FACTORS ASSOCIATED WITH SKIN-CRACKING OF YORK IMPERIAL APPLES

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INTRODUCTION

One of the problems causing considerable difficulty in fruit production is fruit cracking, which is frequently found in various fruits, including the apple. Although it is generally considered that this cracking is most serious with Stayman Winesap and Wealthy, York Imperial is also highly susceptible to cracking. In the case of York Imperial, cracking is usually confined to the skin of the fruit or to the tissues immediately under the skin, whereas Stayman Winesap and Wealthy often develop cracks from 1/4 to 1/2 inches deep into the flesh. York skin-cracking also is referred to as lenticel cracking.

The York Imperial is the leading variety in the Western Maryland apple growing sections, as well as in most of the Shenandoah-Cumberland region, and skin-cracking of this variety is serious in many orchards in this region, causing severe losses to the growers. York skin-cracking is more severe under some conditions than others, and in some cases as many as 70-80 percent of the fruits may be affected. Cracked fruits can neither be placed in U. S. No. 1 grade, nor can they be utilized in by-product manufacture unless they are used immediately after harvest, since affected fruit shrinks, wilts, and develops rots early in the storage period. Since cracking involves not only a serious economic loss to the grower, but also much wastage of fruit, the solution of this problem is considered highly important, and especially vital during the present need for greater food production.

With this view of economic importance, as well as academic interest, the work was initiated with the purpose of determining factors which are responsible for or closely correlated with skin-cracking. The great variability in the percent of cracked fruit on individual trees without any apparent association with edaphic or climatic factors, made it necessary to consider several approaches to this problem. Since it was believed that skin-cracking of York Imperial apples is caused or aggravated either by factors peculiar to the individual fruits, or to a physiological condition of the tree which may depend upon the relationship between the soil and the tree, this investigation was approached from three distinct angles: (1) the treatment of individual fruits, designed to influence or alter the normal development of the fruit epidermis; (2) treatments in which only a branch of the tree was used as a unit in an effort to create differences in nutritional or physiological condition between that branch and the remainder of the tree; and (3) soil treatments in which an attempt was made to change root activity of the trees and to modify moisture and nutrient conditions of the soil.

REVIEW OF LITERATURE

Although it was possible to find in horticultural literature a number of references to skin-cracking of the York Imperial apples, most of the published material was in the nature of observations unsupported by any experimental data.

Some of the literature regarding fruit cracking of various fruits will be reviewed, but although this review does bring out some of the existing ideas on fruit rupturing, it must not be assumed, however, that conditions promoting cracking of other fruits will necessarily cause skin-cracking of the York Imperial apple.

Skin-cracking of York Imperial apples was reported by Reed and Crabill (27) as occurring only " . . . . very rarely in dry seasons". In later literature Gourley and Howlett (17) stated that " . . . . a type of lenticel cracking involving many small cracks is common in York Imperial". Schrader and Haut (29) accentuated the above viewpoints in 1937 by stating that this injury is now much more severe than when it was first reported. Reed and Crabill (27) found that skin-cracking occurred chiefly on trees under 15 years of age, but other authors (17), (29), made no statement limiting this trouble to any particular age of trees.

That cracking was limited almost entirely to the green side of the fruit was noticed by Reed and Crabill (27) and by Fisher (9), (10). They also agreed that cracking was most serious under conditions of drought followed by rain which caused extensive swelling of the fruit. Reed and Crabill (27) suggested that perhaps " . . . . the skin on the shaded side of the fruit may be actually stretched to bursting by the unusual rapid multiplication and growth of pulp cells due to a sudden increase in water supply".

Since skin-cracking of York Imperial presents difficulties in apple washing, Fisher (9), (10) while working on spray removal methods, made numerous observations on the occurrence of this trouble. He stated that the tendency of fruit to crack increased as the fruit approached maturity, it was more severe on trees low in vigor and bearing a light crop, and the affected fruit was more advanced in maturity. He also stated that the cracks showed a tendency to run in a latitudinal direction but, if insect or some other similar injury was present, cracks generally ran concentrically around them.

Schrader and Haut, (29) while conducting preliminary investigations on cracking of York Imperial, also found that low vigor and light crops are conducive to cracking. They suggested that cracking may be due to spray materials, especially late arsenate sprays. They found that growing fruits either covered with white muslin bags, or washed with 1 percent hydrochloric acid, or dipped in miscible wax did not crack as much as untreated fruit. Their findings were not in agreement with Reed and Crabill (27) who stated that "sprayed and unsprayed fruits are affected alike".

To the author's knowledge this exhausts all of the literature pertaining directly to skin-cracking of the York Imperial apple. However, other types of cracking of apples, as well as cracking of other fruits, had received attention by many workers.

Verner (36) stated that: "It has commonly been stated or implied that cracking of fruits is caused by a great and sudden increase in water content of the soil, and that maintenance of a nearly constant soil-moisture content about the tree roots throughout the season of fruit growth should prevent cracking or greatly limit its severity."

Cracking of apples in Western Australia was reported by Carne (5), (6), who was studying cracking on Dunn's and other varieties. He observed that it was more severe on trees low in vigor and bearing a light crop. He believed the trouble to be essentially related to sap movement caused by the irregularity of fruit growth often accentuated by excessive rains.

Van der Bejl (39) also attributed cracking to uneven growth and adverse climatic conditions. McAlpine, in studying Dunn's apple in Victoria, concluded that cracking was due to a "rush of sap" so rapid that the flesh is unable to keep up with it and "something must give way and small rents are produced as well as disruption of stomata . . . ." Verner (36), working on the causes of cracking of the Stayman Winesap apple, thought that, "apparently the immediate mechanical cause of cracking is a form of a tissue strain by which the skin and the adjacent tissues in the restricted area of the apple are excessively stretched because of enlargement in deeper lying tissues beneath the same area".

Miller (22) stated that intense heat without rains, poor water holding capacity of soil, and russeting caused by spraying, greatly contribute to skin-cracking of apples. He added that "it seems to us that too rapid evaporation of the water in the soil hardens the skin of the fruit and cracks the skin".

Magness (20), in discussing cracking of Stayman Winesap and Wealthy apples, stated that cracking was aggravated if the soil is extremely dry before a heavy rainfall. Verner, (36), however, was unable to produce cracking on Stayman by withholding moisture supply of the tree until the soil moisture content in the upper 12 inches of soil was down to 12.4 percent and then irrigating it rapidly, thus increasing the moisture content of the soil to 20 percent in ten hours.

Goodwin (16) recommended severe pruning, manuring and cultivation to control cracking of apples. Campbell (3) added to these recommendations the use of non-caustic sprays. Carne (5) tried to control apple cracking by lime-sulphur sprays but concluded that "there is no evidence that spraying is of any value in controlling this trouble". Magness (20) suggested the use of irrigation, moderate summer cultivation and mulching as possible cures, or at least methods for decreasing apple cracking. Miller (22) also advocated the use of manure and, in addition, some fertilization throughout the growing season.

Verner and Blodget, (35), working on cracking of sweet cherries, concluded that under Idaho conditions it is mainly due to absorption of moisture through the skin of the fruit. It may be aggravated by environmental conditions favoring low transpiration especially if the moisture content of the fruit is already high. They further stated that other factors such as high temperature, high sugar content, large size, and increasing maturity of the fruit, also favored cracking. According to these authors soil moisture content was not correlated with cracking and they were unable to produce cracking artificially by application of water to the soil.

Hartman and Bullis (18) claimed that with cherries " . . . . cracking results from excessive water absorption either through the root system or through the epidermis of the fruit itself". Kertesz and Nebel (19) found that there is a possible correlation between susceptibility of various varieties of sweet cherries to cracking and the size of sub-epidermal cells; more susceptible varieties possessing larger cells.

Verner (36) showed that it is possible to reduce cracking of sweet cherries by using sprays containing calcium. He proved that it was necessary to apply the spray directly to the fruit since spraying of the foliage did not reduce cracking. He stated that cherries with a rapid rate of absorption and a small capacity for expansion were found to be most susceptible.

Cracking was reported on figs by Hixford (28) who attributed it to high humidity but not necessarily accompanied by rain. He observed that figs borne on well-irrigated trees were not very susceptible to this trouble. According to him, cracking is caused by stimulated sap pressure which gorges the fruit with juice until the pressure is greater than the tender skin of the fruit can resist. If the soil is excessively dry he observed that sudden irrigation may also produce cracking.

Crinkle of orange is reported by Carne (6) as due to the irregularity of water supply. He believed that juice cells may swell up at such a rapid rate that rind and rag cannot expand fast enough to accommodate this increase in volume. As much as 75 percent of the fruit is affected in some seasons.

Chandler, (7), in discussing cracking of deciduous fruits in general, stated that cracking " . . . . of the fruit may result from a heavy irrigation late in its development if growth has been checked by lack of water earlier". Gardner, Bradford, and Hooker (15) explain this further by saying: "Apparently the checking of growth is accompanied by changes in the fruit skin rendering it less elastic so that when growth processes are accelerated following a rain it is unable to expand rapidly enough to make provision for the developing tissue within."

The tomato also has been found to be highly susceptible to cracking. Barre (2) found that tomato fruits approaching maturity were especially susceptible and that a rainy period following hot, dry weather promoted cracking by filling the fruit cells with water, thus causing rapid expansion. Poole (25) stated that the cause of tomato cracking is not known but it was thought to be due to irregular water supply during July and August. Frazier (12), (13), (14) found that cracking may be produced by rapid water absorption either through the corky layer of the stem or through the soil. He showed that tomatoes cracked most severely after a heavy irrigation following a prolonged dry period. The best remedy seemed to be maintaining a constant moisture supply (25) and a uniform rate of growth (2).

So far most of the literature review has centered on the external observations of fruits and the effect of edaphic and climatic conditions on the increase or decrease of skin-cracking. Obviously the skin or the epidermis of the apple is primarily involved in this trouble; therefore it is of great interest to review some selected literature concerning the possible structural relation of epidermis to skin-cracking.

Tetley (32), studying anatomical development of varieties of English apples, found that meristematic cell division ceased during flowering and fruit setting stages and was replaced by cell division in vacuolating cells.

This division continued to a later stage in the subepidermal layer and later still in the epidermal cells, thus enabling ". . . . the epidermis to keep pace with the increase in size of the internal tissues".

Smith (30), (31), in studying cell enlargement in apples, concluded that there is a definite gradient in cell sizes, cell sizes increased radially from the core outwards. He also stated that fruit size at maturity is determined by both the amount of cell multiplication and the degree of cell enlargement, either factor may be dominant in determining the final size of fruit at maturity.

Clements (8) showed that the total number of stomata and lenticels per apple varies greatly not only between different varieties, but also within the same variety. He proved that this number may be influenced by environmental conditions in the early stages of fruit development. It appears that new stomata are not formed after the fruit is two to four weeks old.

It was found (8), (32), (33) that lenticels are formed from inactive stomata, from breaks in continuity of the epidermis left by falling out of trichomes, or from other epidermal breaks which may be either brought about by the inability of epidermis to keep pace with expanding inner tissue, or by some other cause.

Clements (8) stated that cell division underneath the stoma is stopped when the apple is still green and from two to four weeks old. Later, as a result of fruit enlargement, a tension is developed at this point which often results in a rupture and destruction of characteristic stoma structure. According to Tetley (33) it was impossible, in the majority of cases, to determine the origin of a mature lenticel.

In some fruits, structure of the cutin may have a definite correlation with cracking, as was shown by Tetley (32). She separated varieties on the basis of their cuticular characteristics and concluded that varieties having cutin " . . . . deposited on tangential wall so that it touches the apex only of the radial wall . . . ." are less susceptible to cracking, whereas, varieties having their cutin " . . . . deposit extended throughout the length of radial wall or even completely surrounding the cell . . . ." are more subject to cracking. She also observed that cold periods produce a comparatively thick and unelastic type of cuticle, which was more likely to develop cracking. This was especially true on the red side of the fruit. She found that cutin was thicker on the green side than on the red side. This is in agreement with Baker (1) who stated that on Grimes apples the average thickness of cutin on the green side was 18.0 microns, while on the red side it was only 13.3 microns. He also stated that cutin irregularity is a result of the irregular epidermal layer.

Verner (37), in his investigation of fruit cracking, attempted to discover some structural differences between varieties of varied susceptibility to cracking. He was unable to find any consistent varietal differences in the epidermal cells or in cutin, but he stated that there were striking differences in the hypodermal layers. Stayman Winesap, which is very susceptible to cracking " . . . . showed unmistakable evidence of deficient growth rate in the later stages of fruit enlargement, but this was not so in the varieties resistant to cracking". Tissues adjacent to or at the crack showed even greater evidence of excessive elongation or stretching. Thus he concluded that " . . . . susceptibility of Stayman Winesap apples to cracking is due chiefly to premature cessation or restriction of growth in the hypodermal layer".

MATERIALS AND METHODS

During the seasons of 1939, 1940, and 1941, investigations on skin-cracking of York Imperial apples were conducted in two separate orchards, the Potomac Highlands Orchard in Western Maryland, owned and operated by the American Fruit Growers, Inc., and the University of Maryland Orchard at College Park, Maryland.

In the American Fruit Growers' Orchard, which will be referred to as the Western Maryland Orchard, two plots of trees were selected. Although these plots were only half a mile apart, one was considered to be severely affected by skin-cracking, and the other was considered to be relatively free from this trouble; the first plot will be referred to as plot 1, and the latter as plot 2. The soil type in this orchard was classified as Dekalb shale loam with an average pH of around 5.0. The trees were fairly uniform in size and age in each plot, and bore a heavy crop every other year. In plot 1, the trees were 27 years old and were only fairly vigorous, while in plot 2 the trees were 25 years old and in a good vigorous condition. In both plots the trees were set 30' x 32' apart.

Previous to the initiation of this experiment plot 1 was in clean cultivation, and a rye cover crop was seeded each fall. During 1940 it was seeded to grass and a good sod was established by 1941. Plot 2 was in a heavy grass sod for a number of years, and remained in sod for the duration of this investigation.

The soil in the College Park Orchard is classified as Sassafras gravelly loam with an average pH of around 5.0. At the start of the experiment in 1939, the trees were nine years old and spaced 20' x 40' apart. The orchard was maintained in clean cultivation and an annual winter cover crop until 1938 when it was allowed to grow into volunteer sod. The sod was poor and the trees were only fairly vigorous.

