THE EFFECT OF WILT-PRUF, ANTITRANSPIRANT ON
REDUCING WATER LOSS OF APPLE TREES

by
Hassan A. Nammah

A thesis submitted in partial fulfillment
of the requirements for the degree
of
MASTER OF SCIENCE
in
Plant Science
(Horticulture)

UTAH STATE UNIVERSITY
Logan, Utah
1979
ACKNOWLEDGMENTS

I would like to express my sincere gratitude to my major professor, Dr. David R. Walker, for his diligent help, advice, patience, encouragement, directing the thesis, and clearing most of the difficulties that I have encountered. He has been a great teacher, a kind father, and a good friend.

I would also like to thank my Graduate Committee, Dr. Herman H. Wiebe, for his valuable suggestions encouragement at all stages of the work, and generosity of his time and assistance; Dr. LaMar A. Anderson for his cooperation, valuable suggestions and his interest.

I also wish to express my sincere appreciation to Dr. Schuyler D. Seeley for his wise suggestions, cooperation, and advice.

I am thankful to the government of Iraq for providing me with complete financial support during my study.

My gratitude is expressed to all faculty members of the Department of Plant Science at Utah State University for their wise instructions and friendly cooperation.

Thanks is given to Mrs. Betty Smith for her typing assistance.

Sincere thanks are extended to my wife, Omaima Al-Jabouri, for her constant encouragement and help and to my son, Ahmad, for allowing me the time away from him that was needed for completing this study.

Hassan A. Nammah
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Acknowledgments</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>List of Tables</td>
<td>v</td>
</tr>
<tr>
<td>List of Figures</td>
<td>vii</td>
</tr>
<tr>
<td>Abstract</td>
<td>ix</td>
</tr>
</tbody>
</table>

**Chapter**

I. INTRODUCTION .................................. 1

II. LITERATURE REVIEW .............................. 3

   - Applying Antitranspirants .................. 3
   - Temperature and Transpiration .............. 4
   - Diffusive Resistance and Plant Water Potential 6
   - Fruit Trees .................................. 11

III. METHODS AND MATERIALS ......................... 13

   - Laboratory Equipment ...................... 13
   - Field Experiment .......................... 14
     - A. Irrigated Treatments .................. 14
     - B. Unirrigated Treatments ............... 18

IV. RESULTS ........................................ 20

   - Laboratory Experiment .................... 20
   - Field Experiment .......................... 20
     - A. Irrigated Treatments .................. 20
     - B. Unirrigated Treatments ............... 37

V. DISCUSSION ...................................... 50

   - Laboratory Experiment .................... 50
   - Field Experiment .......................... 51

VI. CONCLUSIONS ................................... 56

   - Laboratory Experiment .................... 56
   - Field Experiment .......................... 56
TABLE OF CONTENTS (Continued)

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>LITERATURE CITED</td>
<td>58</td>
</tr>
<tr>
<td>APPENDIX</td>
<td>62</td>
</tr>
<tr>
<td>Appendix I</td>
<td>63</td>
</tr>
<tr>
<td>VITA</td>
<td>65</td>
</tr>
</tbody>
</table>
# LIST OF TABLES

<table>
<thead>
<tr>
<th>Table</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Effect of antitranspirant (wilt-pruf) on water loss of one-year-old Malling 106 apple trees</td>
<td>22</td>
</tr>
<tr>
<td>2. Effect of antitranspirant (wilt-pruf) effects on diffusive resistance and water potential of four-year-old Golden Delicious apple trees 9 days after treatment (unirrigated treatment)</td>
<td>26</td>
</tr>
<tr>
<td>3. Effect of antitranspirant (wilt-pruf) on stem water potential of four-year-old Golden Delicious apple trees (irrigated treatment)</td>
<td>30</td>
</tr>
<tr>
<td>4. Effect of antitranspirant (wilt-pruf) on the temperature of four-year-old Golden Delicious apple trees (irrigated treatments)</td>
<td>32</td>
</tr>
<tr>
<td>5. The average soil moisture at the 0-160 cm depth of the irrigated soil at the end of the experiment. Antitranspirant (wilt-pruf) was sprayed on the four-year-old Golden Delicious apple trees growing in the soil (irrigated treatment)</td>
<td>34</td>
</tr>
<tr>
<td>6. Effect of antitranspirant (wilt-pruf) on the soluble solids in four-year-old Golden Delicious apple trees (irrigated treatments)</td>
<td>36</td>
</tr>
<tr>
<td>7. Effect of antitranspirants (wilt-pruf) on leaf diffusive resistance and water potential of four-year-old Golden Delicious apple trees 9 days after treatments (unirrigated treatments)</td>
<td>39</td>
</tr>
<tr>
<td>8. Effect of antitranspirant (wilt-pruf) on stem water potential of four-year-old Golden Delicious apple trees (unirrigated treatments)</td>
<td>43</td>
</tr>
<tr>
<td>9. Effect of the antitranspirant (wilt-pruf) on the leaf temperature of four-year-old Golden Delicious apple trees (unirrigated treatments)</td>
<td>45</td>
</tr>
<tr>
<td>10. The average soil moisture at the 0-160 cm depth of the unirrigated soil at the end of the experiment. Antitranspirant (wilt-pruf) was sprayed on four-year-old Golden Delicious apple trees growing in the soil (unirrigated treatment)</td>
<td>46</td>
</tr>
<tr>
<td>Table</td>
<td>Page</td>
</tr>
<tr>
<td>--------</td>
<td>------</td>
</tr>
<tr>
<td>11. Effect of antitranspirant (wilt-pruf) on the soluble solids in four-year-old Golden Delicious apple trees (unirrigated treatments)</td>
<td>49</td>
</tr>
<tr>
<td>Figure</td>
<td>Description</td>
</tr>
<tr>
<td>--------</td>
<td>------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>1.</td>
<td>Four-year-old tagged Golden Delicious apple fruit diameters were measured with calipers as shown in the photo.</td>
</tr>
<tr>
<td>2.</td>
<td>Four-year-old Golden Delicious apple trees are shown in the photo with polyethylene covering the ground for 2.4 m (8 ft) on either side of the trees (unirrigated treatment).</td>
</tr>
<tr>
<td>3.</td>
<td>Effect of antitranspirant (wilt-pruf), 15% concentration, on rootstock apple trees (M106) after 10 days is shown in the photo on the right, as compared with untreated trees shown on the left.</td>
</tr>
<tr>
<td>4.</td>
<td>Effect of antitranspirant (wilt-pruf) on transpiration of one-year-old M106 apple trees. Data recorded 1 day after treatment.</td>
</tr>
<tr>
<td>5.</td>
<td>Effect of antitranspirant (wilt-pruf) on leaf diffusion resistance of four-year-old Golden Delicious apple trees.</td>
</tr>
<tr>
<td>6.</td>
<td>Effect of antitranspirant (wilt-pruf) on leaf water potential of four-year-old Golden Delicious apple trees (irrigated treatments).</td>
</tr>
<tr>
<td>7.</td>
<td>Effect of antitranspirant (wilt-pruf) on stem water potentials of four-year-old Golden Delicious apple trees (irrigated treatments).</td>
</tr>
<tr>
<td>8.</td>
<td>Effect of antitranspirant (wilt-pruf) on the temperature of four-year-old Golden Delicious apple trees (irrigated treatments).</td>
</tr>
<tr>
<td>9.</td>
<td>Effect of antitranspirant (wilt-pruf) on growth of four-year-old Golden Delicious apple trees (irrigated treatments).</td>
</tr>
<tr>
<td>10.</td>
<td>Effect of antitranspirant (wilt-pruf) on leaf diffusive resistance of four-year-old Golden Delicious apple trees (unirrigated treatments).</td>
</tr>
<tr>
<td>11.</td>
<td>Effect of antitranspirant (wilt-pruf) on leaf water potentials of four-year-old Golden Delicious apple trees (unirrigated treatments).</td>
</tr>
<tr>
<td>Figure</td>
<td>Description</td>
</tr>
<tr>
<td>--------</td>
<td>-----------------------------------------------------------------------------</td>
</tr>
<tr>
<td>12.</td>
<td>Effect of antitranspirant (wilt-pruf) on stem water potentials of four-year-old Golden Delicious apple trees (unirrigated treatments)</td>
</tr>
<tr>
<td>13.</td>
<td>Effect of antitranspirant (wilt-pruf) on growth of four-year-old Golden Delicious apple trees (unirrigated treatment)</td>
</tr>
</tbody>
</table>
ABSTRACT

