T H E S I S

on

INVESTIGATIONS IN THE RELATIVE TRANSPIRATION RATE AND FOLIAR WATER-RETAINING POWER OF VARIOUS APPLE VARIETIES

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INTRODUCTION

The water supply is an important factor in influencing the growth and fruitfulness of fruit plants. It is often a limiting factor in the non-irrigated apple-growing regions, particularly of the northwest, where the chief rainfall occurs during the winter and spring months with very little or none during the summer growing season. This seasonal distribution has brought about the adoption of certain practices in soil management designed to conserve soil moisture. The grower's attention has been centered on these practices without an adequate consideration of the tree itself as a factor in water economy.

This thesis is a report of one summer's study of the transpiration rate of various apple varieties in an endeavor to ascertain what relation this may have to their ability to stand the summer drought. Its importance is based on the fact that the grower wants to know the reason why some varieties stand the summer drought and others do not. Many acres of apples have been planted under these conditions without any consideration of their varietal ability to

maintain satisfactory growth and fruitfulness. Today, growers are confronted with the fact that some of these varieties have not proven adaptable to the existing drought conditions. The study of this problem is justified on the basis of the economic losses occurring when it is necessary to remove these unprofitable varieties or to top work them to other varieties capable of adapting themselves to the temporary drought conditions. Harvey (15), and others, who have observed this situation, suggest that the difference in behavior of these varieties may be due either to a difference in the character of the root system or to a difference in the transpiration rate.

Pickering (28), Hutton (16) and Swarbrick and Roberts (32) have noted that the scion variety of the apple has an appreciable effect upon the root development of the stock. On the other hand, Knight (22) of the East Malling Research Station apparently found that apple scion varieties do have a definite rate of transpiration which is not influenced by the stock upon which they are grafted. Kelly (20) found that species of fruit plants generally acknowledged to be drought resistant have a low transpiration rate while those that are not considered drought resistant have a high transpiration rate. Kisselbach (21) found differences in the transpiration rate of 12 varieties of corn.

The complete study of both the character of root system and the transpiration rate of apple varieties seems desirable in this problem. This thesis is the opening wedge in the study of this

particular problem and concerns itself only with an aerial attack upon the transpiration rate. The literature of transpiration has been carefully studied to ascertain the significance of transpiration, particularly in its relation to drought, the factors influencing transpiration, and the methods of measuring transpiration. The remainder of the paper deals with the methods and materials used in the investigation, the experimental data and the conclusions drawn.

THE SIGNIFICANCE OF TRANSPIRATION

Transpiration a Physiological Process

Transpiration is considered an important physiological process in plants. One group of plant physiologists consider it as an unavoidable evil while the majority of investigators believe that transpiration discharges a series of useful functions which are necessary for the successful development of the plant.

Transpiration arises from the fact that an open connection is maintained by the stomata and other openings between the external atmosphere and the internal moist cells of the plant leaves. These openings allow water-vapor to escape from the intercellular spaces into the atmosphere. This, in turn, brings about evaporation from the internal cells of the leaf and causes an upward movement of water from the roots. This process affects the movement of mineral solutes in the plant, the temperature of the plant, and its degree of turgor.

Transpiration in Relation to Drought Resistance

Numerous investigators have studied transpiration in relation to drought resistance. One group has been convinced that there is a close connection existing between the intensity of transpiration and the degree of xerophytism based on the old definition of xerophytes as "plants of dry habitats exhibiting adaptions for a decrease of transpiration." Maximov (27) quotes Huber as finding that xerophytes can reduce their expenditure of water because their stomata close more efficiently than mesophytes.

Another group--particularly agronomic investigators--has made a series of studies on the ratio between the amount of water expended and the dry substance accumulated by a plant during a given interval of time as a basis for judging its efficiency of transpiration.

Briggs (6), and his co-workers, conducted the most extensive and detailed set of investigations on the efficiency of transpiration. He did not find a close connection between a plant's drought resistance and the amount of water expended by it in the production of a unit of dry substance as he expected.

Classification of Plants as to Drought Resistance.

In a later publication Shantz (30) points out that North American plants may be divided into four ecological groups on the basis of drought resistance: (1) drought-escaping, (2) drought-evading, (3) drought-enduring, (4) drought-resisting.

Drought-escaping:- The drought escaping plants are those which grow under favorable conditions of soil moisture content and ripen

their seeds before the soil moisture is exhausted. They show little capacity to resist desiccation of the soil.

Drought-evading:- The drought evading plants are those which delay the ultimate exhaustion of a limited water supply either by restricting the amount of growth or by the efficient and economical use of water. This group of plants is of practical agricultural importance. It includes millet, sorghum, corn and other plants.

Drought-enduring:- The drought-enduring plants consist mainly of the desert shrubs that remain alive for months when the soil moisture is reduced below the wilting coefficient. Growth is renewed upon the addition of water.

Drought-resisting:- The drought-resisting plants are those which are enabled to resist periods of drought by storing up a supply of water in their fleshy parts to be used when none can be obtained from the soil. This group includes the cacti.

Kinds of Drought.

It is necessary to distinguish between atmospheric drought and soil drought as they affect the plant somewhat differently.

Atmospheric drought:- Reed and Bartholomew (29) show that citrus trees are often severely damaged by hot, dry winds although the water content of the soil is at an optimum. The most conspicuous damage is the defoliation caused by windburn or scorching of the leaves. Windburn seems to be due chiefly to the withdrawal of water faster than the vascular system of the stem can supply it. Scorching is more often produced when the wind is hot. It

is believed that death in this case is due to a coagulation of proteins of the protoplasm as a scorched leaf never recovers.

Soil drought:- Soil drought occurs when the soil is unable to supply water to the plant in quantities sufficient to replace the water lost by evaporation or when it entirely ceases to provide any water to the plant. In any case the plant wilts and wilting is permanent. Under these conditions two types of wilting have been noted; one consists of a rapid loss of turgor accompanied by an insignificant decrease in the water content of the leaf, while the other consists of a gradual transition from incipient drying to actual wilting. The latter type is characteristic of the majority of plants, especially those of dry exposed habitats.

Time of drought:- The exact time at which drought occurs in relation to the degree of development of the plant is of great importance from the agricultural point of view. This may possibly be a cause for varietal differences in behavior.

FACTORS INFLUENCING TRANSPIRATION

The physiological process known as transpiration is more complex than the mere evaporation of water from a non-living free-water surface. Briggs and Shantz (4) obtained results which conclusively show that plants, under conditions favoring high evaporation, do not respond as free evaporation systems, even when well supplied with water and are apparently turgid.

Some investigators distinguish between cuticular and stomatal transpiration. The amount of water lost by cuticular transpiration

is so insignificant compared with that transpired through the stomata that they will be treated as one process in this thesis.

The factors which influence the transpiration rate of plants may be classified as internal and external to the plant.

Internal Factors.

The internal factors include such divisions as the leaf-area, the arrangement of the leaves, the leaf structure, the moisture content of the leaf, the age of the plant or plant part, the root development, the health of the plant and its inherent ability to withstand drought.

Leaf Area.

It is quite apparent that the amount of water transpired by a plant is definitely related to the leaf area. Data are presented by Hartig (14) to show that the reduction of leaf area materially increases the transpiration rate. This would be the case when a tree is defoliated or pruned. The remaining leaves transpire at a higher rate. Cullinan (11) found that pruned apple trees transpire at a higher rate per unit area of leaf surface than unpruned trees.

Arrangement of Leaves.

The arrangement of leaves or their position with relation to exposure of direct sunlight has been considered by some investigators to have an important influence on the transpiration rate. This factor will not be considered in this paper. The difference in the arrangement of leaves of Jonathan, Gravenstein, Grimes and Ortley apples is shown in Illustration II.

Leaf Structure.

Investigations on the relation of leaf structure to the transpiration rate show a difference in the anatomical structure and physiological nature of the upper and lower leaves of the same shoot. Maximov (27) summarizes the chief anatomical differences of the upper leaves as: a thicker network of veins, a more strongly developed palisade and spongy mesophyll, smaller dimensions of all anatomical elements, a greater number of stomata per unit area, and a thicker cuticle. The chief physiological differences of the upper leaves are: a higher osmotic pressure, greater suction pressure, more intense transpiration, more rapid supply of water to the transpiring cells, and a greater intensity of carbon assimilation. Maximov (27) shows that Yapp is inclined to attribute the observed differences of structure, in part, to differences of turgor in the lower and upper leaves, respectively, during development. The upper, more xeromorphic leaves develop during the summer, under conditions favoring a high transpiration rate. Their structure is possibly influenced by the supply of water which they receive. It is believed that the supply of water to the upper leaves is diminished by a partial deflection of the water stream to the lower leaves of the shoot.

Moisture Content of the Leaf.

Livingston and Brown (26) suggest that the water content of leaves under conditions of rapid evaporation affect the transpiration rate by causing a difference in the surface tension and eva-

porating surface of the internally and externally exposed cell walls. This incipient drying increases the resistance to water loss and is an important factor to consider in comparing transpiration rates. Chandler (8) points out that these phenomena of incipient drying increases the resistance of fruit trees to water loss in latersummer and has considerable effect on the transpiration rate.

Age of the Plant or Plant Part.

The age of a leaf effects its transpiration rate. Bakke (1) states that young leaves of plants exhibit greater transpiring power than do the older ones. The youngest leaves probably transpire at a higher rate because the cuticle is thin and permeable; as the leaf ages, the cuticle thickens and the transpiration rate decreases. Boussingault (3) shows that an apple fruit transpires fifty-five times faster after the cuticle has been removed.

Root Development.

The root development influences the supply of water to the plant and consequently that available for transpiration. This may seriously affect the performance of fruit trees grown in fertile soils which are wet in the spring and dry out in the summer. The top in these cases makes a good growth in the early part of the year because of the abundant water and nitrogen supply while the roots do not make a proportional development. Later in the growing season when the water table has been lowered the roots are unable to supply sufficient moisture to the top. This may lead to physiological disturbances or even death due to a de-

ficiency in the ability of the roots to supply water to the tops.

Health of the Plant.

The health of the plant as shown by the vigor and freedom from disease may have bearing on the transpiration rate. Bews and Aitken (2) show that a vigorous growth apparently causes an economy in the water requirement of Bidens pilosa. Viehmeyer (33) on the other hand, states that the use of water per unit of leaf area by young prune trees was not influenced by the state of growth. The intensity of transpiration per unit area apparently was the same in the spring as in the fall when the atmospheric evaporating power was the same. Cullinan (11) also found that the transpiration rate was not a reliable index to growth activity in the apple. He points out that the transpiration rate shows a very marked change when small portions of the stems and foliage are removed. It is inferred from this that diseases which attack the stems or foliage would influence transpiration.

Inherent Drought-resisting Ability.

The inherent resistance to drought is one of the most important properties of plants. It is related to the capacity of the protoplasm to endure considerable fluctations in the degree of swelling without the loss of vital activity. This capacity of enduring water loss may completely mask the significance of the other anatomical and physiological pecularities and upset any endeavor to correlate drought resistance and these external characteristics.

External Factors

The external factors which affect transpiration may be divided into three groups: atmospheric, soil and spray materials.