Soil-Moisture. All soil moisture determinations were made on samples taken with a soil tube to the depth of 18 inches, and usually two or three borings were made for each sample. Soil samples were taken once or twice a month from early spring until harvest.

Root-Pruning and Paper Mulch. Three trees were selected at random on May 24, 1939 for treatments in plot 2 involving the use of root-pruning and paper mulching. A trench about one and one-half feet deep and one foot wide was dug around the tree under the ends of branches, and all of the roots within this area were severed. The entire area from the trunk to two feet beyond the trench was covered with a heavy mulch paper, which was fastened to the ground by sixty-penny nails. (Plate 2). When the paper was torn by wind, or became badly weathered, a new layer was placed on top of the old paper.

Three trees in the College Park Orchard were treated in a similar manner, except that the treatment was started on June 7, 8, and 9, 1939.

In the spring of 1940 these treatments were repeated on the same trees in both orchards except tree 20 in plot 2 in the Western Maryland Orchard. Because this tree appeared very much weakened and lacking in vigor and also had developed severe fruit cracking, as a result of the previous year's treatment, the paper mulch was removed and a straw mulch was applied. Three additional trees were root pruned and paper mulched in plot 1. These trees were root pruned more severely than the trees of the same treatment in plot 2 and in the College Park Orchard, in that a trench was dug only five to six feet from the trunk instead of near the ends of branches. Depth of root pruning was determined by root distribution and digging was terminated only when no more roots were encountered. In some cases the depth of the trench was two to three feet below the surface of the soil.

Straw Mulches. Freshly-cut rye straw was used to mulch trees in plot 2 on June 14, 1939. This mulch was only two to three inches in thickness and was considered as only a start for further mulching.

On March 16, 1940, the three trees previously mulched in plot 2 and three additional trees in plot 1 were heavily mulched with straw. The mulch was about two feet deep and covered the area from the trunk to two feet beyond the ends of branches. A week later a thin covering of manure was spread on top of the straw. Plate 1. On April 2, three trees were similarly treated in the College Park Orchard, but no manure was used.

On January 12, 1941, all trees previously mulched in the Western Maryland Orchard received an additional 200 lbs. of straw mulch, and three more trees were mulched with 600 lbs. of straw in plot 1. This straw was obtained from stables and contained about 15 percent manure. No mulch was added to trees in the College Park Orchard during this season.

Surface Irrigation. Three trees were selected in the College Park Orchard for irrigation studies which extended from June 20 to August 9, 1939. A dike was constructed around each tree and water was applied with a hose at regular intervals so that the moisture supply was more than adequate throughout this period, every tree receiving from

10-13 acre-inches of water.

Fertilization. Three trees in each of the plots in the Western Maryland Orchard were selected for heavy sodium nitrate fertilization. The first application of nitrogen was made on June 23, 1940, when seven pounds of fertilizer were broadcast under the ends of the branches in a band three to four feet wide. Additional applications during 1940 were: nine pounds on July 12, 2.5 pounds on July 30, three pounds on August 13, 7.5 pounds on September 2, and 15 pounds on October 19. Three more trees were fertilized similarly in the College Park Orchard, but the fertilizer applications were from three to five days later than in the Western Maryland Orchard.

In 1941, sodium nitrate fertilization was terminated in the College Park Orchard, but in the Western Maryland Orchard it was continued with the following applications: 22 pounds per tree on April 11, 14 pounds per tree on May 9, and 4.5 pounds on July 2, and on June 11 each of the nitrated trees received surface application of 50 pounds of hydrated lime.

Since it seemed possible that trees in the Western Maryland Orchard, especially those in plot 1, were suffering from some mineral deficiency, seven trees were fertilized with a finely ground mineral mixture of 64 minor elements. This fertilizer was prepared and furnished by Research Foundation, Inc., 10 Park Avenue, New York, New York. It contained the following elements: Fe, Ti, Mn, Cr, Ba, Sr, Zn, Pb, B, As, Cu, F, I, Ni, Sb, Co, W, Mo, Cd, Bi, Li, Se, Te, Br, V, Ag, Rb, Ga, Tl, In, Cs, Ge, Ce, La, Pr, Nd, Il, Sm, Sc, Y, Yb, Dy, Td, Er, Ho, Tm, Lu, Eu, Gd, Th, U, Ac, Po, Pa, Ra, Sn, Be, Hg, Zr, Hf, Ta, Cb, Re, Ma. Three trees received three pounds of this fertilizer per tree on July 12, 1940, three trees received 2.5 pounds per tree on June 20, and an additional 6.5 pounds on July 13, and one tree received 15 pounds of this fertilizer on July 12. In 1941, each of the above trees received three more pounds of the fertilizer on April 11. Fertilizer was poured into holes made with a soil tube from one to one and a half feet deep under the ends of branches; from three to five drillings were made for each pound of fertilizer applied.

Leaf Samples. To determine the effect of soil treatments on foliage (as measured by dry weight), leaf samples were collected from three trees of the paper and straw treatments, two trees receiving sodium nitrate treatment, and from three check trees in both plots in the Western Maryland Orchard, but in plot 2 only two trees with paper mulch were available. Two full grown leaves (usually the fourth and fifth leaf) from fifty terminals and all leaves from fifty spurs were collected. Spur leaves were separated into small and large leaves, counted, dried, and weighed separately. A small leaf was arbitrarily classified as any leaf measuring one and one-half inches or less from the tip to the base of the blade. Terminal leaves were chemically analyzed for nitrogen, phosphorus, and potassium. Total nitrogen determinations were made by the Kjeldahl method as modified by A. E. Murneek and P. H. Heinze (23). The potassium content was determined by the cobaltinitrite method as outlined by L. V. Wilcox (40), and the colorimetric method as outlined by Fiske and Subbarow (11) was used for phosphorus determinations.

Histological Studies. Fruit samples for histological studies on thickness of cutin were collected during harvest time. All fruits of a sample were picked from the east side of the trees about three-quarters of the way up the tree, but only well-exposed fruits were used. Fruits were divided into three classes on the basis of their size, and whenever possible, sixteen fruits of each size were selected from three trees in each of the straw-manure mulch, root pruned-paper mulched, and check treatments. Two sections were taken from each fruit, one from the red side and one from the green side of the fruit. The red and green sections from each of the three size classes were kept separately. Sections were cut out with a 5/8 inch cork borer and trimmed to approximately 1/8 inch in thickness and immediately placed in formalin-aceto-alcohol killing and fixing solution. After two months in this solution, six sections from each sample were run through a regular butyl alcohol dehydrating series and embedded in tissuemat.

Sections were cut 14 microns in thickness and stained in Sudan IV and Bismark Brown. Considerable difficulty was experienced in working out a staining and mounting procedure since either alcohol in concentrations over 85 percent or even a trace of xylol removed Sudan IV stain from the cutin. The following procedure was adopted and proved to be quite satisfactory: 2-5 minutes in xylol, 2-5 minutes in 100 percent ethyl alcohol, 2-5 minutes in 95 percent alcohol, 6-8 hours in Sudan IV in 95 percent alcohol, 1-2 minutes in 85 percent alcohol, 2-4 minutes in Bismark Brown in 50 percent alcohol, 1-2 minutes in 75 percent alcohol, 2-5 minutes in 80 percent alcohol, and mount in glycerine jelly.

After the glycerine jelly was hardened, the slides were examined under a microscope and the cutin thickness was measured with a Baush and Lomb eyepiece micrometer. In measuring cutin thickness extreme difficulty was encountered due to the great irregularity of cutin thickness which was especially variable on the green side of the fruit. It was finally decided to measure cutin thickness only over the center of a "normal" cell (Plate 8) instead of taking measurements entirely at random. A "normal" cell was considered to be any cell which was in the proper position in relation to other cells and which did not show any signs of collapse, undue stretching, or compressing. In this manner, it was thought, a more comparable average of cutin thickness was obtained, since all measurements were taken in similar and apparently normal locations. Nine measurements were made on each of the six sections from a fruit, making a total of 54 measurements for each of the red and green sides of fruit from a given tree.

Branch Treatments. On June 14, 1940, a number of large limbs (5-8 inches in diameter) were selected on different trees for sugar and minor elements injection. Using a 3/8-inch drill, four or five holes 1½ inches deep were drilled in each limb and from 2½-3 grams of either Domino sugar or minor elements mixture (the same as was used for soil applications) were placed in each hole which was immediately sealed with grafting wax.

Branch girdling and defoliation experiments were started in 1940. Selected branches were girdled with a curved saw by cutting a groove 1/8 inch-1/4 inch wide down to the cambium layer, and the cuts were immediately covered with grafting wax. Various branches were defoliated, leaving only three leaves per fruit. Defoliation and girdling in Western Maryland were executed on the same day, September 12, 1939, July 11, 1940, and July 1, 1941 respectively, while in the College Park Orchard defoliation and girdling were accomplished two or three days earlier or later than Western Maryland.

Fruit Treatments. Fruits, selected at random throughout the tree but not higher than 6-7 feet from the ground, were treated on the tree with wax or absolute ethyl alcohol. The alcohol was expected to increase and the wax to decrease the water loss from the surface of the fruit. The fruits were waxed with "Brytene 489-A" commercial miscible wax, (one part wax to one part water), accomplished by either dipping the fruit in this mixture or by pouring the mixture over the fruit. In either case this procedure was repeated until the fruit was thoroughly covered. Fruits which were treated with absolute alcohol were treated in a similar manner. The treatments were started on June 21, 1939, and repeated on the same fruits at approximately two-week intervals until harvest.

Fruits were bagged with white muslin, black sateen, or cellophane from July 11, 1939 and from July 12, 1940, until harvest in each season. Fruits for this purpose were selected throughout the entire tree, and in most cases a number of leaves were included in a bag with the fruit. In 1939, from 20-35 fruits were bagged on many different trees, but in 1940, 75-125 fruits were bagged on four trees.

A rubber band treatment, which was applied on June 21, 1939, consisted in covering a narrow circular portion of a fruit with a thick rubber band. Varied sizes of bands were used to insure a tight fit and as fruits increased in size bands were replaced with larger sizes. Other fruits were similarly treated with a band of parafilm.[1] A tight fit was obtained by stretching the parafilm while wrapping and by pressing it against the fruit. These parafilm band treatments were also started on June 21, 1939, and bands were replaced from time to time in order to maintain a tight and contin-

[1] Manufactured by Menasha Products Co., Menasha, Wisconsin.

uous band on each fruit.

Since it was believed (29) that some caustic sprays may aggravate skin-cracking of York Imperial apples, a few selected branches were sprayed with arsenate of lead, 12 pounds to 100 gallons of water, and a few were sprayed with a lime spray, 12 pounds to 100 gallons of water. Spraying was started on June 26, 1939, and repeated on the same branches at 10 to 15 day intervals, making a total of seven sprays applied through the season. Both sprays were applied in addition to the regular orchard spray program.

Fruitone[2/], a mixture of growth-promoting substances used for stopping pre-harvest drop, and potassium thiocyanate sprays were applied to individual branches in 1940 and 1941. After trying various amounts of Fruitone to find the highest concentration which could be used without severe injury to foliage, it was finally decided to use one gram of Fruitone, (double the recommended strength), to one quart of water; this concentration produced some injury, but none of the branches lost more than 10 percent of their foliage. The spray was applied approximately every two weeks beginning on July 30, 1940, and on July 23, 1941, during the respective seasons. Potassium thiocyanate spray was used at the same concentration and applied at the same time as Fruitone during the season of 1940. This spray was not used in 1941.

[2/] Manufactured by American Chemical Paint Company, Ambler, Pennsylvania.

To further investigate any possible effect which sprays might have on skin-cracking, all sprays after the calyx spray were omitted from some trees in 1939 and 1940; all wormy or diseased fruits were picked off by hand throughout each season.

Tree Growth Measurements. Terminal growth measurements were made during the dormant season and 60 measurements, to the nearest 0.5 centimeter, were made on each tree. All measurements were made on terminals not higher than seven feet from the ground and although they were selected at random, it was attempted to have them fairly evenly distributed throughout the tree. These measurements were averaged for each tree, and although there was considerable variation within them, it was assumed that 60 was a sufficient sample for estimation of the average terminal growth for any particular tree.

Yield and Fruit Grading. No yield records were taken in 1939. In 1940, it was noticed that there might be some relationship between the yield of a tree and the percent of cracked fruit on that tree; therefore, the trees were classed as producing high, medium, or low yield. These estimates seemed to have a definite correlation with cracking, and in 1941, the yield of each tree was recorded. The size of the fruit was not taken into consideration, but on a few trees a bushel or more of fruit was graded into three classes: small (2-1/8 inches-2½ inches), medium (2-5/8 inches-3 inches), and large (3-1/8 inches and over). The percentage of cracked fruit was determined for each size.

In determining the percentage of cracked fruit for a tree, a number of fruits, picked at random throughout the tree, were carefully examined for skin-cracks and the numbers of uncracked, slightly cracked, and severely cracked fruits were recorded. A fruit was considered slightly cracked if most of the cracks were healed over and/or the area involved was not more than 20 percent of the entire surface, a medium cracked fruit one with few open cracks and/or having not more than 50 percent and not less than 20 percent of its area affected, and a severely cracked fruit any fruit with more than 15 percent of open cracks and/or with more than 50 percent of its surface affected by cracking. A large number of fruits dropped just before harvest due to a strong wind, accounting for the small number of fruits in the 1939 sample. Because of the distinct biennial bearing habit of these trees it was also impossible, in some cases, to obtain adequate numbers of fruits per tree in 1940 and 1941.

In order to have one numerical value which would include percentage of cracked fruit as well as the severity of cracking, a "cracking index" was formulated. This index was calculated by assigning a value of 0 to an uncracked fruit, 1 to a slightly cracked fruit, 3 to medium, and 5 to a severely cracked fruit. Although it was observed that fruit with a good, smooth, or greasy finish did not develop cracks, it was thought advisable to obtain some numerical value to establish this point; therefore, fruits on selected trees were graded in regard to their finish as well as degree of cracking. The best finish on a fruit was given a ranking of 10, medium 6, and poor finish 2. The direction of cracks seemed to have some relationship to the main axis of growth or elongation of a fruit, and in order to have a numerical measure of this tendency, 1500 cracked fruits were classified into two groups: Fruits which had cracks running parallel, and fruits with cracks perpendicular to the main axis of growth of the fruit. Cracked fruits for this classification were taken from 34 different trees regardless of the differential fruit or tree treatments. Other fruits were separated into three groups on a different basis, those which had cracks on the red side of the fruit, those with cracks on the green side, and those which had cracking appearing on both the green and the red side.