The Effect of Wilt-pruf, Antitranspirant on Reducing Water Loss of Apple Trees

by

Hassan A. Nammah, Master of Science
Utah State University, 1979

Major Professor: Dr. David R. Walker
Department: Plant Science

The influence of different concentrations of a film-forming antitranspirant (Wilt-Pruf) on the transpiration rate of young apple trees (M106) was studied. One-year-old Malling 106 trees were potted in 10.2 cm (4 inch) metal pots. The plants were placed in a controlled environmental chamber during the study period. Sufficient reductions in water loss resulted with all concentrations of Wilt-Pruf with a 63 percent reduction at the highest concentration. Phytotoxicity was not observed though the higher concentrations imparted a sticky film to plants and they appeared to be lighter green at the end of the test. The effect of Wilt-Pruf on four-year-old apple trees (Golden Delicious) was conducted in August 1977 at Utah State University Experimental Farm in Farmington, Utah. The resistance to water vapor diffusion from the leaves was increased on both Wilt-Pruf treated irrigated and unirrigated trees, and water balance was improved, increasing leaf and stem water potential. The improved water balance of treated apple trees resulted in fruit size
increase. The higher concentration of antitranspirant in both irrigated and unirrigated apple trees resulted in a higher leaf temperature than the irrigated control.
CHAPTER I
INTRODUCTION

Less than 1% of the water absorbed by plant roots is retained within the plant and a much smaller percentage is in the harvested crop. Thus, water use by plants actually constitutes the least efficient step in the system of precipitation, collection, water storage, conveyance, irrigation, and conversion to the harvested crop.

The possibility of reducing plant transpiration, thus saving water and also alleviating the adverse effect of water imbalance on plant growth when transpiration exceeds the rate of water uptake, presents a tremendous challenge in the Intermountain West, which is increasingly plagued with dwindling water resources.

Agriculturists and horticulturists have been interested in using antitranspirants for years, but despite this interest [dating back to the Theophrastus in 300 B.C. (Wills, Favis and Funderburk 1963)], little research has been conducted until recently.

Antitranspirants are chemicals capable of reducing transpiration rates when applied to plant foliage. They provide physical resistance to water vapor diffusion at the transpiring surface, thereby minimizing the transpiration rate (Davenport, Uriu and Hagan 1975, Martin and Link 1973, Davenport, Martin and Hagan 1976). Since water loss normally occurs through the stomatal pores in the leaves, antitranspirants are usually applied as foliar sprays.
Plant growth depends basically on: (1) the accumulation of raw materials, particularly through photosynthesis, for cell production, and (2) the enlargement of these cells during high turgor pressure, which is associated with high plant water potential (Kramer 1969, Boyer 1970). Gale and Hagan (1966) reported several investigations showing that photosynthesis from individual leaves or plants is slowed by antitranspirants of the film-forming and stomatic-inhibiting types. Davenport, Uriu and Hagan (1974) observed that the antitranspirants increased water potential not only in the leaves but also in the fruit by increasing the resistance to water vapor diffusing from leaves. Davenport, Fisher and Hagan (1972), Davenport, Uriu and Hagan (1972), Davenport, Uriu, Martin and Hagan (1972) reported several investigations showing that reducing transpiration would also increase the plant water potential which can enhance the growth of fruit and shoots. Creasy (1976) observed that antitranspirants improve the red color of McIntosh apples.

While use of antitranspirants is not very widespread at present, future use may increase as concern over water resources continues.
CHAPTER II
LITERATURE REVIEW

An explanation of antitranspirant use and effect on plants requires an understanding of how the antitranspirants work. This review will provide a survey of the more recent investigations dealing with the effects of antitranspirants on the plant.

There are three types of antitranspirants: (1) reflecting materials which reduce the adsorption of radiant energy and thereby reduce leaf temperatures and transpiration rates; (2) emulsion of wax, latex or plastics which dry on the foliage to form a thin transparent film which hinders the escape of water vapor from leaves; and (3) chemical compounds which prevent stomata from opening fully, by affecting the guard cells around the stomatal pore (Davenport, Hagan and Martin, 1969).

Applying Antitranspirants

Antitranspirants are normally supplied as liquid concentrates to be diluted in water. The resulting product is usually applied as a spray by a hand spray gun, a mist blower, or a field sprayer. Application rates depend on plant species and size. Plants differ considerably in their sensitivity to these chemicals. For plants not listed on labels of commercially available antitranspirants, it is advisable to test the chemical on a few leaves prior to any extensive use. Plants to be transplanted may be dipped in the material but it is
necessary to protect the roots from the solution so as not to retard water uptake. It is important to use the correct concentration of the stomata-closing materials to avoid phytotoxicity effects. Phenylmercuric acetate (PMP), in particular, must be used with care since it is a mercury-containing metabolic inhibitor (Davenport, Hagan and Martin 1969). Reflecting film-forming materials are not likely to pose problems of phytotoxicity, although some browning may occur on leaf tips if a high concentration of emulsion flows to the leaf tip and congeals there (Davenport, Hagan and Martin 1969). Because of the naturally waxy and hairy nature of many leaf surfaces, coverage of foliage by antitranspirant film is seldom complete, nor is such desirable. Since many plants, particularly fruit trees, have stomates only on the under surface of their leaves, spraying those surfaces is imperative.

Temperature and Transpiration

An antitranspirant will not cause a drastic increase in leaf temperature under normal growing conditions (Davenport, Uriu, Fisher and Hagan 1971). The reflecting stage of antitranspirants usually cause a reduction in leaf temperature, while the film forming and stomata-closing types cause an increase in leaf temperature by reducing transpiration rates and thus reducing evaporative cooling. Thermal emission is the chief way of heat dissipation from the leaves, however, rather than evaporative cooling (Davenport, Hagan and Martin 1969).
There is an apparent discrepancy between previous conclusions regarding studies on this temperature rise. Ansari and Loomis (1959) and Clum (1926) found only a few degrees rise in leaf temperatures when transpiration was suppressed by such means as petroleum jelly. A later worker, however (Nobel 1974), calculated that the percentage of the net energy input removed by the measured transpiration is quite large, sometimes reaching 50%. Nobel concluded that transpiration is "desperately important" to maintenance of leaf temperature. Anti-transpirants other than the reflecting types have been reported to increase leaf temperature from 1°C to as much as 5°C (Thames 1961, Tanuer 1963, Slatyer and Bierhuizen 1964b). Some plant injury by leaf overheating may result from such transpiration retardants (Thames 1961, Pallas et al. 1965). Leaves of the rubber plant, California red kidney, and valencia orange were cooled approximately 4°C by reflecting material (Abou-Khaled, Hagen and Davenport 1970). The following equation shows the effect of an antitranspiration treatment on leaf temperature under varying climatic conditions (Wolpert 1962):

\[
\frac{t_L - t_{air}}{13.5 (A'_L/A_L)(.053V/L)^{1/2} + 11E_L}
\]

where \(t_L\) and \(t_{air}\) are the leaf and air temperature, \((^\circ C)\); \(\theta\) is the angle of the sun's rays to the leaf (degree), \(W_w\) is the transpiration rate (g dm h), \(n\) is the efficiency of leaf hairs for heat exchange, \(A'_L\) is the total area of leaf surface and hair surfaces, \(A_L\) is the area of leaf without hair, \(V\) is the wind velocity (kph), \(L\) is the leaf
diameter (cm), and $E_L$ is the total leaf emissivity, relative to a black body. From this equation, it can be seen that, whereas transpiration may remove a considerable portion of the absorbed net energy, a reduction in transpiration will not cause a proportionate rise in $t_L - t_{air}$. This is attributed to the increased convective cooling when $t_L - t_{air}$ increases. At very low wind velocities, the relative effect of the reduction in transpiration increases markedly. However, at very low windspeeds transpiration is also much reduced because of the build-up of vapor pressure near the leaf surface (Gale and Poljakoff-Mayber 1963). With a wind of less than 1 kph, an antitranspirant raised tomato leaf temperature by about 4°C (Cook, Dixon and Leopold 1964).

