Effect of Preharvest Sprays of 2,4,5-Trichlorophenoxypropionic Acid Upon the Maturation of Fruits of Important Summer-Maturing Apple Varieties

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RICHARD V. LOTT and ROBERT R. RICE[a]

SINCE ABOUT 1940 CERTAIN CHEMICALS, commonly called "growth-regulating substances," have been introduced into fruit growing. Several of these materials have been developed to inhibit apple drop. Because such "growth regulators" may profoundly influence the metabolism of plant tissues and organs and thereby the high edible quality that most consumers want in fruit, their exact effect upon the metabolic processes of fruit should be determined, particularly those processes affecting edible quality.

The effective use of a "growth-promoting substance" for inhibiting apple drop was first reported in 1939.[5, 6*] Those reports concerned naphthaleneacetic acid,[b] the first such material used. Since that time the drop-inhibiting effects of other chemicals have been investigated. Only two of them seem to have been used commercially by apple growers — 2,4-dichlorophenoxyacetic acid[2, 3, 9] and 2,4,5-trichlorophenoxypropionic acid[c] — and at present only NAA and 2,4,5-TP are used extensively.

The introduction in 1951 of 2,4,5-TP under the trade name of Color-set 1004[1] as a drop-inhibiting, preharvest spray to be used on apples was the reason for this investigation. It seemed particularly desirable to study this material because its name implied that it could affect the development of color, and because Illinois apple growers — always interested in materials that may affect the amount and rate of development of red color in their apples — are prone to apply such materials to whole orchards rather than experimentally to small blocks of trees. Since wide use of a relatively untested material can be economically dangerous, the effect of this chemical on the 1951 apple crop

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* Superior figures refer to literature cited on page 30.

[b] Hereafter referred to as NAA.

[c] Hereafter referred to as 2,4,5-TP.

was investigated as extensively as possible. While this publication reports only the effects of 2,4,5-TP on summer-maturing varieties that are of commercial importance in Illinois, two succeeding bulletins will deal with its effects on major fall-maturing varieties.

TERMINOLOGY

In spite of the obvious need for a standard terminology in technical publications dealing with fruit quality, terms are often inconsistently and ambiguously used. This is especially true of the terminology used to describe maturation and ripening, even though these processes are major considerations in any scientific discussion of fruit quality.

To overcome this confusion, the Pomology division at the University of Illinois has adopted a specific terminology in regard to fruit quality. The terminology pertinent to this bulletin is defined below.

Morphology

The morphological terminology of Tukey and Young[27] for apples is usually followed. The pomological terms *skin* and *flesh* are added and defined as follows:

Skin — the externally visible part of the fruit; distinct from *peel,* which refers to the tissues removed in peeling.

Flesh — all the fruit tissues surrounded by epidermis except the cartilaginous pericarp and ovules (seeds).

Maturation and Ripening

The terminology of maturation and ripening described in detail by Lott[14] is used. This terminology is based on the distinction between the preharvest and post-harvest environment of the fruit.

Maturation, mature, maturity — these terms and their modifications refer to the fruit *only* while it is still attached to the tree.

M1, M2, M3, M4 — designate progressive degrees of maturation, beginning with the least degree of maturation (M1) commonly harvested commercially and continuing to the *mature* fruit (M4). For example, the first commercial picking of Transparent apples in southern Illinois is made up almost entirely of M1 fruits. The meaning of M4 or mature fruit has been defined.[14] The fraction *0.5,* added to a matu-

ration symbol, as in M2.5, designates an intermediate stage between two degrees of maturation. An *M* number greater than 4 designates the degree of post-maturity.

Ripening, ripe, ripeness — these terms and their modifications refer to the fruit *only* after it is harvested.

Quality and Related Terms

Quality is the degree of edible desirability. It is not used to refer to condition, even though the terms *quality* and *condition* are often used synonymously in horticultural literature, particularly in trade publications.

Acceptable quality — a degree of quality that, though not definitely undesirable, fails to stimulate a desire for repeated consumption.

