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Pistachio frost damage in Iran and new methods of frost protection

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Abstract. Because of global warming as levels of CO_2 concentration rise, climate has changed nowadays. With climate change we can expect increased damage to orchards, such as increased winter and spring frost, summer droughts, storms, and increased damages from fungi and insect attacks. Particularly in winter we can expect a temperature increase, and the trees natural annual rhythm will gradually fall further out of step with the climate of the region. Higher winter temperatures will reduce the hardiness and lead to an earlier growth start. The tree mechanisms for avoiding such damage do not appear to be able to prevent this. First, trees can have problems with de-hardening in mild weather periods and frost damage in the subsequent cold periods. Particularly unfortunate are fluctuations between above- and below-freezing temperatures (thaw-freeze cycles) for trees that are adapted to a continental climate. In the south and west parts of Iran, there has been a wide-spread and increasing problem with such damage over several years. In average 50% of pistachio was damaged by spring frost in the last five years. New methods of frost protection were applied in the last few years for controlling frost damage in pistachio orchards in Kerman province. One of these methods was the design and manufacturing of a SIS (selective inverted sink) system and testing it in pistachio orchards. Results showed that this system can protect orchards and can increase temperature by 2℃. The other system was the fogger machine. This system was also designed and manufactured and tested in pistachio orchards. The results of this system showed 11.5% increase in relative humidity and 1.9℃ increase in temperature of orchards. The new methods of frost control in orchards in Iran are explained in this paper and the importance of frost damage in horticultural plants in Iran is discussed.

Keywords. Horticulture – Iran – Frost damage – Control – SIS – Fogger machine.

Dégâts du gel sur les pistachiers en Iran et nouvelles méthodes de protection contre le gel

Résumé. *En raison du réchauffement global et des niveaux plus élevés de concentration de CO_2, le climat a changé de nos jours. Nous pouvons attendre des dégâts accrus sur les vergers – comme l'augmentation du gel en hiver et au printemps, la sécheresse en été, les orages, et des dommages accrus dus aux champignons et attaques d'insectes. C'est en particulier en hiver que nous pouvons nous attendre à une augmentation de la température, et le rythme annuel normal des arbres sera de plus en plus décalé par rapport au climat de la région. Les températures plus élevées en hiver réduiront la robustesse et mèneront à un début de croissance plus précoce. Les mécanismes de l'arbre pour éviter un tel dommage ne semblent pas pouvoir empêcher ceci. D'abord, les arbres peuvent avoir des problèmes avec la perte de durcissement lors des périodes de temps doux et des dommages de gel dans les périodes froides subséquentes. Les fluctuations entre températures positives et négatives sont particulièrement dommageables (cycles de gel et dégel) pour les arbres adaptés à un climat continental. Dans la région du sud et de l'ouest iranien, il y a eu un problème répandu et croissant de ce type de dommage sur plusieurs années. En moyenne 50% des pistachiers ont été endommagés par les gelées de printemps lors des cinq dernières années. De nouvelles méthodes de protection contre le gel ont été appliquées en vergers de pistachiers dans la province de Kerman. Une de ces méthodes consistant à concevoir et fabriquer un système de SIS (ventilateur à inversion sélective) a été examinée dans des vergers de pistachiers. Les résultats ont montré que ce système peut protéger les vergers en augmentant la température de 2℃ en moyenne. L'autre système était un nébulisateur. Ce système a également été conçu, fabriqué et testé en vergers de pistachiers. Les résultats de ce système ont également montré une augmentation de 11,5% de l'humidité relative et de 1,9℃ de la température du verger. Cet article présente les nouvelles méthodes de lutte contre le gel dans les vergers en Iran et examine l'importance des dommages du gel sur les cultures horticoles en Iran.*

Mots-clés. *Horticulture – Iran – Dommages du gel – Méthodes de protection contre le gel.*