It appears, therefore, that only under extreme conditions of high incident, radiation, and very low wind velocity would leaf temperatures be significantly raised by a reduction of transpiration. In hot arid regions, when the soil moisture conditions are less than optimal, stomata very often close during the hottest hours of the day when the cooling effect of transpiration would be most advantageous. This has been observed for apples (Furr and Degmann 1931), coffee (Nutman 1937), citrus (Mendel 1945), and palm (Rees 1958).

**Diffusive Resistance and Plant Water Potential**

The water balance of a plant depends on the relative rates of water uptake by the roots and loss by the shoots, mainly by transpiration via leaf stomata (Kozlowski 1968).

Antitranspirants provide a physical resistance to water vapor diffusion at the transpiring surface, thereby minimizing the
transpiration rate (Davenport, Uriu, and Hagan 1975) and increasing the plant's water potential. This counteractive effect is represented by Davenport, Hagan and Martin (1969) as an increase in stomata resistance to the passage of water vapor out of, and carbon dioxide into, the leaf. When antitranspirant films are used, leaf water potential increases. The greater this potential, the greater the turgidity of the guard cells, resulting in wider stomatal apertures (Davenport, Fisher and Hagan 1972). Since stomata are common portals for escape of water vapor and entry of carbon dioxide, antitranspirants are expected to reduce photosynthesis and hence growth (Davenport, Hagan and Martin 1969, Gale and Hagan 1966, Waggoner 1966). Davenport et al. (1971) also report that antitranspirant film may be a barrier to CO$_2$ exchange, thereby decreasing photosynthesis and growth. Reflecting materials do not cause blockage of stomatal pores when they are applied to the upper surface of the leaves with stomata exclusively on the lower surface. However, such coatings may curtail photosynthesis on overcast days when light is limited (Davenport, Hagan and Martin 1969). Abou-Khaled, Hagan and Davenport (1970) reported that kaolinite reduced the rate of photosynthesis at lower light intensities in lower leaves of the canopy. They found no reduction in photosynthesis under high light intensities. All antitranspirant chemicals are more permeable to water vapor than to carbon dioxide (Sage 1976, Gale 1967). To prevent a retardation of growth, investigators recommend the application of antitranspirants when the plant is more dependent on maintaining turgid cells than on photosynthesis (Davenport, Uriu and Martin 1972). In some situations, however, reduced growth may be advantageous (Martin 1974).
The possible effect of the transpiration stream on the uptake and transport of minerals has been much debated and reviewed in recent years (Brouwer 1965, Russell and Barber 1960). There is no question that transpiration expedites mineral movement within the plant. There appears to be some effect of transpiration rate on ion uptake, but this varies according to the type of the plant and the specific ion involved. There is usually no proportionality between uptake and transpiration rates (Lagerwerff and Eagle 1962, Lopushinsky and Dramer 1961).

The reduction of transpiration by an antitranspirant reduced to a significant extent, the uptake of rubidium by sugar beet and the transport of rubidium within bean plants and sugar beets during a 100-hour period (Gale and Poljakoff-Mayber 1963). Another way in which the transpiration stream may possibly affect plant nutrition is to expedite movement of mobile ions in the soil towards the rhizosphere (Eaton and Bernardin 1964). It appears, therefore, that a very large reduction in transpiration may, under extreme circumstances, affect the plant's mineral balance.

According to the literature, then, transpiration could probably be at least halved without harmful effects on leaf temperature or mineral nutrition except under the most extreme conditions (Gale and Hagan 1966). Methods for retarding transpiration should also allow growth to continue, or at least reduce the transpiration/growth ratio. Consequently, materials applied as antitranspirants should operate at the leaf-air interface.
In transpiration, water vapor diffuses through two resistances acting in series, the stomatal aperture resistance \( r_s \) and the boundary layer resistance \( r_a \), which results from the lengthening of the diffusion path outside of the stomata and is an inverse function of wind and turbulence. The resistance to cuticular water loss \( r_c \) is very large and is in parallel to \( r_s \). The conductance via the cuticle, \( r_c^{-1} \), is very small and may be neglected, unless \( r_s \) is large, and when the stomata close. Thus, by analogy to Fick’s law, Gaastra gives the following equation for transpiration (Gaastra 1962):

\[
T = \frac{(H_2O)_{\text{int}} - (H_2O)_{\text{ext}}}{r_s + r_a}
\]

where \( T \) is the transpiration \( (\text{cm}^3/\text{water vapor, cm}^2/\text{sec}) \), \( (H_2O)_{\text{int}} \) is the water vapor concentration at the mesophyll surface, \( (H_2O)_{\text{ext}} \) is the vapor concentration of the air \( (\text{cm}^3/\text{vapor cm}^{-3}\text{ air}) \), and \( r_s \) and \( r_a \) are the resistances as defined above \( (\text{sec cm}^{-1}) \). Photosynthesis may be similarly described as a diffusion process of \( \text{CP}_2 \) from the outside air to the chloroplasts, but here a third resistance to diffusion of \( \text{CO}_2 \) is present in the liquid phase from the mesophyll wall to the chloroplast \( (r_{me}') \). In addition to liquid phase \( \text{CO}_2 \) diffusion resistance, \( r_{me}' \), also includes all the metabolic factors which are liable to affect the photosynthetic rate. Thus, photosynthesis may be expressed as follows:

\[
P = \frac{(\text{CO}_2)_{\text{ext}} - (\text{CO}_2)_{\text{int}}}{r_s' + r_a' + r_{me}'}
\]

where \( P \) is the photosynthesis \( (\text{cm}^3/\text{CO}_2/\text{cm}^2/\text{sec}) \), \( (\text{CO}_2)_{\text{ext}} \) is the
concentration of the carbon dioxide in the outside air and \( CO_2 \text{int} \) at the site of the \( CO_2 \) sink, i.e. the chloroplast (\( cm^3 \) \( CO_2 \text{cm}^{-3} \text{air} \)), and \( r_s' \), \( r_a' \), and \( r_{me}' \) are the resistances to \( CO_2 \) diffusion as defined above (sec cm\(^{-1}\)).

The theoretical basis for closing stomata as a means of reducing transpiration more than photosynthesis has been described (Zelitch 1961, Zelitch and Waggoner 1962, Slatyer and Bierhuizen 1964). Gaastra (1962) and Slatyer and Bierhuizen (1964) give data for \( r_s \), \( r_a \), and \( r_{me} \) for different plant species which indicate that, under good growing conditions with at least a slight breeze, \( r_{me} \) may be as great as \( r_s' + r_a' \). This being the case, it follows from equation 2 and 3 that any increase in stomatal resistance will reduce transpiration more than photosynthesis. The reduction of transpiration caused by increased resistance will tend to raise the leaf temperature, thus increasing \( (H_2O)\text{int} \) and hence \( (H_2O)\text{int} - (H_2O)\text{ext} \). This will also raise the transpiration rate. However, this effect may be small because of increased convective cooling.

Materials forming relatively thick films have been used; the purpose of this type of antitranspirant is to cover the stomata with a film whose resistance to water vapor transmission is greater than its resistance to \( CO_2 \) and \( O_2 \) (\( r_{anti} > r_{anti'} \)). Equation 2 then becomes:

\[
T = (H_2O \text{int} - H_2O \text{ext})(r_s + r_a + r_{anti})
\]

and equation 3 becomes:
\[ P = (CO_2_{\text{ext}} - CO_2_{\text{int}})(r_{s'} + r_{a'} + r_{me'} + r_{anti}). \]

As before, because of the presence of a substantial \( r_{me'} \) in the photosynthesis equation, even if the permeability of the film is the same for both water vapor and \( CO_2 \) \( \left( r_{anti}^{-1} = r_{anti}^{-1} \right) \), transpiration should be reduced more than photosynthesis. These materials should reduce water loss much more than \( CO_2 \) uptake, and are formed on the leaf surface at normal air temperature from nonphototoxic emulsions.

