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EXPERIMENTS ON THE USE OF ARTIFICIAL VENTILATION FOR PREVENTION OF RADIATION FROST

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Experiments were made on artificial ventilation during frost conditions, the apparatus used being a centrifugal cold air blower with a capacity of 75 m^3min^{-1}. The heating effect due to air mixing, under conditions favourable for the method, was only some tenths of a degree at a distance of 5 metres from the action centre. The conclusion drawn, in accordance with earlier results, is that centrifugal ventilators are not effective mixers. Further, a fixed mounting and continuous operation of a wind machine are needed for profitable use.

1. *Introduction*

Protection against radiation frost by means of wind machines is widely practised in many countries. It should be pointed out that this method is limited to restricted areas and it is applicable only during calm clear nights with strong inversion above the ground.

A good survey of wind machines designed and used until 1955 was presented by VAN EIMERN [1]. He concluded that the cost of ventilation is considerably lower than that of heating during frosty nights. The cost, however, is still high enough to limit the use of the ventilation method to rather small areas with high productivity, such as orchards or vineyards. The propellers used in this connection are normally installed at a certain height above the vegetation to be protected. The blowing direction recommended is inclined downwards and the purpose, of course, is to break the film of cold air near the ground and to shift warm air from the inversion layer downwards to the vegetation layer. Such wind machines are commonly used, for instance, in California to protect citrus groves against winter frosts.

In Finland, farming blowers are widely used with threshing machines. Some experiments were made by the writers, using a farming blower during three autumn nights under frost conditions. All the tests were made at the Pelso Frost Research Station, 85 km southeast of Oulu. The coordinates of the station are 64°31'N and 26°27'E.

2. *Thermal stratification at Pelso during summer nights near the ground*

The idea of the ventilation method is to increase the temperature of the vegetation layer by mixing the lowest air layers and/or by shifting warmer air from the higher layers downwards to the colder layers during the inversion period. The method, accordingly, is only effective if a marked inversion exists near the ground. Other methods, such as heating of air or sprinkling of water on plants, should be applied during wind frosts.

It is of importance to have an idea of the nightly thermal stratification in the vertical layer near the ground when estimating the expected heating effect due to ventilation. No long-term statistics are available

Table 1. Mean differences in minimum temperatures and their standard deviations (C°), observed at heights of 200 cm, 50 cm and 5 cm above short-cut grass and in the thermometer screen at Pelsonsuo. (Period 1961—1964, standard minimum thermometers without radiation shields.)

	200 cm—50 cm air		50 cm—5 cm air		200 cm —5 cm air	200 cm screen—200 cm air		200 cm screen—5 cm air
	ΔT	σ	ΔT	σ	ΔT	ΔT	σ	ΔT
June	0.92	0.80	0.96	0.73	1.88	0.84	0.44	2.72
July	0.84	0.72	0.83	0.65	1.67	0.87	0.45	2.54
August	0.71	0.68	0.92	0.76	1.63	0.74	0.53	2.37
June—August	0.82		0.90		1.72	0.82		2.54

at Pelso for layers over 2 metres above the ground. There are, however, carefully prepared observations of minimum temperatures at heights of 200 cm, 50 cm and 5 cm above short-cut grass and summaries of these observations are presented in Table 1 and Fig. 1. We see in Table 1, for instance, that the minimum temperature at a height of 200 cm, as a mean for the period June—August, is 1.7° higher than at a height of 5 cm above short-cut grass. The mean minimum temperature in the thermometer screen, respectively, is about 2.5°C higher than the temperature indicated by the unshielded thermometer at 5 cm height. The frequency distributions of these differences are shown in Fig. 1. We can conclude that, if the air layer between the heights of 5 cm and 200 cm could be thoroughly mixed, the warming of air at 5 cm would maximally be of an order of 4°C and as a mean of an order of 1.2°—1.3°C. Such a mixing, of course, is theoretical, since artificial mixing is always interfered with by natural advection and vertical streams which tend to undo the

