / maximum temperature differences during load operation (1-3.5 h after ignition) at the respective measuring points (29.11.2018)

Measuring point distance to heat source	1,25 [m]		1,25 [m]		2,50 [m]		2,50 [m]	
Measuring point height	1,00 [m]		2,00 [m]		1,00 [m]		2,00 [m]	
Temperature increase	ØdT4 [°C]		ØdT5 [°C]		ØdT6 [°C]		ØdT7 [°C]	
Oven-peat briquettes	**3,49**	4,46 max	**2,38**	3,05 max	**2,46**	3,17 max	**2,24**	3,27 max
		1,89 min		1,59 min		1,67 min		1,59 min
Oven-wood briquettes	**5,21**	6,27 max	**5,38**	7,07 max	**3,55**	4,80 max	**3,51**	4,41 max
		4,49 min		3,85 min		2,90 min		2,98 min
Candl	**1,66**	2,04 max	**1,46**	2,01 max	**0,97**	1,24 max	**1,03**	1,42 max
		1,18 min		0,83 min		0,60 min		0,57 min

Taking into account the power required to increase the temperature at one point (specifically at point T4) by z. For example, to increase 5 ° C compared to ambient temperature, a potential savings of 53% can be achieved by using freeze ovens with peat briquettes and 68% by using freeze ovens with wood briquettes compared to the use of frost candles for the number of energy sources required to calculate. In other words, this means that with the same number of heat sources with the OPST freezing ovens (with the corresponding amounts of fuel) a higher temperature increase is possible than with commercially available frost candles.
However, the temperature increase is also to be seen in connection with the duration over which this increase can be achieved. The burning time per se does not allow any statement about the efficiency of the antifreeze: it is crucial for how long a relevant increase in temperature can be achieved. In the case of frost furnaces, this can be influenced by appropriate process control (eg train control, reheating).
The costs for the freezing ovens consist of fixed costs (purchase of the freezing ovens) and variable costs (fuel, working hours). At the expected life of the freezing ovens and multiple

The frost heaters are a cost-effective alternative to frost candles. In addition, the benefits of heating with a renewable (and potentially domestic) raw material such as wood to mention.
The availability of suitable hardwood briquettes is currently limited, but OPST GmbH is working on this.
The efficiency and effect in total other weather conditions, such. B. in the presence of wind, could not be answered with the two series of measurements. On the basis of experience with frost candles, it is to be expected that there will also be an effect in wind, but this will be reduced in comparison to windless conditions due to the increased convective heat dissipation.
Practical recommendations
The following recommendations can be made on the basis of the measurements and practical tests:
- The storage of the wood briquettes before and during the frosty night must be absolutely dry
- The ideal stratification of wood briquettes in the frost oven is standing. To save time, the briquettes should be delivered already packaged
- To avoid smoke when using wood briquettes in OPST ovens as possible, the tension control is completely open
- Wood briquettes with the highest possible hardwood content or according to the specifications of OPST GmbH are to be used

- When using peat briquettes, use 3 pieces of 15 cm firewood for the heating phase
- Flammers recommend flamax kerosene cubes from OPST GmbH
- A warm-up phase until full heating power is reached must be taken into account for all heating-up systems. For frost candles and freeze ovens with wood briquettes the heating phase is about half an hour, for freezing ovens with peat briquettes it is about one hour much longer.
- Based on the current state of knowledge, when using the OPST freeze ovens a set-up density of 300 ovens / ha with approx. 20 kg hardwood briquettes is recommended. Thus, a temperature increase at radiation frost condition (practically windless) of 3-6 ° C, depending on the distance to the heat source and altitude, about 4.5 hours to achieve, the burning time is about 6 hours, but the performance is nearing the end the burning time significantly.
- When using peat briquettes, a temperature increase of 2-4 ° C, depending on the distance to the heat source and height, can be expected over approximately 3.5 hours under conditions of freezing (practically no wind) and an installation density of 300 ovens / ha. The burning time is about 5 hours, but the power drops significantly towards the end of the burning time.
- The use of firewood in the freezing ovens is possible, but a shorter burning time is to be expected (maximum 4.5 hours). For possible temperature increase no statement can be made.
- Reheating, in the case of long periods of frost, is both possible with the use of briquettes and logs and also necessary if a corresponding increase in temperature over a longer period is required.
- When using frosted candles, a significantly longer burning time (about 8-11 hours, depending on the make) 1 can be achieved, but due to the low power level over the entire burning time, more heat sources are required for efficient frost protection, depending on the minus temperatures.
- Regardless of the frost protection system used, a staggered installation in the systems and, depending on the row spacing, the positioning of heat sources in each tramline is recommended.

In a practice application in the night from 11 to 12.03.2019 with apricot in the flowering phase could be achieved with 300 ovens / ha and heating with wood briquettes, a temperature increase of 4 ° C, from -3 ° C to 1 ° C (not calibrated Measurements of the operation). Tis result from practice thus corresponds to the experimental measurements.

Who is spoken by OPST Frost oven is meant by the WIESEL frost oven.