Atmospheric Factors.

The atmospheric factors include relative humidity, air temperature, air movement, light intensity, composition of the air and air pressure.

Relative humidity:- Atmospheric humidity undoubtedly is the most potent factor influencing the transpiration rate. Briggs and Shantz (5) found the water requirement of plants was invariably less when grown under humid conditions than when grown under dry atmospheric conditions. Maximov (27) states that the influence of atmospheric humidity or transpiration is exceedingly complicated and cannot be expressed by a simple formula.

Air temperature:- The air temperature indirectly affects transpiration in many ways by its effect upon the various functions of the plant. It exerts an important influence on transpiration by affecting the surface tension films of the mesophyll cells and changing their rate of molecular diffusion. Increased temperature accelerates evaporation or diffusion of water from the mesophyll cells, increasing the relative humidity in the intercellular spaces of the leaf and at the same time decreasing the relative humidity of the atmosphere outside of the leaf, so there is more rapid diffusion of water vapor through the stomata. Livingston (26) refers to temperature as the probable controlling factor

in causing fluctuations in the transpiration stream. Briggs and Shantz found that the water requirements of cool-weather plants are increased by a higher temperature while the water requirements of warm-weather plants are increased by lower temperatures. Generally speaking the transpiration rate is increased by higher temperatures. The cooler temperatures of northern slopes may be influential in reducing excessive transpiration of fruit trees when water is a limiting factor. Reed and Bartholomew (29) show that hot, dry winds causing excessive transpiration of citrus leaves cause various degrees of plasmolysis and may bring about a coagulation of the proteins in the leaf so that the entire leaf or portions of it may be killed. Injury apparently similar to this was noted on the leaves of the Spitzenburg variety of apple in the present study.

Air movement:- The transpiration rate is increased by wind or air movement but it is difficult to establish any quantitative relationship between them. Windbreaks may be utilized to lessen transpiration in the orchard.

Light intensity:- The increased rate of transpiration in plants exposed to sunlight may be due to its physical effect on the opening of the stomata or to its physiological effects on the permeability of the membranes.

Composition of the air and air pressure:- The influence of atmospheric pressure or the amount of carbon-dioxide in the air is too insignificant, in comparison with other factors, to be considered

in detail in most transpiration studies.

Soil Conditions.

The soil conditions which influence the rate of transpiration are: soil temperature, oxygen content, concentration of the soil solution, acidity of the soil, soil texture and moisture content.

Soil temperature:- Soil temperature plays a prominent part in influencing the transpiration rate. Cribbs (9) noted a close parallel existed between average soil temperatures and average transpiration indices. A high transpiration rate accompanied a high soil temperature but the relationship is not definitely known because there was less water present than under conditions of low temperature. Low soil temperatures seem to inhibit water absorption by the root system and probably would cause a lower rate of water loss from the leaf.

Oxygen content:- The oxygen content of the soil has an important influence on root activity. De Saussure and other investigators have noted that the lack of oxygen in the soil affects the absorption of water by the root system.

Concentration of soil solution:- The concentration of the soil solution affects the absorption of water by the roots. Some plants are incapable of increasing their osmotic pressure sufficiently to overcome the resistance to absorption shown by concentrated soil solutions while others can increase their osmotic pressures and overcome this resistance.

Acidity:- Maximov (27) shows that numerous investigators con-

sider that a high concentration of acids in the soil increases transpiration and consequently absorption, while a weak concentration (not exceeding 0.018 N.) checks absorption. Other investigators found that the permeability of protoplasm to water is decreased by weak acids.

Soil texture:- The texture of the soil is an indirect factor because it affects the nature of the root system, the supply of water available to the plant and the temperature of the soil. Cribbs (9) found the maximum daily transpiration rate lower on clay soils than on sandy soils.

Moisture content:- The moisture content of the soil affects the growth and vigor of the plant but seems to have relatively little effect on the transpiration rate provided it does not fall below the wilting coefficient. Cribbs (9) found that the transpiration rate was not conspicuously influenced by changes in soil moisture content of from 2.5 per cent to 157.0 per cent. Hendrickson and Veihmeyer (18) found that as long as orchard trees show that they are using water at a uniform rate, or as fast as evaporating conditions necessitate, although there is a progressive decrease in soil moisture from week to week, neither the growth of the trees nor the growth of the fruit can be altered by the addition of water to the soil.

Spray Materials.

The spray materials known to influence transpiration are the oil sprays, Bordeaux mixture, and lime-sulphur.

Oil sprays:- Burroughs (7) found that a 2 per cent oil spray scarcely decreased the transpiration rate of one-year old apple twigs when the leaves were uninjured by the oil but that the transpiration rate was markedly reduced when the leaves were injured by the oil or after dipping the twigs in a 2 per cent emulsion. Kelley (19), also found dipping shoots of apple, peach, pear, plum and cherry in various oil emulsions markedly reduced the transpiration rate. He reports that oil sprays when applied to the upper surface of the leaf had little if any affect on the transpiration rate but when applied to the lower surface markedly reduced transpiration. The depression of transpiration is greater on older leaves than on younger leaves with the greatest depression occurring when the transpiration rate is the highest. A change in rate of transpiration was noticed 30 minutes after the oil was applied and lasted as long as it was possible to continue transpiration studies on cut shoots. Likewise, Knight, Chamberlain and Samuels (24) found that the application of oil sprays to sour-orange nursery stock caused a sharp and abnormal drop in the transpiration rate, the extent of the depression varying directly with the viscosity of the oil. This depression appeared to be due to physical handicaps caused by penetration of the oil into the leaf. Transpiration returned to normal in one to six weeks depending on the viscosity of the oil and the amount applied.

Bordeaux mixture:- In 1914, Duggar and Cooley (12) found

that transpiration rate of the castor bean and tomato was accelerated by the application of a film of 4-6-50 Bordeaux mixture while the other films and dusts employed did not seem to affect the rate of transpiration to the same extent. Dutton (13), in 1923, found that cut shoots of Bordeaux-sprayed Morello cherries transpired at a higher rate than unsprayed or lime-sulphur-sprayed shoots. He attributes the smaller size of Bordeaux-sprayed cherries to the fact that the foliage, transpiring at a higher rate, has a greater power of drawing water from the green fruits than the unsprayed or lime-sulphur sprayed foliage. The water deficit in the Bordeaux-sprayed cherries, measured by immersing fresh paraffin-coated fruits of each lot in water, was seven times that of similarly treated unsprayed cherries. In other words, the Bordeaux-sprayed fruits when coated with paraffin and immersed in water absorbed seven times the amount of water through their stems than similarly treated unsprayed cherries of the same variety.

Lime-sulphur:- Reed and Bartholomew (29) found that applications of lime-sulphur increased the transpiration rate of Valencia orange leaves 12 to 26 per cent over that of unsprayed leaves. The transpiration rate of sprayed leaves was reduced 2 to 5 per cent about 10 days after application but after 30 to 40 days it was 15 to 19 per cent higher than that of unsprayed leaves.

METHODS OF MEASURING TRANSPIRATION

Types of Transpiration Study

There are three types of transpiration study: studies of the

total transpiration rate of an entire plant, studies of the transpiration rate per unit weight of dry matter produced and studies of the transpiration rate per unit area of the leaf surface.

Types of Methods

The methods of measuring transpiration may be divided into two general types: a study of water intake and a study of water loss.

Water Intake.

The methods of studying water intake are by means of potometers of various types. A potometer consists of a container in which a plant or plant part is held in soil, water, or nutrient solution while its transpiration rate is being determined. A burette-potometer or a weight-potometer may be used. These terms are self-explanatory. The former measures the intake of water by means of a burette and the latter by the loss in weight or by the weight of the water added to the potometer.

Water Loss.

The methods of studying transpiration by water loss are by means of cobalt chloride papers, calcium chloride or by weighing potometers.

Cobalt chloride method:- The cobalt chloride paper method has been used satisfactorily in certain physiological and ecological studies by Livingston, Bakke, and others to get the diurnal changes in foliar transpiring power, the transpiring power of leaves of different ages, the transpiring power of leaves in different positions on the stem and the relation between diurnal and

nocturnal transpiration rates. It consists of placing a blue slip of dry cobalt chloride paper on a leaf and noting the time required for it to change to a pink color due to the absorption of moisture. The slip is held in place by glass-tipped spring forceps to exclude the moisture of the air. Livingston (25) devised a triparte slip in which the cobalt chloride indicator paper is held between two color indicators.

Calcium chloride:- The calcium chloride method involves the use of this compound to absorb the moisture given off by the leaf. Heinicke (17) describes a satisfactory means of measuring transpiration by this method. Various modifications of this method are found in the literature.

Potometer method:- The potometer method has been discussed under the methods used in studying water intake.

MATERIALS AND METHODS

Plant Materials

Apple varieties found on the horticultural farm of the Oregon State College were used for practically all of the experimental studies. Two experiments were made on apple varieties from Oaco Orchards at Monroe, Oregon. The transpiration rates were determined on terminal shoots of the current season's growth. These shoots were cut at random from all parts of the tree or trees, immediately placed in a pail of water, and taken to the college greenhouse where they were sorted. Care was used to select only healthy shoots, typical of the variety, which were uniform in

amount of growth and free from spray and insect injury. These shoots were again cut, under water, with a sharp knife and connected to a continuous column of water in the burette-potometer. They were allowed to transpire for an hour, or more, to make sure there were no air leaks before starting the actual measurement of transpiration. These shoots were collected in the orchard in the morning and attached to the potometers by noon so that practically all studies started at 1 o'clock p. m.

The leaves, used in studying the water-retaining power on drying, were stripped from terminal shoots of the current season's growth and taken to the laboratory where they were weighed and spread on the table to dry.

Terminal leaves of the current season's shoot growth gathered from all sides of the tree were used in the anatomical studies. These were gathered October 4, 1930 and stored in a 5 per cent. formalin solution.

Methods Used

Cobalt Chloride Paper.

Cobalt chloride paper was prepared by placing Genuine Whatman Filter Paper Number 1 (12.5 cm. dia.) in a cobalt chloride solution containing 6 grams of the salt in 100 cc. of distilled water for one minute. The excess liquid was squeezed out with a squeegee rubber roller on a porcelain plate using fresh pieces of blotting paper to absorb the excess liquid. The circle of paper was then dried by hanging it over a hot-plate until it started to turn blue

and then drying it between several dry sheets of blotting paper on a warm hot-plate. It was placed in a desiccator over concentrated sulphuric acid where it remained until used for making the composite slips. The permanent color standards for the composite slips were made by immersing the same brand of filter paper, first, in distilled water, second, in a solution of ferric chloride and finally in a solution of potassium ferrocyanide. The excess solution was squeezed out by rolling with a squeege rubber roller. The paper was dried over a hot plate. The darker color standard was dipped in a solution containing 1.14 grams of ferric chloride in 100 cc of solution and then into a potassium ferrocyanide solution containing 18.4 grams of the salt in 100 cc. This was made slightly acid by adding HCL. The paper was left in this for two minutes. The less intense color standard was made in a similar manner using similar solutions. The ferric chloride solution used for this contained 0.57 grams of the salt in 100 cc. and was made distinctly acid to litmus by adding HCL. The potassium ferrocyanide solution contained 18.4 grams of the salt in 100 cc. and was also made distinctly acid by adding HCL. The paper was removed when a light blue color was obtained. Much practice in getting the proper concentration of solutions was necessary. If high concentrations are used the precipitate is composed of large particles and does not enter the filter paper. The lower concentrations form a fine blue precipitate which dyes the paper readily. Care must be used to get the paper dyed uniformly.