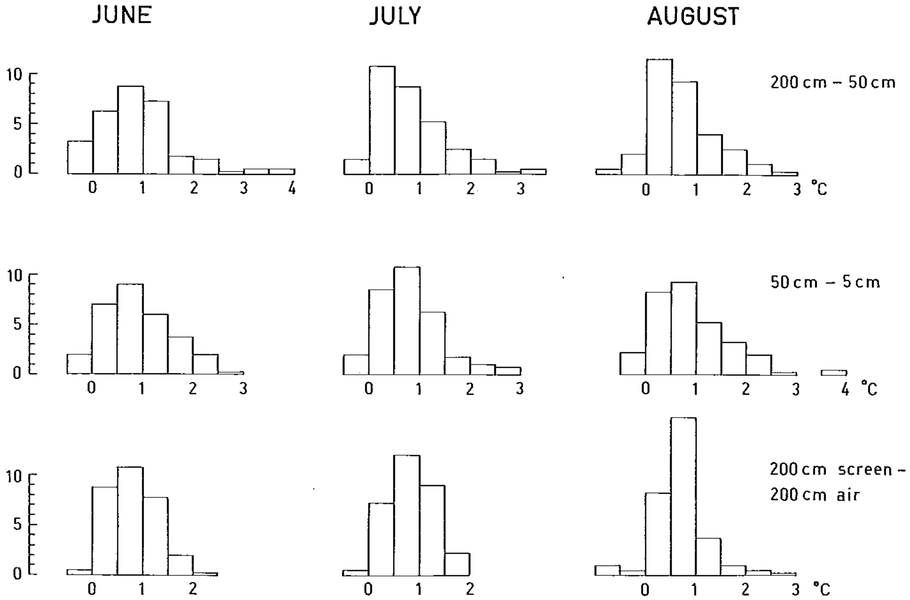

Fig. 1. Frequency distribution of the differences in nightly minimum temperatures at Pelso, measured by means of ordinary minimum thermometers without radiation shields at heights of 5 cm, 50 cm and 200 cm above short-cut grass and in an ordinary thermometer screen at a height of 200 cm above the same surface. Vertical scale = days in a month. Data from the years 1961—1964.

artificial effects. Actual tests with propellers installed at heights of 10—20 metres above the ground have revealed maximal heating effects of 5°—8°C just at the function centre of the propellers [1] but this is naturally due to transport of air through temperature differences which are far greater than those of Table 1 and Fig. 1.

A common feature of the ventilation tests is that even a short interruption of the ventilation will lead to nullification of the heating effect and continuous operation is thus needed during frosty nights. A preliminary test made by HUOVILA (Fig. 2) at the University of Oulu during a winter night in 1963 revealed that an interruption of one minute in the ventilation led to stratification which prevailed during a calm situation. The importance of uninterrupted operation is also pointed out in [2].

3. *Equipment, installations and measurements*

An ordinary farming blower (Fig. 8) driven by a Ferguson TEA 20 tractor was used as a ventilator. The ventilation speed during the tests was 18 ms^{-1} and the diameter of the blowing tube 30 cm. The amount of air passing through the blower was thus 1.25 $\mathrm{m}^3\mathrm{s}^{-1}$ or 75 $\mathrm{m}^3\mathrm{min}^{-1}$.

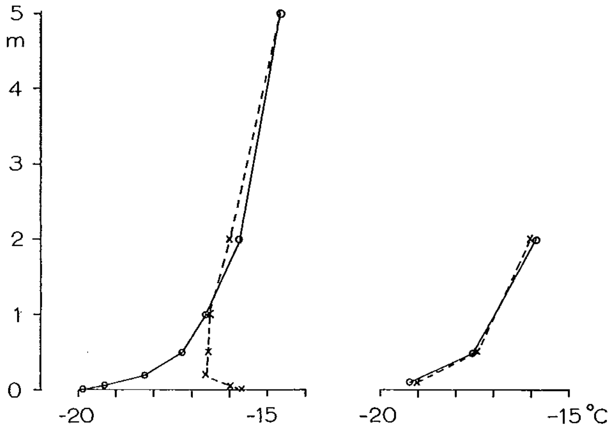

Fig. 2. Example of mixing of the lowest air layers created by suction of cold air downwards from a height of 4 m above a snow-covered surface. A small-size vacuum cleaner with a 27 mm tube diameter was lying on the ground during a calm winter night. Dotted curves refer to situations during air suction and solid curves during calm air. Left-hand curves were recorded at a distance of 0.2 m and right-hand curves at a distance of 5 m from the vacuum cleaner.