I – Introduction

Pistachio (*Pistacia vera* L.) has been grown commercially in Iran for many years and, currently, pistachio plantations encompass about 470,000 ha with an annual production of around 200,000 t of pistachio nuts. Kerman province is one of major pistachio production and exportation areas in Iran and all around of world. The second and third provinces in pistachio production in Iran are Yazd and Khorasan respectively. One of the major problems arising in some pistachio cultivation areas includes different levels of injuries caused by lower temperatures in early spring. In average 50% of pistachio was damaged by spring frost in the last five years. Just in Kerman province the data showed more than 60% of frost damage in 2004 and 2005. In 2004, 420 million dollars frost damage in pistachio was observed in Kerman province. Although pistachio does not bloom as early as almond and apricot, with climate change we can expect increased damages to orchard, such as increased winter and spring frost, summer droughtd, storms, and increased damages from fungi and insect attacks. It is particularly in the winter that we can expect a temperature increase, and the trees' natural annual rhythm will gradually fall further out of step with the climate of the region. Higher winter temperatures will reduce the hardiness and lead to an earlier growth start. The tree's mechanisms for avoiding such damage do not appear to be able to prevent this. First, trees can have problems with de-hardening in mild weather periods and frost damage in the subsequent cold periods. This phenomena potentially increase frost damage to pistachio especially in southern and eastern areas of pistachio plantation. In this paper symptoms of frost damage in pistachio orchard, critical temperatures and levels of resistance in different cultivars and new methods of frost protection will be discussed.

II – Symptoms of frost damage

Spring chilling adversely affects phenomena involved in fruit set and development processes such as pollination rate and fertilization quality. In some years, final total yield is also severely influenced by this stress and alternate bearing is accelerated and increased. These damages occur through decreasing fruit set rate (through stigma and style deterioration, decreasing ovary reception period and flower age, and increasing pollen tube growth period), female flower abscission and inflorescence die back (Fig. 1). Flower buds' death and abscission can also happen increasing the alternate bearing rate of the tree.

III – Critical temperature and levels of resistance in different cultivars

Chilling may adversely affect the reproductive structures in different thermal basis and morphological-anatomical levels. The most severe injuries (from lower to higher temperatures) were deterioration and necrosis of complete flower buds, current spring shoot (containing inflorescences), inflorescence, pistil style, and stigma, respectively based on three main phenological stages, bud, blooming bud and bloomed flowers. Critical temperatures for reversible (tissue color change) and irreversible (tissue browning) damages are explained below.

Flower buds' chilling resistance is the highest among all reproductive structures. Their resistance, however, decreases as they finish their dormancy, especially just before blooming. Light injury (low to about -4^{o}C for about 2 h) can lead to their delayed bloom with some blooming and flowering abnormalities. Deeper injuries (-4 to -6 ^{o}C for about 6 hours) resulted in the necrosis and deterioration of very young pistils in closed buds. Complete necrosis of flowers, and then, inflorescence, was caused by about -4 for about 2h. Research showed no significant difference in resistance to frost damage between four cultivars including, Kalleh-Ghouchi, Ahmadaghaie (Hazzanzadeh, *et al*., 2007), Ouhadi and Ghazvini (Ghoilipour, 2006).

