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ASSESSMENT OF THE EFFECTIVENESS OF SPRINKLING TO PROTECT APPLE BLOSSOMS AGAINST SPRING FROST

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Abstract

Spring frosts can cause very significant losses on fruit farms. The most common method of active protection against frost is sprinkling. The aim of this study was to assess the effectiveness of a sprinkling system used to protect apple trees against the effects of a spring frost. The experiment was conducted on the Mączewscy Fruit Farm. The orchard in which the observations were made is equipped with a system of sprinklers. When the temperature readings showed values close to zero, the sprinkler system was activated. Due to a limited water supply, one row of sprinklers had not been activated, and thus some of the trees were not sprayed at all. The assessment of fruit yield carried out in the autumn of 2015 demonstrated high effectiveness of the sprinkling used to protect apple trees against the spring frost. The frost had damaged most of the flowers of the unprotected trees, which resulted in a decrease in yield of as much as 85 – 93%.

Key words: *Malus domestica,* irrigation system, fruit quality

INTRODUCTION

The aim of this study was to assess the effectiveness of a sprinkling system used to protect apple trees against the effects of a spring frost. Spring frosts can cause very significant losses on fruit farms (Kruczyńska *et al.* 2001, Doroszewski *et al.* 2013). Low temperature damages the flower buds, flowers, and also fruitlets. Even if a fruit crop has been harvested, there are often visible signs of frost damage on the fruit (Nybom 1992, Krzewińska *et al.* 2003). Unfortunately, periodic falls in temperature very often occur right at the time when fruit trees are in blossom stage (Koźmiński 1976, Kołodziejczak 1979). Plant resistance to frost is a characteristic that is not only specific to a given species or even cultivar but also dependents on the stage of plant growth (degree of flower bud development) and also on plant health. In late April and early May, flower buds are damaged at a temperature of -3.9°C at the green bud stage, at -2.7°C at the pink bud stage, at -2.9°C at full bloom, and at -2.3°C after blooming (Ballard 1981). A temperature drop below 0°C causes the formation of ice crystals in the intercellular spaces, which ultimately results in the destruction of the cell structure (Modlibowska 1946, Kacperska 2001, Xiong *et al.* 2002). In fruit growing practice, both passive and active methods are used to reduce the extent of frost damage. The passive methods involve selection of an appropriate cultivation site (with no frost hollows), cultivation of late-flowering plants, and agrotechnical treatments that limit heat loss from the soil through radiation (Riger 1989). The active methods include, for example, covering, smudging, air mixing and heating, and sprinkling (Kołodziejczak and Mika 1984, Rabcewicz and Treder 2004, Ribeiro *et al.* 2006). The most common method of active protection against frost is sprinkling. During sprinkling, advantage is taken of the fact that heat is emitted in the process of freezing water. In addition, the ice that forms on flower buds and flowers or fruitlets provides thermal insulation and protects them from frost. During the freezing of 1 litre of water, 0,33MJ of heat is released. However, to evaporate 1 litre of water, it is necessary to supply approx. 2,55MJ of heat. Thus, from an Energy consumption point of view, to raise the temperature of the flower buds being protected, approx. 7.5 times more water should freeze than evaporate in a given unit of time. If this condition is not met, the use of sprinkling can cause additional losses (Rogers *et al.* 1964, Keller and Bliesner 1990, Solanelles and Planas 1993). The type of sprinkler, its working pressure and the spacing between sprinklers must be so chosen as to ensure that enough water freezes to provide sufficient energy to counterbalance the fall in air temperature in the orchard. The effectiveness of the treatment depends on the changes in temperature, air humidity, wind speed and the stage of plant development (Treder and Pinos 2001).

The aim of this study was to assess the effectiveness of a sprinkling system used to protect apple trees against the effects of a spring frost.