RESULTS

Effect of Soil Mulches, Root Pruning, Irrigation, and Fertilization on Skin-Cracking and Related Responses of York Imperial Apples

Before studying the results of any of these treatments, it should be noted that there was variability among the untreated trees as to the percentage of cracked fruit produced. Therefore, in order for any treatment to be considered definitely effective, it must not only be consistent in its effect, but it also must produce differences greater than the differences existing within untreated trees.

Skin-Cracking. The results for the plot 1 for 1940 and 1941 seasons are presented in Tables 1 and 2.

No differences in skin-cracking in 1940 were produced by the straw-manure treatment, in fact, every tree in this treatment produced as high a percentage of cracked fruit as the average of the untreated trees, although this treatment proved effective in the next season. The straw-manure mulch was applied during the month of March, and evidence of straw decomposition was not present until early July. Thus, it is possible that this treatment was not influencing tree growth in 1940 to any great extent (not considering the effect on soil moisture) until late summer. Throughout the summer and fall there was no apparent difference between these and the check trees, but some differences were noted at the time of leaf fall. The straw mulched trees, which had a deeper green foliage, retained their foliage about a week longer.

Three more trees were added to the straw-manure mulch treatment in 1941, but since straw-manure in its second year may have a different or more pronounced effect on the tree or fruit growth, these trees are grouped separately.

Trees in the straw-manure mulch treatment were noticeably more vigorous in 1941 than in 1940. This difference, which was noticed in the early spring, was expressed in greener and larger foliage, in thicker and longer terminal

Table 1

EFFECT OF SOIL MULCHES, ROOT PRUNING, FERTILIZATION AND SPRAY OMISSION ON SKIN-CRACKING OF YORK IMPERIAL APPLES

Western Maryland Orchard Plot 1

1940 Season

Tree	Treatment	Percent of cracked fruit	Index of cracking	Relative tree growth status
61*	Straw-manure mulch	35.5	0.52	good -
62		44.2	0.66	medium
72		30.8	0.35	medium +
54*	Root pruned and paper mulched	29.5	0.39	medium +
66		65.5	1.42	poor +
77		20.2	0.27	medium +
55*	Heavy fertilization with nitrate of soda**	44.1	0.72	medium
65		38.2	0.48	medium
70		60.7	1.21	poor +
59	3 lbs. minor elements fertilizer	51.0	0.82	medium -
64		15.1	0.20	medium
73		48.1	0.90	medium
56	9 lbs. minor elements fertilizer	37.6	0.68	medium
71		46.0	0.60	medium
76		47.4	0.74	medium
74	15 lbs. minor elements fertilizer	58.8	0.59	medium -
60	None	15.3	0.19	medium
68		16.6	0.21	medium
53		22.3	0.37	medium
57		22.6	0.28	medium
78		27.5	0.28	medium
67		35.1	0.57	medium
75*		42.9	0.52	medium
69		45.5	0.69	medium
63*		48.3	0.75	poor +
52		53.1	0.93	medium -
58		56.5	0.94	medium -
51		56.7	0.83	poor +

From 150 to 280 fruits were used for each sample.
*All sprays after calyx spray were omitted on these trees.
**Each tree received 44 lbs. of nitrate of soda.

Table 2

EFFECT OF SOIL MULCHES, ROOT PRUNING AND FERTILIZATION TREATMENTS ON SKIN-CRACKING OF YORK IMPERIAL APPLES

Western Maryland Orchard Plot 1

1941 Season

Tree	Treatment	Percent of cracked fruit	Index of cracking	Relative tree growth status
51	Straw-manure mulch	2.0	0.02	medium +
58	1 year	2.0	0.02	medium +
69		0.0	0.00	medium +
61	Straw-manure mulch	0.0	0.00	excellent
62	2 years	0.0	0.00	excellent
72		0.0	0.00	good +
54	Root pruned and paper	59.3	0.92	medium -
66	mulched	82.2	1.79	poor -
77		0.0	0.00	medium +
55	Heavy fertilization	1.1	0.01	medium -
65	with nitrate of soda*	41.9	0.57	medium
70		32.5	0.47	medium
56	3 lbs. minor elements	11.6	0.12	medium
59	fertilizer	71.6	1.08	medium -
64		52.0	0.54	medium
71		19.0	0.19	medium
73		56.9	0.73	medium
74		31.9	0.32	medium
76		48.1	0.54	medium
63	None	00.0	0.00	medium -
78		16.3	0.16	medium
68		18.5	0.21	medium
53		21.9	0.23	medium -
57		36.4	0.40	medium -
52		36.7	0.45	medium -
60		46.5	0.50	medium -
75		49.7	0.51	medium
67		69.0	1.31	poor

From 100 to 150 fruits were used for each sample.
*Each tree received 40 lbs. of nitrate of soda plus 50 lbs. of hydrated lime.

growth, and also in longer retention of foliage in the fall. These differences were noticed not only on trees having a straw-manure mulch for the second year, but also on trees having this treatment for only 1941. The differences in the latter were not as pronounced, but were still noticeable even by untrained observers. Just why this effect was not produced in 1940 is not known, but it may be partially due to the fact that the straw mulch in 1940 was applied in March, while in 1941 it was applied in January, thus giving it a longer time for decomposition and accumulation of moisture in the deeper layers of soil. No records on root distribution were taken but, upon examination, it was found that trees with straw-manure mulch had developed numerous fibrous roots immediately under the straw. These roots were also more numerous under the two year than one year old straw-manure mulch.

From data in Table 2, it may be safe to conclude that the straw-manure mulch decreased cracking, but one should take into consideration that 1941 was the first year that such an effect was observed and, as will be discussed later, data in Table 3 will show that cracking is more or less a fluctuating phenomenon and it takes three years to complete a cycle. In order to justify conclusions as to the effect of straw mulch on skin-cracking in plot 1, records should be taken again in 1942. Tree 63 illustrates this point quite clearly. This tree produced 48.3 percent of cracked fruit in 1940, many of the fruits, as shown by cracking index, were more than slightly cracked, but in 1941 this tree was absolutely free from cracking and, since no treatment was applied, this change certainly cannot be attributed to any treatment.

Root pruned and paper mulched trees were also seemingly unaffected by their treatments in 1940, with the exception of tree 66, which produced an abnormally high index of cracked fruits. This tree was somewhat smaller than the rest of the trees in this plot and it may be that a greater proportion of its roots was removed during root pruning. With the exception of this one tree, the percentage of cracked fruit was not altered sufficiently to draw any conclusion.

In 1941, root pruned and paper mulched trees 54 and 66, as a result of treatment,had short, thin terminal growth and small, sparse foliage which began to turn yellow before harvest. This condition was much more pronounced on tree 66 than on 54. It is hard to offer any explanation for the behavior of tree 77 since, although the terminal growth on this tree was reduced, the general apparent vigor of the tree, judging from the appearance and size of its foliage, was good. Fruit on this tree had a good finish and dark green ground color resembling more closely the fruit on straw-manure mulched trees than on other paper mulched trees.

The data show that, although the actual percentage of cracked fruit was different in 1941 than 1940, these trees maintained their respective positions within this treatment.

Tree 66 produced the highest percentage of cracked fruit in both years, and tree 77 the lowest. Root pruning and paper mulching may have increased cracking, but apparently these treatments were not major influences.

The growth status of the trees was derived from observations throughout the growing period, taking into consideration terminal growth, size, amount, and color of foliage and the time of leaf drop. The trees were divided into four classes: Excellent, good, medium, and poor; plus and minus were used to designate variations within each class.

It may be observed from Tables 1 and 2 that there is a close correlation between the growth status of a tree and the percentage of cracked fruit on that tree. This is in agreement with Fisher (9), (10) who found that trees lacking in vigor were more subject to skin-cracking, the correlation is especially noticeable in case of tree 66. It may be that a tree in poorer physiological condition will suffer more readily from a drastic treatment, such as root pruning and paper mulching, than a tree in good condition and having a greater amount of reserve food.

Heavy nitrogen fertilization was used in an attempt to increase vigor of trees which, in turn, was considered as possibly effective in reduction of skin-cracking. The results obtained were not only negative but, in the case of tree 70, seemed to increase skin-cracking.

In 1941 the same three trees were again fertilized with sodium nitrate, but, in addition, 50 lbs. of hydrated lime was spread around each tree. Two weeks after the application of lime a typical nitrogen injury was apparent on trees 55 and 65. This injury was slight on tree 65, but tree 55 lost about 45 percent of its foliage. Most of the fruit for grading had to be picked from defoliated branches, which averaged about 70 percent red color, thus accounting for the low percentage of cracked fruit from this tree, (relationship of skin-cracking to color will be discussed later).

The minor element mixture was applied to seven trees. Different amounts of this fertilizer were used, in order to determine if rate of application would provide any additional data on the effect of this fertilizer on skin-cracking. From Table 1 it is obvious that there was no difference between fertilized and non-fertilized trees, as well as between the trees receiving different amounts of minor elements fertilizer.

Trees receiving different amounts of minor elements fertilizer in 1940 were all given the same amount of fertilizer in 1941, and again the results obtained were not indicative of any effect produced by this fertilizer.

Before discussing the data for plot 2, it should be stated that, although all trees in this plot were fairly uniform, trees 20 and 21 were located on the edge of the plot where the soil was much poorer, almost devoid of sod, and suffering badly from soil erosion. Tree 32 was in a similar location but on the opposite end of the plot where soil variability was not so pronounced.

Three years' data for plot 2 are presented in Table 3. In examining these data, it is interesting to note the presence of seasonal variation. Taking plot 2 as a unit, skin-cracking was slight in 1939, severe in 1940 and again slight in 1941, thus indicating that there may be some relationship between biennial bearing and occurrence of cracking. This belief is strengthened by the fact that the only two trees which were definitely in their "off" year in 1941 (trees 24 and 32) produced the highest percentage of cracked fruit in this plot. This will be discussed in greater detail later. In 1939, three unsprayed trees were considered as checks and used as standards in determining the effectiveness of mulch and root pruning treatments. The results in Table 3 are very similar to the two previous tables, in that they have not shown any striking differences in skin-cracking, during the three seasons, indicating that the treatments applied had no pronounced effect.

The effect on foliage by the straw-manure mulch treatment in plot 2 was not nearly as pronounced as in plot 1, but the trees with paper mulch and root pruning were noticeably lacking in vigor, and the latter trees were characterized by poor foliage which was turning yellow even before harvest, and by their short, thin, terminal growth. The fruits on the straw-mulched trees were exceptionally small, but did not have a light yellow ground color which

Table 3

EFFECT OF SOIL MULCHES, ROOT PRUNING, FERTILIZATION AND SPRAY OMISSION ON SKIN-CRACKING OF YORK IMPERIAL APPLES

Western Maryland Orchard Plot 2

Tree	Fruits per sample	Treatment	Percent of cracked fruit	Index of cracking	Relative tree growth status
		1939 Season			
21	60	Straw mulched	11.7	0.15	medium
25	67		3.0	0.03	good
29	60		3.3	0.03	good
20	30	Root pruned and	23.3	0.37	medium
26	46	paper mulched	0.0	0.00	medium +
27	49		0.0	0.00	medium +
22	50	Unsprayed*	0.0	0.00	good
23	31		0.0	0.00	good
24	41		18.2	0.18	good -
		1940 Season			
21*	273	Straw-manure	67.4	1.53	poor +
25	269	mulched	13.1	0.18	medium +
29	81		1.1	0.01	medium +
20*	272	Root pruned and	68.9	1.24	poor
26	277	paper mulched	31.0	0.51	medium +
27	200		54.0	1.21	medium -
23	259	Heavy fertiliza-	43.6	0.78	medium
30	258	tion with nitrate	14.0	0.18	medium +
31	264	of soda**	16.3	0.22	medium +
22*	18	None	38.9	0.50	medium +
24	302		11.3	0.15	medium +
32	306		22.5	0.26	poor +
		1941 Season			
21	92	Straw-manure	3.2	0.03	good -
25	200	mulched	0.0	0.00	excellent
29	200		0.0	0.00	excellent
26	263	Root pruned and	5.3	0.05	medium
27	248	paper mulched	1.6	0.02	medium
23	200	Heavy fertiliza-	0.0	0.00	good
30	149	tion with nitrate	18.8	0.19	good -
31	197	of soda**	0.5	0.01	good
22	200	None	0.0	0.00	good
24	150		50.0	0.56	medium
32	104		60.6	0.61	medium

*All sprays after calyx spray were omitted.

**Each tree received 44 lbs. of nitrate of soda in 1940 and 40 lbs. of nitrate of soda plus 50 lbs. of hydrated lime in 1941.

was found to be so characteristic of cracked fruit.

Since tree 20 was changed from the root-pruning and paper mulch treatment to a straw-manure treatment during January, 1941, it was not included in the table, but the records of this tree show that it produced 34.3 percent of cracked fruit in 1941. It may seem that the reduction in the percentage of cracked fruit from 68.9 in 1940 to 34.3 in 1941 may be attributed to the change from paper to straw mulch, but when we examine trees 26 and 27 on which a similar reduction occurred, although they remained in the same treatment, it is obvious that no such conclusion could be justified.

Whenever the percentage of cracked fruit was high there was a higher percentage of badly cracked fruit, which is represented by the magnitude of the cracking index. This suggests that the tendency or susceptibility of a tree is expressed not only in the number of fruits which may be affected, but also in the severity of cracking.

In the College Park Orchard, Table 4, the effect of straw-mulch on the vigor of trees was similar to plot 2 in the Western Maryland Orchard, although it was estimated to be slightly more pronounced.