The first experiments were carried out on an open field covered by short-cut grass within the area of the experiments. The situation of the blower and of the temperature measuring points are shown in Fig. 3. A Wallac resistance thermometer was used in the blowing direction and a Miniterm thermistor thermometer in the direction normal to the blowing. Temperature values were read at heights of 1 m, 0.5 m and 0.1 m above the ground at the points marked with crosses in Fig. 3. In addition, standard minimum thermometers were installed at heights of 2 m, 1 m and 0.5 m at a point marked with a circle in Fig. 3.

In the first test (I) the blower was used without accessories, whereas during the second test (II) the blower was blowing through an iron tube 26 metres in length and of the same diameter as the blower, i.e. 30 cm. The time-table during tests I and II was:

Time	Action:
21.30 — 21.44	No ventilation. All thermometers were read
21.45	Ventilation started
21.50 — 21.55	» » »
21.56	» stopped
22.05 — 22.10	» » »
22.11	» started
22.20 — 22.25	» » »
22.26	» stopped etc.
23.40 — 00.25	Pause for installations
00.26 — 01.30	Test II as above, three ventilation periods.

The thermal stratification near the ground is to be seen in Fig. 5. The inversion between the 0.5 and 2.0 m levels is at first fairly strong but diminishes with time. Conditions for the ventilation method thus weaken with time. Wind speed, measured with a Wallac hot wire anemometer, was of the order of 1 ms^{-1} or less at 2 m height during the tests.

Another set of experiments (III and IV) were carried out within an area where a number of plots were surrounded by rows of willows of a mean height of 3—5 metres (Fig. 9). The area was thus a good approximation of a field surrounded by an effective shelter against the wind. The purpose of these tests was to lead off cold air from a plot by means of the blower and to allow the warmer air above the plot to descend and warm up the layers near the ground. The situation of the blower, the suction tube and the measuring instruments is to be seen in Fig. 4. The curves of the vertical temperature distribution between the 5 cm and 5 m

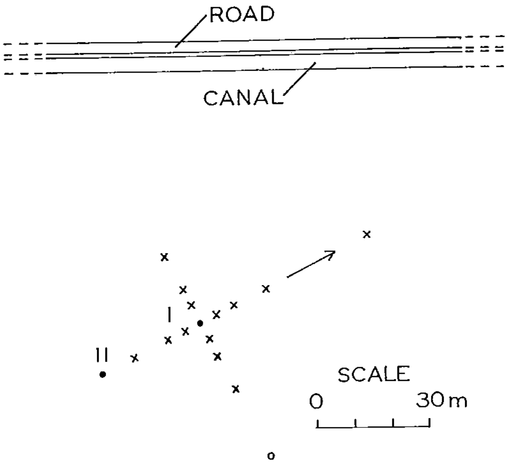

Fig. 3. Installation of the equipment during tests I and II. The field is open to a distance of at least 1 km except in the northern (upwards) direction, where trees are growing as a wind shelter behind the road. Measuring points for electric thermometers are marked with crosses and the point for standard minimum thermometers with a circle. The black points I and II refer to the situation of the blower's mouth during the tests and the arrow shows the direction of blowing.