MATERIALS AND METHODS

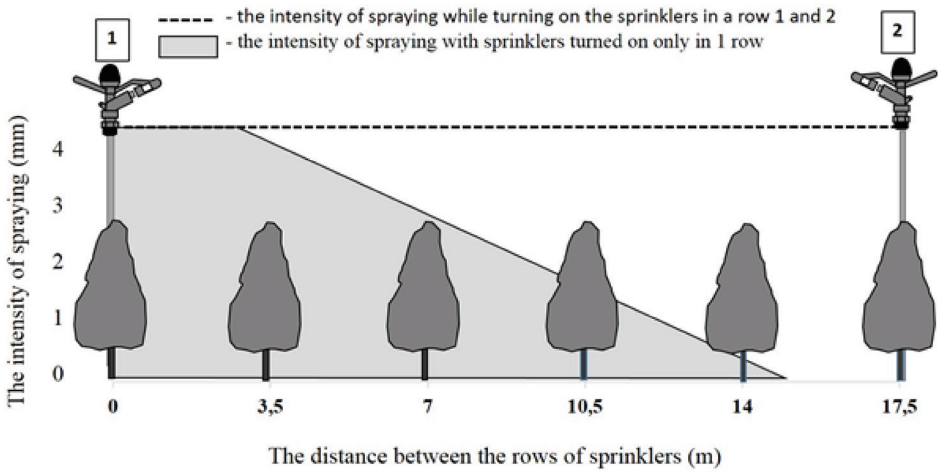
The experiment was conducted on the Mączewscy Fruit Farm in the village of Pęsy, the Municipality of Raciąż (52°45’44.28’N; 20°10’43.052’E). Apple trees of the cultivar 'Idared' grafted on rootstock 'P60' were planted in 2011 at a spacing of 3.5 m x 1.1 m in two separate sectors with different levels of soil fertility, which directly influenced tree growth vigour. Sector I (Idared I) – soil class III A, average tree trunk diameter measured at a height of 30 cm – 44.9 mm; average tree height – 2.9 m. Sector II (Idared II) – soil class IV, average tree trunk diameter measured at a height of 30 cm – 33.4 mm; average tree height – 2.1 m. 'Idared' is a late-winter cultivar, suitable for both fresh consumption and processing. The apples reach harvest maturity in the first half of October; they are characterized by very good keeping quality.

The 'P60' rootstock has a slightly higher growth vigour than M.9 and lower than M.26. Agrotechnical treatments were carried out in accordance with valid recommendations for Integrated Production. Diseases and pests were controlled as they occurred, in accordance with the recommendations of Integrated Protection of Fruit Plants. The orchard in which the observations were made is equipped with a system of sprinklers. These are VYR-33 sprinklers with a 4 mm diameter nozzle (Vyrsa – Spain), arranged at a spacing of 17.5 x 18.6 m, which ensures an average sprinkling intensity of 4 $mm \cdot h^{-1}$. In the spring, the system is used to protect plants from spring frosts, and during the rest of the growing season for irrigation. The Farm is under continuous monitoring of weather conditions by an iMetos1 (Pessl – Austria) on-site weather station. The data collected by the station are transmitted automatically to a server of the station's manufacturer. Access to the data, with a choice of reading the selected parameters, is obtained by logging in to a website and entering a personal access code.

On the night of 15 and 16 May 2015, the air temperature in the orchard began to fall rapidly, indicating the possibility of an impending frost. When the temperature readings showed values close to zero, the sprinkler system was activated at 11:30 p.m. on 15 May 2015, and was kept operating until 8:00 a.m. on 16 May 2015. Spring frost lasted for 7.5 h, 30 mm of water was applied to the trees (7.5 h x 4$mm \cdot h^{-1}$= 30mm). Due to a limited water supply, one row of sprinklers in each experimental sector (I and II) had not been activated, and thus some of the trees were not sprayed at all (Fig. 1). The fruit crop was harvested on 23 October 2015. Assessments of fruit yield and quality were performed for the protected trees – in the row with activated sprinklers (1), and for the unprotected control trees (2).

Fruit yield in $kg \cdot tree^{-1}$ was assessed individually for 15 randomly selected trees from a combination (3 replications, each with 5 trees per plot). Fruit size was determined by manual calibration of a sample of 100 apples from a combination. The apples were divided into seven size classes from 6 to 9 cm in diameter. Skin coloration was assessed visually on the same sample by dividing the apples into 4 classes representing <25%, 25-50%, 50-75%, > 75% of fruit surface covered with blush.

The results of measurements were presented graphically using STATISTICA 10.



Source: own study.

Figure 1. The intensity of spraying (mm).