The effect of all mulches and root pruning treatments was similar in this orchard to the Western Maryland Orchard. It may be mentioned again, that these trees also maintained their respective positions within the treatment from 1939 to 1940. Tree 166 was in a very poor gravelly soil. Ter-

Table 4

EFFECT OF SOIL MULCHES, ROOT PRUNING, FERTILIZATION AND SPRAY OMISSION ON SKIN-CRACKING OF YORK IMPERIAL APPLES

College Park Orchard

Tree	Fruits per sample	Treatment	Percent of cracked fruit	Index of cracking	Relative tree growth status
		1939 Season			
107	32	Root pruned and	21.8	0.25	medium
110	33	paper mulched	3.0	0.03	medium
114	34		17.2	0.17	medium
116	37		81.1	1.68	poor
101	23	None	60.9	1.09	medium -
103	20		20.0	0.20	medium
104	25		0.0	0.00	medium
105	14		21.4	0.21	medium
106	19		77.7	1.22	medium -
108	22		68.1	1.41	medium -
109	26		30.8	0.38	medium
111	31		25.8	0.38	medium
112	15		53.3	0.53	medium -
113	32		0.0	0.00	medium
117	37		46.6	0.60	medium
118	14		42.9	0.43	medium -
119	40		30.0	0.35	medium
		1940 Season			
201**	145	Straw mulch	17.2	0.17	good
203	109		9.2	0.09	good
208	152		12.8	0.13	good
107**	80	Root pruned and	23.8	0.26	medium
110	160	paper mulched	11.3	0.11	medium
114	137		21.9	0.22	medium
116	152		62.5	0.86	poor
115	106	Heavy fertiliza-	4.7	0.05	medium
206	140	tion with nitrate	30.7	0.32	medium
207**	115	of soda*	20.0	0.20	medium
108	111	Unsprayed**	87.4	1.34	medium -
204	101		54.5	0.74	medium
209	145		44.1	0.46	medium
109	127	Irrigated***	12.6	0.13	medium
119	114		13.2	0.13	medium
205	107		15.1	0.17	medium
101	134	None	43.3	0.49	medium -
105	80		53.8	0.54	medium
106	155		30.3	0.32	medium
112	138		18.8	0.22	medium
210	157		23.6	0.24	medium
211	130		23.1	0.23	medium
220	160		18.1	0.18	medium

*Each tree received 44 lbs. of nitrate of soda.
**All sprays after the calyx spray were omitted on these trees.
***Each tree received about 3000-4000 gal. water from June 20 to Aug. 9.

minal growth was short and thin and foliage condition, in general, was much worse than in any of the other trees included in the root-pruning and paper mulching treatment.

Although trees 109 and 110 showed no special responses, both of these trees received an additional treatment on August 18, 1939, consisting of irrigation with 900 gallons of water. Some of the water was applied to the surface of the soil, but most of it was applied in the subsoil, by inserting three-foot long irrigating rods attached to a spray house. In this manner water was forced (with the pressure from the spray pump) into the soil two to three feet below the surface. Soil moisture content before irrigation was between 2 and 3 percent under both trees. Since this treatment produced no influence on cracking of the fruit during the next few weeks, these trees were not considered as a separate treatment. Verner (38), who performed a similar experiment, has also reported that no increase in cracking of Stayman Winesap apples was produced by sudden increase in soil moisture. In 1940, trees 109, 119, and 205 were surface irrigated from June 20 to August 9. In general, this treatment seemed to reduce skin-cracking but too much emphasis should not be placed on one year's results.

Because 1941 was an "off" year for the trees in College Park Orchard, the amount of fruit produced was not sufficient to warrant continuation of treatments.

Soil Moisture. Results of soil moisture determinations in the Western Maryland Orchard are presented in Table 5. In ascribing any effect to soil moisture, it must be remem-

[redacted]

Table 5

SOIL MOISTURE CONTENT IN WESTERN MARYLAND ORCHARD

	1940 Season					1941 Season							
	Percent of Moisture					Percent of Moisture							
Treatment	July 31	Aug. 31	Sept. 2	Sept. 17	Sept. 27	Apr. 12	May 10	June 12	July 1	July 23	Aug. 10	Aug. 29	Oct. 14
						Plot 1							
Straw-manure mulched	15.8	17.9	15.3	13.5	20.3	15.9	15.2	13.1	15.4	14.8	11.2	15.6	7.8
Paper mulched and root pruned	4.8	6.0	7.2	9.9	6.7	14.3	12.3	6.2	6.9	8.3	10.8	7.9	4.3
None	9.2	8.7	16.9	12.0	13.1	14.4	11.6	13.1	11.4	10.8	9.7	12.4	7.1
						Plot 2							
Straw-manure mulched	10.7	10.4	13.3	12.5	16.7	16.1	12.9	14.0	11.5	14.4	13.5	14.5	5.3
Paper mulched and root pruned	4.3	4.6	5.3	5.9	5.4	12.7	9.8	5.7	4.8	5.5	4.9	4.4	4.6
None	7.1	10.4	17.9	10.1	17.1	15.6	12.1	12.1	10.6	9.8	10.4	13.5	4.9

[redacted]

bered that all determinations were made on the upper 18 inches of the soil, and naturally may not necessarily indicate moisture conditions below this depth. It is evident that the moisture content of the soil was markedly decreased under the paper mulch and somewhat increased under the straw mulch.

Some inconsistencies among differences in soil moisture between the three treatments may be attributed to the time of soil sampling. The amount of water from a light rainfall does not penetrate the straw-mulch and therefore, whenever soil samples were taken soon after such a rain, differences in moisture content between the straw mulched soil and unmulched soil were decreased. Whenever the soil samples were taken following a heavy rainfall, which was sufficient occasionally to penetrate or seep under the paper mulch as well as the straw mulch, the soil moisture differences between these two treatments were also decreased. This was true not only immediately following such a rain, but for a considerable time afterwards, as both paper and straw-mulch restricted evaporation from the soil.

The soil moisture content under the paper was often found to be less than half of that under the untreated trees in any particular plot; therefore, it may be safely stated that if the moisture supply in the upper 18 inches was a determining factor in causing skin-cracking, the trees in this treatment should have produced a consistently higher percentage of cracked fruit, but from examining Tables 1, 2, 3, and 4 it is obvious that this was not the case.

separated on the basis of color. Fruits over 2.5 inches in diameter were subdivided into two groups: Those possessing more than 15 percent of color and those with color less than 15 percent.

If the straw-manure treatment is disregarded, the other treatments show a definite relationship between the total yield and the percentage of small fruits; the higher the yield, the higher is the percentage of small fruits. This relationship, however, does not hold in the case of the straw-manure mulched trees. Two of these trees show an exceptionally high percentage of small fruits and the relationship between the yield and size of fruit is reversed. Tree 62, producing the lowest yield in this group, produced the highest percentage of small fruits. These trees have also produced the lowest percentage of well colored fruit. The lack of color may be explained by the fact that these trees were in vigorous vegetative condition, which caused excessive shading of the fruit. Although ground color of the fruit was not recorded, it was observed that trees receiving the root pruning and paper mulch treatments produced fruit with yellow ground color, indicating a more advanced maturity of the fruit, while the fruit from the straw-manured trees had a darker green ground color, was firmer, and had much smoother and a more greasy finish.

Leaf Development. Table 7 summarizes the effect of the mulch and fertilization treatments on relative amount of foliage. All leaves from 50 spurs and two leaves from each

[redacted]

Table 7

EFFECT OF SOIL TREATMENTS ON THE WEIGHT OF SPUR AND TERMINAL LEAVES

1941 Season

Treatment	Number of leaves per 50 spurs			Dry weight of leaves per 50 spur leaves (in grams)			Dry weight of 100 terminal leaves (in grams)
	Small leaves	Large leaves	Total leaves	Small leaves	Large leaves	Total leaves	
			Western Maryland Orchard Plot 1				
Straw-manure mulched	113.3	130.7	244.0	5.6	26.0	31.6	43.7
Root pruned and paper mulched	78.7	102.3	181.0	2.8	12.9	15.7	30.0
Heavy fertilization with nitrate of soda	106.0	128.5	234.5	3.2	20.0	23.2	39.5
None	107.3	111.3	218.6	4.8	17.4	22.2	35.8
			Western Maryland Orchard Plot 2				
Straw-manure mulched	135.0	145.7	280.7	6.0	26.2	32.2	35.5
Root pruned and paper mulched	127.0	116.5	243.5	6.7	19.6	26.3	30.1
Heavy fertilization with nitrate of soda	127.0	153.0	280.0	5.1	27.2	32.3	40.2
None	131.7	126.7	258.3	5.8	20.6	26.4	32.8

[redacted]

of 50 terminals were collected on September 13, 1941. The total number of leaves per 50 spurs was greatest on trees in the straw-manure treatment; the others in decreasing order were: Heavy fertilization, check, and root pruning plus paper mulching. The differences between treatments were more pronounced in plot 1, indicating that they were more effective in that plot than in plot 2, both as to number and weight. On the dry weight basis, there was practically no difference between straw-manure mulch and heavy fertilization in plot 2. Dry weights indicate that all trees in plot 2 produced a larger amount of dry weight of spur leaves than trees in plot 1 (with the exception of straw-manure treatment). Judging from the data in this table, it is safe to conclude that root pruning and paper mulching decreased foliage development more in plot 1 than plot 2, which may be attributed to greater severity of root pruning in that plot.

Dry weights of terminal leaves indicate similar differences but to a greater degree, thus substantiating the results obtained with spur leaves.

The same terminal leaves were chemically analyzed for total nitrogen, phosphorous, and potassium content. From the data obtained, (Table 8), there were no significant differences between any of the treatments and none of the leaves seemed to approach a deficiency level for any of the analyzed elements, thus indicating that these trees were not suffering from nitrogen, phosphorous and potassium deficiency.

Table 8

CHEMICAL ANALYSIS OF TERMINAL LEAVES
OF YORK IMPERIAL APPLES
(Expressed in percent of dry weight)

Western Maryland Orchard Plot 1

1941 Season

Tree	Treatment	Total Nitrogen Content	Phosphorus Content	Potassium Content
54	Root pruned	1.10	0.221	1.379
66	and	1.06	0.150	1.306
77	paper mulched	1.11	0.170	1.208
61	Straw-manure	1.06	0.166	1.260
62	mulched	1.04	0.200	1.185
72		.93	0.157	1.181
57	Check	1.10	0.147	1.502
67		1.07	0.173	1.364
76		1.17	0.146	1.082

Relationship of Cutin Thickness and
Structure of York Imperial Apples to Size
and Color of Fruit, Soil Treatments and
Skin-cracking.

The average cutin thickness for the red and green sides of medium and large sized fruits is summarized in Table 9. With the exception of trees 66 and 72, cutin thickness was greater on the green than on the red side of the fruit. This is in agreement with the findings of Baker (1) who was studying cutin on Grimes Golden apples. It is possible that medium fruit from tree 66 had developed nearly the maximum thickness of cutin, and therefore normal differences were not present, but the data obtained from the medium fruit of tree 72 cannot be explained and can only be attributed to experimental error.

Table 9

RELATIONSHIP BETWEEN PERCENT OF CRACKED FRUIT AND CUTIN THICKNESS OF YORK IMPERIAL APPLES

1941 Season

Tree	Percent of cracked fruit	Thickness of cutin (in microns) Red side	Green side	Mean cutin thickness
	Medium sized fruit (2-5/8"-3")			
66	82.0	16.3	16.3	16.3
67	69.0	13.3	15.4	11.4
54	59.3	14.4	15.5	15.0
76	48.1	14.2	15.5	14.8
57	36.4	14.1	14.9	14.5
62	0.0	14.1	15.9	15.0
77	0.0	13.3	13.5	13.4
72	0.0	13.3	10.5	11.9
61	0.0	10.7	11.8	11.3
	Large sized fruit (3" and up)			
66	82.0	15.1	16.9	16.0
67	69.0	13.7	16.2	14.9
54	59.3	15.8	17.4	16.6
76	48.1	13.7	15.9	14.8
57	36.4	13.7	16.2	14.9
62	0.0	13.9	14.4	14.1
72	0.0	12.0	12.5	12.2
61	0.0	11.4	12.0	11.7

Each figure represents 9 measurements per fruit on 6 fruits (54 measurements).

The correlation coefficient for cutin thickness and the percentage of cracked fruit on a tree was calculated to determine the degree of relationship between these measurements. In medium sized fruit, the correlations between percentage of cracked fruit and cutin thickness on the red side, green side and the mean cutin thickness were +0.661, +0.688 and +0.731 respectively. Correlation coefficient needed for significance at the 5 percent level is

0.666, thus indicating that the only correlation not significant at this level was between cutin thickness on the red side and the percentage of cracked fruit.

The calculated correlation coefficients between cutin thickness of large fruits on the red and green sides, mean cutin thickness and percentages of cracked fruit were: +0.692, +0.817 and +0.782 respectively. The correlation coefficient needed for significance at the 5 percent level is 0.707 and at the 2 percent level it is 0.789. In collecting samples of large fruit, it was impossible to obtain any fruit of this size in the selected location, namely, on the east side of the tree, from tree 77.

It may be concluded from these correlations that the relationship between cutin thickness and the percentage of cracked fruit is very pronounced, but due to occasional variability and probably an insufficient number of trees examined, they are not significant at the 1 percent level. However, since most of the correlations are significant at the 5 percent level, they are indicative of a close direct relationship between skin-cracking and cutin thickness.

In order to determine if the treatments had any effect on cutin thickness these measurements were analyzed by analysis of variance. It should be mentioned that the differences between measurements on the same fruit and between different fruits on the same tree were found to be not significant and therefore only averages for the whole tree were used in further statistical analysis. The results are presented in Table 10.

It was found that the differences between all treatments, except one, were highly significant. The nonsignificance between the root pruning plus paper mulching treatment and untreated trees in medium sized fruit is probably due to thin cutin on the fruit from tree 77. This tree, as was mentioned before, was not characteristic of its group.

In examining these data further, it may be observed that in the large fruit there are no significant differences in cutin thickness between trees in any one treatment, with the exception of tree 62 of straw-manure treatment, but the trees of any one treatment were significantly different from trees in other treatments. The same relationship is true in medium fruit, but in addition to tree 62, tree 77 is also significantly different from trees of the same treatment.

It is apparent that treatments tending to increase cracking produced thicker cutin, while treatments reducing cracking produced thinner cutin. It is also interesting to note that the green side of the fruit, which is more subject to cracking, has a significantly thicker cutin than the red side.