**Fruit Trees**

Various experiments show that antitranspirant sprays improve the water balance of fruit trees. Despite the reductions in photosynthesis, this condition may increase fruit size especially if the trees are sprayed shortly before the fruit mature (Davenport, Uriu, Fisher and Hagan 1971).

Davenport, Uriu and Hagan (1972) found a film-forming antitranspirant sprayed on Bing cherry trees 10 days before harvest resulted in a fruit size increase of 15% without affecting dry weight. Application too early (2 weeks before harvest) reduced dry weight. Davenport, Uriu and Hagan (1972) found that the persistence of antitranspirant film on cherry fruit after harvest reduced post-harvest dissection by as much as 50%. Creasy (1976) found that the antitranspirant di-1-p-methene (Wilt-Pruf) increased red color development in "McIntosh" apples when used alone or in combination with diuron or CaCO₃. Davenport, Martin and Hagan (1972) observed that treating citrus trees that were 7 years old with antitranspirants
before transplanting, increased leaf water potential. After transplanting, leaf water potential decreased by as much as 21 atmospheres on the unsprayed, and as little as 6 atmospheres in sprayed trees.

An obvious use of antitranspiration is to conserve soil water and thereby reduce irrigation frequency. However, application for this purpose would be justified only if water costs were very high or if water were in short supply.
CHAPTER III
METHODS AND MATERIALS

Laboratory Equipment

Materials

A wilt-pruf (antitranspirant) water solution was used for this study at the following concentrations: 1%, 2%, 3%, 4%, 5%, 10%, and 15%.

One-year-old Malling 106 trees were potted in 10.2 cm (4 inch) pots for this study. The experiment was initiated August 9, 1977, at Utah State University, Logan, Utah. The trees were placed in the greenhouse and treated at that time.

Methods Used

The chemical was applied by a hand pressure sprayer. Plants were sprayed with a fine mist of antitranspirant until run-off, covering all parts (including individual leaves) of the plants. Untreated control trees were sprayed with water and used to compare chemical effectiveness.

The pots were watered and allowed to drain. The pots were then sealed in poly-bags with water proof tape limiting water loss to just the exposed parts of the trees. Pots were weighed immediately after sealing to establish an initial weight of the container at field capacity. Transpiration was determined gravimetrically using a balance (Mettler P10) and expressed in grams of water lost per day for the
period of the study. The pots were weighed daily for a 10-day period. All the pots were numbered with individual tree records kept.

The trees were placed in a controlled environment chamber (Percival, Boone, Iowa 50036). The temperature within the chamber was maintained at 32 ± 2°C for 15 hours and 18 ± 2°C for 9 hours each day. Thermometer and thermographs were used to record the temperature. A 15-hour photoperiod with an abrupt light-dark change was maintained using a bank of cool-white fluorescent lamps (F72T12-CW-VHO) suspended 11 cm above the plants, supplying 160 foot candles. A GE multi-range light meter, model MR-100, was used to measure light intensity in foot candles. Overhead fans provided a gentle air circulation in the chamber but air speed was not measured.

The trees were statistically grouped prior to treatment according to antitranspirant concentration. The 64 trees were divided equally among 8 treatments, each with 8 trees per treatment. Results of the experiment were analyzed together for simplicity of presentation, utilizing a combined analysis of variance.

Field Experiment

A. Irrigated Treatments

A wilt-pruf (antitranspirant) water solution was used in this study at the following concentrations: 5%, 10%, and 15%. Four-year-old Golden Delicious apple trees in good vigor were sprayed with 2.5
gallons of solution. Untreated trees were sprayed with water and used to evaluate chemical effectiveness. The three antitranspirant treatments and the untreated control were each replicated on four trees.

The trees received one foliar spray August 31, 1977 at the Utah State University Horticultural Experiment Station in Farmington, Utah. The soil in the orchard was of fine sandy loam and the trees received the same cultural practices and irrigation as would a commercial orchard.

The antitranspirant was applied with a handgun from an orchard sprayer.

Method of Determining Effect of Foliar Antitranspirant Treatments on the Foliage

Water status of the trees. The diffusion porometer (LI-Cor-Autoporometer) apparatus was used to measure resistance to water vapor diffusion from leaves, using the second four leaves on a twig from the terminal end. The leaves were picked from the tree one hour after sunrise and put immediately into a pressure bomb apparatus to determine their water potential (Wieve 1971). Terminal twigs having 3-5 leaves were used to determine stem-water potential.

Leaf temperature. An IR leaf temperature meter was used to determine the effect of different antitranspirant concentrations on leaf temperature.

Measurement of soil water content. Soil water was determined by a neutron probe (Hanks and Ashcroft 1976). Aluminum access tubes for measuring the water content at different depths were located between
selected trees. Readings were made at depths of 30, 45, 60, 90, 120, and 150 cm, and were taken just prior to each irrigation. The access tubes were closed at the soil surface with plastic stoppers.

Moisture content on a volume basis was determined by taking neutron counts at the desired depths, comparing them to standard neutron counts, and then applying a calibration equation. The calibration equation was obtained by correlating the neutron probe reading with gravimetrically determined soil water contents. Volumetric water content was obtained by multiplying the gravimetric water content by the bulk density characteristic of each depth.

Method of Determining Effect of Foliar Antitranspirant Treatments on the Fruit

Fruit size. Twenty fruit, distributed around the periphery of the trees were tagged on each tree (80 tagged fruit per treatment). The tagged apples were numbered and an individual record was kept for each fruit (Figure 1). The increase in fruit size was determined throughout the experiment by measuring the diameter of the fruit by calipers. The first measurement was taken one week after spraying. The last measurement was taken just before the fruit was picked. Diameters were converted to volume per fruit by using a regression equation relating fruit diameter to volume (obtaining a water displacement in a measuring cylinder).

Determination of maturity. Maturity was determined just before the fruit was picked by means of the standard government apple pressure tester. A hand refractometer was used to determine soluble solids.
Figure 1. Four-year-old tagged Golden Delicious apple fruit diameters were measured with calipers as shown in the photo.
Determining color. It is very hard to evaluate the effect of the antitranspirant on color because so many influencing factors such as light, water, temperature etc. cannot be controlled. Color was, however determined by comparing redness of treated fruit to that of the untreated fruit.

B. Unirrigated Treatments

The same materials and procedures were used in unirrigated and irrigated studies with the following exceptions: (a) The trees were not irrigated. (b) The ground under the trees was covered with polyethylene which extended 2.4 m (8 ft) from each side of the tree (Figure 2). (c) The antitranspirant concentrations used were as follows: 1%, 2%, 3%, 4%, 5%, 10%, and 15% and untreated. (d) Each treatment was replicated on 4 trees, resulting in a total of 32 trees in the experiment.
Figure 2. Four-year-old Golden Delicious apple trees are shown in the photo with polyethylene covering the ground for 2.4 m (8 ft) on either side of the trees (unirrigated treatment).
CHAPTER IV
RESULTS

Laboratory Experiment

Antitranspirants, at all concentrations applied, significantly reduced transpiration in the M106 apple trees as compared to the untreated trees (Figure 3). The higher the concentration, the more effective the antitranspirant was in reducing the transpiration (Table 1). Mean reductions in transpiration for the concentrations 1%, 2%, 3%, 4%, 5%, 10% and 15% rates were 18%, 32%, 26%, 40%, 46%, 58% and 63%, respectively. The daily readings indicated that the antitranspirant (all concentrations) was effective in reducing transpiration (Figure 4). Phytotoxicity was not observed, though plants treated with the 10% and 15% concentrations were lighter green in color at the end of the experiment. Leaves from trees receiving the 15% antitranspirant treatment were lighter green than the leaves receiving the 10% treatment. Antitranspirants at concentrations of 4-15% imparted a sticky film to plants.