RESULTS AND DISCUSSION

On the night of 15 and 16 May 2015, many orchards in Mazovia experienced a ground frost. Readings of meteorological stations (taken at a height of 2 m) showed a fall in air temperature below 0°C in Dębe (-3.2°C), Wójtostwo (-2.0°C), and Tymbark (-2.0°C). A still greater fall in temperature was recorded in Pęsy. The lowest temperature there at ground level was -4.6°C (measured with a 'manual' thermometer). According to the classification given by Koźmiński and Michalska (2010), the lowering of air temperature below -4.0°C is assessed as severe frost. The weather station in the orchard where the experiment was conducted is located within the working range of the sprinklers, and so the graph in Figure 2 shows the changes in temperature only in the protected area. It can be noted here that thanks to the operation of the sprinklers the temperature throughout the night did not fall below -1.0°C.

The assessment of fruit yield carried out in the autumn of 2015 demonstrated high effectiveness of the sprinkling used to protect apple trees against the spring frost. In Sector I (Idared I), an average of 147.9 apples were collected from each of the sprinkled trees, and only 17.4 (8.5 times fewer) from each tree in the control row. By comparison, in Sector II (Idared II) 45.13 apples were collected from each tree in the protected row, and only 3.2 (14 times fewer) from each tree in the control row (Fig. 3).