It was observed that, in addition to different cutin thickness on the red and green side of the fruit, there is also a definite structural difference peculiar to each side. The cutin surface on the red side was found to be much

Table 10

CUTIN THICKNESS OF YORK IMPERIAL APPLES
AS INFLUENCED BY SOIL TREATMENTS, ROOT
PRUNING, AND COLORATION OF FRUITS

1941 Season

Treatment	Tree	Size of fruit	Cutin thickness in microns: Green side	Red side	Average both sides
Straw-manure mulched	61	large	12.0	11.4	11.7
	62	"	14.4	13.9	14.1
	72	"	12.5	12.0	12.2
Mean					12.7
Root pruned and paper mulched	54	large	17.4	15.8	16.6
	66	"	16.9	15.1	16.0
Mean					16.3
None	57	large	16.2	13.7	14.9
	67	"	16.2	13.7	14.9
	76	"	15.9	13.7	14.8
Mean			15.2	13.7	14.9
Straw-manure mulched	61	medium	11.8	10.7	11.3
	62	"	15.9	14.1	15.0
	72	"	10.5	13.3	11.9
Mean					12.7
Root pruned and paper mulched	54	medium	15.5	14.4	15.0
	66	"	16.3	16.3	16.3
	77	"	13.5	13.3	13.4
Mean					14.9
None	57	medium	14.9	14.1	14.5
	67	"	15.4	13.3	14.4
	76	"	15.5	14.2	14.8
Mean			14.4	13.7	14.6

Difference required for significance

	large fruit @ 5%	large fruit @ 1%	medium fruit @ 5%	medium fruit @ 1%
between treatments	0.572	0.759	0.364	0.482
between trees	0.809	1.073	0.630	0.836
between sides	0.403	0.536	0.297	0.395

smoother and showed much less irregularity (Plates 13 and 14). Cutin on the green side was characterized by sharp, and often deep, indentations and by the odd shaped cells in the epidermal layer. The epidermal cells on the green side were often found to be entirely separated from each other by a layer of cutin, and although this was also noticed on the red side, the separations between cells were not as frequent or as long. Tetley (32) has found that varieties with uneven cutin, which penetrated between cells, were more subject to cracking than varieties having the cutin which touched only the apex of the radial wall of the epidermal cells.

In this study it was impossible to determine whether a break in the apple skin, similar to one shown in Plate 9, is a lenticel or a skin-crack. It was suggested by Verner (37) that lenticel hypertrophy may constitute an initial stage of fruit cracking; Tetley (32), however, stated that many cracks may occur on the fruit ". . . . which have no reference to the bases of hairs or to the lenticels". From studying prepared slides of York it was concluded that even though some cracks may have originated from lenticels, the origin of cracking can be only partially attributed to this source. Many open cracks, without any formation of a corky layer, were found on the slides examined. These cracks, obviously, had no connection with previously formed lenticels, but whenever a small crack had a corky layer, it was impossible to distinguish it from a normal lenticel.

In some cases a lenticel may be broken open and thus become a crack. From a study of Plate 11, it may be observed that although part of the side is corked over, there is no cork formation at the lower part of the lesion, thus indicating that it is a crack and not a lenticel, but it may have originated from a lenticel, which, however, is impossible to determine at this stage. Plates 10 and 12 show cracks which have formed a well defined cork layer, but here again, it is impossible to determine their origin.

Skin-cracking of York Imperial Apples As Influenced by Individual Branch and Fruit Treatments

Branch girdling data are presented in Table 11. In 1939 girdling was not done until the early part of September, which accounts for the inconsistency of the data obtained. In 1940 and 1941, however, when girdling was done in June, this treatment increased cracking on every tree which produced some cracked fruit on untreated branches. By comparing differences in the percentage of cracking and the differences in cracking index, it is observed that an increase in percentage was not always followed by an equivalent increase in severity of cracking, but in most instances girdling increased the severity as well as the percentage of cracked fruit.

Branch defoliation, which was performed on the same date as branch girdling, produced opposite results from branch girdling. The data in table 12 also bear out the

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Table 11

EFFECT OF BRANCH GIRDLING ON SKIN-CRACKING OF YORK IMPERIAL APPLES

Tree*	Percent of Cracked Fruit: Check		Percent of Cracked Fruit: Girdled branches		Difference due to treatment	Index of Cracking: Check	Index of Cracking: Girdled branches	Difference due to treatment
					1939 Season			
3	36.4	(55)**	57.1	(14)**	+20.7	0.47	0.57	+0.10
23	0.0	(31)	0.0	(25)	0.0	0.00	0.00	0.00
26	0.0	(46)	0.0	(21)	0.0	0.00	0.00	0.00
27	0.0	(49)	0.0	(25)	0.0	0.00	0.00	0.00
110	3.0	(33)	0.0	(26)	-3.0	0.03	0.00	-0.03
111	25.8	(31)	60.0	(20)	+34.2	0.38	0.80	+0.42
112	53.3	(15)	20.0	(15)	-22.2	0.53	0.20	-0.33
119	30.0	(40)	53.8	(13)	+23.8	0.35	0.69	+0.34
					1940 Season			
52	53.1	(147)	65.3	(49)	+12.2	0.93	1.18	+0.25
60	15.3	(236)	56.0	(116)	+40.7	0.19	1.13	+0.94
101	43.3	(134)	76.5	(51)	+33.2	0.49	0.88	+0.39
105	53.8	(80)	56.1	(66)	+2.3	0.54	0.69	+0.15
					1941 Season			
21	3.2	(92)	4.0	(28)	+0.8	0.03	0.04	+0.01
22	0.0	(200)	0.0	(35)	0.0	0.00	0.00	0.00
26	5.3	(263)	7.0	(20)	+1.7	0.05	0.07	+0.02
27	1.6	(248)	4.0	(23)	+2.4	0.02	0.04	+0.02
30	18.8	(149)	25.0	(27)	+6.2	0.19	0.25	+0.06
31	0.5	(197)	0.5	(30)	0.0	0.01	0.01	0.00
54	59.3	(491)	75.1	(58)	+15.8	0.92	1.12	+0.20
60	46.5	(236)	71.0	(100)	+24.5	0.15	1.63	+1.48
62	0.0	(260)	0.0	(100)	0.0	0.00	0.00	0.00
63	0.0	(259)	10.7	(38)	+10.7	0.00	0.11	+0.11
65	41.9	(238)	57.9	(19)	+16.0	0.57	0.58	+0.01
70	32.5	(270)	68.3	(106)	+35.8	0.47	0.84	+0.37
72	0.0	(254)	0.0	(48)	0.0	0.00	0.00	0.00
77	0.0	(252)	0.0	(43)	0.0	0.00	0.00	0.00

*Trees 20 to 32 were located in Western Maryland Orchard plot 1, trees 1 to 10 and 51 to 79 in Western Maryland Orchard plot 2, and trees 101 and above in College Park Orchard.
**Number of fruits per sample.

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Table 12

EFFECT OF BRANCH DEFOLIATION ON SKIN-CRACKING OF YORK IMPERIAL APPLES

Tree*	Percent of Cracked Fruit: Check		Percent of Cracked Fruit: Defoliated branches		Difference due to treatment	Index of Cracking: Check	Index of Cracking: Defoliated branches	Difference due to treatment
					1939 Season			
5	78.6	(28)**	54.0	(13)**	-24.6	1.25	0.54	-0.71
6	35.0	(20)	50.0	(14)	-15.0	0.55	0.50	-0.05
20	23.3	(30)	46.7	(15)	+23.4	0.37	0.47	+0.10
23	0.0	(31)	6.7	(15)	+6.7	0.00	0.67	+0.67
111	25.8	(31)	27.3	(22)	-1.5	0.38	0.36	-0.04
112	53.3	(15)	42.9	(7)	+10.4	0.53	0.43	+0.10
117	46.6	(37)	33.4	(12)	-1.3	0.60	0.33	-0.27
118	42.9	(14)	28.6	(14)	-14.3	0.43	0.29	-0.14
					1940 Season			
24	11.3	(302)	0.0	(35)	-11.3	0.15	0.00	-0.15
52	53.1	(147)	7.8	(69)	-45.3	0.93	0.07	-0.86
60	15.3	(236)	1.1	(88)	-14.2	0.19	0.01	-0.18
101	43.3	(134)	5.0	(50)	-38.3	0.49	0.05	-0.44
105	53.8	(80)	3.1	(32)	-50.7	0.54	0.03	-0.51
106	30.3	(155)	0.0	(74)	-30.3	0.32	0.00	-0.32
					1941 Season			
21	3.2	(92)	0.0	(20)	-3.2	0.03	0.00	-0.03
22	0.0	(200)	0.0	(25)	0.0	0.00	0.00	0.00
24	50.0	(150)	0.0	(30)	-50.0	0.56	0.00	-0.56
26	5.3	(263)	0.0	(28)	-5.3	0.05	0.00	-0.05
27	1.6	(248)	0.0	(31)	-1.6	0.02	0.00	-0.02
30	18.8	(149)	0.0	(40)	-18.8	0.19	0.00	-0.19
31	0.5	(197)	0.0	(27)	-0.5	0.01	0.00	-0.01
54	59.3	(491)	9.5	(21)	-49.8	0.92	0.10	-0.82
62	0.0	(260)	0.0	(46)	0.0	0.00	0.00	0.00
63	0.0	(259)	0.0	(35)	0.0	0.00	0.00	0.00
65	41.9	(238)	14.8	(27)	-27.1	0.57	0.15	-0.42
70	32.5	(270)	20.0	(20)	-12.5	0.47	0.20	-0.27
72	0.0	(250)	0.0	(97)	0.0	0.00	0.00	0.00
75	49.7	(254)	0.0	(25)	-49.7	0.51	0.00	-0.51
77	0.0	(252)	0.0	(25)	0.0	0.00	0.00	0.00

*Trees 20 to 32 were located in the Western Maryland Orchard plot 1, trees 1 to 10 and 51 to 79 in the Western Maryland Orchard plot 2, and trees 101 and above in the College Park Orchard.

**Number of fruits per sample.

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fact that defoliation late in the season was not as effective as that which was done earlier. In 1939 when the branches were girdled in early September, this treatment, in some instances, seemed to increase cracking. This, however, may be attributed to variability in the percentage of cracked fruits within the tree. The data for 1940 and 1941 show a very consistent reduction in cracking in every case whenever there was any evidence of cracking on the check fruits. This consistency of the results may be attributed to the greater effectiveness of the treatment, which, apparently, was sufficient to overcome any variability within a tree.

The data (expressed as percentage of cracked fruit) on the effect of bagging fruits with various types of bags are presented in Table 13. These data were also calculated on the basis of cracking index but, since no additional conclusions could be drawn from these figures, they are not presented.

Bagging reduced cracking on a few trees during the 1939 season, but the prevalence of increased cracking produced on the rest of the trees indicates that bagging, in general, increased cracking. The results are more consistent in 1940, but the increase in cracking produced by bagging still varies considerably from tree to tree. This is not in agreement with Verner (36) who, while working on cracking of Stayman Winesap, stated that fruits bagged with paper bags did not develop cracking.

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Table 13

EFFECT OF BAGGING OF INDIVIDUAL FRUITS ON SKIN-CRACKING OF YORK IMPERIAL APPLES

Tree**	Percent of cracked fruits under:				Difference by comparison to no bagging		
	No bagging	Black bag	White bag	Cellophane bag	Black bag	White bag	Cellophane bag
				1939 Season			
3	36.4	45.8	40.9	50.0	+9.4	+4.5	+13.6
5	78.6	92.0	80.0	69.6	+13.4	+1.4	-9.0
7	25.6	53.8	21.1	23.5	+28.2	-4.5	-2.1
8	50.0	77.8	46.7	50.0	+27.8	-3.3	0.0
9	45.8	54.5	58.8	50.0	+8.7	+13.0	+4.2
10	42.9	66.7	21.4	87.5	+23.8	-21.5	+44.6
23	0.0	30.0	18.2	10.0	+30.0	+18.2	+10.0
24	18.2	14.3	27.3	28.6	-3.9	+9.1	+10.4
25	3.0	0.0	0.0	0.0	-3.0	-3.0	-3.0
26	0.0	7.7	0.0	0.0	+7.7	0.0	0.0
27	0.0	0.0	0.0	0.0	0.0	0.0	0.0
28	3.3	28.6	0.0	40.0	+25.3	-3.3	+36.7
101	60.9	50.0	100.0	100.0	-10.9	+38.1	+38.1
110	3.0	11.1	25.0	40.0	+8.1	+22.0	+37.0
114	17.2	37.5	40.0	44.4	+20.3	+22.8	+27.2
				1940 Season			
24	10.1	27.5	19.8	29.6	+17.4	+9.7	+19.5
32	26.4	37.1	43.6	36.1	+10.7	+17.2	+9.7
53	10.3	33.3	21.6	24.0	+23.0	+11.3	+13.7
78	23.4	25.3	27.3	21.4	+1.9	+3.9	-2.0

**Trees 20 to 32 were located in Western Maryland Orchard plot 1, trees 1 to 10 and 51 to 79 in Western Maryland Orchard plot 2, and trees 101 and above in College Park Orchard.

[redacted]

The relative effectiveness of different types of bags is not definite. It seems that in 1939 the white bags were least effective in inducing cracking, but in 1940 this was not the case. There is even less relationship between the effects of black and cellophane bags. Apparently the type of bag was not a very important factor.

Fruits bagged with black bags were devoid of any red color and had developed, at time of harvest, a bright yellow ground color. In a number of instances these fruits were found to have developed skin-cracking completely around the fruit, that was never found on normally exposed fruit.

Since parafilm bands, rubber bands, waxing and alcohol wash all increased cracking in every case, the data were summarized and only the means for each treatment are presented in Table 14.

The difference in cracking of fruit areas under the band and outside the band was used to calculate the effectiveness of these treatments. The characteristic effect of bands is shown on Plate 4. The treatments in the order of their ability to induce cracking are: Parafilm bands, rubber bands, waxing and alcohol wash. Severity of cracking was noticeably increased by the first two treatments, but the last two had less effect in this respect.

The effect of lime spray, as shown in Table 15, was inconsistent in that increases and decreases in cracking resulted from this treatment. The results of arsenic sprays were equally erratic. Taking into consideration the trees

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Table 14

EFFECT OF PARAFILM BANDS, RUBBER BANDS, WAXING, AND ALCOHOL WASH ON SKIN-CRACKING OF YORK IMPERIAL APPLES

1939 Season

Number of trees	Treatment	Mean percentage of cracked fruit		Mean index of cracking	
17	Parafilm bands				
	Under the band	90.9		2.33	
	Outside the band	27.2		0.29	
	Mean difference		+63.7		+2.04
12	Rubber bands				
	Under the band	77.5		1.17	
	Outside the band	27.9		0.27	
	Mean difference		+49.6		+0.90
14	Waxing				
	Waxed	59.2		0.67	
	Check	17.7		0.26	
	Mean difference		+41.5		+0.41
11	Alcohol wash				
	Washed	38.3		0.45	
	Check	15.2		0.21	
	Mean difference		+23.1		+0.24

From 100 to 500 fruits were used for each sample.