Field Experiment

A. Irrigated Treatments

Effect of Antitranspirant on Diffusive Resistance

Figure 5 shows the trend of resistance to diffusion of water vapor from the leaves by treatment. On day 2 diffusive resistance of the untreated trees remained lower than that of the sprayed trees.
Figure 3. Effect of antitranspirant (wilt-pruf), 15% concentration, on rootstock apple tree (M106) after 10 days is shown in photo on the right as compared with untreated tree shown on the left.
Table 1. Effect of antitranspirant (wilt-pruf) on water loss* of one-year-old Malling 106 apple trees

<table>
<thead>
<tr>
<th>Wilt-pruf treatment (%)</th>
<th>Total water loss (g/10-day)</th>
<th>% of water in trees above untreated trees</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1484</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>1206</td>
<td>18*</td>
</tr>
<tr>
<td>2</td>
<td>996</td>
<td>32</td>
</tr>
<tr>
<td>3</td>
<td>946</td>
<td>36</td>
</tr>
<tr>
<td>4</td>
<td>879</td>
<td>40</td>
</tr>
<tr>
<td>5</td>
<td>799</td>
<td>46</td>
</tr>
<tr>
<td>10</td>
<td>621</td>
<td>58</td>
</tr>
<tr>
<td>15</td>
<td>545</td>
<td>63</td>
</tr>
</tbody>
</table>

*Each observation is the mean of 8 trees.

LSD  
0.05  0.33  
0.025  0.42
Figure 4. Effect of antitranspirant (wilt-pruf) on transpiration of one-year-old M106 apple trees. Data recorded 1 day after treatment.
Figure 5. Effect of antitranspirant (wilt-pruf) on leaf diffusion resistance of four-year-old Golden Delicious apple trees.
Diffusive resistance of leaves receiving concentrations of 5% and 10% remained lower than those receiving the 15% concentration. In a more precise manner, Table 2 shows that the tree leaves receiving the 5% concentration seemed to have higher diffusive resistance \((6 \text{ cm}^{-1} \text{ min})\) than the control, \((.4 \text{ cm}^{-1} \text{ min})\). Likewise, leaves receiving 10% and 15% concentrations showed a higher rate of diffusive resistance, \(1 \text{ cm}^{-1} \text{ min}\) and \(2 \text{ cm}^{-1} \text{ min}\), respectively. The antitranspirant spray appeared to increase the resistance significantly \((P < 5\%)\) for all the treatments compared to the control and was effective even 3 weeks after spraying at all concentrations. The antitranspirant showed no phytotoxicity at any of the concentrations applied.

**Effect of Antitranspirant on Plant Water Potential**

The antitranspirant effect on plant water potential for the leaves and stems of apple trees was evaluated using the pressure bomb. Figures 6 and 7 show the apparent continued effects of the antitranspirant until the end of the experiment as compared to the control. Table 2 indicates the effect of treatment on the ninth day after the antitranspirant was applied. As shown in this table, the leaf water potential increased 24-55%.

The antitranspirant thus had a significant effect \((P < 5\%)\) for all the treatments compared to the control. Figure 6 shows graphically the trends of water potential by treatment, with the control remaining lower than the sprayed trees. The antitranspirant appeared to increase the leaf water potential significantly for all treatments up to the end of the experiment. Table 2 and Figure 5 show that as the concentration
Table 2. Effect of antitranspirant (wilt-pruf) effects on diffusive resistance and water potential of four-year-old Golden Delicious apple trees 9 days after treatment

<table>
<thead>
<tr>
<th>Wilt-pruf treatment (%)</th>
<th>Leaf resistance (sec cm(^{-1}))</th>
<th>Leaf potential* (bar)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>.4</td>
<td>-18</td>
</tr>
<tr>
<td>5%</td>
<td>.6</td>
<td>-13.6</td>
</tr>
<tr>
<td>10%</td>
<td>1.0</td>
<td>-11.03</td>
</tr>
<tr>
<td>15%</td>
<td>2.0</td>
<td>-8.03</td>
</tr>
</tbody>
</table>

*A greater negative value indicates more water stress and lower water potential.

LSD 0.05 0.36 2.52
Figure 6. Effect of antitranspirant (wilt-pruf) on leaf water potential of four-year-old Golden Delicious apple trees (irrigated treatments).
Figure 7. Effect of antitranspirant (wilt-pruf) on stem water potentials of four-year-old Golden Delicious apple trees (irrigated treatments).
of antitranspirant decreases, the leaf water potential decreases and vice-versa.

The water potential was lower on the control than on treated trees beginning the second day after treatment. Figure 7 shows graphically the trends of stem water potential by treatment. Trees receiving 5% and 10% concentrations of antitranspirant had lower stem water potential than the trees receiving 15%. Comparative values of the stem water potential are shown in Table 3. The treatments receiving the 15% concentration had a higher water potential (-7 atm) than the control (-18 atm). Likewise, the treatments receiving 10% and 15% concentrations had a higher stem water potential, -11 atm and -14 atm, respectively. There was a significant difference between the treatments and the control. Trees receiving the antitranspirant increased stem water potential effectively for 3 weeks after spraying at all concentrations.

Effect of Antitranspirant on Leaf Temperature

Antitranspirant at 5%, 10%, and 15% concentrations indicates clearly that leaf temperature may be as much as 4°C warmer than on the untreated trees (Figure 8). Daily average observations showed that antitranspirant application at 5% concentration increased leaf temperature 1°C above the control (Table 4). The 10% antitranspirant treatment increased the temperature 1.5°C above the untreated. The 15% antitranspirant treatment increased leaf temperature 2.5°C above the untreated (Table 4).
Table 3. Effect of antitranspirant (wilt-pruf) on stem water potential of four-year-old Golden Delicious apple trees (irrigated treatment)

<table>
<thead>
<tr>
<th>Wilt-pruf treatment (%)</th>
<th>Stem water potential (bars)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>-18</td>
</tr>
<tr>
<td>5%</td>
<td>-14</td>
</tr>
<tr>
<td>10%</td>
<td>-11</td>
</tr>
<tr>
<td>15%</td>
<td>-7</td>
</tr>
</tbody>
</table>

LSD 0.05 1.3
Figure 8. Effect of antitranspirant (wilt-pruf) on the temperature of four-year-old Golden Delicious apple trees (irrigated treatments).
Table 4. Effect of antitranspirant (wilt-pruf) on the temperature of four-year-old Golden Delicious apple trees (irrigated treatments)

<table>
<thead>
<tr>
<th>Wilt-pruf treatment (%)</th>
<th>Leaf temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>26</td>
</tr>
<tr>
<td>5</td>
<td>27</td>
</tr>
<tr>
<td>10</td>
<td>27.5</td>
</tr>
<tr>
<td>15</td>
<td>28.5</td>
</tr>
</tbody>
</table>

*Average leaf temperature for 21 days of treatments.

LSD 0.05 0.2
Effect of Antitranspirant on Soil Moisture

The day before applying the antitranspirant, all trees were irrigated. The field capacity of the soil was .19. Table 5 shows that when the antitranspirant concentration is increased, the water content of the soil also increased, and vice-versa. Trees treated with 15% antitranspirant had the highest water content, .16, while the other concentrations, 5% and 10%, had .13 and .14, respectively.

Effect of Antitranspirant on Fruit

Fruit size. The effect of the antitranspirant on fruit growth is shown in Figure 9. Measurements began August 31, harvest was on September 23. At harvest, the fruit from trees receiving 5% concentration of antitranspirant were approximately 5% larger than the control, while fruit from trees receiving 10% antitranspirant concentration was 7.5% larger than the control fruit. Fruit from trees receiving 15% concentration was 8% larger than the control. The above data suggest that fruit from trees receiving 10% and 15% antitranspirant grew practically at the same rate.

Maturity. The firmness and sugar concentration (hand refractometer readings) of the fruit are given in Table 6. The antitranspirant concentrations had little influence on the firmness of the fruit. Soluble solids at harvest ranged from 15.8% (15% treated trees) to 17.4% (control) which was not significant between treatments.

Color. Antitranspirant treatments did not appear to influence fruit color.
Table 5. The average soil moisture at the 0-160 depth of the irrigated soil at the end of the experiment. Antitranspirant (wilt-pruf) was sprayed on four-year-old Golden Delicious apple trees growing in the soil.