Triparte composite slips were formed and numbered. Each was tested over a free water surface for the time required to change color before they were tried on the apple leaf. This method proved unsatisfactory under existing weather conditions in the orchard and was abandoned after several days of preliminary study.

Burette-Potometers.

A battery of potometers was set up in the greenhouse where higher temperatures prevailed than out-of-doors. It is under these high temperatures that varieties show their greatest difference in ability to withstand drought. These consisted at first of a "U" shaped device with a 50 cc. burette on one side and a glass tube on the other. The shoot was connected to the glass tube by a rubber tube. The shoot and the burette were clamped to the stand by means of clothes pins. This set-up is shown in Illustration Number 1. In the latter potometer experiments the burette was disconnected and the glass tube extended directly into a capped pint milk-bottle which was filled to a definite mark each time readings were made. Distilled water was used in all potometers.

Calcium Chloride.

One test of this method as described by Heinicke (17) was made. It was found that the heavy clamp used by Heinicke could be avoided by using an ordinary metal washer and a wide rubber band to hold the leaf in close contact with the rubber-lipped weighing bottle containing the calcium chloride. Dr. E. T. Bartholomew of the Riverside Citrus Experiment Station used this method. He

sealed the tube to the leaf with wax to prevent any possible air leaks.

This method is convenient to use directly on the trees. It has the disadvantage of measuring transpiration of only one side of a leaf at a time and of measuring transpiration into a closed system where the evaporating power of the air is not the same as that of the atmosphere.

Atmospheric Conditions.

The evaporating power of the air was determined by the use of two white spherical atmometers. These were set at each end of the battery of potometers. Wet and dry bulb readings on a sling psychrometer were taken at convenient intervals and the relative humidity calculated from the proper tables in Psychrometric Tables, Part 1, published by the United States Weather Bureau.

Leaf Areas.

At the end of each potometer experiment the individual leaves from each shoot which completed the experiment were carefully traced with a planimeter to get the leaf area. This was determined in square centimeters. A unit area of surface represents a square centimeter of surface as measured on one side of the leaf. The upper surface of the leaf is not considered in calculating the total leaf surface.

Anatomical Studies.

The total thickness of 14 varieties of apple leaves was determined on terminal leaves of the current season's growth. These

were collected October fourth and placed in 5 per cent formalin solution until they were sectioned. Measurements of the thickness of the cuticle, the upper epidermis, the palisade cells, the spongy mesophyll, lower epidermis, and the entire leaf were made by means of an ocular micrometer on free hand sections from thirty leaves of each variety.

Statistical Studies.

In the first potometer studies it was noticed that the individual shoots showed a tendency to vary in their transpiration rates. In the later potometer experiments a larger number of shoots of each variety were used and a statistical analysis made of the data. The mean transpiration rate was calculated from the formula $M = \frac{FV}{N}$. The probable error of the mean was calculated from the formula $E_m = \frac{0.6745}{\sqrt{N}} \times$ (standard deviation). The standard deviation was calculated by the formula. Standard Deviation $= \sqrt{\frac{Fd^2}{N}}$.

EXPERIMENTAL DATA

This study was designed to open up the investigation of the transpiration rate and foliar water-retaining power of various apple varieties. The study was divided into three parts: studies on the foliar water-retaining power, studies on the transpiration rate by: potometers, cobalt-chloride, and calcium chloride and anatomical studies of the leaves.

Foliar Water-Retaining Power

Studies of the foliar water-retaining power were made on healthy leaves stripped from the current season's shoot growth to

see if the various varieties exhibited a difference in their foliar resistance to water loss upon drying. The leaves were weighed and spread upon a table in the laboratory. The leaf surface was determined by planimeter. A deep petri dish containing tap water at room temperature was set on the table so that the rate of water loss from the leaves could be compared to the rate of water loss from a free water surface. Data, presented in Table I, indicate that the Rome variety lost water at the most rapid rate, of the varieties tested, during the first 18 hours of drying. The leaves of this particular variety were dry and crisp at the end of this period while the leaves of the other varieties were yet moist and pliable. Evidently Rome did not possess the power to resist loss of foliar water upon drying. Delicious, Patten and Gravenstein also lost water at a high rate while Wealthy and Benoni seemed to resist the loss of water. The table also shows the total loss of weight, the loss of weight per unit area of surface, and the percentage of foliar-water lost in relation to free water lost for each of the varieties tested.

Table II gives data on the same varieties in another experiment. The weather was cloudy and humid at this time. Again, Rome, Delicious, Patten and Gravenstein lost water at a more rapid rate than Wealthy and Benoni. Large numbers of leaves were used to reduce the error of weighing.

Table I Experiment 1 Foliar Water-Retaining Power, May 13

Variety	Number Leaves	Total Leaf Surface	Fresh Weight	Loss of Weight			Loss of Weight per sq. cm.			Foliar water loss in Relation to Free H_2O		
				Hours 1-18	Hours 18-42	Hours 42-96	Hours 1-18	Hours 18-42	Hours 42-96	Hours 1-18	Hours 18-42	Hours 42-96
		Sq.cm.	gms.	gms.	gms.	gms.	gms.	gms.	gms.	%	%	%
Delicious	25	721	25.80	12.50	3.33	0.87	.0173	.0046	.0012	8.25	1.33	0.18
Gravenstein	22	1469	48.00	23.10	7.68	1.37	.0157	.0052	.0009	7.49	1.50	0.13
Wealthy	25	1145	33.02	14.12	5.30	0.85	.0123	.0046	.0007	5.87	1.33	0.10
Patten	43	1014	33.57	17.12	4.55	0.75	.0168	.0045	.0007	8.01	1.30	0.10
Rome	37	858	31.30	17.68 *	1.82	0.68	.0205	.0021	.0008	9.78	0.61	0.12
Benoni	50	1510	42.00	16.78	8.02	1.36	.0111	.0053	.0009	5.29	1.53	0.13
Water	--	84.5	355.6	17.72	29.32	56.90	.2097	.3470	.6734	100.0	100.0	100.0

* Leaves crisp at end of 18 hours; other varieties were still pliable.

Table II Experiment 2 Foliar Water-Retaining Power, May 17

Variety	Number Leaves	Total Leaf Surface	Fresh Weight	Loss of Weight				Foliar water lost in Relation to Free H_2O			
				Hours 1-18	Hours 18-42	Hours 42-96	Total	Hours 1-18	Hours 18-42	Hours 42-96	Total
		Sq.cm.	gms.	gms.	gms.	gms.	gms.	%	%	%	%
Delicious	50	1535	45.40	22.00	5.45	1.58	29.03	6.31	1.64	0.15	1.71
Gravenstein	40	2528	72.20	29.98	14.20	3.63	47.81	5.25	2.56	0.21	1.71
Wealthy	50	2140	60.20	23.13	9.32	2.95	35.40	4.77	2.01	0.21	1.49
Patten	60	1956	46.12	22.92	6.43	0.77	30.12	5.17	1.50	0.06	1.39
Rome	54	1307	54.94	18.49	2.75	0.80	22.04	6.23	0.96	0.09	1.52
Benoni	54	2090	47.00	16.40	9.36	2.72	28.48	3.44	2.05	0.19	1.23
Water	--	84.5	412.45	19.13	13.48	56.27	93.88	100.0	100.0	100.0	100.0

Table III Experiment 3 Foliar Water-Retaining Power, May 21

Variety	Number Leaves	Total Leaf Surface	Fresh Weight	Oven Dry Weight	Per cent Water	Loss of Weight				Per Cent H_2O lost per sq. cm.			
						Hours 1-6	Hours 6-18	Hours 18-30	Hours 30-40	Hours 1-6	Hours 6-18	Hours 18-30	Hours 30-40
		sq.cm	gms.	gms.	%	gms.	gms.	gms.	gms.	%	%	%	%
Gravenstein	10	654	16.75	5.15	69.3	5.98	2.97	2.00	0.05	7.55	3.57	1.04	0.09
King	10	773	24.35	9.27	61.9	3.35	3.40	2.46	(1)--	3.96	3.49	1.07	----
McIntosh	10	352	12.29	4.37	64.4	4.29	1.93	1.35	(2)--	10.12	4.37	1.27	----
Baldwin	10	273	8.65	2.35	67.1	2.90	1.46	1.04	0.05	7.30	4.21	1.27	0.09
N. Spy	10	392	11.95	4.05	66.1	4.66	1.72	1.12	0.01	9.88	3.49	0.97	0.00
Jonathan	10	306	8.75	2.90	66.9	2.96	1.50	1.07	0.00	8.05	3.89	1.17	0.00
Wealthy	10	447	12.46	4.72	62.1	3.99	1.93	1.40	0.00	7.39	3.41	1.04	0.00
Water	--	84.5	428.77	----	----	10.18	10.65	25.19	9.78	100.0	100.0	100.0	100.0

(1.) Gained 0.05 gm. wt.

(2.) Gained 0.02 gm. wt.

Data, in Table III, show that McIntosh, N. Spy and King lost water at a higher rate than Baldwin, Jonathan and Wealthy. The water content of these leaves based on fresh weight is shown. The rate of loss the first 6 hours is about 7 to 10 per cent that of free water and only about 3 to 4 per cent during the next twelve hours. This shows that the leaves show a greater "water-retaining power" as the incipient drying increases. The humidity of the atmosphere was higher during the 30 to 40 hour period than it was during the 18 to 30 hour period which accounts for the gain in weight of the King and McIntosh varieties which had previously lost water at a high rate. This experiment was repeated on May 31, 1930. The results of this are shown in Table IV. This shows that the percentage of moisture in the leaves was less in all cases than it was in Experiment 3. Gravenstein, Baldwin, King and Wealthy lost water at a higher rate the first six hours than did N. Spy, Jonathan or McIntosh. Comparing Experiments 3 and 4, it is noticed that Gravenstein, King and McIntosh show a high percentage of water loss per unit area the first six hours of drying compared to the lower rate of Baldwin, N. Spy, Jonathan and Wealthy. It is thought that this may be significant in affecting the water loss of these varieties when grown under drought conditions.