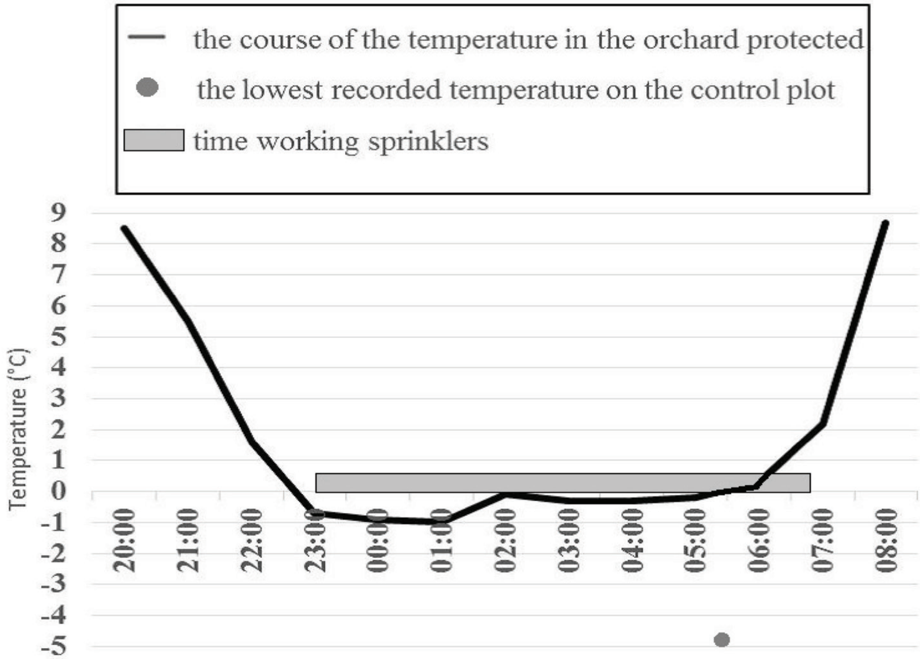


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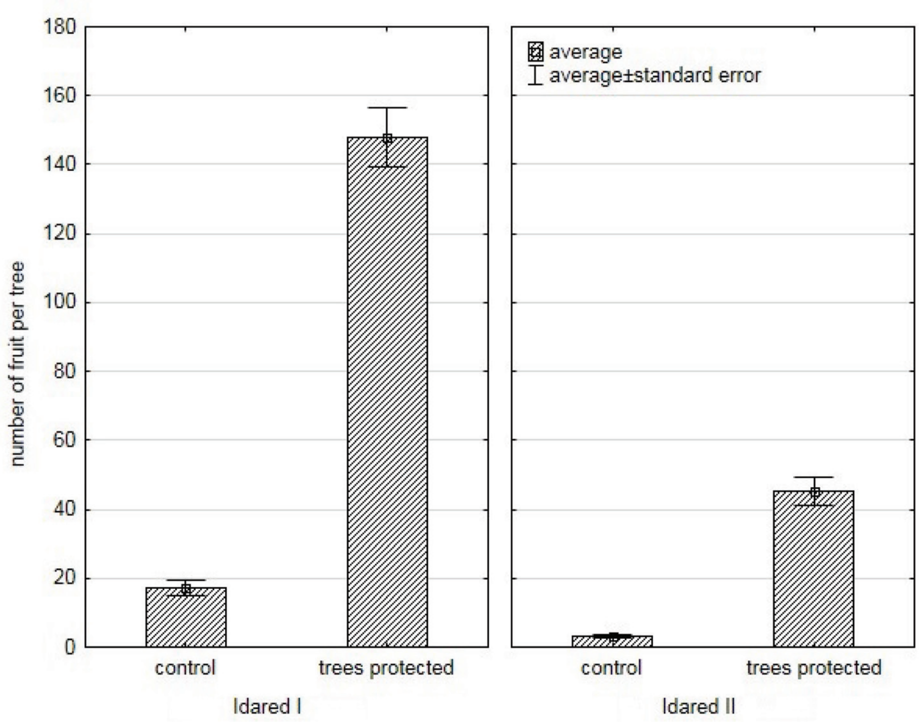
Figure 2. The changes in temperature in the protected area.

These considerable differences in the number of fruit per tree obviously influenced the yields produced by the trees. In Sector I (Idared I), the average yield from the protected trees amounted to 22.16 kg·tree^{-1} (57.6 Mg·ha^{-1}), and from the control trees to only 3.26 kg·tree^{-1} (8.5 Mg·ha^{-1}) (Fig. 4). Here the frost had damaged most of the flowers of the unprotected trees, which resulted in a decrease in yield of as much as 85.2%. The difference in yielding between the protected and control trees was in this sector as high as 49.1 Mg·ha^{-1}. In Sector II (Idared II), because of the smaller trees (less fertile soil), lower yields were obtained. But here also, the high usefulness of sprinkling for reducing frost losses was demonstrated. The average yield from the protected trees was 8.29 kg·tree^{-1} (21.5 Mg·ha^{-1}), and from the control trees only 0.58 kg·tree^{-1} (1.5 Mg·ha^{-1}). The frost reduced the yield here by as much as 93.3%. The difference in yielding between the protected and control trees in this sector was 20.0 Mg·ha^{-1}.

The frost that occurred locally on the night of 15 and 16 May 2015 was very severe. The documented reduction of 85.2-93.3% in the yielding of apple trees is even higher than the data presented in the work by Doroszewski et al. (2013) describing the losses caused by the frost that had occurred in 2011. In the region of Wielkopolska, where frost losses were then the highest, the Central

Statistical Office had estimated a decrease in apple fruit yields at 80.2%. The results obtained confirm the information published by Snyder and Melo-Abrau (2005) that, in the case of apple trees, a fall in temperature to -4.7°C during full blossom causes damage to at least 90% of the flowers.



Source: own study.

Figure 3. Effectiveness of the sprinkling used to protect apple trees against the spring frost (number of fruit per tree).

The smaller crop collected from the control row in Sector I (Idared I) was reflected in the size of the harvested fruit. For the control trees, the mean fruit weight was 187 grams, and for the sprinkled trees 150 grams. This kind of difference was not observed in Sector II (Idared II), where the mean fruit weight was 179 grams for the control trees, and 187 grams for the protected trees (Fig. 5). The size of apples is significantly dependent on the number of fruit per branch or tree. With too high a density of fruit, the harvested apples are smaller. The density of fruit in a tree can be assessed using the crop density coefficient (CD), which is expressed as the number of fruit per unit cross-sectional area of the tree trunk (no. of fruit per cm^2) (Treder et al. 1999). For the sprinkled trees in Sector

I (Idared I), the average CD coefficient was as high as 9.3 apples·cm^{-2}, whereas for the control trees it was only 1.1 apples·cm^{-2}. In Sector II (Idared II), this coefficient reached the values of 5.3 apples·cm^{-2} and 0.4 apples·cm^{-2}, respectively. According to Weber (1996), the optimal size of 'Idared' apples is 170 grams. The results obtained in the experiment show too large a number of fruit left on the protected trees in Sector I. It thus appears that sprinkling was such an effective method of protecting flowers from frost that in this particular case additional thinning of fruitlets would have been advisable.