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Table 13

EFFECT OF ARSENIC, LIME, POTASSIUM THIOCYANATE, AND FRUITONE SPRAYS ON SKIN-CRACKING OF YORK IMPERIAL APPLES

Tree*	Percent of cracked fruit: Check	Percent of cracked fruit: Sprayed	Difference in percent of cracked fruit	Index of cracking: Check	Index of cracking: Sprayed	Difference in cracking index
			Arsenic Sprays, 1939 Season			
3	36.4	23.1	-13.3	0.47	0.23	-0.24
20	23.3	16.6	-6.7	0.37	0.33	-0.04
26	0.0	0.0	0.0	0.00	0.00	0.00
27	0.0	0.0	0.0	0.00	0.00	0.00
117	46.6	64.7	+18.1	0.60	0.77	+0.17
118	42.9	30.0	-12.9	0.43	0.30	-0.13
			Lime Sprays, 1939 Season			
3	36.4	28.6	-7.8	0.47	0.28	-0.19
5	78.6	53.0	-25.6	1.25	0.54	-0.71
6	35.0	50.0	+15.0	0.55	0.50	-0.05
7	25.6	16.7	-8.9	0.26	0.17	-0.09
20	23.3	25.0	+1.7	0.37	0.25	-0.12
26	0.0	0.0	0.0	0.00	0.00	0.00
27	0.0	0.0	0.0	0.00	0.00	0.00
104	0.0	0.0	0.0	0.00	0.00	0.00
105	21.4	25.0	+3.6	0.21	0.25	+0.04
106	77.7	33.3	-44.4	1.22	1.00	-0.22
111	25.8	53.8	+28.0	0.38	0.77	+0.39
			Potassium Thiocyanate Sprays, 1940 Season			
24	11.3	0.0	-11.3	0.15	0.00	-0.15
52	53.1	36.7	-16.4	0.93	0.45	-0.48
67	35.1	37.3	+2.2	0.57	0.73	+0.16
101	43.3	20.3	-23.0	0.49	0.24	-0.25
105	53.8	20.3	-23.5	0.54	0.24	-0.30
106	30.3	52.5	+22.2	0.32	0.58	+0.26
220	18.1	3.8	-11.3	0.18	0.04	-0.15
			Fruitone Sprays, 1940 Season			
52	53.1	25.5	-29.6	0.93	0.33	-0.60
57	22.6	8.0	-14.6	0.28	0.08	-0.20
67	35.1	20.3	-14.8	0.57	0.46	-0.11
101	43.3	15.0	-38.3	0.49	0.20	-0.29
105	53.8	7.1	-46.7	0.54	0.07	-0.47
			Fruitone Sprays, 1941 Season			
20	34.3	0.0	-34.3	0.35	0.00	-0.35
26	5.3	0.0	-5.3	0.05	0.00	-0.05
27	1.6	0.0	-1.6	0.02	0.00	-0.02
28	0.0	0.0	0.0	0.00	0.00	0.00
52	36.7	17.8	-18.9	0.45	0.22	-0.23
54	59.3	9.5	-49.8	0.92	0.09	-0.83
64	52.0	4.8	-47.2	0.54	0.05	-0.49
66	82.2	11.8	-70.4	1.79	0.17	-1.62
67	69.0	2.9	-66.1	1.31	0.03	-1.28
68	18.5	0.0	-18.5	0.21	0.00	-0.21
77	0.0	0.0	0.0	0.00	0.00	0.00
79	33.3	0.0	-33.3	0.50	0.00	-0.50

*Trees 20 to 32 were located in the Western Maryland Orchard plot 1, trees 1 to 10 and 51 to 79 in the Western Maryland Orchard plot 2, and trees 101 and above in the College Park Orchard.

without any cracking of unsprayed fruits, there is a predominance of evidence that cracking was not induced by either lime or arsenic sprays. To determine further any possible effect that regular fruit sprays might have on skin-cracking, some trees had all sprays, after a calyx spray, omitted. The data presented in Tables 1, 3 and 4 are insufficient to draw any definite conclusion as to effect of sprays on cracking, but it is obvious that under the conditions of this experiment, sprays did not decrease cracking. This is especially evident from the data obtained in 1940, plot 2, Table 3. One tree was left unsprayed in each of the mulched treatments in addition to untreated check tree. In every case the unsprayed trees produced the highest percentage of cracked fruits within their respective treatments. This was further substantiated by data from the College Park Orchard, Table 4, where two unsprayed trees, 108 and 204, produced first and third highest percentage of cracked fruit in the whole plot. These results are not in agreement with the suggestion made by Schrader and Haut (29) that cracking may be aggravated caustic sprays used commercially in orchard spraying.

The data for potassium thiocyanate sprays, presented in table 15, indicate that, in general, a reduction in cracking was obtained as a result of application of this material. Sprayed fruit developed a better color, which may be partially responsible for the reduction in cracking.

Data for Fruitone spraying, presented in the same table, show a consistent reduction in cracking. It was found that, usually, the higher the percentage of cracking of unsprayed fruits, the greater the reduction obtained with Fruitone spray. Sprayed fruit developed a slightly better color and finish than check fruits, but this may be attributed only partially to a slight defoliation caused by this spray.

Two branches on each of the three trees were selected for sugar and minor element injections. Branches injected with minor elements produced higher percentage of cracked fruits, but the increase varied from 2.1 percent to 20.6 percent. Sugar injections in two out of three cases have also caused an increase in the percentage of cracked fruit, but in the other case a decrease of 1 percent was recorded. Since these results were tending to increase rather than decrease skin-cracking, this experiment was not repeated in 1941. No residual effect of these injections was noticed in 1941.

Other Factors Associated with Skin-cracking of York Imperial Apples

Yield. There is a definite correlation between the percentage of cracked fruits and the yield of a tree. It may be observed in Table 16 that this correlation is not perfect and that a number of exceptions are present in each plot. Since these trees were grouped regardless of their treatments, some of the variations can be definitely attributed to the effect of a treatment. Tree 58 is the only straw-manure mulched tree which produced an exceptionally

Table 16

RELATIONSHIP BETWEEN YIELD AND SKIN-
CRACKING OF YORK IMPERIAL APPLES

Western Maryland Orchard

1941 Season

Tree	Yield per tree (in bu.)	Percent of cracked fruit	Index of cracking
		Plot 1	
66	1.5	82.2	1.79
58	2.0	2.0	0.02
73	4.0	56.9	0.73
67	4.5	69.0	1.31
54	5.5	59.0	0.92
59	6.0	71.6	1.08
64	6.0	52.0	0.54
69	6.0	0.0	0.00
75	7.0	49.7	0.51
74	7.0	31.9	0.32
68	7.0	18.5	0.21
71	7.0	19.0	0.19
78	7.5	16.3	0.16
70	8.0	32.5	0.47
65	9.0	41.9	0.57
60	9.0	46.5	0.50
57	9.0	36.4	0.40
53	9.0	21.9	0.23
56	9.5	11.6	0.12
52	10.0	36.7	0.45
62	12.0	0.0	0.00
61	13.0	0.0	0.00
51	14.0	2.0	0.02
77	14.0	0.0	0.00
72	25.0	0.0	0.00
63	30.0	0.0	0.00
		Plot 2	
32	7.0	60.6	0.61
20	9.0	34.3	0.35
27	11.0	1.6	0.02
24	13.0	50.0	0.56
26	19.0	5.3	0.05
28	20.0	0.0	0.00
30	23.0	18.8	0.19
25	23.0	0.0	0.00
31	25.0	0.5	0.01
23	25.0	0.0	0.00
22	28.0	0.0	0.00
21	29.0	3.2	0.03
29	33.0	0.0	0.00

low yield in 1941 and apparently this treatment had enough effect to overbalance the effect of low yield. Tree 69, which was also in the same treatment, did not produce any cracking in spite of its light yield. It is interesting to note the degree of relationship between yield and percentage of cracked fruit. The coefficient of correlation was found to be -0.570 and the coefficient of correlation required for significance for 24 degrees of freedom is, at 1 percent level, 0.496. Therefore, it is obvious that notwithstanding the differences produced by various treatments, the correlation is highly significant.

In plot 2, trees 26 and 27 produced exceptionally small fruit, and the size of fruit on tree 27 was smaller than on tree 26. The size of fruit,which was apparently reduced by the root pruning and paper mulching treatment, accounts for the lower yield on these trees, since the yield was measured in bushels and not in number of fruits produced. Since the calculated correlation coefficient between the percentage of cracked fruit and the yield was -0.749 and the correlation coefficient needed for significance at 1 percent level is 0.684, it is obvious that this relationship was highly significant. These findings are in agreement with Fisher (9) and Schrader and Haut (29) who have also found that York Imperial apple trees bearing a heavy yield were less susceptible to this trouble.

Although there is a close relationship between the percentage of cracked fruit and the yield within each plot, there is a distinct difference between the two plots. In plot 1, whenever the tree yield exceeded 10 bushels there was practically no cracking produced on those trees, while in plot 2, the tree yield had to exceed 23 bushels before the same effect was produced. This is probably due to a difference in vigor of the trees in the two plots.

Biennial Bearing. This relationship between yields and cracking of York Imperial apples is emphasized further when biennial bearing is considered. From the data presented in Table 17, it is apparent that there is a definite fluctuation in the degree of cracking from year to year. This fluctuation is just the opposite to the biennial bearing habit of these trees. A higher percentage of cracked fruits is always associated with the "off" year of a tree, and vice versa for the "on" year. It may be mentioned that this relationship apparently supercedes the effect of any treatment which may have been applied to the tree, since these trees, similarly to Table 16, were grouped regardless of their treatments. It must be remembered that this relationship may be partially due to the higher percentage of small fruits produced by the tree in its "on" year.

Size of Fruit. To determine the relationship between the percentage of small fruit (2-1/8"-2½") and cracking on a particular tree, twenty trees from two plots in the Western Maryland Orchard were selected. Between one and three bushels of fruit were picked at random throughout the tree from each of these trees. The percentage of small fruit was

[redacted]

Table 17

RELATIONSHIP BETWEEN BIENNIAL BEARING AND SKIN-CRACKING
OF YORK IMPERIAL APPLES

Western Maryland Orchard

Tree	1939 Season		1940 Season		1941 Season	
	"On" or "Off" Year	Percent of cracked fruit	"On" or "Off" Year	Percent of cracked fruit	"On" or "Off" Year	Percent of cracked fruit
			Plot 1			
51			"Off"	56.7	"On"	2.0
61			"	35.5	"	0.0
62			"	44.2	"	0.0
63			"	48.3	"	0.0
72			"	30.8	"	0.0
77			"	20.2	"	0.0
54			"On"	29.5	"Off"	59.3
60			"	15.3	"	46.5
64			"	15.1	"	52.0
67			"	35.1	"	69.0
			Plot 2			
20	"On"	23.3	"Off"	68.9	"On"	34.3
21	"	11.7	"	67.4	"	3.2
22	"	0.0	"	38.9	"	0.0
23	"	0.0	"	43.6	"	0.0
25	"	3.0	"	13.4	"	0.0
26	"	0.0	"	31.0	"	5.3
27	"	0.0	"	54.0	"	1.6
24	"Off"	18.2	"On"	11.3	"Off"	50.0

[redacted]

calculated for each tree and the coefficient of correlation between the percentage of small fruit and cracking was calculated. The coefficient of correlation, which was found to be -0.785, is highly significant at the 1 percent level. It was interesting to note that whenever the percentage of small fruits exceeded 22 percent, there was no cracking in excess of 3.2 percent on any of the trees.

Finish and Color of Fruit. There was also a definite relationship between the finish of a fruit and the degree of cracking. Fruits from eleven trees, while being graded for cracking, were also graded in regard to their finish. A coefficient of correlation of -0.914 was obtained between finish and the percentage of cracking. This exceptionally high negative correlation clearly indicates that fruit with smoother, greasy finish is less likely to develop skin-cracking than fruit with a dry, rough finish.

It was found that most of the skin-cracking occurs on the unblushed side of the fruit. Data presented in Table 18 clearly bear out this point. Out of 1100 cracked fruits,

Table 18

THE LOCATION AND SEVERITY OF CRACKING IN RELATION TO THE COLORATION OF THE INDIVIDUAL FRUITS OF YORK IMPERIAL APPLE
1939

Location of cracks Relative to Color	% of Fruit* with Cracks			Total percentage of cracked fruit
	Slightly cracked	Medium cracked	Severely cracked	
Only on green side	60.2	11.6	1.8	73.6
On both green and red sides	14.5	6.3	2.8	23.6
Only on red side	2.8	0.0	0.0	2.8

*1100 cracked fruits from 34 different trees and 3 different plots were examined.

73.6 percent cracked on the green side, while only 2.8 percent had cracking on the red side alone. It was observed that most of the cracked fruits had a yellow instead of green ground color. Fisher (9) and Reed and Crabill (27) have also found that most of the cracking in York Imperial apples appeared on the shaded side of the fruit, but Verner (36), working with Stayman Winesap apples, stated that cracking was usually never found on a densely shaded fruit and that most cracking developed on the blushed side. Tetley (33) has also stated that on James Grieve and Beauty of Bath apples, cracking first appeared on the red side of the fruit.

Axis of Fruit Growth. Data in Table 19 indicate that

Table 19

DIRECTION OF CRACKS RELATIVE TO THE AXIS OF GREATER GROWTH OF FRUIT

1940 Season

Direction of cracks	Percentages of fruit* with cracks			Totals
	Slightly cracked	Medium cracked	Severely cracked	
Cracks perpendicular to main axis of growth	62.7	16.8	5.0	84.5
Cracks parallel to main axis of growth	12.5	3.0	0.0	15.5

*Total of 560 cracked fruits were examined.