Table IV Experiment 4 Foliar Water-Retaining Power, May 31

Variety	Number Leaves	Total Leaf Surface	Fresh Weight	Oven Dry Weight	Per Cent Water	Loss of Weight				Per Cent H_2O lost per sq. cm.			
						Hours 1-6	Hours 6-18	Hours 18-30	Hours 30-40	Hours 1-6	Hours 6-18	Hours 18-30	Hours 30-40
		sq.cm	gms.	gms.	%	gms.	gms.	gms.	gms.	%	%	%	%
Gravenstein	10	705	24.25	8.30	65.7	8.78	4.15	1.67	0.21	15.60	5.50	1.12	0.35
King	10	796	28.15	11.15	60.4	8.15	4.73	2.52	0.13	12.73	5.50	1.49	0.23
McIntosh	10	260	9.30	3.42	63.2	2.33	1.67	1.40	0.08	11.23	5.97	2.52	0.35
Baldwin	10	565	19.51	7.48	61.7	5.94	3.12	1.73	0.15	13.10	5.13	1.45	0.35
N. Spy	10	672	22.57	8.55	62.1	5.60	3.47	2.60	0.38	10.36	4.85	1.82	0.71
Jonathan	10	324	10.52	3.94	62.5	2.92	1.78	1.23	0.09	11.23	5.13	1.77	0.35
Wealthy	10	424	14.95	6.36	57.5	4.15	2.25	1.33	0.12	12.23	4.94	1.45	0.35
Water	--	84.5	399.02	----	----	6.77	9.05	18.05	7.10	100.0	100.0	100.0	100.0

Table V Percentage of Water in Leaves

Variety	Per Cent Water May 21 %	May 31 %	Oct. 4 %
Gravenstein	69.3	65.7	60.1
King	61.9	60.4	56.8
McIntosh	64.4	63.2	56.8
Baldwin	67.1	61.7	58.1
N. Spy	66.1	62.1	----
Jonathan	66.9	62.5	56.6
Wealthy	62.1	57.5	53.5

Table V shows a consistent decrease in the water content of apple leaves during the growing season. Knight (23) showed that the water content of the leaf played an important part in the control of transpiration, a high water content tending to increase transpiration and a lower one to decrease it. However, data in Table III and Table IV do not show any consistent relation between a high water content of the leaves and a high rate of water loss per unit area of surface the first six hours of drying. Table VI shows the percentage of water in a larger number of varieties on October fourth.

Table VI	Water Content of Leaves			October 4
Variety	Fresh Weight	Dry Weight	Weight Loss	Per cent Water
Baldwin	421.0	176.5	244.5	58.07
McIntosh	391.5	169.0	222.5	56.83
Wealthy	207.5	96.5	111.0	53.49
Ben Davis	183.5	81.5	102.0	55.58
King	358.5	155.0	203.5	56.76
N. W. Greening	445.0	185.0	260.0	58.42
Red Canada	357.5	163.0	194.5	54.40
Delicious	294.0	122.5	171.5	54.93
Fameuse	348.5	141.5	207.0	59.40
Duchess	309.5	135.5	174.0	56.22
Gravenstein	426.0	170.0	256.0	60.10
Grimes	544.0	236.5	307.5	56.53
Ark. Black	514.5	215.0	299.5	58.21
Ortley	462.0	214.0	248.0	53.68
Jonathan	587.0	255.0	332.0	56.56

Transpiration by Potometers

The first potometer studies were made on small numbers of shoots of each variety so more varieties could be studied with the limited supply of potometers. After a survey of many varieties had been made, larger numbers of shoots of each variety were used so that a statistical analysis could be made of the variations of transpiration rate occurring within the variety. In several cases the same varieties were compared in other experiments to see if their relative transpiration rate remained the same.

The transpiration rate of varieties in a single experiment may be compared with each other but cannot be compared to varieties in other experiments because atmospheric conditions are distinctly different in each experiment.

Transpiration During Different Periods of the Day.

Results in Table VII show the amount of water transpired at various periods of the day. These show that 89.3 per cent of the total water used in the twenty-four-hour period was used during the twelve-hour day from 7 o'clock a. m. to 7 o'clock p. m., while the remainder, 10.7 per cent, was used during the twelve-hour night period from 7 o'clock p. m. to 7 o'clock a. m.

Records of temperature and relative humidity, unfortunately, are not available for this experiment. The percentage of total water used during the four six-hour periods is as follows: the afternoon-period 1 o'clock p. m. to 7 o'clock p. m. 57.02 per cent; the early-night-period 7 o'clock p. m. to 1 o'clock a. m.

Table VII Experiment V (cont'd) Two Day Transpiration Studies - First Day June 21

No. of Shoot	Variety	No. OF Leaves	Total Leaf Surface	Amount of Water Used: 1 p. m. to 7 p. m.	7 p. m. to 1 a. m.	1 a. m. to 7 a. m.	7 a. m. to 1 p. m.	First Day: Day 7 a. m. to 7 p. m.	Night 7 p. m. to 7 a. m.	Total 1-24 Hours	Volume H_2O used per sq. cm. 1-24 hours	av'g.
			sq. cm.	cc.	cc.	cc.	cc.	cc.	cc.	cc.	cc.	
1.		15	648	58.5	6.9	6.2	37.9	96.4	13.1	109.5	0.169	
2.	King	19	676	76.7	7.2	6.5	45.1	121.8	13.7	135.5	0.200	
3.		18	733	74.3	7.7	7.1	42.2	116.5	14.8	131.3	0.179	0.183
4.		--	---	----	---	---	----	-----	----	-----	-----	-----
5.	McIntosh	13	351	29.8	3.3	2.4	10.1	39.9	5.7	45.6	0.130	
6.		17	453	52.1	3.0	3.1	26.1	78.2	6.1	84.3	0.186	0.158
7.		16	535	28.6	5.2	3.5	13.7	42.3	8.7	51.0	0.095	
8.	Baldwin	14	552	69.5	6.0	6.1	43.4	112.9	12.1	125.0	0.226	
9.		15	445	40.4	4.2	3.9	27.3	67.7	8.1	75.8	0.170	0.164
10.		12	259	27.1	3.2	2.6	9.8	36.9	5.8	42.7	0.165	
11.	Fameuse	12	280	33.3	4.1	2.9	13.9	47.2	7.0	54.2	0.194	
12.		13	268	40.3	3.6	3.2	23.7	64.0	6.8	70.8	0.264	0.208
13.		13	317	42.9	3.2	3.6	26.9	69.8	6.8	76.6	0.242	
14.	Wealthy	--	---	----	---	---	----	----	---	----	-----	
15.		16	456	57.7	4.7	5.0	37.3	95.0	9.7	104.7	0.230	0.236
Total		193	5973	631.2	62.3	56.1	357.4	988.6	118.4	1107.0		0.185

Table VIII Experiment 5 (cont'd) Two day Transpiration Studies - Second Day June 23-24

No. of shoot	Variety	No. of Leaves	Total Leaf Surface	Amount of Water Used Second Day: 1 p.m. to 7 p.m.	7 p.m. to 1 a.m.	1 a.m. to 7 a.m.	7 a.m. to 1 p.m.	Day 7 a.m. to 7 p.m.	Night 7 p.m. to 7 a.m.	Total 1-24 Hours	Volume H_2O used per sq. cm. 1-24 hours	
			sq. cm.	cc.	cc.	cc.	cc.	cc.	cc.	cc.	cc.	av'g. cc
1.		15	648	49.2	7.6	8.4	52.9	102.1	16.0	118.1	0.182	
2.	King	19	676	58.9	8.2	9.4	64.1	123.0	17.6	140.6	0.208	
3.		18	733	49.3	8.3	8.4	35.9	85.2	16.7	101.9	0.139	0.176
4.		--	---	----	---	---	----	-----	----	-----	-----	
5.	McIntosh	13	351	10.5	2.8	2.1	7.0	17.5	4.9	22.4	0.064	
6.		17	453	28.7	2.9	3.1	18.3	47.0	6.0	53.0	0.117	0.091
7.												
7.		16	535	15.7	4.0	3.2	12.4	28.1	7.2	35.3	0.066	
8.	Baldwin	14	552	53.0	6.5	7.8	54.5	107.5	14.3	121.8	0.221	
9.		15	445	33.9	4.4	5.1	37.0	70.9	9.5	80.4	0.181	0.156
10.		12	259	9.9	2.5	2.0	7.0	16.9	4.5	21.4	0.083	
11.	Fameuse	12	280	15.2	3.1	2.7	11.4	26.6	5.8	32.4	0.116	
12.		13	268	30.3	4.2	4.4	23.0	53.3	8.6	61.9	0.231	0.143
13.		13	317	35.8	2.8	4.8	32.7	68.5	7.6	76.1	0.240	
14.	Wealthy	--	---	----	---	---	----	----	---	----	-----	
15.		16	456	46.7	5.5	6.5	47.8	94.5	12.0	106.5	-.234	0.237
Total		193	5973	437.1	62.3	67.9	404.0	841.1	130.7	971.8		0.163

Table IX Experiment 6 (cont'd) Two Day Transpiration Studies - First Day June 24-25

No. of Shoot	Variety	No. of Leaves	Total Leaf Surface	Amount of water used: 12 am. to 6 p. m.	6 p.m. to 12 pm.	12 pm. to 6 a. m.	6 a.m. to 12 am.	First Day: Day 6 a.m. to 6 p.m.	Night 6 p.m. to 6 a.m.	Total 1-24 Hours	Volume H_2O used per sq. cm. 1-24 hours	
			sq.cm.	cc.	cc.	cc.	cc.	cc.	cc.	cc.	cc	Av'g. cc.
1.		16	574	84.2	17.7	3.8	19.2	103.4	21.5	124.9	0.218	
2.	Wealthy	15	486	87.0	16.5	3.2	16.9	103.9	19.7	123.6	0.254	
3.		17	562	90.7	17.8	3.5	17.7	108.4	21.3	129.7	0.231	0.234
4.		22	657	104.8	18.4	5.0	20.2	125.0	23.4	148.4	0.226	
5.	Starking	28	807	114.5	23.0	6.3	25.0	139.5	29.3	168.8	0.209	
6.		27	828	122.2	23.6	6.3	26.8	149.0	29.9	178.9	0.216	0.217
7.		20	611	77.6	17.9	4.3	15.9	93.5	22.2	115.7	0.189	
8.	Delicious	21	570	73.8	16.7	3.9	16.4	90.2	20.6	110.8	0.194	
9.		20	506	76.4	17.7	3.8	16.8	93.2	21.5	114.7	0.227	0.203
10.		18	546	85.4	14.4	2.1	15.6	101.0	16.5	117.5	0.215	
11.	McIntosh	25	655	97.7	16.0	2.3	17.3	115.0	18.3	133.3	0.204	
12.		24	547	89.4	14.8	2.2	16.1	105.5	17.0	122.5	0.224	0.214
Total		253	7349	1103.7	214.5	45.7	223.9	1327.6	261.2	1588.8		0.216

Table X Experiment 6 (cont'd) Two day Transpiration Studies Second Day June 25-26

No. of Shoot	Variety	No. of Leaves	Total Leaf Surface	Amount of Water Used Second Day: 12 a.m. to 6 p.m.	6 p.m. to 12p.m.	12 pm. to 6 a.m.	6 a.m. to 12 a.m.	Day 6 a.m. to 6 p.m.	Night 6 p.m. to 6 a.m.	Total 1-24 Hours	Volume H_2O used per sq. cm. 1-24 hours	
			sq.cm.	cc.	cc.	cc.	cc.	cc.	cc.	cc.	cc.	Av'g. cc.
1.		16	574	24.1	4.8	2.2	12.5	36.6	7.0	43.6	0.076	
2.	Wealthy	15	486	22.6	4.2	1.9	12.0	34.6	6.1	40.7	0.084	
3.		17	562	23.2	4.4	2.0	12.9	36.1	6.4	42.5	0.076	0.079
4.		22	657	25.9	5.7	2.7	13.5	39.4	8.4	47.8	0.073	
5.	Starking	28	807	31.6	7.3	3.3	15.2	46.8	10.6	57.4	0.071	
6.		27	828	34.3	8.0	3.5	17.5	51.8	11.5	63.3	0.076	0.073
7.		20	611	20.7	4.7	2.3	12.4	33.1	7.0	40.1	0.066	
8.	Delicious	21	570	21.8	4.6	2.2	11.6	32.9	6.8	39.7	0.070	
9.		20	506	21.3	4.7	2.2	11.6	32.9	6.9	39.8	0.079	0.072
10.		18	546	21.1	2.8	1.3	11.3	32.4	4.1	36.5	0.067	
11.	McIntosh	25	655	24.2	3.1	1.5	12.8	37.0	4.6	41.6	0.064	
12.		24	547	21.5	2.8	1.4	11.7	33.2	4.2	37.4	0.068	0.066
Total		253	7349	291.8	57.1	26.5	155.0	448.8	83.6	530.4		0.072

5.62 per cent, the late-night-period 1 o'clock a. m. to 7 o'clock a. m. 5.07 per cent, and the forenoon-period 7 o'clock a. m. to 1 o'clock p. m. 32.9 per cent. The average amount of water transpired per square centimeter by each variety is shown as an indication of the transpiration rate of the varieties in that particular experiment.