Satisfactory quality — a degree of quality that stimulates a desire for repeated consumption.

Poor, fair, good, very good, excellent — used to rate the quality of a given sample of apples in comparison with the highest quality attained by apples. For example, the rating *excellent* can be given only to certain samples of a few varieties. Jonathans, for instance, that are well-grown and mature are rated *excellent.* Transparent apples, on the other hand, are rated only *good* at maturity; at the immature stage at which they are commonly harvested commercially they are rated only *fair* or slightly higher. These terms when used in conjunction with the actual composition of the fruit become much more specific, and are used whenever they add to an understanding of the materials. *Very good* and *excellent* are the approximate equivalents of *satisfactory quality. Good* is the approximate equivalent of *acceptable quality. Very poor, poor,* and *fair* are the approximate equivalents of *unacceptable quality.*

Flavor — the psychological reaction to the combination of *smell* and *taste* in a food. In dealing with fruits, the term *aroma* is commonly used instead of smell because the aromatic compounds contribute most of the smell to normal fruits. However, undesirable smells may develop from rots, foreign odors, or the products of metabolism. The term *apple aroma* is used to designate the aroma common to the mature or ripe fruits of all varieties. At the same time, each variety has a characteristic aroma which is usually much more pronounced than the apple

aroma. Of the four fundamental *tastes* — sweet, sour, bitter, and salt — only the sweet taste of sugars and the sour taste of acids are common in apples, though a bitter taste sometimes occurs. Consequently flavor in apples is nearly always a combination of aromatic compounds, sugars, and acids. For detailed explanations of flavor see Crocker[4] and Moncrieff.[18]

Texture — the physical reaction or "feel" as fruits are chewed. In apples, such terms as hard, firm, crisp, mealy, juicy, and dry are used to describe texture.

Keepability — replaces the common term *keeping quality* to allow *quality* to retain a specific meaning, and signifies the degree to which any lot of fruit retains the potential quality that it had at harvest when placed in a specific storage environment, or, conversely, the rate at which it loses its potential harvest quality in a given environment.

Condition

Condition is a phenomenon separate and distinct from quality, concerned with freedom from and incidence of such defects as those resulting from insects, diseases, russeting, handling, and storage disorders.

Color

Background or background color — refers to the green and yellow colors and their combinations found in the skin or peel of apples. These terms replace the commonly used term *ground color* that is neither specific nor expressive of the situations encountered.

Overlying color — refers to the red colors and their modifications in conjunction with a background color.

Amount — the proportion of apple surface covered with the red color characteristic of the mature fruits of a given variety.

Intensity — the amount of red or yellow pigment per unit area of surface. *Redder* and *reddest* refer to increasing intensity of red pigment; *yellower* and *yellowest* refer to the increasing predominance of yellow over green in background color.

Flesh color — refers to color of edible tissues within the peel. It is measured near the radial center of the cortex unless otherwise stated.

Handling and Storage

Handling — any movement of the fruit, from harvesting to consumption; includes picking, packing, transporting, storing, distributing, retailing, and handling by the consumer.

Storage — the environment during the *ripening* life of the apple. As soon as the fruit is separated from the tree, it is in some sort of storage environment, ranging from that environment in which the fruit is merely lying on the ground under the tree to that in special structures in which there is control of one or more of the environmental factors.

MATERIALS AND METHODS

The formulation of 2,4,5-TP introduced commercially in 1951 as Color-Set 1004 was used throughout this work. According to Southwick,[24] this formulation is an amine salt of the material. Various concentrations and frequencies of applications were employed, as shown in Tables 1 and 2 (pages 16 to 19). The major results were obtained during the 1951 season; other results, also reported in this bulletin, were obtained in 1952 from applications made for observational purposes.

The apple varieties treated with 2,4,5-TP were Transparent, Giant Transparent, Lodi,[a] Red Duchess, and Wealthy. All were growing on the University farm at Urbana. The trees, which were 15 years old and of medium size and vigor, had been moderately pruned and were bearing a full crop. Five trees of each variety were used per treatment and per check; the single exception, Sample 1 in Table 2, is explained on page 22.