<table>
<thead>
<tr>
<th>Wilt-pruf treatment (%)</th>
<th>Water content (cm³/cm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.11</td>
</tr>
<tr>
<td>5</td>
<td>0.13</td>
</tr>
<tr>
<td>10</td>
<td>0.14</td>
</tr>
<tr>
<td>15</td>
<td>0.16</td>
</tr>
<tr>
<td>LSD</td>
<td>0.05</td>
</tr>
</tbody>
</table>


Figure 9. Effect of antitranspirant (wilt-pruf) on growth of four-year-old Golden Delicious apple trees (irrigated treatments).
Table 6. Effect of antitranspirant (wilt-pruf) on the soluble solids in four-year-old Golden Delicious apple trees (irrigated treatments)

<table>
<thead>
<tr>
<th>Wilt-pruf treatment (%)</th>
<th>Solid soluble (%)</th>
<th>Pressure (PSI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>17.4</td>
<td>13.7</td>
</tr>
<tr>
<td>5</td>
<td>17.0</td>
<td>12.8</td>
</tr>
<tr>
<td>10</td>
<td>16.6</td>
<td>11.9</td>
</tr>
<tr>
<td>15</td>
<td>15.8</td>
<td>11.3</td>
</tr>
<tr>
<td>LSD</td>
<td>NS</td>
<td>NS</td>
</tr>
</tbody>
</table>

LSD NS NS
B. Unirrigated Treatments

Effect of Antitranspirant on Diffusive Resistance

Leaves on trees receiving the 1% concentration of antitranspirant showed lower diffusive resistance than the control. As the concentration of antitranspirant was increased, the diffusive resistance increased (Figure 10). The diffusive resistance of leaves the ninth day of the experiment are shown in Table 7. Leaves of trees receiving a 2% concentration seemed to have higher diffusive resistance \(1.2 \text{ cm}^{-1} \text{ min}\) compared to the control \(0.9 \text{ cm}^{-1} \text{ min}\). Likewise, leaves receiving 3%, 4%, 5%, 10%, and 15% concentration had higher diffusive resistance \(1.5, 1.6, 1.7, 2.6 \text{ and } 3.1 \text{ cm}^{-1} \text{ min, respectively}\) than the control. The antitranspirant appeared to increase diffuse resistance significantly above the control \((P < 5\%\) for all the treatments except at the 1% concentration. There was a significant difference between irrigated and unirrigated diffusive resistance. The unirrigated showed a higher rate. Antitranspirant was effective 3 weeks after spraying and showed no phytotoxicity.

Effect of Antitranspirant on Plant Water Potential

There was a continuous effect on the antitranspirant on both leaves and stems from the time of application until the end of the experiment (Figures 11 and 12). Treatments of 1-2% concentrations showed no significant difference from the control, while the higher concentrations showed a significant difference \((P < 5\%\) from the control. The data in Table 7 indicate that 9 days after spraying the antitranspirant
Fig 10. Effect of antitranspirant (wilt-pruf) on leaf diffusive resistance of four-year-old Golden Delicious apple trees (unirrigated treatments).
Table 7. Effect of antitranspirants (wilt-pruf) on leaf diffusive resistance and water potential of four-year-old Golden Delicious apple trees 9 days after treatments (unirrigated treatments)

<table>
<thead>
<tr>
<th>Wilt-pruf treatment (%)</th>
<th>Leaf resistance (sec cm(^{-1}))</th>
<th>Leaf water potential* (bar)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.9</td>
<td>-18.7</td>
</tr>
<tr>
<td>1</td>
<td>0.92</td>
<td>-18.5</td>
</tr>
<tr>
<td>2</td>
<td>1.2</td>
<td>-17</td>
</tr>
<tr>
<td>3</td>
<td>1.5</td>
<td>-16.5</td>
</tr>
<tr>
<td>4</td>
<td>1.6</td>
<td>-15.8</td>
</tr>
<tr>
<td>5</td>
<td>1.7</td>
<td>-14.7</td>
</tr>
<tr>
<td>10</td>
<td>2.6</td>
<td>-13.4</td>
</tr>
<tr>
<td>15</td>
<td>3.1</td>
<td>-11.2</td>
</tr>
</tbody>
</table>

*Greatest negative value indicates more water stress and low water potential.

LSD 0.05 0.21 0.44
Figure 11. Effect of antitranspirant (wilt-pruf) on leaf water potentials of four-year-old Golden Delicious apple trees (unirrigated treatments).
Figure 12. Effect of antitranspirant (wilt-pruf) on stem water potentials of four-year-old Golden Delicious apple trees (unirrigated treatments).
the leaf water potential increased from a -18.7 for the control to -11.2 bars for the 15% treatment. No phytotoxicity appeared as a result of the antitranspirant treatments.

Figure 12 shows the effect of various concentrations of antitranspirant on the stem water potential graphically. Leaves receiving 1% concentration of antitranspirant approached the same level of stem water potential as the control. As concentrations increased, so did stem water potential. Comparative values of the stem water potential are shown in Table 8. As the concentration of antitranspirant applied was increased, the stem water potential increased. The treatments receiving 15% antitranspirant had the highest stem water potential (-7.2 atm), while the lowest stem water potential (-12.4 atm) occurred at 2% concentration of antitranspirant. Antitranspirant effectively increased stem water potential up to 3 weeks after spraying when the experiment was concluded.

Irrigated trees had significantly higher rates of water potential than unirrigated trees.

Effect of Antitranspirant on Leaf Temperature

Antitranspirants (3% or above) applied to unirrigated trees, had a significant effect on leaf temperatures. Trees receiving low concentrations (1% and 2%) showed no difference from the control, while the high antitranspirant concentrations resulted in higher leaf temperatures. Rates of antitranspirant concentration was positively correlated with an increase of leaf temperature. The 3 and 4% rate showed only a 1°C increase in leaf temperature, while the 5, 10, and 15% treatments
Table 8. Effect of antitranspirant (wilt-pruf) on stem water potential of four-year-old Golden Delicious apple trees (unirrigated treatments)

<table>
<thead>
<tr>
<th>Wilt-pruf treatment (%)</th>
<th>Stem water potential (bar)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>-14</td>
</tr>
<tr>
<td>1</td>
<td>-13.5</td>
</tr>
<tr>
<td>2</td>
<td>-12.4</td>
</tr>
<tr>
<td>3</td>
<td>-11.5</td>
</tr>
<tr>
<td>4</td>
<td>-10</td>
</tr>
<tr>
<td>5</td>
<td>-9.6</td>
</tr>
<tr>
<td>10</td>
<td>-8</td>
</tr>
<tr>
<td>15</td>
<td>-7.2</td>
</tr>
<tr>
<td>LSD</td>
<td>0.05</td>
</tr>
<tr>
<td></td>
<td>0.65</td>
</tr>
</tbody>
</table>
showed a 1.25°C, 1.75°C and 2.75°C increase, respectively.

Unirrigated trees generally had a higher leaf temperature than irrigated trees. At 5% concentration, leaves from irrigated trees were 1°C higher than the control (Table 4), while those from unirrigated trees were 1.25°C higher than the control (Table 9). The same phenomenon was exhibited at the higher antitranspirant concentrations. Concentrations of 10 and 15% resulted in a 1.5°C and 2.5°C increase over the control of the irrigated trees, but the unirrigated trees showed a 1.75°C and 2.75°C increase above the control, respectively. There were significant differences in leaf temperature between irrigated treatments and unirrigated treatments.

**Effect of Antitranspirant on Soil Moisture**

The day before spraying, all the trees were irrigated. The field capacity of the soil was 19% water. Table 10 indicates very clearly that when the concentration of antitranspirant increases, the water content of the soil remains higher than at lower antitranspirant rate.