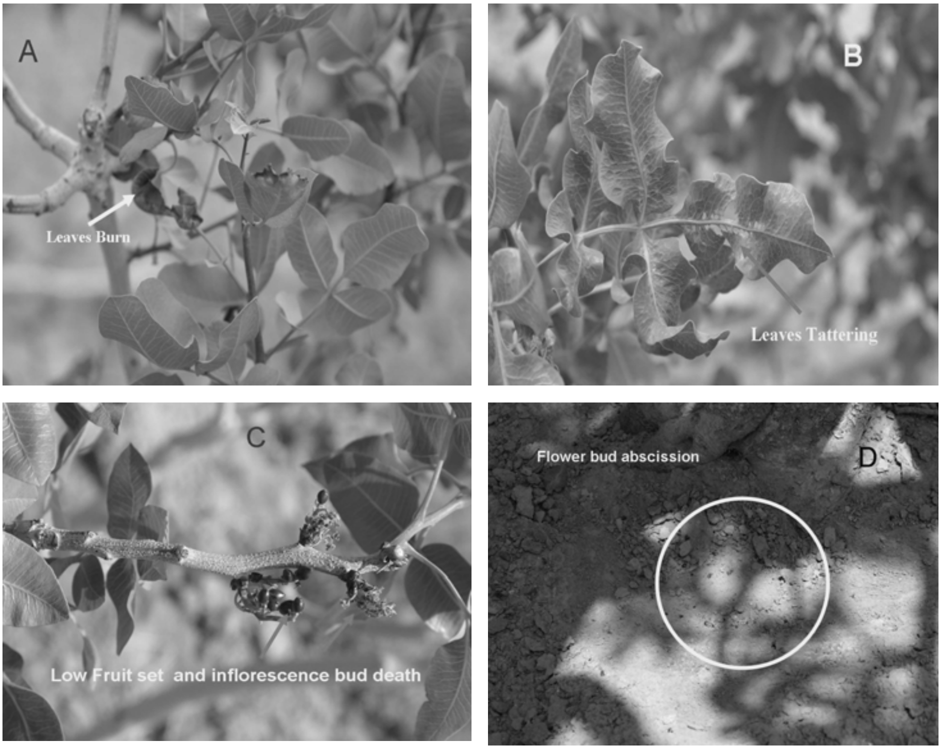

Fig. 1. Different symptoms of frost damage in pistachio orchards in the last few years of stress. A: leaves burring; B: leaves tattering; C: poor fruit set and flower bud die back`; and D: flower bud abscission).

IV – Methods of protection

Radiation frosts are common occurrences in Southeastern part of pistachio cultivation area of Iran. They are characterized by clear skies, calm winds, and temperature inversions. Radiation frosts occur because of heat losses in the form of radiant energy. Under clear, nighttime skies, more heat is radiated away from an orchard than the heat that it receives, so the temperature drops. The temperature falls faster near the radiating surface causing a temperature inversion. Most frost protection methods are more effective during low ceiling, strong inversion conditions. Many methods of frost protection were investigated in the last few years, some of which are be discussed here.

1. Orchard soil management

In an experiment different soil management alternatives were investigated to find and recommended the better management option for heat energy saving for growers and to protect pistachio from spring frost. Results revealed that a weed- free, firm, moist soil can add 1 to 1.7 degrees of protection during a radiation frost/freeze event (Table 1). Soils which are dry, freshly cultivated or covered with live or dead grass give the opposite effect. Also important is the fact that wet or moist soils have a higher heat capacity than dry soils, and packed soils are able to absorb more heat than recently cultivated soils. This means that clean, moist, and packed soil surfaces will absorb more radiant energy during the day, and protect from frost by releasing this heat during the night. In general, unmowed cover crops are cooler than mowed covers, which are cooler than loose cultivated soils. Packed bare soils are warmer than loose soils and wet soils are the warmest of all (Snyder and Connell, 1993).

Table 1. Comparison of minimum temperatures of soil surfaces under various types of floor management practices

Bare, firm moist ground	1.7ºC Warmest
Shredded cover crop, moist ground	1ºC colder
Low cover crop, moist ground	1.1ºC colder
Dry, firm ground	1.2ºC colder
Freshly disked ground	0.9ºC colder
Higher cover crop	1.3ºC colder