Sampling

On the sample dates shown in Tables 1 and 2, one bushel of fruit was picked from each check and treated tree, the apples being selected from all parts of the tree to represent the average of the tree in degree of maturation and in size.

The picked apples were sorted in the orchard to remove those that were defective, misshapen, or otherwise different from the majority. During the sorting process the apples from all the treated trees of each variety were put into a composite group. The check fruits were similarly combined. Two bushels of apples from each of these composite

[a] Hereafter these three varieties are referred to as Transparent-type fruits.

groups were stored overnight at 32° F. The following day each lot was removed from storage and wiped with damp towels to remove dust and most of the spray residue. A representative sample of 25 fruits was selected for chemical determinations, a similar sample of 25 fruits for pressure tests, a sample of 10 fruits for starch determinations, and the remainder was stored at 32° F. for observation during ripening.

Determination of Color

The only accurate way to measure color is to use a spectrophotometer.[8] From the spectral curves the equivalent Munsell color notations[19, 20] can be calculated. These notations can also be expressed as Inter-Society Color Council — National Bureau of Standards color names, commonly referred to as ISCC-NBS color names.[11] The names pertinent to this publication are shown in the illustrations on pages 10 and 11 and described below.

It was not feasible to measure the skin and flesh colors with the spectrophotometer, but the extensive spectrophotometric measurements of skin and flesh of the same and similar varieties in previous years by the senior author made it possible to use the ISCC-NBS color names with at least moderate specificity in the tables and to avoid the vague color terminology too often encountered in horticultural literature. Those spectrophotometric measurements showed that the background color of mature fruits of the Transparent-type varieties is pale yellow, and pale yellow to light yellow for mature Red Duchess and Wealthy, and that the mature flesh color for all these varieties is pale yellow.

The following is an explanation of the ISCC-NBS color names used in Tables 1 and 2 to describe skin and flesh colors in relation to degree of maturation. The background color names ranged from pale yellow for the mature check fruits of Red Duchess and Wealthy[a] (*top,* page 10), through pale greenish yellow, light greenish yellow, and moderate greenish yellow (*bottom,* page 10), then to light yellow green and moderate yellow green for the least nearly mature fruits (page 11). Similarly the *flesh* color names ranged from pale yellow for the mature fruits of Red Duchess and Wealthy (*top,* page 10), through pale greenish yellow (*bottom,* page 10), to pale yellow green and light yellow green for the least nearly mature apples (page 11).

The term *light* when used to modify the same hue as the term *pale* means a higher chroma at the same value level.[11, 21] For example, the illustration on top of page 10 shows that, in the hue group 4Y to 7Y

[a] These were the only varieties for which mature fruits were available.

and at values above 8.0, pale yellow includes the chroma range from 2.0 to 5.0, whereas light yellow includes the chroma range from 5.0 to 8.0. Because of its greater degree of chroma saturation, light yellow is brighter (not lighter) than pale yellow.

Similarly that illustration shows that the term *moderate* is used to designate colors with a lower value level than *light* at the same chroma intensity, the value in this case being 6.5 to 8.0 for moderate yellow and above 8.0 for light yellow. The *moderate* yellow appears to be yellower than *light* yellow because of its darker color. Actually they have the same degree of saturation with yellow (chroma).