**Effect of Antitranspirant on Fruit**

Fruit size. Fruit receiving the 1% antitranspirant concentration was smaller than the control. The treatments receiving 2% concentration showed increase in growth the second week after application, while the other treatments showed an increase in growth after the first week. The treatments receiving 2% and 3% antitranspirant concentrations each grew about .5% above the control fruit over a two-week period (Figure 13). Likewise, the fruits in treatments receiving 4% and 5% antitranspirant
Table 9. Effect of the antitranspirant (wilt-pruf) on the leaf temperature of four-year-old Golden Delicious apple trees (unirrigated treatments)

<table>
<thead>
<tr>
<th>Wilt-pruf treatment (%)</th>
<th>Leaf temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>27</td>
</tr>
<tr>
<td>1</td>
<td>27</td>
</tr>
<tr>
<td>2</td>
<td>27</td>
</tr>
<tr>
<td>3</td>
<td>28</td>
</tr>
<tr>
<td>4</td>
<td>28</td>
</tr>
<tr>
<td>5</td>
<td>28.5</td>
</tr>
<tr>
<td>10</td>
<td>28.75</td>
</tr>
<tr>
<td>15</td>
<td>29.75</td>
</tr>
<tr>
<td>LSD</td>
<td>0.05</td>
</tr>
</tbody>
</table>
Table 10. The average soil moisture at the 0-160 cm depth of the unirrigated soil at the end of the experiment. Antitranspirant (wilt-pruf) was sprayed on four-year-old Golden Delicious apple trees growing in the soil.

<table>
<thead>
<tr>
<th>Wilt-pruf treatment (%)</th>
<th>Water content (cm³/cm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>.09</td>
</tr>
<tr>
<td>1</td>
<td>.09</td>
</tr>
<tr>
<td>2</td>
<td>.10</td>
</tr>
<tr>
<td>3</td>
<td>.10</td>
</tr>
<tr>
<td>4</td>
<td>.11</td>
</tr>
<tr>
<td>5</td>
<td>.11</td>
</tr>
<tr>
<td>10</td>
<td>.13</td>
</tr>
<tr>
<td>15</td>
<td>.14</td>
</tr>
</tbody>
</table>

LSD 0.05 0.01
Figure 13. Effect of antitranspirant (wilt-pruf) on growth of four-year-old Golden Delicious apple trees (unirrigated treatment).
concentrations grew at practically the same rate (1.5%), while the fruit in the treatment receiving 10% antitranspirant showed a 3% increase in fruit size during the two-week period. The fruit from trees receiving 15% antitranspirant concentration became distinctly larger (5% above the control) than the fruit receiving the other treatments.

**Maturity.** The antitranspirant had no influence on the firmness nor the soluble solids of the fruit in any of the treatments (Table 11). The soluble solids ranged from 16.5% for treated trees to 17.6% for the control.

**Color.** The antitranspirant did not influence fruit color.
Table 11. Effect of antitranspirant (wilt-pruf) on the soluble solid in four-year-old Golden Delicious apple trees (unirrigated treatments)

<table>
<thead>
<tr>
<th>Wilt-pruf treatment (%)</th>
<th>Soluble solid (%)</th>
<th>Pressure (PSI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>17.6</td>
<td>13.9</td>
</tr>
<tr>
<td>1</td>
<td>16.6</td>
<td>11.6</td>
</tr>
<tr>
<td>2</td>
<td>17.0</td>
<td>12.8</td>
</tr>
<tr>
<td>3</td>
<td>16.5</td>
<td>11.8</td>
</tr>
<tr>
<td>4</td>
<td>16.5</td>
<td>11.9</td>
</tr>
<tr>
<td>5</td>
<td>17.5</td>
<td>12.5</td>
</tr>
<tr>
<td>10</td>
<td>17.3</td>
<td>12.2</td>
</tr>
<tr>
<td>15</td>
<td>17.1</td>
<td>12.85</td>
</tr>
</tbody>
</table>

LSD  NS  NS
CHAPTER V
DISCUSSION

Laboratory Experiment

Antitranspirant applied to young M106 apple trees reduced water vapor loss in an indoor environment and remained effective until the end of the 10-day test period.

Davenport, Hagan and Martin (1969) reported that the longevity of antitranspirant effectiveness is dependent on a number of factors, including the ability of films to withstand environmental elements. The overall effectiveness of an antitranspirant spray must be of a short duration if applied to actively growing plants because of leaf expansion. The environmental conditions surrounding the trees in this experiment are neither demanding on the film nor conducive to active growth.

Transpiration was relatively low compared to that of more actively growing plants out of doors with higher temperatures. Light intensity and its destructive ultra-violet radiation were also low in the controlled environment.

Gale and Hagan (1966) reported that solar ultra-violet radiation, temperature extremes, oxidation and microorganisms cause degradation of antitranspirant films. Davenport et al. (1971) reported that an experimental film material and a wax emulsion were effective in reducing transpiration of essentially nonexpanding ivy leaves. Stomata distribution on the leaves is an important factor. Obviously a stomata-closing or film forming antitranspirant is of little value if
applied to nonstomata-bearing surfaces of leaves. Since the distribution of stomata of the apple is hypostomatous, it is important to adequately cover the lower surface of the leaves.

Some undesirable effects such as sticky film and yellowing were observed following antitranspirant application. Hacskayo (1960) reports that film over cut Christmas tree needles glues them in place. This may be due to its polyterpene formulations which do not as completely solidify. Effectiveness in reducing transpiration increased significantly as concentration increased, although higher concentrations of antitranspirant appeared to be detrimental to plant vigor resulting in lighter green color as compared to untreated plants. Davenport, Uriu, Fisher and Hagan (1971) report yellowing of fruit tree leaves after a 20% application of antitranspirant. This yellowing may have been a result of suffocation, since CO₂ intake and perhaps O₂ exchange was drastically reduced by the film. This suffocation may have been the reason for the light green color of the M106 apple trees receiving the 10% and 15% antitranspirant sprays. Stomata are common portals for the escape of water vapor and entry of carbon dioxide, thus antitranspirants are reported to reduce photosynthesis and, hence, growth (Davenport, Hagan and Martin 1969, Gale and Hagan 1966, and Waggoner 1966).

Field Experiment

Diffusive Resistance

The antitranspirant significantly increased the diffusive resistance of the leaves in both the unirrigated and irrigated treatments
by forming a film highly impervious to water vapor and stomatal resistance. The flux of water vapor from stomata was directly proportional to the water vapor concentration gradient between the leaf and the atmosphere. It is inversely proportional to the resistance in the water vapor pathway including a boundary layer resistance and a stomatal resistance. As the antitranspirant concentrations were increased, the diffusive resistance increased in both the irrigated and unirrigated treatments. The increase in the concentration of antitranspirant resulted in a more dense film and greater resistance to the loss of water vapor and exchange of other gases. The amount of antitranspirant of a given concentration sprayed per unit area of foliage was also an important factor. Trees in unirrigated treatments showed higher diffusive resistance than in untreated irrigated treatments, suggesting that the antitranspirant offset the lack of soil water. Unirrigated treatments showed higher diffusive resistance than irrigated treatments. This was due to the soil moisture which resulted in a large difference in transpiration. Davenport, Uriu and Hagan (1975) found that the leaves of unirrigated olive trees had higher diffusive resistance and lower plant water potential than irrigated treatments. The increase of resistance was effective up to 3 weeks after spraying, suggesting that the film was not degraded by the environment.

Plant Water Potential

The effective reduction in transpiration by antitranspirants resulted in improving water status of plants as was indicated by
the increase in leaf water potential in all treatments receiving the antitranspirant. As the antitranspirant concentration increased, the water stress decreased from additional diffusive resistance. The high concentration resulted in a denser film thus creating greater resistance to water vapor diffusion from leaves and increasing the water potential of the leaves and the stems. The irrigated trees had a higher water potential than the unirrigated trees due to the increased soil moisture.

Unirrigated trees receiving antitranspirant had a higher water potential than the untreated trees, suggesting that the antitranspirant conserves soil water and thereby reduces the irrigation frequency. Since the antitranspirant covers all the areas of leaf surface it may prevent physiologic drought, especially when plant cuticles are very thin and evaporative demand is very high because of intense radiation and/or low humidities.

Temperature

Leaf temperature increased linearly with increasing antitranspirant concentration in both the irrigated and unirrigated treatments. The maximum increase in leaf temperature (2.5 °C) occurred in the irrigated treatment trees receiving 15% antitranspirant. The minimum increase in leaf temperature was 1°C occurring in the unirrigated trees receiving 3% and 4% antitranspirant. Antitranspirants other than the reflecting type have been reported to increase leaf temperature from 1°C to 5°C (Thames 1961, Tanner 1963, Slatyer and Bierhuizen 1964). There was no leaf injury observed due to the
increase in leaf temperature. The low concentration of antitranspirant resulted in a higher rate of transpiration than the other treatments.