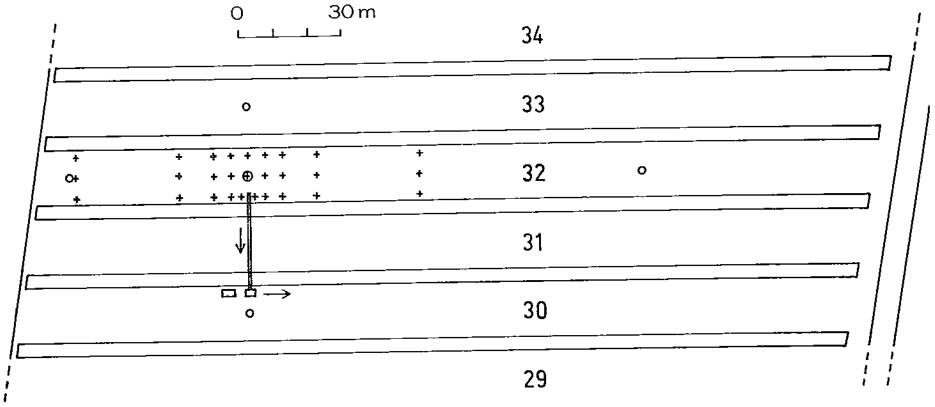

Fig. 4. Installation of the equipment during tests III and IV. Suction was created in the direction of the arrows from plot 32 to plot 30 through two willow hedges. Circles and crosses as in Fig. 3.

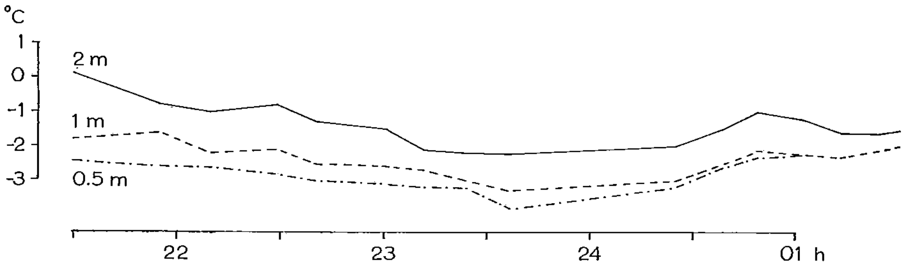

Fig. 5. Temperature curves at the circle point of Fig. 3 during the tests I and II at heights of 2 m, 1 m and 0.5 m above the ground, 17—18 Aug.

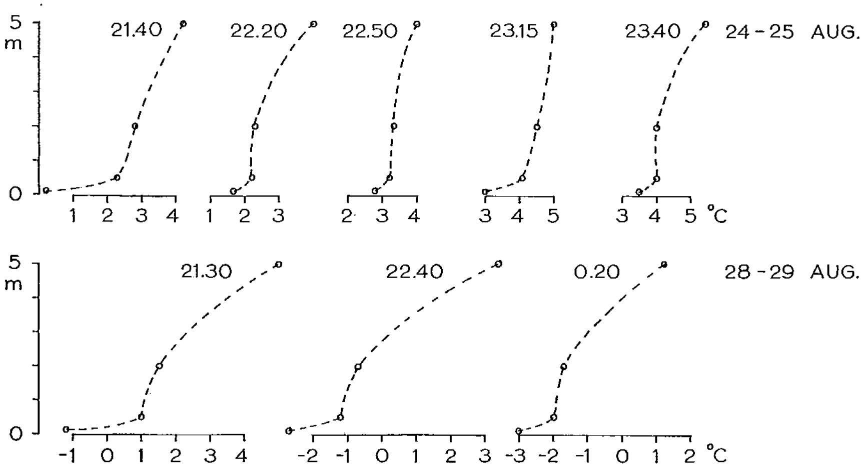

Fig. 6. Vertical temperature distribution between the 5 cm and 5 m levels during tests III and IV. Observed during calm intervals.

levels during these tests are shown in Fig. 6. Conditions were particularly well suited for the ventilation method during test IV, since the temperature difference between the heights of 5 cm and 5 m was of the order of 5°—6°C. The time-table was similar to that described above for test I. The mean value of the wind speed on an open field was of an order of 0.4 ms^{-1} at a height of 2 m above the ground.

4. *Results and conclusions*

The temperature differences between the ventilated and calm intervals, as a mean of 3 or 4 cycles during each test, are given in Fig. 7.