Firmness

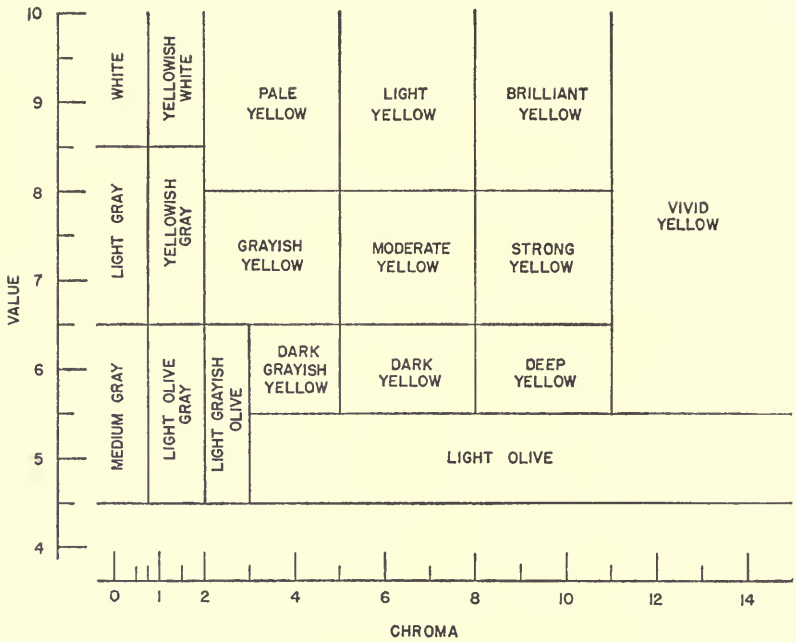
The firmness of the apples was measured with a Ballauf pressure tester, using a 7/16-inch-diameter plunger. Three determinations were made upon the flesh immediately after removing and discarding a thin slice at each of the three points to be measured. These test points were approximately equally distributed around the apple in the region of greatest transverse diameter. The plunger was pushed into the flesh to a depth of 5/16 inch and the pressure recorded in pounds, as shown in Tables 1 and 2.

Chemical Determinations on Fresh Material

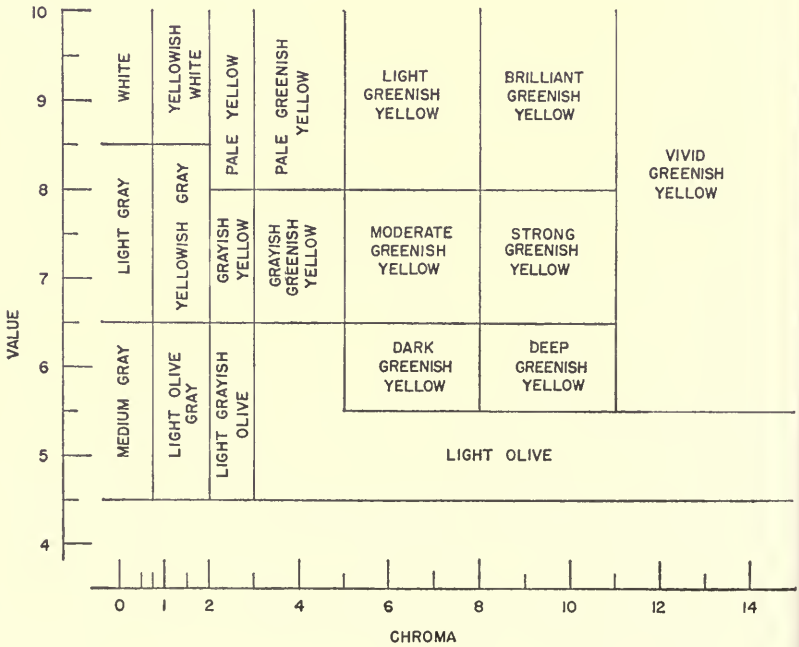
Preparation. From each of the 25 apples selected for chemical analyses, four wedge-shaped slices were cut, each extending from the blossom-end to the stem-end and from the epidermis to the carpel blade. The first slice was taken from the reddest cheek of the red varieties and from the yellowest cheek of the yellow varieties. The three remaining slices were taken at successive 90-degree intervals around the apple. This gave a slice from each quarter of the fruit — a necessary procedure if a sample representative of the whole fruit is to be obtained, since the opposite sides of an apple are different in composition.[7, 16] The slices were approximately 1/8-inch thick at the epidermis and tapered to the carpel blade in order to get about the same percentage of each of the tissues in the slice.