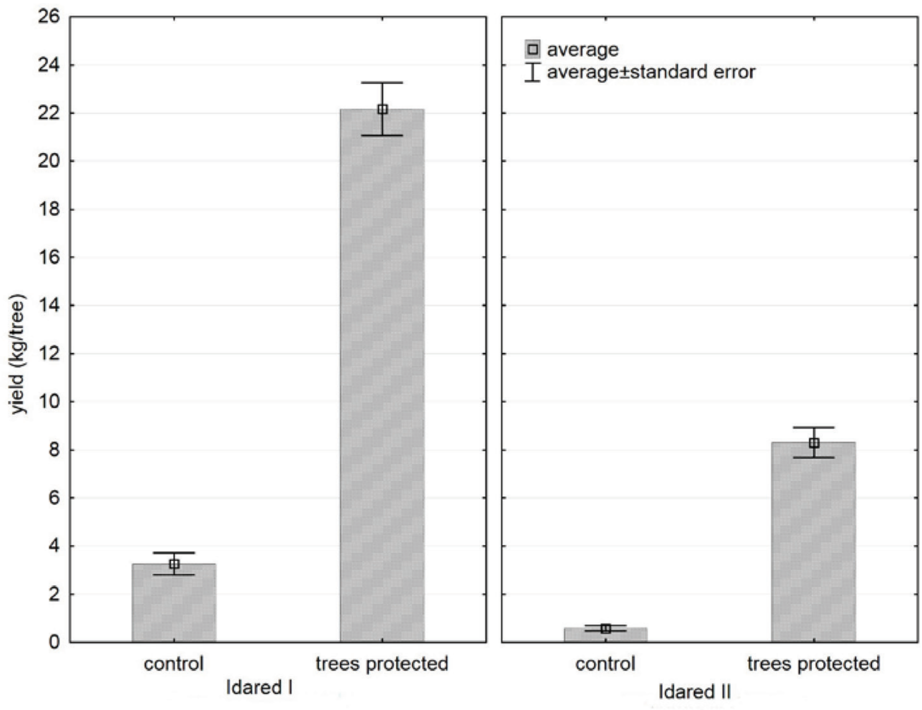


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Figure 4. The yields produced by the trees Idared.

Fruit quality was also assessed on the basis of calibration (size classes) and the extent of skin coloration. In Sector I (Idared I), in the protected row, the highest percentage of apples (46%) did not exceed a diameter of 7 cm, and 22.3% of apples were in both the 6.0-6.5 cm and 7.0-7.5 cm diameter classes; the lowest percentage of only 2.9% were classified into the diameter class of 7.5-8 cm. Larger apples were not found in this combination. In the control row of Sector I (Idared I), the majority of apples were large, with a diameter of 7.5-8 cm – 23.9%, 8.0-8.5 cm – 24.8%, and 8.5-9 cm – 10.1%. In the classes of medium-size fruit with a diameter of 6.5-7 cm and 7.0-7.5 cm there were 16.5% and 11.9% of apples, respectively, and in the small fruit classes of <6.0 cm – 5.55% and 6-6.5 cm – 7.34%. In Sector II (Idared II), with a lower crop density, there was evidently a greater share of large fruit. In the protected row, the highest percentage of apples (45.4%) did not exceed a diameter of 8 cm; 22.7% of apples were in the 8.0-8.5 cm class, and 22.7% were 7.0-7.5 cm in diameter; the lowest percentage of 4.12% of apples were in each of the 8.5-9 cm and 6.5-7 cm diameter classes (smaller apples were not found). In the control row of Sector II (Idared II), the majority were apples with a diameter of 7.5-8 cm – 35.6%; 7.0-7.5 cm – 26.7%; 8.0-8.5 cm – 17.8%; 8.5-9 cm – 2.2%. In the 6.5-7 cm diameter class there were 15.6% of the harvested apples, and in the small fruit class of <6.0 cm – 2.2% (Fig. 6).