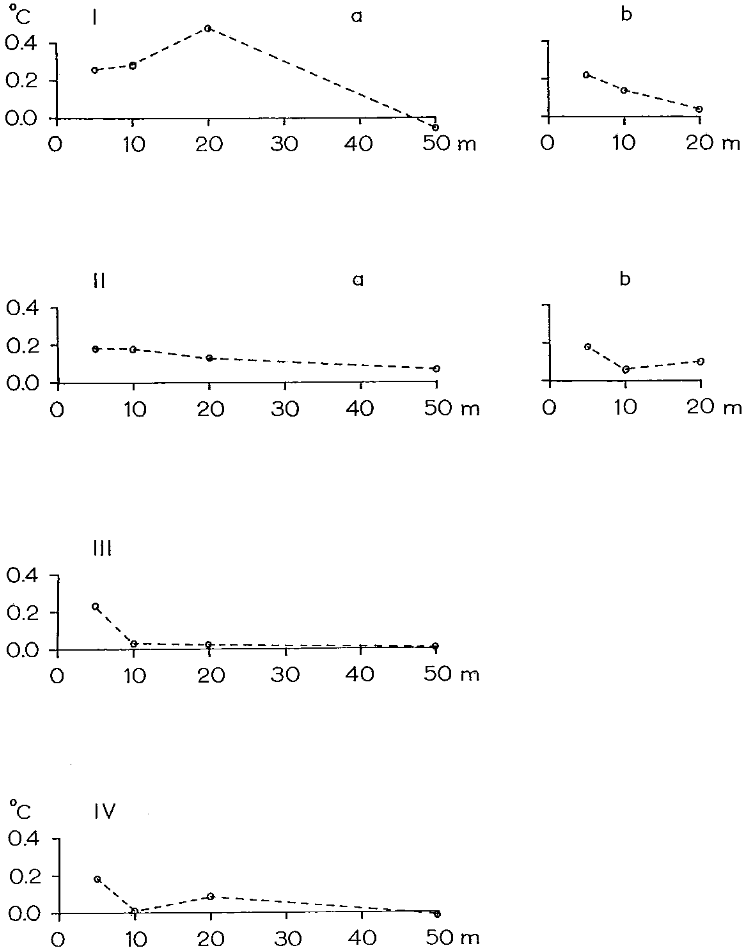

Fig. 7. Temperature differences between ventilated and calm intervals versus distance from the blower (test I) or from the end of the tube (tests II—IV). Longitudinal line is denoted with a and transversal line with b. I—IV refer to corresponding tests. All tests were made in August 1964.

We can readily conclude that the heating effect due to ventilation is rather small, of the order of 0.2°C at a distance of 5 metres from the action (blowing or suction) centre and practically zero at a distance of 40—50 metres. It is also possible that the best effect obtained during test I is partly due to the heating effect of the tractor engine, which was situated at a distance of about 10 metres from the action centre during