Table VIII, a continuation of Table VII, shows the rate of transpiration during the second day. Wealthy continued to transpire at the highest rate and McIntosh as the lowest rate of the varieties tested although the average transpiration rate was lower the second day. Attention is called to the fact that Wealthy also lost water at a more rapid rate than did McIntosh in experiments on the loss of weight upon drying as shown by Tables III and IV. The transpiration rate of Wealthy and McIntosh was again studied June 24, to June 26. The results, given in Tables IX, and X, again show that Wealthy transpires at a relatively higher rate than McIntosh throughout the two-day interval. The general transpiration rate tended to follow the temperature curve during this experiment. Table X shows that there was but little variation in the rate of transpiration within the variety. Records of atmospheric conditions are not available for this experiment.

Transpiration Survey.

As soon as a larger number of potometers were procured, a transpiration survey of many varieties was made to see if apple

Table XI - Expt. 7 : Transpiration Survey June 28-29

Number of Shoot	Variety	Leaf Area sq.cm.	Total H_2O Used 1-24 hours cc.	Total H_2O Used per sq. cm. 1-24 hrs. cc.	Average cc.
1.		634	180.9	0.285	
2.	Red Canada	599	171.2	0.286	
3.		663	167.2	0.252	0.274
4.		505	111.1	0.220	
5.	Duchess	633	101.1	0.160	
6.		490	107.0	0.218	0.199
7.		414	103.9	0.251	
8.	Fameuse	444	129.9	0.293	
9.		396	105.0	0.265	0.270
10.		605	150.8	0.249	
11.	Delicious	475	102.9	0.217	
12.		607	131.6	0.217	
13.		557	126.5	0.227	0.228
14.		---	-----	-----	
15.	McIntosh	694	155.9	0.225	
16.		707	176.4	0.250	
17.		602	126.3	0.210	0.228
18.		510	119.6	0.235	
19.	Wealthy	523	120.7	0.231	
20.		519	114.6	0.221	0.229
21.		701	200.6	0.286	
22.		819	212.9	0.260	
23.	Starking	516	132.7	0.257	
24.		461	125.5	0.272	
25.		---	-----	-----	0.269
26.		644	160.4	0.249	
27.	Baldwin	---	-----	-----	
28.		588	138.2	0.235	0.242
29.		982	227.9	0.232	
30.	Gravenstein	1048	209.7	0.200	
31.		945	251.9	0.267	0.333
32.		868	224.0	0.258	
33.	King	894	257.6	0.288	
34.		701	189.7	0.271	0.272
35.		920	185.0	0.201	
36.	Ark. Black	---	-----	-----	
37.		840	165.1	0.197	0.199
38.		909	210.6	0.232	
39.	N.W. Greening	824	160.5	0.195	
40.		1095	212.9	0.194	0.207
Total		24332	5767.9	-----	0.237

Table XII Atmospheric Conditions June 28-29

	Time	Air Temperature F.	Relative Humidity %
June 28	1:30 p.m.	76.0	59.0
	3:30 p.m.	78.0	56.0
	5:00 p.m.	79.5	58.5
	6:15 p.m.	72.0	67.0
	7:30 p.m.	69.5	67.5
June 29	1:30 p.m.	53.0	84.0
	7:30 p.m.	60.5	81.0
	10:15 p.m.	79.0	68.0
	11:30 p.m.	84.0	57.5
	12:30 p.m.	89.0	45.0
	1:30 p.m.	91.0	52.5
Average		75.6	63.3

varieties did transpire at different rates and to determine, if possible, which varieties had a high rate of transpiration and which a low rate. The results of this experiment, shown in Table XI, indicate that such varieties as Gravenstein, Starking, King and Red Canada transpire at a high rate while such varieties as Duchess, Arkansas Black, N. W. Greening, McIntosh and Delicious transpire at a low rate. The atmospheric conditions during this experiment are shown in Table XII.

Relation of Varieties in Duplicated Experiments.

With the limited supply of potometers, it was not possible to compare many varieties and at the same time use large numbers of shoots of each variety. It was thought best under the circumstances to compare four varieties each time using 10 shoots of each variety and to repeat the experiments to see if their relative transpiration rate remained about the same.

Starking, Baldwin, Arkansas Black, and N. W. Greening.

The survey showed that Starking and Baldwin transpired at a high rate while Arkansas Black and N. W. Greening transpired at a low rate. These varieties were compared in Experiments 7 and 8 and 16 on June 29, July 8, and September 24, respectively. The results of these experiments are shown in Table XIII, XIV, and XV, respectively. A summary of Tables XIII and XIV shows Starking and Baldwin transpired at a high rate compared to Arkansas Black. The relative ranking of these varieties based on the transpiration rate of Starking arbitrarily set at 100 shows the difference between varieties.

The atmospheric conditions for Experiment 7, 8 and 16 are respectively shown in Tables XII, XVII and XVIII. It was clear, hot, and dry during Experiment 7, and clear and warm during Experiment 8. During Experiment 16 it was cloudy, cool and raining most of the time. The heat was turned on in the greenhouse at night while these shoots were transpiring. It will be noted that the shoots transpired at a higher rate in

the first two experiments and at a lower rate in the last experiment and that the amount of water transpired the first 24 hours in the last experiment is considerably less than in Experiment 8. Atmometer readings are not available for Experiment 7.

Table XIII-Expt. 7 Transpiration of Varieties
June 28-29

Variety	No. of shoots	Total no. leaves	Total leaf area sq. cm.	Total Water Used 1-24 hr.	Average Water Used per sq.cm. 1-24 hours
			sq. cm.	cc.	cc.
Starking	4	99	2491	671.2	0.269
Baldwin	2	35	1232	298.6	0.242
N.W. Greening	3	68	2828	584.1	0.207
Ark. Black	2	44	1760	350.1	0.199
Average	2.75	61.5	2078	476.0	0.229

Experiment 8 was run for forty-eight hours. The results are shown in Table XIV. The average rate of transpiration was lower during the second day and a smaller number of shoots continued to draw water from the potometers. In case the column of water broke at any time the shoot was immediately discarded. This accounts for the variation in the number of shoots used as each variety started with ten shoots. It is believed that the breaking of the water column is partly due to air leaks in the rubber connections and not due to any characteristic of the shoots used. However it seems that the varieties transpir-

Table XIV Experiment 8 Transpiration Studies July 8-10

Variety	1 to 24 hours					24 to 48 hours				
	No. of Shoots	No. of Leaves	Leaf Area sq.cm.	Amount Water Used cc.	Rate per Unit Area cc.	No. of Shoots	No. of Leaves	Leaf Area sq.cm.	Amount Water Used cc.	Rate per Unit Area cc.
Starking	10	221	5176	1845.3	0.357	7	141	3443	1053.8	0.306
Ark. Black	9	159	5898	1533.5	0.268	8	137	5155	1049.0	0.203
Baldwin	9	147	5557	1734.2	0.312	5	78	2938	694.6	0.236
N.W. Greening	8	116	6265	1560.1	0.249	6	84	4487	825.5	0.184
Total	36	643	22896	6723.1	-----	26	440	16023	3622.9	-----
Average	9.0	161	5724	1680.8	0.294	6.5	110	4006	905.7	0.226

ing at a low rate were more susceptible to breaks in the column of water which was being pulled from the burette than were those transpiring at a high rate.

Table XV--Expt. 16 Transpiration Studies
September 24-25

Variety	No. of shoots	No. of leaves	Total leaf area sq.cm.	Total Water Used 1-24 hr. cc.	Water used per sq.cm. 1-24 hrs. Mean Average cc.
Starking	10	226	6514	1214.9	0.1875±0.003
Arkansas Black	8	136	4259	815.7	0.194 ±0.007
Baldwin	9	172	6036	1200.9	0.200 ±0.007
N.W. Greening	1	---	----	124.8	----------
Average of 3	9	178	5603	1077.2	.194 ±0.006

(Effect of Fruit Crop on Transpiration) :- In Experiment 16, four of the Baldwin shoots were taken from a tree heavily loaded with fruit while 5 of them came from an adjacent Baldwin tree of the same age and size but which was not bearing fruit. While only a summary of the individual rates of these shoots is shown in Table XV the four shoots from the bearing tree transpired at the average rate of 0.2325 cc. of water, per square centimeter, in 24 hours, while the 5 shoots from the non-bearing tree transpired at the rate of 0.1782 cc. per unit area for the same

time. It is believed that this is due to the crop of fruit rather than to an individual tree difference for the average rate of Jonathan shoots taken from the different trees bearing about the same crop of fruit, was found to be the same in Experiment 10.