The pairwise meanings in the same letters do not differ significantly P = 0.05, Duncan's test

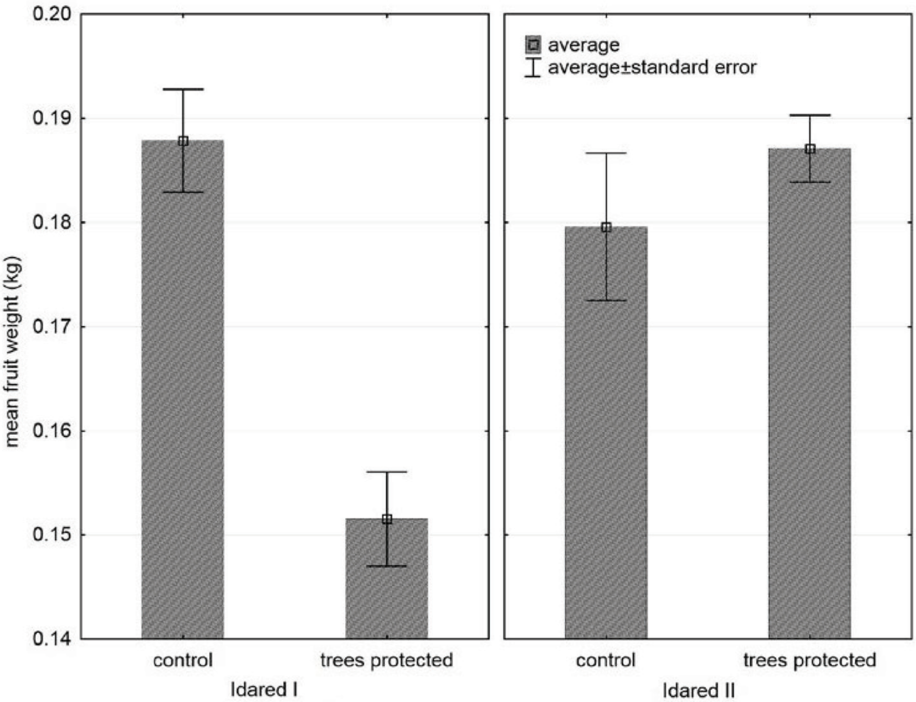

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Figure 5. The size of the harvested fruit.

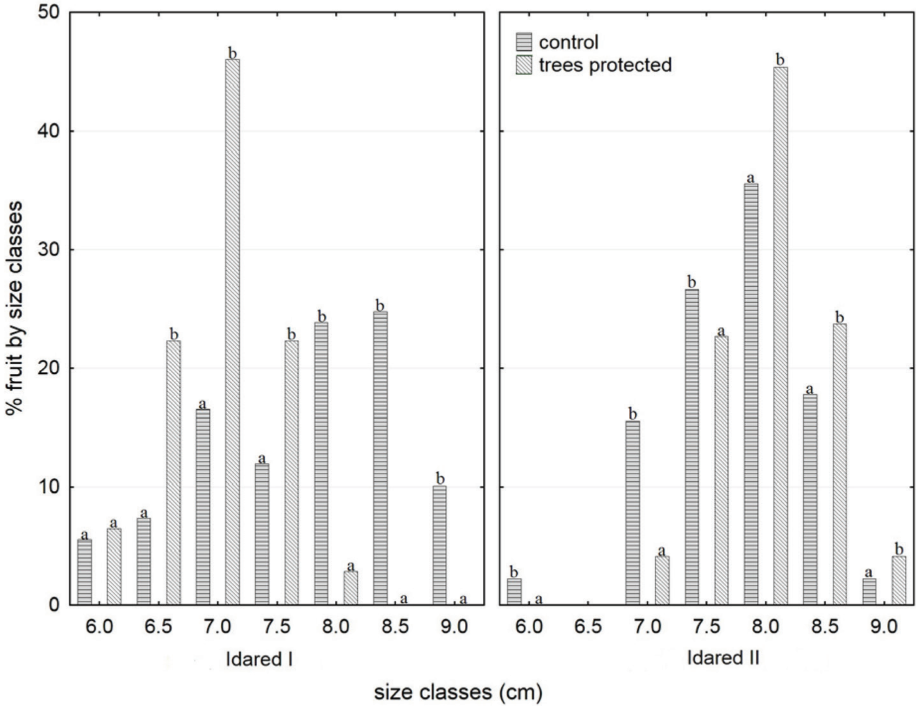

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Figure 6. Fruit quality in size classes.