Davenport (1967) and Shimshi (1963) reported that stomata closing antitranspirants reduced transpiration which caused an increase in leaf temperature from 1°C to 4°C. Unirrigated trees showed a higher increase in leaf temperature than did irrigated trees. This difference is consistent with stomatal closure and the soil moisture differences among the treatments. Leaf temperature in irrigated and nonirrigated trees receiving the high concentration of antitranspirant was higher than in leaves receiving the lower concentrations of antitranspirant. The film-forming and stomata-closing antitranspirants tend to increase leaf temperature by curtailing transpiration thus reducing evaporative cooling (Davenport, Hagan and Martin 1969). There was a higher soil moisture in the irrigated plots. In both plots the higher concentration of antitranspirant applied to the trees resulted in higher soil moisture than in the soil under trees receiving the lower concentration of antitranspirant. The differences in leaf temperature also may be due to the differences in soil moisture.

Fruit

Fruit growth depends not only on photosynthetic accumulation and minerals but also on high plant turgidity which depends on high water potential. The data indicate that the antitranspirant improved the water potential of the plants and enhanced fruit growth. Increases in fruit growth resulted from antitranspirant treatments were thus not attributed to photosynthetic accumulation but mainly to the effect of
the antitranspirant on increasing plant water potential. The effect of antitranspirant on fruit growth in this study is similar to those reported by Davenport, Fisher and Hagan (1972) on peaches and by Davenport, Uriu, Martin and Hagan (1972) on olives. Davenport, Uriu and Hagan (1973) state that the increase occurred because of antitranspirant coverage of the stomata-bearing surface of the leaves rather than coverage of the fruit itself. The effect of high concentration of antitranspirant on fruit growth was more pronounced than the lower concentrations. This is attributed to the reduction of the transpiration rate, which causes high cell turgidity. The antitranspirant had no apparent effect on fruit maturity and color. Davenport, Uriu and Hagan (1974) found similar results on peaches.

There was no difference in fruit soluble solids between the treated tree and the untreated. The antitranspirant improved water potential but it reduced photosynthesis. Davenport, Uriu and Hagan (1972) reported no significant loss of fruit dry weight occurred unless the antitranspirant was applied too early. The fruit enlarged as a result of antitranspirant and percent soluble not change with treatment, yet in the laboratory experiment the leaves receiving the higher concentration turned light green. There may have been a conversion of starch to sugar from the leaves or stem and transfer to the fruit to explain this apparent contradiction.
CHAPTER VI

CONCLUSIONS

Laboratory Experiment

Results of this experiment indicate that the transpiration rate of young M106 apple trees is reduced by the film-forming antitranspirant, wilt-pruf. Effectiveness in reducing transpiration increased significantly as the antitranspirant concentration was increased. Higher concentrations of antitranspirant resulted in undesirable effects such as a sticky film and yellowing of leaves.

Field Experiment

Wilt-pruf antitranspirant increased resistance to water vapor diffusion from the foliage of Golden Delicious apple trees and reduced transpiration. Effectiveness in improving diffusion resistance increased significantly as concentrations of antitranspirant increased in both irrigated and unirrigated treatments. Unirrigated treatments showed higher diffusive resistance than irrigated treatments. The antitranspirant (wilt-pruf) provided a substantial barrier to diffusion of water vapor from Golden Delicious apple trees, increasing the water potential of leaves, fruit, and the tree as a whole.

Irrigated treatments showed higher water potential than unirrigated treatments. The unirrigated trees, in turn, showed a significant higher water potential than the irrigated control which suggests the
antitranspirant offset the lower soil moisture level in the non-irrigated trees. In both irrigated and unirrigated treatments when the concentration of the antitranspirant increased, the plant water potential increased.

The temperature increased as a result of the antitranspirant treatments. Leaf temperature increased with increasing antitranspirant concentrations in trees in both the irrigated and unirrigated soils. In irrigated treatments, the increase was 1 to 2.5°C, while in the unirrigated treatments the increase ranged from 1.25 to 2.75°C. Generally, unirrigated treatments showed higher leaf temperature than irrigated treatments. Antitranspirant aided water conservation in both irrigated and unirrigated treatments. As the antitranspirant concentration was increased, the soil water content increased. Fruit size increased as antitranspirant concentrations increased, apparently because of increase in water potential. Unirrigated treatments showed lower water potential and hence a lower increase in fruit growth than the irrigated treatments. It can be concluded that wilt-pruf reduced the water requirement in the apple trees. The optimum time of application and antitranspirant concentration for a given cultivar, age of tree, location of orchard and type of soil would require additional studies. Further studies are needed to develop other materials which have a minimum resistance to the passage of gases other than water vapor.
LITERATURE CITED


Appendix I

Wilt-pruf

Spray Stay (trade name for wilt-pruf) is a low molecular weight, Lewis acid catalyzed polymer of beta pinene (B-pinene) one of the major constituents of pine oil. It is chemically di-l-p-methene. It has two sub-units in the polymer for a molecular weight of 274. Its physical and biological properties are given as follows:

Chemical and Physical Properties of Wilt-pruf

State at room temperature . . . . . . liquid
Acid number . . . . . . . . . . approx. zero
Average specific gravity . . . . . . . 0.95
Iodine number . . . . . . . . . . approx. 98
Solubility . . . . . . . . . .

Unpolymerized, SPRAY STAY is soluble in all aliphatic and aromatic solvents, ketones (except acetone), higher molecular weight alcohols, and chlorinated solvents. After polymerization, solubility is generally decreased in all solvents. SPRAY STAY is soluble in water or kerosene.

Vapor pressure . . . . . . . . . .
200°F - 2mm Hg
300°F - 15 mm Hg
Flash point . . . . . . . . . . 330°F
Refractive index . . . . . . . . . . 1.5098
Approximate pH . . . . . . . . . . 8.7
Biological Properties of Wilt-pruf

LD₀ (mice and dogs) in excess of . . . . . 20,000
Antibacterial activity . . . . . . . . None
Antifungal activity . . . . . . . . None
Intraperitoneally injected (mice)

500 mg/kg/day - twice daily for 7 days
No deaths with weight gains
No intoxication

Primary eye irritation score . . . . . zero
Primary skin irritation
(Human skin-patch test) . . . . . none
Skin irritation score . . . . . . . 0.4
Nonsensitizing to human skin
(Human panels - patch test) . . .

Nontoxic to: mosquito larvae, Virginia saw-worm,
bees, stable flies, rodents, cats, dogs, and other mammals,
birds (ducks, swans, geese, other wild birds), fish.
Nonphytotoxic to evergreens, deciduous trees, flowers
(hothouse). No chemical phytotoxic effects whatsoever.
Suffocation marks on hothouse flowers (safe range - 1-5%);
Conifers (safe range - 1-33%); Deciduous trees (dormant
safe range - 1-33%, nondormant safe range - 1-5%).
No skin reactions of primary irritancy or allergic reactivity - insult
test.
VITA
Hassan A. Nammah
Candidate for the Degree of
Master of Science

Thesis: The Effect of Wilt-Pruf, Antitranspirant or Reducing Water Loss of Apple Trees

Major Field: Plant Science (Horticulture)

Biographical Information:

Personal Data: Born at Dyalla, Iraq, July 7, 1948, son of Aoedh N. Al-Jumaly and Najod A. Al-Jumaly; married Omaima M. Al-Jabouri on June 24, 1974; one child Ahmad Hassan.

Education: Attended elementary school in Baghdad, Iraq; graduated Al-Sharki High School in 1968; received the High Diploma degree from Baghdad University with a major in Horticulture in 1971; received the Bachelor of Science degree from Utah State University in 1977, with a major in Plant Science; completed the requirements for the Master of Science degree at Utah State University in 1979.

Professional Experience: Teaching assistant in the Department of Plant Science at High Institute of Agriculture, 1971-72; Assistant Director of the High Institute of Agriculture, 1973-74; Farm Director, 1974-75.