Table XVI Summary of Tables XIII and XIV

Variety	Total No. of Shoots	Total No. of Leaves	Total leaf Surface sq. cm.	Total Water Used 1-24 hr. cc.	Average H_2O Used per sq.cm. 1-24 hr. cc.	Relative Ranking
Starking	14	320	7667	2516.8	0.328	100.0
Baldwin	11	182	6789	2032.8	0.299	91.2
Ark. Black	11	203	7658	1933.6	0.252	76.8
N.W. Greening	11	184	9093	2144.2	0.236	72.0
Average	12	222	7802	2156.8	0.276	84.1

Grimes, Jonathan, Ortley and Gravenstein:- The Grimes, Jonathan, Ortley and Gravenstein varieties were selected for a series of experiments because they are important commercial varieties and are growing in close proximity to each other in the Harvey block of the college orchard. These are vigorous trees about twelve years old. Three experiments were made on these varieties. The results are given in Tables XIX, XX, and XXI and are summed up in Table XXII. The summary shows that Grimes and Jonathan trans-

Table XVII Atmospheric Conditions July 8-10

Time		Air Temperature F.	Relative Humidity %	Atmometer S23-348 Coef.78 cc.	Atmometer 17-136 Coef.93 cc.
July 8	1:00 p.m.	86	47.0	0.0	0.0
	3:45 p.m.	89	42.0		
	5:30 p.m.	84	52.0		
	7:25 p.m.	74	60.0	17.1	17.3
July 9	5:30 a.m.	58	83.0		
	7:00 a.m.	65	72.0	22.3	21.7
	8:50 a.m.	74	61.0		
	10:15 a.m.	84	57.5		
	11:20 a.m.	83	60.0		
	1:00 p.m.	83	53.5	31.7	30.7
Average		78.0	58.8		
July 9	1:00 p.m.	83.0	53.5	0.0	0.0
	2:15 p.m.	82.5	57.0		
	3:15 p.m.	83.0	57.0		
	5:15 p.m.	79.0	64.0		
	7:00 p.m.	72.0	69.0	10.0	9.3
July 10	5:30 a.m.	58.5	80.0		
	7:00 a.m.	65.0	75.0		
	8:40 a.m.	74.0	65.0		
	10:00 a.m.	76.0	66.0	18.7	17.2
	12:00 a.m.	90.0	55.0		
	1:00 p.m.	92.0	54.5	25.8	23.8

Table XVIII	Expt. 16	Atmospheric Conditions		
			Atmometer	
Time	Air Temperature	Relative Humidity	S30-121 Coef.78	S29-620 Coef.78
	F.	%	cc.	cc.
Sept. 24 1:00 p.m.	79.0	57.0	0.0	0.0
4:00 p.m.	74.0	74.0	4.4	4.8
10:30 p.m.	77.5	65.0	8.1	8.4
Sept. 25 7:00 p.m.	86.0	60.0	15.4	15.6
1:00 p.m.	78.0	71	21.2	21.1
Average	78.9	65.4	----	----

pired at a high rate and Ortley and Gravenstein at a low rate in the three experiments. It will be noted that Ortley transpired water at an average rate of 0.2096 cc. per square centimeter or 19.9 per cent less rapidly than Grimes which transpired at the rate of 0.2616 cc. per square centimeter. The averages given for the Gravenstein variety are based on Experiments 11 and 12, only, and should not be compared to the averages of the other varieties which are based on three experiments. Ortley and Gravenstein are some of the varieties which seem to resist the drought.

The statistical analysis on the average rate of transpiration per square centimeter or twenty-four hours shows that the

variation within each variety, during Experiments 11 and 12, is small, and that Grimes and Jonathan transpire at a higher rate than do Ortley and Gravenstein. Additional data should be obtained before drawing more definite conclusions regarding the individual relative ranking of these varieties.

From the data presented in Table XXII the rate of transpiration of each of the varieties during the day and night periods may be compared. It was found that the transpiration rate at night of Grimes, Jonathan, Ortley and Gravenstein was 10.55 per cent, 10.55 per cent, 5.54 per cent and 6.23 per cent, respectively of the rate during the day period. This would indicate the Grimes and Jonathan did not possess the ability to reduce their transpiration rate at night as markedly as did Ortley and Gravenstein.

In Experiment 11, the atmometers transpired more water than in Experiment 12 showing that the atmospheric conditions favored a high rate of transpiration. Grimes transpired in accordance with these conditions while Jonathan, Ortley and Gravenstein showed a lower rate of transpiration under the conditions favoring a high rate of water loss. This would indicate that under certain conditions these varieties show a resistance to water loss while Grimes does not. This possibly explains why Grimes variety goes into a rest period during periods of summer drought while other varieties maintain normal growth.

Table XIX Experiment 10 Transpiration Studies August 9-10

Variety	Number of Shoots	Total Number Leaves	Total Leaf Area	Amount Water Used: 1 p.m. to 7 p.m.	Amount Water Used: 7 p.m. to 7 a.m.	Amount Water Used: 7 a.m. to 1 p.m.	Amount Water Used: Total 1-24 hr.	Average Water used per sq.cm. 1-24 hr.
			sq.cm.	cc.	cc.	cc.	cc.	cc.
Gravenstein	5	---	----	438.5	----	-----	-----	-----
Grimes	4	78	1547	342.8	66.7	278.1	687.6	0.444
Jonathan	6	117	2636	535.4	108.0	415.7	1059.1	0.402
Ortley	6	120	2816	488.5	41.1	395.7	925.3	0.329

Table XX Experiment 11 Transpiration Studies September 3-4

Variety	Number of Shoots	Total Number Leaves	Total Leaf Area	Water Used: 1 p.m. to 7 p.m.	Water Used: 7 p.m. to 7 a.m.	Water Used: 7 a.m. to 1 p.m.	Water Used: Total 1-24 hr.	Water Used per sq.cm. 1-24 hr. Mean Average
			sq.cm.	cc.	cc.	cc.	cc.	cc
Grimes	4	77	2069	317.7	52.5	101.0	471.2	0.236±0.008
Jonathan	8	173	5181	598.6	91.3	230.9	920.8	0.180±0.005
Ortley	9	180	5355	562.4	50.4	184.7	797.5	0.153±0.019
Gravenstein	8	145	5718	614.1	64.9	207.7	886.7	0.155±0.003

Table XXI Experiment 12 Transpiration Studies September 5-6

Variety	Number of Shoots	Total Number Leaves	Total Leaf Area sq.cm.	Water Used: 1 p.m. to 7 p.m. cc.	Water Used: 7 p.m. to 7 a.m. cc.	Water Used: 7 a.m. to 1 p.m. cc.	Water Used: Total 1-24 hrs. cc.	Water Used per sq. cm. 1-24 hrs. Mean Average cc.
Grimes	10	189	5301	509.2	104.6	584.5	1198.3	0.223±0.006
Jonathan	10	218	6304	683.4	119.7	634.4	1417.5	0.226±0.003
Ortley	10	245	7285	686.0	81.0	750.3	1517.3	0.209±0.002
Gravenstein	10	206	7930	680.8	75.5	685.5	1441.8	0.183±0.003

Table XXII — Summary of Tables XIX, XX and XXI

Variety	Total Number Shoots	Total Number Leaves	Total Leaf Area sq.cm.	Amount Water Used: 1 p.m. to 7 p.m. cc.	7 p.m. to 7 a.m. cc.	7 a.m. to 1 p.m. cc.	Total 1-24 hr. cc.	Av'g. rate of transpiration per sq. cm. 1-24 hr. cc.	Relative Ranking
Grimes	18	344	9007	1169.7	223.8	963.6	2357.1	0.2616	100.0
Jonathan	24	508	14121	1797.4	319.0	1281.0	3397.4	0.2405	91.9
Ortley	25	555	15456	1736.9	172.5	1330.7	3240.1	0.2096	80.1
Gravenstein*	18	351	13648	1294.9	140.4	893.2	2328.5	0.1706	65.2

* Data from Tables XIX and XX only. This should not be compared with the average of the other varieties which is based on three experiments.

It is thought possible that the difference in the transpiration rate of these varieties may be an explanation of the difference in their ability to stand the summer drought. Mr. B. W. Johnson, Manager of the Oaco Orchard Company at Monroe, Oregon, has grafted many acres of Jonathan over to Ortley because Jonathan does not seem to be a profitable variety. This difference in transpiration rate may be a possible explanation why Jonathan is unprofitable under non-irrigated conditions where the water supply is limited.

The leaf characters which are typical for these varieties are shown in Illustration Number 2.

Table XXIII Experiment 10 Atmospheric Conditions August 9-10

Time	Air temperature	Relative Humidity	Atmometer S23-348 Coef. 78	Atmometer 17-136 Coef. 93
	F.	%	cc.	cc.
August 9 1:00 p.m.	85.0	56.5	0.0	0.0
7:00 p.m.	78.0	71.0	12.2	11.7
August 10 7:00 p.m.	64.0	84.0	16.9	15.8
1:00 p.m.	89.0	67.6	25.6	24.7

Table XXIV Experiment 11 Atmospheric Conditions
September 3-4

Time	Air temperature F.	Relative Humidity %	Atmometer S30-121 .78 cc.	Atmometer S29-620 .78 cc.
Sept. 3 1:10 p.m.	90	49	0.0	0.0
7:00 p.m.	68	78	11.6	12.9
Sept. 4 7:00 a.m.	58	83	15.1	16.4
10:00 a.m.	64	84	15.6	16.9
1:10 p.m.	77	71	18.1	19.6

Table XXV Experiment 12 Atmospheric Conditions
September 5-6

Time	Air temperature F.	Relative Humidity %	Atmometer S30-121 .78 cc.	Atmometer S29-620 .78 cc.
Sept. 5 1:00 p.m.	75	70.0	0.0	0.0
4:00 p.m.	77	67.0	5.1	5.9
7:00 p.m.	65.5	77.5	8.1	8.9
Sept. 6 7:00 a.m.	60	83.0	10.5	11.1
10:30 a.m.	67	80.0	12.3	13.1
1:00 p.m.	79	71.0	16.7	17.7

The atmospheric conditions for Experiments 10, 11, and 12 are respectively shown in Tables XXIII, XXIV, and XXV. The atmometers show very slight differences in the amounts of water which they transpired during the twenty-four hour period showing that the evaporating power of the air was remarkably uniform along the battery of potometers. It was cloudy, smoky and humid during Experiment 10. It was clear and warm during Experiment 11, and cloudy or partly cloudy during Experiment 12.

King, Wealthy, Delicious and Red Canada:- These varieties were compared in two experiments. The results are shown in Tables XXVI and XXVII. A summary of these is shown in Table XXVIII. This summary shows that King and Wealthy transpired at a high rate and Delicious and Red Canada at a low rate in these two experiments. The relative ranking shows a wide spread difference in the transpiration rate of King and Red Canada.