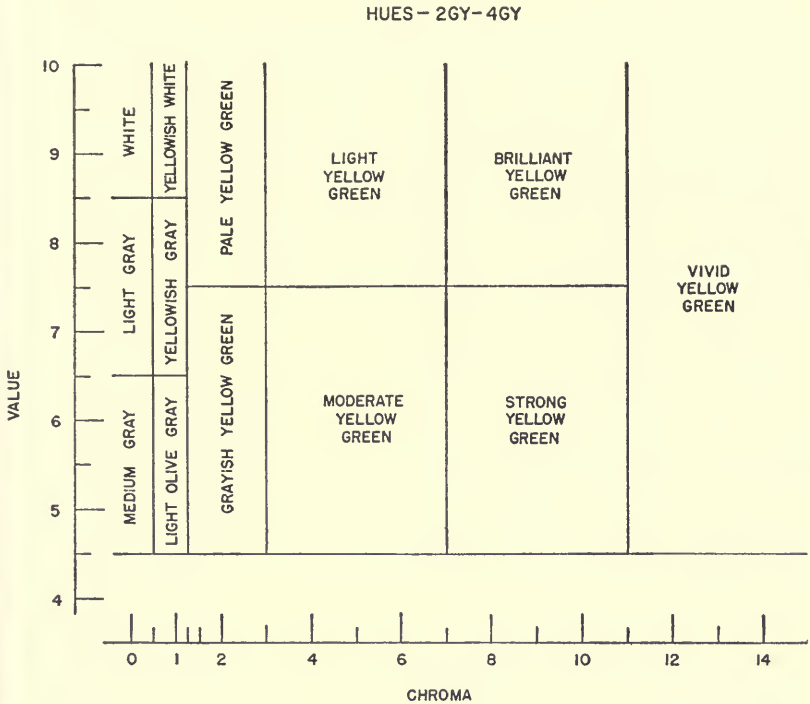
The 100 slices were cut into pieces about 1/8 inch wide and mixed rapidly by hand; then two 100-gram aliquots were weighed out on a torsion balance sensitive to 0.05 gram. These 100-gram samples were put into a forced-draft electric oven and left for 45 minutes at 100° C., after which the temperature was reduced to 65° C. and drying was continued for 7 or 8 hours to nearly constant weight. The two samples

HUES – 4Y–7Y



HUES – 7Y–9Y





These three illustrations show the ISCC-NBS (Inter-Society Color Council — National Bureau of Standards) color names for certain hues, together with the value and chroma limits of each name. Names below value 4.5 are omitted because those colors do not occur in apples. (Adapted from U.S. National Bureau of Standards Circular 533.[11])

were then removed from the oven, put into desiccators over activated aluminum oxide, and dried to constant weight. Finally they were put into glass jars and stored in the dark until ground for the analyses.

From that portion of each quarter left after taking the slice for the dried sample, a thin slice was removed at each flesh surface in order to discard the flesh that had oxidized during the preparation of the oven sample. The remainder of the quarters was ground in an Enterprise Seprosieve food grinder and the resultant juice, strained through four thicknesses of cheesecloth, was transferred to 250-milliliter beakers. Determinations of soluble solids and acidity were made on this juice sample.

Soluble solids. The juice sample was well mixed and duplicate determinations were made with a Zeiss hand sugar refractometer — an instrument calibrated to be read directly in percent of soluble solids.

Acidity. Duplicate 10-milliliter aliquots of the juice were pipetted into 500-milliliter Erlenmeyer flasks, diluted to 300 milliliters, 10 drops of phenolphthalein added, and then titrated to a faint pink end point with 0.10 normal NaOH. (Previous experience in the electrometric titration of apple juice showed that the end point was reached when a permanent faint pink color appeared.) The results were calculated as percent of malic acid. The pH of these samples was not determined.

Starch. Each of the 10 fruits taken for starch determinations was cut in two transversely at the approximate equator of the apple, and the cut surface covered with I-KI solution (0.3-gram iodine crystals, 1.5-grams KI, 100-milliliters water) and allowed to stand 10 minutes. Starch content was estimated as *absent, light, moderate,* or *abundant* according to the percentage of the surface that took on the blue color characteristic of the reaction of starch with iodine and the intensity of this blue color.