2. Smoke effects

Many pistachio growers tried burning old rubber tires for frost protection. Few growers found effects of old rubber tires smoking in frost protection. Also some growers used pistachio debris (including shell, bank pistachio, hull debris and …) for protection. They used the debris in a bag mixing with some fuel and water. Some growers used this kind of protection in last few years and found good results of protection. In order to asses the smoke effect on pistachio orchard frost protection an experiment was carried out in 2006 in Iran's Pistachio Research Institute (IPRI). Old rubber tires and pistachio debris put in a bag mixed with 4 litres of water and fuel was compared with control in terms of increasing of orchard temperature. Results indicated that old rubber tires had negligible effect on the apparent orchard temperature (Fig. 2), however pistachio debris in the bag increased 0.5 to 3.5ºC compared to control (Fig. 2). Studies have shown that the dimension of the average smoke particle is less than 1.0 mm diameter (Mee and Bartholic, 1979), which reduces radiation in the visible range (0.4-0.7 mm) but has little effect on transmission of long-wave radiation. Therefore, upward long-wave radiation from the surface mainly passes through the smoke without being absorbed. Consequently, old rubber tires smoke has little effect on upward or downward long-wave radiation at night and hence has little benefit for frost protection. Because smoke offers little or no benefit and it pollutes the air, it is better to minimize smoke production and maximize thermal efficiency of the combustion. Also smoke at sunrise blocks solar radiation and delays heating of the crop, which can lead to higher fuel consumption and possibly more damage. However, regarding using of debris we found good results of protection. Mixing of water with smoke may increase the diameters of smoke particles and this increase protection. But as orchards are small and close to roads, smoke has been known to cause automobile accidents, which led to serious legal problems. Consequently, smoke generation is not recommended for frost protection.

3. Orchard heater with solid fuel

One method to replace the losses of energy from a crop, in a frost situation, is to compensate it with the massive use of fuel (solid, liquid or gas) burnt in heaters of various types. In an experiment the effect of a small heater (Fig. 3) with coke fuel was investigated in 2005. Results showed that 65 heaters per hectare can increase orchard temperatures at least $2^{o}C$ and can save and protect orchard of radiation frosts. It was discovered that the ratio of radiation to total energy released was about 40 percent for burning solid fuels (e.g. wood, coal and coke) in comparison with 25 percent for burning liquid fuels (Kepner, 1951), so there was a revival in the use of solid fuels. The main disadvantage of solid fuels is that the energy release diminishes as the fuel is used up, and energy release thus becomes limiting when most needed (Hensz, 1969; Martsolf, 1979). Another drawback is that solid fuels are difficult to light, so they must be started early. They are also difficult to extinguish, so fuel is often wasted if started when unnecessary.

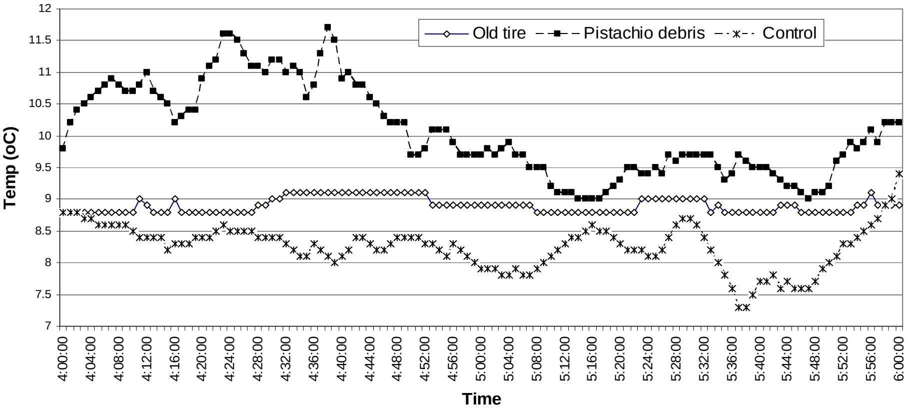

Fig. 2. Smoke effects of old rubber tires and pistachio debris in orchard temperatures and frost protection.