The statistical analysis shows that there is an actual difference in the mean transpiration rate of the varieties compared. The mean varietal transpiration rates show slightly greater differences under conditions favoring high transpiration than under conditions favoring a low transpiration rate. This is clearly illustrated in Tables XXVI and XXVII where there is a difference of 34.4 per cent and 32.7 per cent respectively between the rate of the high and the low transpir-

Table XXVI Experiment 9 Transpiration Studies July 10-20

Variety	Number of Shoots	Total Number Leaves	Total Leaf Area	Water Used: 2 p.m. to 8 p.m.	Water Used: 8 p.m. to 8 a.m.	Water Used: 8 a.m. to 2 p.m.	Water Used: Total 1-24 hrs.	Water Used per sq. cm. 1-24 hrs. Mean Average
			sq.cm.	cc.	cc.	cc.	cc.	cc.
Wealthy	10	166	5730	1086.1	140.7	833.7	2060.5	0.363±0.008
King	9	182	5828	969.3	144.5	887.4	2002.2	0.344±0.013
Delicious	10	201	5221	763.9	145.8	650.0	1559.7	0.306±0.001
Red Canada	8	132	4567	583.9	90.6	403.0	1080.5	0.238±0.011

Table XXVII Experiment 13 Transpiration Studies September 9-10

Variety	Number of Shoots	Total Number Leaves	Total Leaf Area	Water Used: 2 p.m. to 8 p.m.	Water Used: 8 p.m. to 8 a.m.	Water Used: 8 a.m. to 2 p.m.	Water Used: total 1-24 hr.	Water Used per sq. cm. 1-24 hrs. Mean Average
			sq.cm.	cc.	cc.	cc.	cc.	cc.
King	4	84	2716	219.4	37.6	45.8	302.8	0.113±0.004
Wealthy	9	141	4454	331.4	46.3	66.7	444.4	0.101±0.004
Delicious	10	209	5382	377.2	55.3	89.9	522.4	0.098±0.001
Red Canada	8	148	5600	288.8	61.8	70.7	421.3	0.076±0.001

Table XXVIII — Summary of Tables XXVI and XXVII

Variety	Number of Shoots	Total Number Leaves	Total Leaf Area sq.cm.	Water Used: 2 p.m. to 8 p.m. cc.	Water Used: 8 p.m. to 8 a.m. cc.	Water Used: 8 p.m. to 2 p.m. cc.	Water Used: Total 1-24 hr. cc.	Average water used per sq. cm. 1-24 hr. cc.	Relative Ranking
King	13	266	8544	1188.7	183.1	933.2	2305.0	0.2697	100.00
Wealthy	19	307	10184	1417.5	187.0	900.4	2504.9	0.2459	91.17
Delicious	20	410	10603	1141.1	201.1	739.9	2082.1	0.1963	72.78
Red Canada	16	280	10167	875.7	152.4	473.7	1501.8	0.1477	54.76

Table XXIX Experiment 9 Atmospheric Conditions
July 19-20

Time		Air temperature	Relative Humidity	Atmometer S23-348 Coef. .78	Atmometer 17-136 Coef. .93
		F.	%	cc.	cc.
July 19	1:00 p.m.	83.0	51.5	0.0	0.0
	3:00 p.m.	87.5	49.3	5.0	5.4
	4:00 p.m.	86.0	53.0	8.2	8.8
	5:00 p.m.	85.0	56.5	---	---
	7:00 p.m.	75.0	64.0	15.1	16.0
July 20	7:00 a.m.	64.0	72.0	20.4	20.6
	9:15 a.m.	74.5	65.5	22.3	22.9
	10:30 a.m.	80.0	57.0	24.4	25.2
	11:30 a.m.	84.0	52.0	26.7	27.8
	1:00 a.m.	87.0	53.5	30.6	31.7
Average		80.6	57.4	----	----

Table XXX Experiment 13 Atmospheric Conditions
September 9-10

Time	Air temperature	Relative Humidity	Atmometer S30-121 Coef. .78	Atmometer S29-620 Coef. .78
	F.	%	cc.	cc.
Sept. 9 2:30 p.m.	86.0	53.0	0.0	0.0
5:30 p.m.	74.0	74.0	6.3	6.7
8:30 p.m.	62.0	84.0	9.4	9.7
Sept. 10 8:30 a.m.	58.5	91.0	11.3	11.6
11:30 a.m.	63.0	84.0	11.9	12.2
2:30 p.m.	62.5	86.5	12.7	13.0

ing variety. It is under the conditions favoring a high transpiration rate that varieties really meet a severe test which determines whether or not they are capable of surviving.

Spitzenburg, Grimes, Ortley Yellow Newtown and Jonathan:- These varieties were compared in Experiments 14 and 15 on September 15-16 and September 17-18 respectively. The results are shown in Tables XXXI and XXXII respectively. Most of the columns of water attached to these shoots broke during the 24 hour period so very little data were obtained. Table XXXI indicates that the transpiration rate of Grimes and Spitzenburg is nearly the same. It will be recalled that Experiments 10, 11, and 12 showed that Grimes transpired at a high rate so we

infer that Spitzenburg also transpires at a high rate. Nothing can be said regarding the transpiration rate of the other varieties.

Apparently the evaporating conditions of the air, during these experiments, was so high that the leaves were not able to draw water from the potometers as rapidly as it was transpired and consequently they wilted. St. Johns and Morris (31) mention a similar condition in the orchard where the foliage transpired water faster than the tree supplies it and draws directly from the fruits until it wilts them under very hot weather conditions. In the potometers these shoots evidently were undergoing a severe transpiration test, as the air temperature was over 90°F., They could not draw from the fruit, and consequently wilted.

At the beginning of Experiment 14 the air temperature was 101°F., three hours later at 4:00 p.m. the air temperature was 90°F. Four Grimes shoots, two Spitzenburg shoots, seven Ortley shoots, and all of the ten yellow Newtown shoots had wilted. The mortality of shoots continued from 4 o'clock p. m. to 7 o'clock p. m.

The atmospheric conditions for Experiments 14 and 15 are shown in Tables XXXIII and XXXIV.

Cobalt Chloride Studies

The tripartite composite cobalt-chloride slips were tested for the time required to change from a deep to light blue over a standard free-water evaporating surface, at a given temperature,

Table XXXI Experiment 14 Transpiration Studies September 15-16

Variety	No. Shoots	Number Leaves	Leaf Area	Water Used: 1 p.m. to 7 p.m.	Water Used: 7 p.m. to 7 a.m.	Water Used: 7 a.m. to 1 p.m.	Water Used: Total 1-24 hr.	Average rate of water loss per sq. cm. 1-24 hr.	Relative Ranking
		sq.cm.		cc.	cc.	cc.	cc.	cc.	
Grimes	2	39	777	126.6	45.1	146.9	318.6	0.410	100.00
Spitzenburg	3	84	1763	260.7	38.4	319.3	668.4	0.379	92.43
Yellow Newtown	-	--	---	-----	-----	-----	-----	-----	-----
Ortley	3	--	---	200.7	-----	-----	-----	-----	-----

Table XXXI Experiment 15 Transpiration Studies September 17-18

Variety	No. Shoots	No. Leaves	Total Leaf Area sq.cm.	Water Used: 1 p.m. to 7 p.m. cc.	Water Used: 7 a.m. to 7 a.m. cc.	Water Used: 7 a.m. to 1 p.m. cc.	Total 1-24 hr. cc.	Average rate per sq. cm. 1-24 hr.
Spitzenburg	5	112	2467	441.8	65.9	371.8	379.5	0.3565
Ortley	-	---	----	-----	----	-----	-----	------
Yellow Newtown	-	---	----	-----	----	-----	-----	------
Jonathan	4	---	----	385.9	----	-----	-----	------

Table XXXIII Experiment 14 Atmospheric Conditions
September 15-16

Time	Air temperature	Relative Humidity	Atmometer S30-121 .78	Atmometer S29-620 .78
	F	%	cc.	cc.
Sept. 15 1:00 p.m.	101	46.5	0.0	0.0
4:00 p.m.	90	49.0	12.5	12.5
7:00 p.m.	78	63.0	17.4	17.4
Sept. 16 7:00 a.m.	84	59.0	27.6	27.6
1:00 p.m.	96	55.0	43.2	42.6
Average	89.8	54.5	----	----

Table XXXIV Experiment 15 Atmospheric Conditions
September 17-18

Time	Air temperature	Relative Humidity	Atmometer S30-121 .78	Atmometer S29-620 .78
	F.	%	cc.	cc.
Sept. 17 1:00 p.m.	92.0	53.0	0.0	0.0
4:00 p.m.	90.0	52.0	11.5	11.7
7:00 p.m.	80.0	61.0	17.3	17.5
Sept. 18 7:00 a.m.	69.5	81.0	22.4	22.0
1:00 p.m.	91.0	49.5	33.5	33.0
Average	84.5	49.7	----	----

in the laboratory before going to the orchard.

After four days of trying the slips on apple leaves they were discarded as an impracticable method because of the wide differences in the time required for the color change, the loss of slips by burning when dried over an alcohol lamp, the presence of dust on the leaves which decreased the efficiency of the slips and the great changes in temperature which took place while the tests were being made. A sample of the data obtained on August 29 shows the reason why this could not be used as a quantitative means of determining the transpiration rate: air temperature 17°C.; slip Number 14, in ten trials on the underside of a Grimes leaf varied from 10.8 to 21.7 seconds in making the color change and took 2 to 5 minutes to change color on the upper side of the leaf. This same slip took from 15.8 seconds to 41.0 seconds in 9 trials to change color on the underside of the terminal leaves of Gravenstein and 7'42.4" to change color on the upper side. The same slip varied from 15.2 to 21.7 seconds with an average of 18.1 seconds in making the color change over a standard free-water surface at 23°C.

The same unsatisfactory comparisons were made for four days and the method discarded for this study.

Calcium Chloride Studies

Preliminary tests of transpiration by the calcium chloride method showed that the method described by Heinicke (17)

was satisfactory except for the heavy metal clamp which held the bottle to the leaf. After a few trials on some lilac leaves growing just outside the laboratory window it was found that a metal washer and a wide rubber band could be used more satisfactorily to hold the leaf to the rubber-lipped weighing bottle. The metal washers, obtained from the Chevrolet garage provided a stiff rim which held the leaf to the bottle, and at the same time did not cover the leaf over the middle of the bottle. Only three of these bottles were available in the laboratory supplies. The result of a test made on shoots in the potometers is shown in Table XXXV.

Table XXXV Calcium Chloride Studies

Number of Shoot	Rate of Water Loss per sq. cm. 1-24 hours	
	Potometer	$CaCl_2$
	cc.	cc.
1	0.0492	0.0560*
2	0.0521	0.0400
3	0.0534	0.0453

* Bottle tipped up so $CaCl_2$ fell on the leaf.

Further study should be made of transpiration rates both on the trees and in potometers by this method. The data shown here is not sufficient to draw any conclusions from although it indicates that the $CaCl_2$ bottles attached to the under side of the leaf absorbed about 80% of the water transpired per unit

area as measured by the potometers.

Anatomical Studies of the Leaves

Thickness of the Leaves.

Thirty leaves of each variety were sectioned and the various parts of the leaf measured to see if there were any differences in the leaf structure which might have a bearing on the transpiration rate. The results of this study are shown in Table XXXVI.

The measurements were made with an ocular micrometer on free hand sections of 30 leaves of each variety. It will be noted that Wealthy was found to have the thickest leaf, Baldwin the thinnest leaf and that the average thickness of the leaves was about one-fourth of a millimeter.

The cuticle, upper and lower epidermis of all varieties measured seemed to be about the same. The greatest variation between varieties occurred in the thickness of the palisade cells and spongy mesophyll. Some leaves had three rows of palisade cells in place of the usual two rows. This variation was not constant throughout the leaves of any one variety. The probable error of the mean total thickness is small in all cases so this mean average is probably representative of the variety.

Relationship of Leaf structure and transpiration rate:-The relationship of the thickness of the average leaf and leaf parts of a variety is shown in Table XXXVII.