The extent of coloration of the harvested apples was assessed in four classes: 0-25%, 25-50%, 50-75%, and 75-100% of fruit surface covered with blush. In Sector I (Idered I), in the protected row, almost 40% of apples were in the blush coverage class of 25-50%, 47% were in the 50-75% class, and only 13% were covered with blush to the extent of 75-100%. In the control row, 9% of apples were 25-50% coloured, 45% showed 50-75% blush coverage, and 46% of apples were covered with blush to the extent of 75-100%. In Sector II (Idared II), in the protected row, 14% of apples were 25-50% coloured, 59% were 50-75% coloured, and only 27% were covered with blush to the extent of 75-100%. In the control row, 47% of apples were in the 50-75% coloration class, and 53% showed blush coverage of 75-100% (Fig.7). Regardless of the experimental combination, the harvested ‘Idared’ apples showed no damage that might have been caused by the fall in air temperature. However, this type of damage was seen in the same orchard on the fruit of the cultivar ‘Alwa’ (not part of this experiment). The better colour development on apples from the control trees was due to their location in the tree. The control trees set fruit only in the upper part of the canopy where, in the course of colour development, the fruits were not shaded by the leaves. All of the flowers located in the lower part of the canopy had been damaged by the frost. This is confirmed by the widely known fact that during frosts the lowest temperatures occur at ground level (Doroszewski *et al*. 2013).

The pairwise meanings in the same letters do not differ significantly P = 0.05, Duncan's test

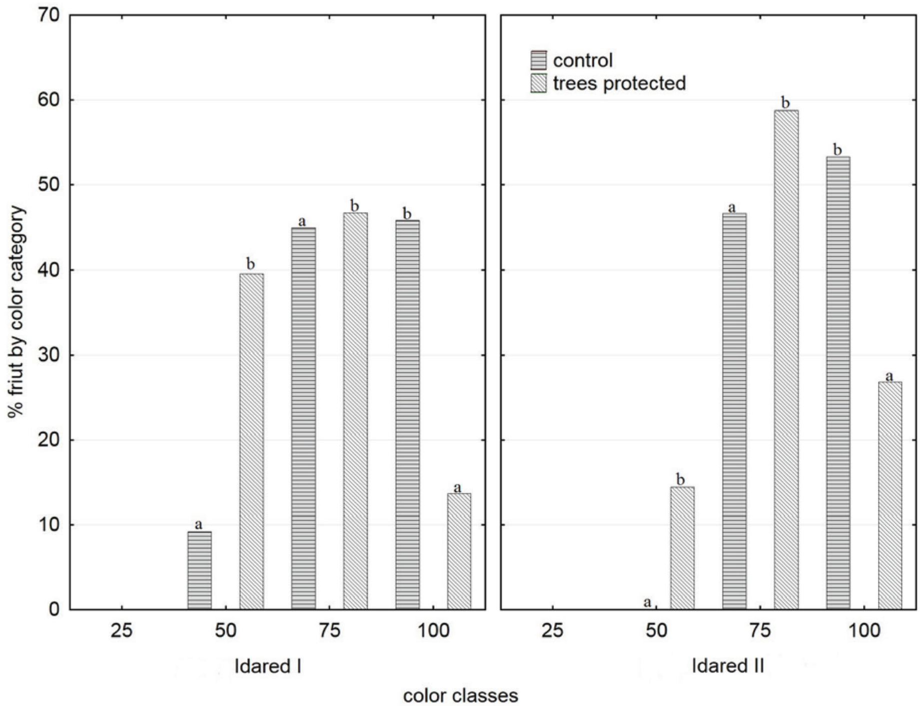

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Figure 7. Coloration of the harvested apples.

SUMMARY

Sprinkling is an effective way to protect apple trees against spring frost. With a drop in air temperature to -4.6°C at the ground, sprinkling with a precipitation intensity of 4 mm·h^{-1} practically eliminated frost losses, which in unprotected areas ranged from 85-93%.

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