84.5 percent of the skin cracks are perpendicular to the axis of greatest fruit growth. The cracking around injured spots on the fruit was not taken into consideration because in this case cracks were concentric around the injury. Both of these relationships are illustrated in Plates 6 and 7. Fisher (10) has noticed the same relationship between location of cracking and insect injury on the fruit, and also stated that most of the cracks ran perpendicular to the axis of the apple. Schrader and Haut (29) found that the direction of a cracking was usually parallel with the ground regardless of the fruit axis.

Fruits from ten trees were further subdivided into medium (2-5/8"-3") and large (3-1/8" and over) sizes and the percentage of cracked fruit within each of these three classes was calculated. The calculated percentage of cracking for small fruits was 10.5 ± 4.58, for medium sized fruit 43.8 ± 15.67, and large sized fruit 61.6 ± 20.81. The standard errors for each of these classes clearly indicate that the small fruits developed a significantly lower percentage of cracked fruit, but that the standard errors of medium and large sized fruit indicate that there is a distinct overlapping, indicating that there is no clear separation between these two classes in their susceptibility to cracking.

Association of Factors. The relationships between the percentage of cracked fruit on the tree and other associated factors are presented in Table 20. The correlation coefficient representing the relation of the percentage of cracked fruit to terminal growth was found to be -0.759, to dry weight of spur leaves -0.745, to the dry weight of

Table 20

RELATIONSHIP OF THE PERCENT OF CRACKED FRUIT TO THE TERMINAL GROWTH, WEIGHT OF LEAVES, YIELD PER TREE, CUTIN THICKNESS, AND PERCENT OF SMALL FRUIT

1941 Season

Tree	Percent of cracked fruit	Terminal growth (in cm.)	Dry weight of leaves from 50 spurs (in grams)	Dry weight of 100 terminal leaves (in grams)	Yield per tree (in bu.)	Mean cutin thickness (in microns)	Percent of fruit less than 2½" in diameter
66	82.0	3.08	11.32	24.45	1.5	16.2	14.3
67	69.0	7.96	23.67	34.85	4.5	14.6	5.7
54	59.3	5.18	17.68	20.05	5.5	15.8	17.3
76	48.1	8.70	20.35	34.67	7.0	14.8	15.7
57	36.4	11.67	22.90	37.95	9.0	14.7	21.8
77	0.0	7.49	19.08	36.50	13.5	13.4	23.4
62	0.0	22.35	33.55	40.08	12.0	14.5	56.2
61	0.0	25.26	28.59	43.78	13.0	11.5	39.8
72	0.0	15.70	32.46	47.20	25.0	12.0	32.2

The cutin thickness is a mean for red and green sides of medium and large sizes of fruit. Tree #77 had only medium sized fruit available.

terminal leaves -0.750, to the yield of the tree -0.839, to the mean cutin thickness +0.813 and to the percentage of small fruits -0.795. Since the correlation coefficient necessary for significance at 1 percent level is 0.798, and at 5 percent level 0.666, it may be concluded that all of the factors presented in this table were associated in varying degrees with the occurrence of skin-cracking.

Terminal growth measurements were also taken in 1940 and 1941 on additional trees to those presented in table 20, in the Western Maryland Orchard. A highly significant correlation between terminal growth and the percentage of cracked fruit on a tree was obtained in 1940, but in 1941, this relationship was not nearly so pronounced.

On some trees the terminal growth and percentage of cracking data was available for three consecutive years. It illustrated that generally, an increase in terminal growth was accompanied by a decrease in percentage of cracked fruit. On tree 82 terminal growth in 1940 averaged 7.8 cm. and the tree produced 44.2 percent of cracked fruit, while in 1941 the same tree had averaged 25.3 cm. of terminal growth and was entirely free from cracking. Tree 25 had an average terminal growth of 18.2 cm., 16.8 cm., and 21.6 cm. for 1939, 1940, and 1941 respectively, but the percentage of cracked fruit on this tree showed a reverse trend, 3.0 percent, 13.4 percent and 0.0 percent for these same years. There were some exceptions, as in the case of tree 77, in which the average terminal growth was reduced from 23.3 cm. in 1940 to 7.5 cm. in 1941, but the percentage of cracking was also reduced from 20.2 percent in 1940 to 0.0 percent in 1941. In general, however, most of the trees showed a decrease in the percentage of cracked fruit produced whenever the average terminal growth was increased.

Some partial correlations were determined on the data presented in Table 20. It was interesting to note that, when terminal growth and cutin thickness were kept constant, the correlation between the percentage of cracked fruit and the yield was increased from -0.839 to -0.964 indicating, that whenever cutin thickness and terminal growth are the same on a number of trees, yield is the determining factor in causing cracking. On the other hand, if terminal growth and yield are kept constant, the correlation between cutin thickness and the percentage of cracked fruit is reduced to +0.0047, thus indicating that cutin thickness depends to a great degree on terminal growth and yield, and that its relation to cracking is in reality due to the close relationship of cracking to yield and terminal growth. However, it still may be a contributing factor in increasing fruit susceptibility to this trouble.

DISCUSSION

Although it is not intended to attempt an explanation of the mechanics which are actually responsible for the formation of skin cracks, it is probably the inability of the outer tissues of the fruit to compensate for the increase in volume of the inner tissues of the fruit. This is the accepted viewpoint of most of the investigators who have observed or investigated fruit cracking. This conclusion is further substantiated by observations made on the direction of cracks on the fruit in relation to the axis of greatest growth, as shown on Plate 6, which illustrates quite clearly that cracks are formed perpendicular to the axis of greatest growth and, conceivably, to the direction of greatest strain or pull on the epidermal tissues, thus indicating that the force was either too great or the expansion too rapid for the outer tissues to compensate for this enlargement. The type of cracking found around insect stings or similar injuries, as shown in Plate 7, illustrates that whenever any part of a fruit is injured, cracks formed around that spot also follow the natural lines of greatest stress. The same concentric location of cracks around injured spots on apples was recorded by Fisher (9), and Schrader and Haut (29).

Why do apples from one tree develop skin-cracking, while the fruit on another tree remain uncracked?

In an attempt to answer this question, the various characteristics of cracked and uncracked fruits can now be compared on the basis of the experimental results, as given. The uncracked fruit was characterized by a deep green ground color, greenish flesh, smooth, greasy finish, small to medium size, and the ability to hang on the tree for two or three weeks after the commercial harvest date. The cracked fruit, however, had a yellowish green or, more often, yellow ground color, yellowish flesh, rough, dry finish, medium to large size, and dropped badly even before the time of normal harvest.

Considering the entire picture of both tree and fruit characteristics associated with skin-cracking, it is possible to make some clear separation as listed in Table 21, important points of which will be discussed in more detail.

Apparently, light is one of the important factors preventing cracking. The red side of the fruit generally possessed a better finish and was free from cracking, even on the fruit which was in the senescent state. An interesting feature was observed on fruits bagged with cellophane which were well exposed to sunlight. The leaves adjacent to the fruit were usually bagged with the fruit and in some instances they were pressed against the red side of the fruit. Whenever such apples were affected, the cracking had invariably developed on the area directly under the pressed leaf, while the exposed colored portion of the fruit remained unaffected. This is illustrated in Plate 5. The increased cracking of bagged fruit may be attributed, at least in part, to the exclusion of light and increased humidity. The black bags were obviously more effective in excluding light, while an increase in humidity was undoubtedly the more important factor in the cellophane bags. Verner (36) has found that a low evaporation rate was very closely associated with cracking of Stayman Winesap apples. He also stated that: "There appears to be no correlation at

Table 21

TREE AND FRUIT CHARACTERISTICS ASSOCIATED WITH CRACKED AND NON-CRACKED FRUIT OF YORK IMPERIAL APPLES

	Characteristics associated with non-cracked fruits	Characteristics associated with cracked fruit
	Tree Characteristics	
Vigor:	medium to good	medium to poor
	long thick terminal growth	short thin terminal growth
	large leaves	medium to small leaves
	dark green foliage	green to light green foliage
	heavy crop	light crop
	Fruit Characteristics	
Size:	small to medium	medium to large
Color:	green ground color	yellow green to yellow ground color
Finish:	smooth and greasy	rough and dry
Maturity:	matures later	matures earlier
Dropping:	hangs until late fall	drops easily at harvest time or before
Storage:	keeps well	shrivels and develops rots
Cutin:	thinner smoother	thicker rougher

all between air-temperature fluctuation and the occurrence of cracking . . ."

It was found that the thickness of cutin was closely correlated with the susceptibility of fruit to skin-cracking. It is interesting to note that cutin formation was smoother, thinner, and more regular on the blushed side. Tetley (32) found that apples with irregular cutin are more subject to cracking, which also appears to be true in the present investigation, for the cutin on the green side of York apples was characterized by deep indentations (Plate 14), thus suggesting that cracks may often occur at these points. The epidermal and subepidermal layers of cells also exhibited pronounced irregularities in shape and arrangement on the green side of the fruit. It is suggested that these irregularities of cutin formation and of tissues immediately underneath the cutin may influence the susceptibility of the fruit to cracking. It is natural to suppose that thin, smooth, continuous cutin with a more regular epidermal layer is more resistant to the stress caused by the internal increase in volume than the thick cutin with indentations often penetrating between the epidermal cells which are pulled apart and otherwise distorted. It may be that this latter condition could be referred to as a precursor of cracking.

It is suggested that these irregularities in the cutin and epidermal cells on the shaded side of the fruits may be due either to a lack of direct sunlight or to an insufficient amount of it. If this is true, it may be assumed that since the cells are more active on the sunny side of the fruit they are capable of greater growth and stretching, and that the formation of cutin proceeds at a normal rate, thus maintaining a smooth, uninterrupted cutin layer. The decrease of skin-cracking caused by defoliation may also be partially attributed to these phenomena, since defoliated fruit developed as much as 90 percent red color.

In general terms, it appears that skin-cracking is due to the physiological condition of the fruit, which in turn depends upon the vigor of the tree and the size of the crop. It is possible that the differences between cracked and uncracked fruit may be explained on the basis of "physiological age" of the fruit; therefore, the term "senescent" will be used to designate those fruits which had reached a certain stage of growth or maturity and possessed characteristics of cracking. This term was selected because it indicates old age, which is normally associated with the loss of activity and ability of the epidermal cells to adapt themselves to environmental changes. The term "active fruit" will be used to designate the fruit in which the epidermis has not lost its green color and the cells apparently are carrying on the normal functions of living cells.

The ground color of fruit on the defoliated branches was always greener than that of untreated fruit on the same tree, indicating that the fruit on the defoliated branches was in a more active state of growth. Whenever the girdling treatment was effective in increasing cracking, the fruits were always more mature and exhibited the more typical characteristics of a senescent fruit than check fruits on the same tree.

The effects of girdling and defoliation may also be explained on a nutritional basis. Obviously, the carbohydrate content of the defoliated branches was reduced, thus delaying maturity of the fruit. Girdling, on the other hand, resulted in an increased supply of synthesized material which forced the fruit into maturity at much earlier date. It is interesting to note that girdling was relatively ineffective on the trees which produced fruits that were definitely in an active state, while defoliation was not very effective on trees which were producing fruit in a senescent state of growth. These differences again indicate that the influence of the relative vigor of the tree is very strong and is often greater than the effect of the treatment.

The results of all the fruit and branch treatments clearly indicate that the effectiveness of some treatments which induce cracking largely depends upon the vigor and the yield of the tree. These two factors are closely related and are practically inseparable. It was found that whenever a combination of these two factors was present it was more difficult to induce cracking by artificial means. A vigorous tree with a heavy crop invariably produced an active type of fruit, while a tree which lacked vigor and bore a light or medium crop produced the senescent type of fruit. When a tree bearing a heavy crop was artificially reduced in vigor (as in the case of trees 26 and 27 in 1941) the fruits retained the active state, indicating the presence of other factors. One of these factors was found to be the biennial bearing habit of the trees. As was previously pointed out, the percentage of cracked fruit was always higher in the "off" year, indicating that the actual number of bushels produced per tree is not the only factor affecting the susceptibility of fruit to cracking, but that the condition of the tree in its "on" and "off" years is also exerting some influence. The other factor was found to be the size of the fruit. Small-sized fruit rarely cracked, but it is impossible to state whether this was due mainly to its size, or to its physiological age, since small fruits were not classified according to active or senescent characteristics. From observations, however, it was concluded that the low percentage of cracked fruit among this size was mainly due to their active state of growth and not to their size since most of the small fruits in the senescent state, although few in number, were affected by cracking.

On the other hand, it may be surmised that whenever vigor of the tree is definitely increased, cracking may be decreased, notwithstanding the small crop produced by the tree. This point, however, needs further verification, since most of the trees on which vigor was definitely increased by straw-manure mulch were bearing a heavy crop.

It is realized that the senescent and active terms indicate a difference in the physiological age of a fruit, although no accurate measurements of cell activities, such as respiration or photosynthesis, were attempted. It is realized that some measurements of the relative activity of cells should have been taken in order to determine definitely if a difference in physiological age was actually present in these different types of fruit. An iodine starch test was attempted at harvest time. All fruits, however, contained large amounts of starch and therefore it was impossible to distinguish between these two types of fruit on the basis of starch content. Starch tests were tried again after 3-4 months of storage, and although the number of samples was insufficient to draw any definite conclusions, there was a clear indication that the cracked fruit contained larger amounts of starch than the fruit in the active state. Whether or not this may be considered as an indication that senescent fruit was lacking in the capacity to change starch to sugar is not certain and is merely suggested as a possible proof of senescence. It is further realized that this arbitrary classification of fruits also involved many fruits which exhibited intermediate characteristics. Naturally, the question arises as to whether or not all fruits on every tree may eventually reach the senescent stage. Some of the uncracked fruits on good, vigorous trees, which were left from two to four weeks after the normal harvest date, still retained all characteristics of active fruits and did not develop any skin-cracking.

To further determine the rate of decline of an active fruit to a state of senescence, some of the fruit exhibiting all characteristics of the active state were placed in cold storage on October 15, 1941. This fruit was still in the active state during the last examination, April 27, 1942. Some changes in appearance were noticed, but none of the fruit possessed characteristics of a senescent fruit. This indicates that the conditions under which the fruit is growing are determining factors as to whether the fruit will develop into a senescent type or remain active for a long time after harvest. It is possible, however, that the fruit which is developing senescent characteristics may be retarded or even prevented from reaching that state. The effect of Fruitone sprays may be attributed to the fact that this spray contains growth-promoting substances which permit the fruit cells to remain in an active state. The fruits sprayed with Fruitone had a greener ground color and better finish than check fruits on the same tree, further indicating retardation of senescence. It is probable that Fruitone may also prevent the formation of premature abscission layers in the stem, thereby delaying the transmission from the active to the senescent state.