Table XXXVI Average Thickness of Apple Leaves

Variety	Cuticle	Upper Epidermis	Palisade Cells	Spongy Mesophyll	Lower Epidermis	Mean Total and Probable Error
	microns	microns	microns	microns	microns	microns
Red Canada	4.1	9.6	140.3	87.2	14.2	256.3±2.0
Wealthy	3.9	11.5	194.0	107.7	15.2	323.4±2.5
Delicious	4.0	10.7	150.3	89.0	13.8	272.1±3.7
McIntosh	4.4	10.7	135.0	86.3	14.6	251.3±3.0
Starking	4.2	9.6	132.2	78.9	13.6	238.2±3.5
Arkansas Black	4.3	12.4	148.6	89.6	13.8	271.0±2.6
Baldwin	4.1	10.7	126.7	71.9	13.4	225.1±2.3
Gravenstein	4.7	14.0	144.7	92.1	15.5	271.5±3.6
Grimes	4.1	11.5	126.3	74.9	13.6	229.5±3.5
Jonathan	4.2	10.3	133.5	87.5	14.0	249.7±2.6
Ortley	4.4	12.5	120.8	85.6	14.2	237.1±2.0
Spitzenburg	4.7	10.3	144.4	104.9	13.0	278.6±3.2
N.W. Greening	4.7	10.2	143.3	75.4	12.8	248.8±3.6
King	4.4	12.0	134.9	54.6	13.8	253.1±2.5

Table XXXVII Relation of Average Leaf Thickness to Transpiration

Variety	Cuticle	Upper Epidermis	Palisade	Spongy Mesophyll	Lower Epidermis	Total
	microns	microns	microns	microns	microns	microns
High						
Baldwin	4.1	10.7	126.7	71.9	13.4	225.1
Grimes	4.1	11.5	126.3	74.9	13.6	229.5
King	4.4	12.0	134.9	54.6	13.8	253.1
Starking	4.2	9.6	132.2	78.9	13.6	238.2
Gravenstein	4.7	14.0	144.7	92.1	15.5	271.5
Wealthy	3.9	11.5	194.0	107.7	15.2	328.4
Jonathan	4.2	10.3	153.5	87.5	14.0	249.7
Average	4.2	11.4	141.8	81.1	14.2	256.5
Low						
Red Canada	4.1	9.6	140.3	87.2	14.2	256.3
N.W. Greening	4.7	10.2	143.3	75.4	12.8	248.8
Delicious	4.0	10.7	150.3	89.0	13.8	272.1
McIntosh	4.4	10.7	135.0	86.3	14.6	251.3
Ortley	4.4	12.5	120.8	85.3	14.2	237.1
Average	4.4	13.4	137.9	84.7	13.9	253.1

All varieties found to be transpiring at a high rate in the potometer experiments are listed in the "High" transpiring varieties and those which transpired at a low rate are listed in the "Low" transpiring varieties. There seems to be but little difference in the average thickness of leaf parts of the varieties which transpired at a relative high and low rate. The small difference of a few microns is within the range of the probable error so there seems to be no definite relationship between the average thickness of the terminal leaves of apple varieties and the transpiration rate of shoots of that variety as measured under the existing conditions.

CONCLUSIONS

(1.) Conditions which favor a high transpiration rate are suitable for studying the ability of apple varieties to withstand drought conditions.

(2.) The burette-potometer method of measuring transpiration is satisfactory for studying the transpiration rate of shoots. In future studies, it is recommended that the shoots be suspended in a capped pint milk-bottle to eliminate air leaks between the shoot and the supply of water. A small opening made in the cap may be used to insert the tip of a 100 cc. burette for refilling the bottle at intervals. The chief objection to this method is the amount of time required to determine the leaf area after each experiment.

(3.) The calcium chloride method as modified for this

study is recommended for future studies of this nature, both on shoots in the potometer and on the tree. It eliminates the laborious task of measuring the leaf area of hundreds of leaves after each test of the transpiration rate.

(4.) The cobalt chloride method is not considered satisfactory as a quantitative means of studying the transpiration rate of apple varieties.

(5.) Varieties of apples showed striking differences in their foliar water-retaining power when the leaves were dried in the laboratory. Varieties which lost water rapidly upon drying transpired at a high rate in the potometer. The water-retaining power of all varieties of apple leaves tested, increased as drying proceeded. The percentage of water in the leaves decreased throughout the season.

(6.) The transpiration rate of apple shoots is much lower at night than during the day. The transpiration rate of shoots in potometers is lower the second day than the first day under similar atmospheric conditions.

(7.) Transpiration studies on shoots of apple varieties show but little variation within the variety; the varieties studied show distinct differences in their rate of transpiration.

(8.) Wealthy transpired at a higher rate than McIntosh in two duplicate experiments. Starking and Baldwin transpired at a higher rate than Arkansas Black and N. W. Greening in three

experiments. Grimes and Jonathan transpired at a higher rate than Ortley and Gravenstein in three experiments. King and Wealthy transpired at a higher rate than Delicious and Red Canada in two experiments.

(9.) The crop of fruit seemed to affect the transpiration rate. Shoots from a Baldwin tree bearing a good crop of fruit transpired at a higher rate than Baldwin shoots from a non-bearing tree.

(10.) Two experiments show that temperatures above 90°F. for a considerable period of time tends to cause transpiration at a faster rate than the vascular system of the cut shoot can supply it with the result that the shoot wilts.

(11.) The average thickness of apple leaves is about one-fourth of a millimeter. The cuticle and epiderms of all varieties are of approximately the same thickness while the average thickness of the palisade and mesophyll of different varieties vary.

SUMMARY

(1.) An extensive study of the literature dealing with transpiration was made and is briefly summarized in this paper.

(2.) Significant differences in the transpiration rate of various apple varieties were found.

(3.) There seems to be no relation between the total thickness of terminal leaves or leaf parts of various varieties and the transpiration rate of shoots of that variety.

(4.) The varieties which have a low transpiration rate seem more capable of withstanding the summer drought than do those transpiring at a high rate.

(5.) Apple shoots transpire more water during the day than they do at night.

(6.) The water content of apple leaves was found to decrease during the growing season.

1. Bakke, A. L.

Studies on the transpiring power of plants as indicated by the method of standardized hygrometric paper.

Jour. of Ecology 2:145-173. 1914

2. Bews, J. W., and Aitken, R. D.

The water requirement and transpiration of a common Natal weed, Bidens pilosa.

So. Afr. (Dept. Agr.) Bot Survey Mem. 8 (1925): 41-65.

Expt. Sta. R. 57:218.

3. Boussingault, J.

Agronomie 6:349. 1878

4. Briggs, L. J., and Shantz, H. L

Hourly transpiration rate on clear days as determined by cyclic environmental factors.

Jour. Ag. Res. 5:583-649. 1916

5. Briggs, L. J., and Shantz, H. L.

The water requirements of plants as influenced by environment.

Proc. Second Pan-Amer. Sci. Congress 1915-16

Vol. 3: 95-107. 1917

6. Briggs, L. J., and Shantz, H. L.

The water requirement of plants. I Investigations in the Great Plains in 1910 and 1911. II A review of the literature.

U. S. Dept. of Agri. Bur. of Plant Ind., Bull. 284:148 and 285: 1-96. 1913

7. Burroughs, A. M.

Effects of oil sprays on fruit trees.

Amer. Soc. Hort. Sci. Proc. 1923, pp. 269-277.

8. Chandler, W. H.

Osmotic relationships and incipient drying with apples.

Proc. Amer. Soc. Hort. Sci. (1914):112-116.

9. Cribbs, J. E.

Ecology of Tilia americana II. Comparative studies of the foliar transpiring power.

Bot. Gaz. 71:289-313 1921

10. Cribbs, J. E.

Ecology of Tilia americana. I Comparative studies of the foliar transpiring power.

Bot. Gaz. 68:262-286 1919

11. Cullinan, F. P.

Transpiration studies with the apple.

Amer. Soc. Hort. Sci. Proc. 17:232-240 1920

12. Duggar, B. M., and Cooley, J. S.

The effect of surface films and dusts on the rate of transpiration.

Annals of Mo. Bot. Garden 1:1-23 1914

13. Dutton, W. C., and Wells, H. L.

Some physiological effects of Bordeaux.

Amer. Soc. Hort. Sci. Proc. (1923) pp. 277-281.

14. Hartig, T.

Allg. Forst u Jagdzeit. N. F. 54 1878

Cit. by Gardner Bradford and Hooker, Fundamentals of Fruit Production. p. 26 1922.

15. Harvey, E. M.

Unpublished data

Oregon Sta. Expt. Sta. 1930

16. Hatton, R. G., and Others.

Some factors influencing root development.

Ann. Rept. East Malling Res. Sta. (1923), pp. 110-113.

17. Heinicke, A. J.

A method for studying the relative rates of transpiration of apple leaves and fruits.

A. S. H. S. 26:312-314 1929

18. Hendrickson, A. H., and Veihmeyer, J. V.

Some facts concerning soil moisture of interest to horticulturists.

Amer. Soc. Hort. Sci. (1929) pp. 105-108.

19. Kelley, V. W.

The effect of oil sprays upon the transpiration of some deciduous fruits.

Amer. Soc. Hort. Sci. (1926) pp. 321-325.

20. Kelley, V. W.

A comparison of the transpiration rates of twenty-one deciduous fruit species.

Univ. of Ill. Ag. Exp. Sta. B. 341 1930

21. Kiesselbach, T. A.

Transpiration as a factor in crop production.

Univ. of Neb. Ag. Exp. Sta. Res. B. 6 1916

22. Knight, R. C.

Water relations of stocks and scions. Physiology II

Ann. Rpt. East Malling (Kent) Res. Sta. (1924) p. 103.

23. Knight, R. C.

The interrelations of stomatal aperature, leaf water content, and transpiration rate.

Ann. Bot. 31:221-240 1917

24. Knight, H. G., Chamberlain, J. C., and Samuels, C. D.

On some limiting factors in the use of saturated petroleum oils as insecticides.

Plant Physiology 4:299-321 1929

25. Livingston, B. E., and Shreve, E. B.

Improvements in the method for determining the transpiring power of plant surfaces by hygrometric paper.

Plant World 19:287-309 1916

26. Livingston, B. E., and Brown, W. H.

Relation of the daily march of transpiration to variations in the water content of foliage leaves.

Bot. Gaz. 53:309-330 1912

27. Maximov, N. A.

The plant in relation to water.

Macmillian Co. 1929

28. Pickering, S. V.

Science and fruit-growing.

London

29. Reed, H. S., and Bartholomew, E. T.

The effects of desiccating winds on citrus trees.

Univ. of Calif. Ag. Exp. B. 484 1930

30. Shantz, H. L.

Drought resistance and soil moisture.

Ecology 8:145-157 1927

31. St. John, J. L., and Morris, O. M.

Studies of quality and maturity of apples.

Jour. Ag. Res. 39:623-659. 1929

32. Swarbrick, T., and Roberts, R. H.

The relation of scion variety to character of root growth in apple trees.

Univ. of Misc. Ag. Exp. Sta. Res. B. 73 1927

33. Veihmeyer, F. J.

Some factors affecting the irrigation requirements of deciduous orchards.

Univ. of Calif. Agr. Exp. Sta. Hilgardia 2:125-284 1927

Illustration I. Burette - Potometers Used In Transpiration Studies.

Illustration II. Typical Shoots Of Gravenstein, Jonathan, Grimes And Ortley Used In Experiment 12.