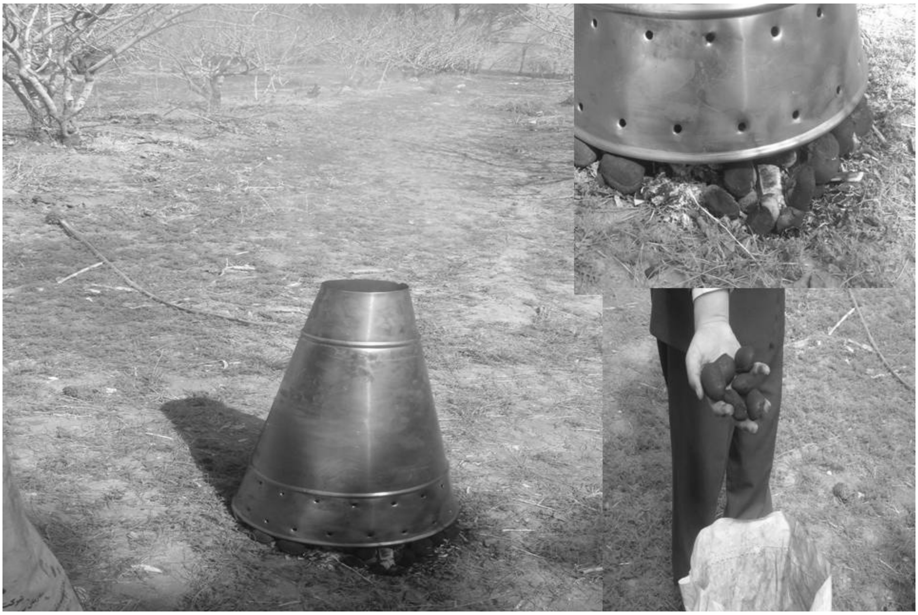

Fig. 3. Orchard heater with solid fuel using for pistachio orchard frost protection.

4. Technical investigation of using a fog producer machine to protect pistachio orchards from spring frost damage

Natural fog is known to provide protection against freezing, so artificial fogs have also been studied as possible methods against frost damage (McGill, 1984). Fog lines that use high-pressure lines and special nozzles to make small (i.e. 10 to 20 mm diameter) fog droplets have been reported to provide good protection under calm wind conditions (Mee and Bartholic, 1979). In this research a designed and manufactured fog machine was used in pistachio orchards. This machine was moved by tractor between tree rows using PTO of tractor to move a fan (2000 rpm) that took warm air from inversion layer and pulled it by 479 $m^3.h^{-1}$ and created a wind of 120 $km.h^{-1}$ speed (Fig. 3). This machine covered 6 ha of orchards in 45 min with tractor speed of 5 km/h^{-1}. The machine was used in one pistachio orchard in Rafsanjan and evaluated in 2006 and 2007. During the experiment four data loggers were installed beside flower buds one meter above ground and registered temperature in a minute interval as fog machine operated, whereas one data logger registered temperature of the control orchard. Results showed that in both years the fog machine increased in average 1.6ºC temperature and 12% relative humidity, compared to the control orchard.

Fig. 3. Designed and manufactured fog machine was used in pistachio orchards frost protection.

5. Evaluation of Selective Inverted Sink (SIS) System to protect pistachio orchards from spring frost

The SIS technology was developed in Uruguay by Dr. Rafael Guarga in 1991. SIS Frost Protection has been successfully used for over 15 years in nine countries, including Argentina, Australia, Canada, Chile, New Zealand, South Africa, Spain, United States and Uruguay. It is currently being used to protect almonds, apples, apricots, avocados, berries, cherries, grapes, kiwi, lemons, plums, nectarines, oranges, and more. This system was designed and manufactured in Iran's Pistachio Research Institute (IPRI) during of 2005 and the evaluation was carried out for two years and now this system is produced in Iran under license of IPRI. Its (5kW, 7hp) motor drives a fan positioned horizontally which acts to suck in cold air at ground level, pushing it up through the inversion layer present during radiation frosts. As the cold air moves in toward the SIS unit, warmer air follows in behind, pulled down from above the inversion layer. In this research we tested two systems of SIS, one of them working with electricity as power and the other using PTO of tractor as power (Fig. 4). Both systems were installed in one of pistachio orchard in Sirjan pistachio area and both systems were evaluated in 2006 and 2007. During the system turning on, four data loggers that were installed beside flower buds one meter above ground registered temperature in a minute interval in the SIS operated orchard and one data logger registered temperature of the control orchard. Results showed that in average both SIS systems increased temperature 2ºC in average, 3.2º maximum and 0.3º minimum compared to the control (Fig. 5). Similar results were obtain by Guarga *et al.*, in 2002.