Whenever the fruit reaches the senescent state it becomes susceptible to cracking and will crack whenever the conditions causing cracking are present. However, when the fruit is in the active state, it is capable of resisting or adapting itself to unfavorable conditions, and therefore remains uncracked. In exceptional cases, conditions causing cracking may overbalence this adaptation or ability of an active fruit to resist this trouble.

It appears that the condition of the outer layers of cells of the fruit is as important as the condition of the whole fruit and, it is not unlikely, that in some cases the "senescent state" may be confined only to these outer layers. It was possible to cause cracking on specific isolated areas of a fruit by changing the environmental conditions surrounding these portions. This was done by parafilm and rubber band treatments. Excessive cracking was formed under the band while, in many cases, the rest of the fruit was free from any skin-cracking. Although, in some cases, areas of a given fruit which were not covered by the band developed cracking, in every case cracking was increased to a great extent under the band. Sections of the epidermis which were covered by bands usually developed a greenish yellow or yellow color. It is suggested that the natural functions of epidermal cells underneath the band were either greatly reduced or stopped because of the lack of oxygen and light, thus forcing those cells into an inactive or senescent state, and rendering them incapable or less capable of further growth and stretching.

Is it not possible, therefore, that the phenomena of fruit susceptibility to skin-cracking may be explained on the basis of the physiological age of the fruit?

SUMMARY AND CONCLUSIONS

This study was undertaken in an attempt to discover the possible causes and remedies of skin-cracking of the York Imperial apple. The investigation was conducted in the American Fruit Growers' Orchard in Western Maryland and in the University Orchard at College Park, Maryland, from 1939 to 1941.

Various treatments, in an attempt to alter the external environment and nutritional conditions of a tree, a branch, an individual fruit, or a part of a fruit, were applied. Tree treatments included straw-manure mulch, root pruning plus paper mulching, fertilization with nitrate of soda or minor elements mixture, irrigation, and omission of all regular sprays after the calyx spray. The effect of various soil treatments on soil moisture, dry weight and chemical composition of leaves (total nitrogen, phosphorous and potassium), was also studied. Developing fruits were bagged with black sateen, white muslin or cellophane bags, waxed with Brytene 489-A miscible wax, washed in absolute ethyl alcohol, or banded with rubber or parafilm bands. Branches were defoliated, girdled, injected with minor elements fertilizer or sugar, or sprayed with lime, arsenic, potassium thiocyanate, or Fruitone sprays.

Measurements on factors associated with or influencing cracking included records on size, color, finish of fruit, biennial bearing, yield, terminal growth, general vigor of the tree, and cutin development, especially in relation to thickness and surface smoothness. The following conclusions were reached:

1. Straw-manure mulch definitely increased the vigor of the tree and seemed to markedly decrease skin-cracking of fruit, but one more year's results are necessary to confirm this tendency.

2. Root pruning and paper mulching, which effectively decreased soil moisture to a low level, decreased vigor of the tree but did not induce skin-cracking of fruit to any considerable extent on trees bearing a heavy crop. Skin-cracking of fruit on trees with a light or medium crop seemed to be increased by this combination of treatments.

3. None of the soil fertilization treatments had any effect on skin-cracking.

4. Soil moisture was increased under straw-manure mulch and greatly decreased under paper mulch, but soil moisture is not considered a major factor in causing skin-cracking, although heavy irrigations seemed to have a slight tendency to decrease cracking.

5. There was no apparent effect of any of the soil treatments on the total nitrogen, potassium and phosphorous content of leaves.

6. Fruits with thin cutin were less susceptible to skin-cracking. The red side of the fruit, which is less subject to skin-cracking, possessed thin, regular cutin and showed little distortion of the epidermal and subepidermal

layers of cells. The cutin on the green side was thick, irregular, and the epidermal and subepidermal layers of cells showed much distortion. A significant correlation was found to exist between thickness of cutin and the percentage of cracked fruits on a given tree.

7. Girdling increased, while defoliation decreased skin-cracking. Injections of minor elements or sugar had no consistent effect.

8. Bagging, waxing, banding or alcohol wash increased skin-cracking.

9. Spray omission had no effect on skin-cracking. Lime and arsenate spray applications did not increase cracking. Potassium thiocyanate sprays increased color of fruit but the effects on cracking were not consistent. Fruitone sprays definitely decreased cracking.

10. Biennial bearing had a definite relation to skin-cracking. A higher percentage of cracked fruit was found on the "off" year than on the "on" year. Trees with heavy crops were less susceptible to skin-cracking.

11. Small, highly finished fruit with a deep green ground color was less susceptible to skin-cracking.

12. Fruits on highly vigorous trees were less susceptible to skin-cracking. Terminal growth and foliage development were closely related to the percentage of cracked fruit on a given tree.

13. It is believed that cracking is caused by the inability of the outer cell layers of the fruit to compensate

for the internal increase in volume. This belief is substantiated by the fact that most of the skin-cracks were found to be perpendicular to the main axis of growth.

14. It is suggested that the physiological age of a fruit determines its susceptibility to cracking; the older the fruit (physiologically) the more susceptible it is to this trouble.

Plate 1. York Imperial apple tree in Western Maryland Orchard, plot 2, heavily mulched with straw and manure.

Plate 2. York Imperial apple tree in the College Park Orchard mulched with paper. The extent of paper coverage is representative of all trees receiving this treatment.

Plate 3. From left to right, York Imperial apples representative of uncracked, slightly cracked and severely cracked fruit.

Plate 4. Effect of parafilm (left) and rubber band (right) on skin-cracking of the York Imperial apple. Note concentration of cracks in areas previously covered by bands.

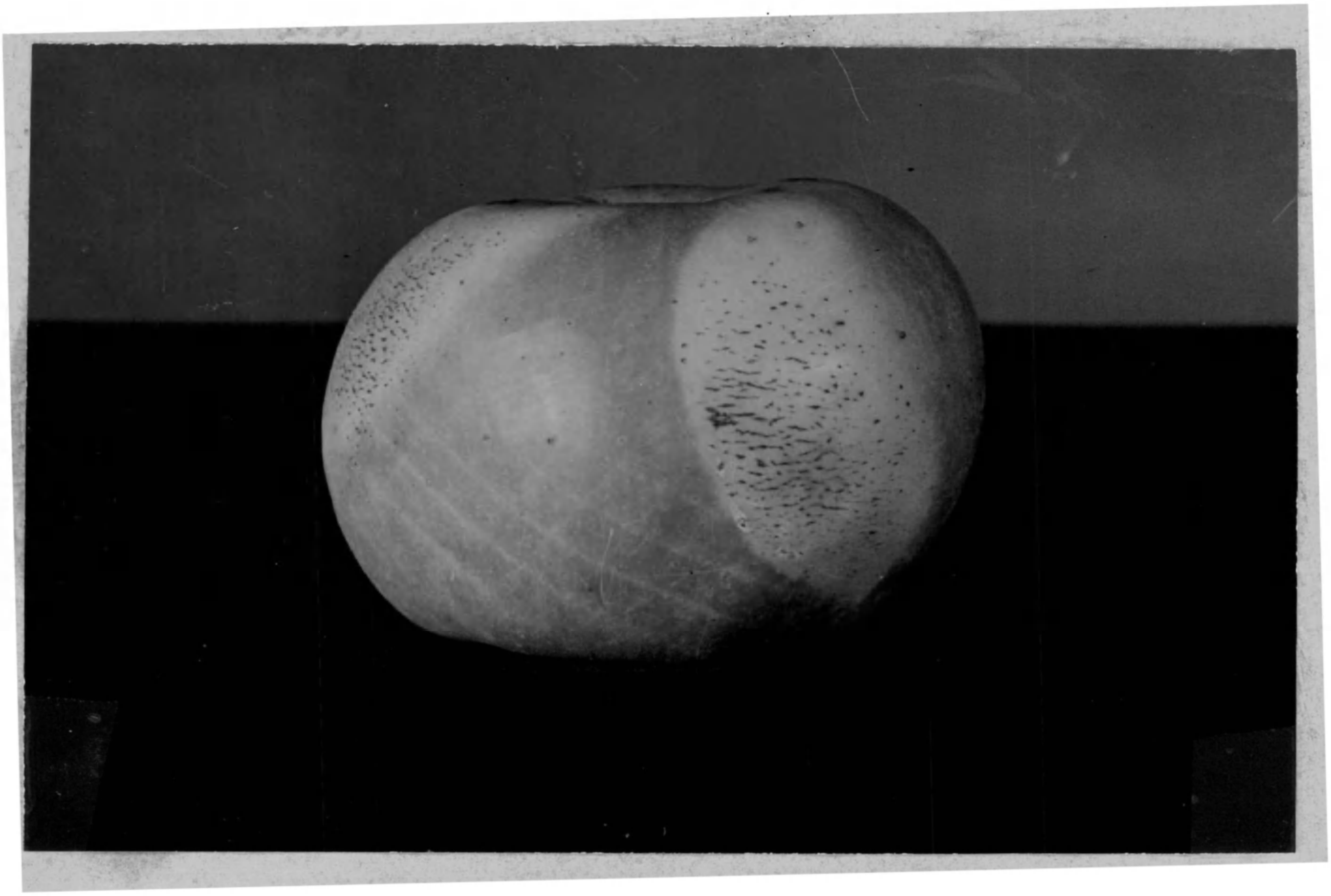

Plate 5. A York Imperial apple showing skin-cracking on areas which were covered closely with leaves, while enclosed in a cellophane bag.

Plate 6. The relationship of direction of cracks to the greatest axis of growth. Top, greatest enlargement of fruit perpendicular to core axis with cracks parallel to core axis. Bottom, greatest enlargement parallel with core axis and cracks perpendicular to core axis.

Plate 7. Concentric skin-cracks of York Imperial apples developed around insect injury.

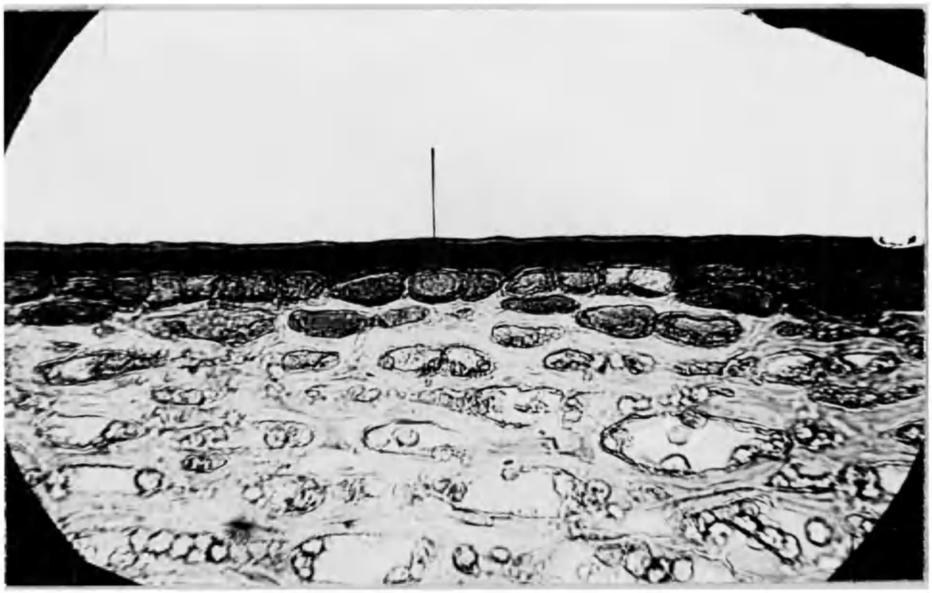

Plate 8. Cross section through the red side of the York Imperial apple showing very regular cutin and epidermal layers. Arrow indicates the representative point at which all cutin measurements were taken. Approximately x300

Plate 9. Cross section through the green side of the York Imperial apple showing a break through the cutin and epidermal layers. Approximately x90.

Plate 10. Cross section showing a corked-over skin-crack of York Imperial apple which may have originated from a lenticel. Approximately x90.

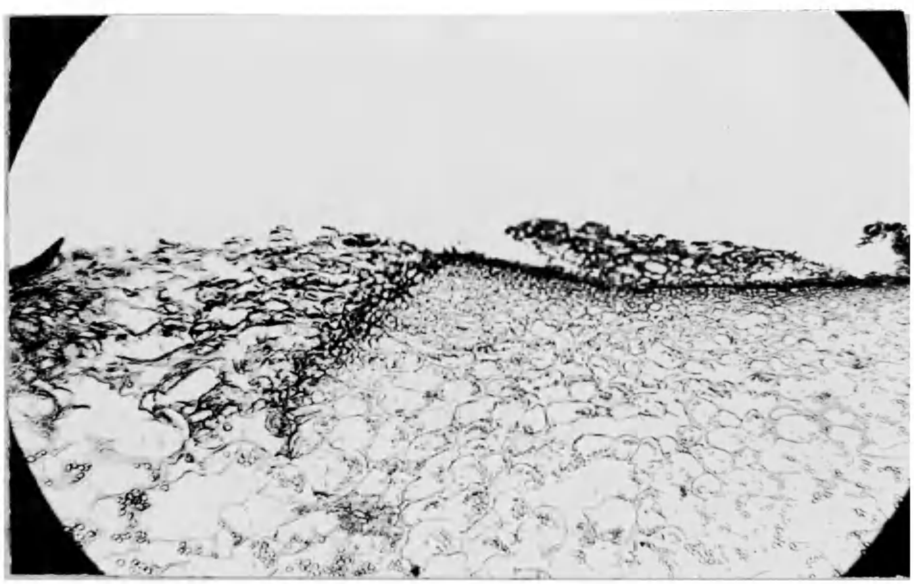

Plate 11. Cross section of a skin-crack, similar to the one in Plate 10, but with the cork layer broken and thereby exposing the cortical tissue. Approximately x90.

Plate 12. Cross section through a corked-over skin-crack of the York Imperial apple. Approximately x180.

Plate 13. Cross section through the red side of a York Imperial apple showing the smooth and regular development of cutin. Approximately x650.

Plate 14. Cross section through the green side of a York Imperial apple showing irregular cutin and cell distortion in the epidermal layer. Approximately x650.

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