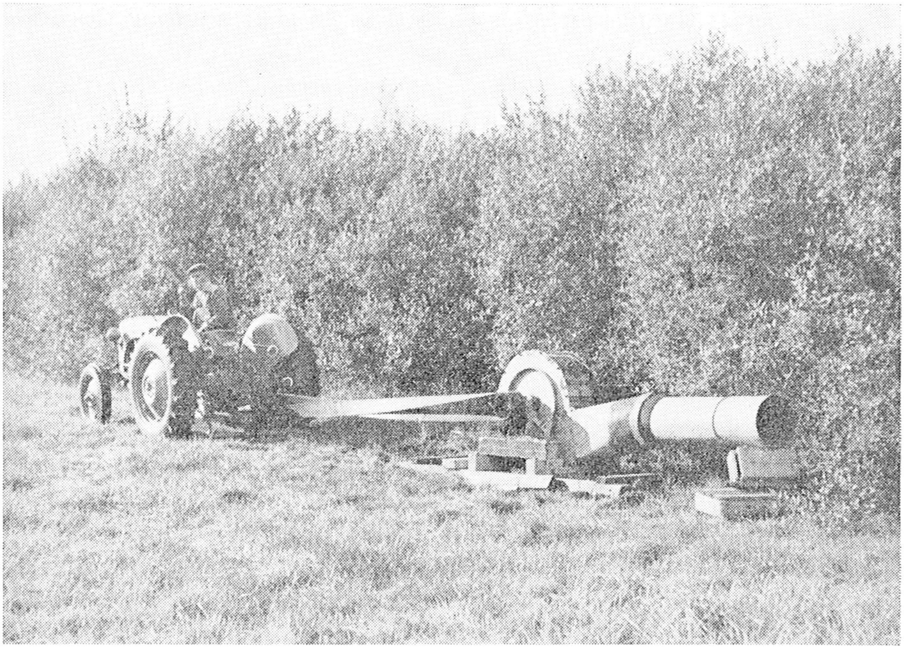

Fig. 8. Mounting of the blower during tests III—IV.

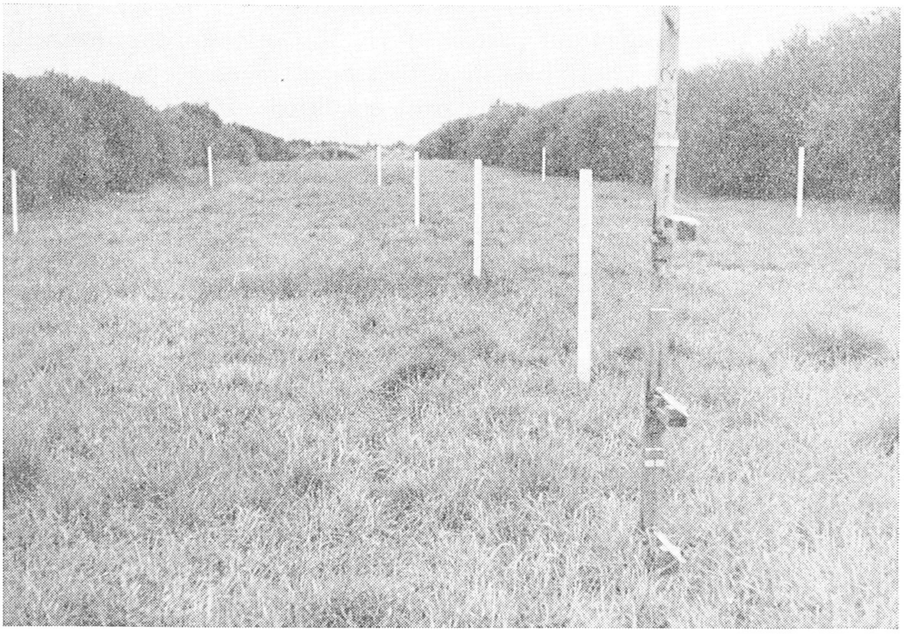

Fig. 9. View of the measuring site during tests III—IV.

test I, whereas the distance was more than 30 metres during the other tests.

The similarity of the results during the tests indicates that there is no obvious difference between the blowing or suction functions or between an open and a sheltered site. The latter result, of course, confirms the inefficiency of the blower and depends on the fact that even weak natural advection can undo the results produced by the blower. An interesting feature of the results was also the general heating rather than vertical mixing of the air near to the blower. This indicates that the blower was not able to break the film of cold air near the ground but the suction rather gave rise to a slight subsidence of the warmer air above the cold which was blown off.

We can conclude that the suction or blowing capacity of the blower, 75 m^3min^{-1}, was too low to extend protective measures over an area of practical importance. Further, a centrifugal ventilator seems not to break the film of cold air near the ground. It must be pointed out, however, that the most favourable results gained with propellers are probably due to the fact that, when blowing against treetops in orchards, there is warmer air both above and below the coldest layer and the situation is thus more favourable for mixing than in the case of low vegetation.

Our results seem to confirm the inefficiency of centrifugal blowers which has been pointed out previously [1, 3]. Our tests, together with earlier observations [2, 3], also show that uninterrupted operation of a wind machine is necessary during frost conditions. It is thus probable that only large propellers and fixed mountings are efficient enough for profitable use.

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