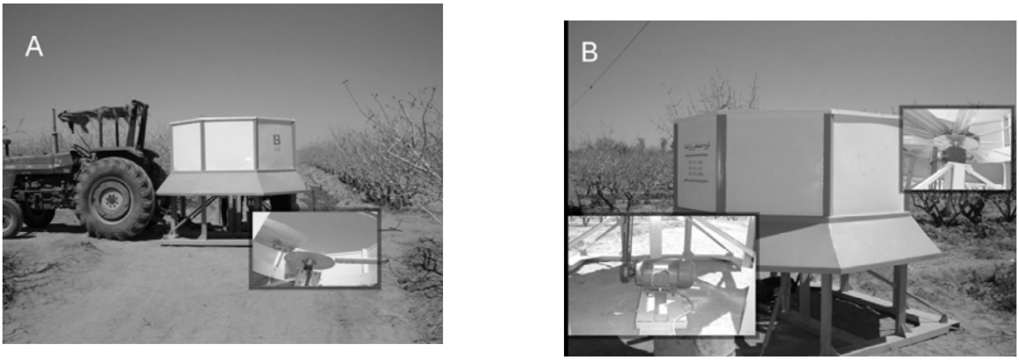

Fig. 4. SIS system for protection of pistachio orchard from frost damage. A: SIS with electricity as power; and B: SIS system using PTO of tractor as power.

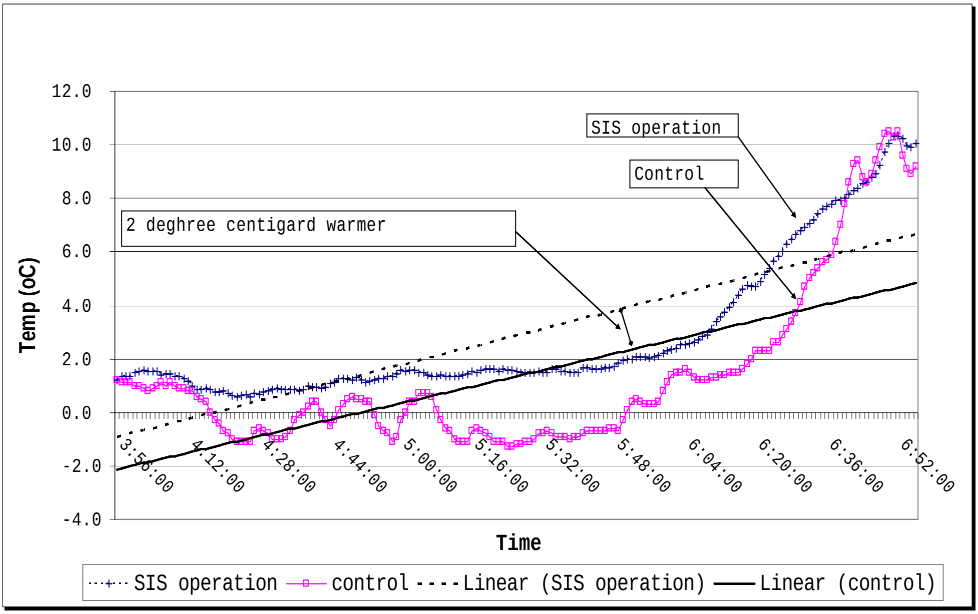

Fig. 5. Observed temperature behavior with SIS operation and in control (no SIS operation).

V – Conclusion

Because of global warming and climate change, potential risk of low temperature damages may increase in pistachio trees and growers must know methods of protection and as well passive methods of protection to prevent frost damage in pistachio orchards. Critical temperature in

Iranian commercial pistachio cultivars at bloomed flower period is about -1.7 ^{o}C. However for better protection, growers are recommended to use fog machine and SIS system.

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