Chemical Determinations on Dry Material

Dry matter. The dry weight of the two 100-gram oven samples at their final weighing from the desiccators was averaged and divided by 100 to get the percentage of dry matter on a fresh-weight basis. Because of the hygroscopic nature of dried-fruit samples, the samples were ground in a room kept at 0° to –10° F., at which temperature they grind readily to a fine powder in an Enterprise mill. After grinding they were put into desiccators for 72 hours to remove the moisture absorbed during grinding, removed, sealed again, and returned to the dark until brought out for the analyses.

Sugars. The methods used for the extraction and determination of sugars from dried-fruit samples were those adopted by the Pomology division of the Department of Horticulture. They require considerably less time than some other methods, and detailed tests have shown that they are of adequate accuracy for fruit samples.

Extraction. A 1-gram sample of the dry apple powder was weighed out and transferred to a 120-milliliter porcelain mortar containing just enough water to form a moderately thick paste when mixed with the powder by grinding with a pestle. A maximum of 25 to 30 milliliters of water was used, and grinding continued until the sample and water

formed a finely reduced homogeneous mass. One milliliter of a saturated solution of neutral lead acetate was mixed in and the sample allowed to stand for 5 minutes. This precipitated the materials interfering with extraction and made subsequent washing much less difficult. The sample was then washed onto 9-centimeter Whatman No. 4 filter paper in a 106-millimeter porcelain Buechner funnel in a 500-milliliter filter flask and the filtrate carried through with slight suction. The sample was washed ten times, using only enough water each time to cover the sample completely. Tests showed that this washing removed all the sugars. Duplicate 1-gram samples were used for all sugar determinations.

The extracted solution was transferred from the filter flask to a 250-milliliter beaker and enough of a saturated solution of potassium oxalate added to precipitate the excess lead. It was then filtered on Whatman No. 40 filter paper in an 80-millimeter glass funnel, catching the filtrate in a 250-milliliter volumetric flask. After washing the precipitate thoroughly, the filtrate was made to volume and aliquots were taken for the sugar determinations.

Reducing sugars. Duplicate aliquots of the filtrate were used for the determination of reducing sugars by the Shaffer-Somogyi method[22] as modified by Heinze and Murneek.[10] Reducing sugar percentages are not shown in the tables but were necessary for calculating the percentages of dextrose, levulose, and sucrose.

Dextrose and levulose. Duplicate aliquots of the solution were used for the determination of dextrose and levulose by the method of Lothrop and Holmes,[12] except that the quantity of each reagent was halved because the sugar concentration was less than half that used by Lothrop and Holmes. A further modification was the removal of interfering pigments in the extract by the use of decolorizing carbon as described by Lott.[15] The true percentages of dextrose and levulose were calculated by the formula given by Lothrop and Holmes,[12] which takes into account the slight oxidation of levulose by the iodine used in the method.

Sucrose. Duplicate aliquots of the extract were inverted as described by Lott,[13] and total reducing power was determined by the same method that was used to determine reducing sugars. The percentage thus obtained minus the percentage of the reducing sugars was considered to be the sucrose percentage, calculated as dextrose, and was multiplied by 0.95 to give the sucrose percentages shown in Tables 1 and 2.

Total sugars. The calculated percentages of dextrose, levulose, and sucrose were added to obtain the total sugar percentages.

RESULTS

The results are presented in two divisions: observed effects and measured effects. The reason for these divisions is that certain effects such as juiciness can be described only on a qualitative basis whereas others, such as sugar content, can be determined on a quantitative basis.

Observed Effects

The major observed effects are shown in Tables 1 and 2. Other important observed effects that cannot be conveniently included in the tables are discussed here.

Drop. Since 2,4,5-TP was developed as a drop-inhibitor, its effects on drop are very important. Because of the severe cracking of the Transparent-type fruits, it was not feasible to obtain detailed drop records. However, 2,4,5-TP was very effective in reducing drop on these varieties as well as on Red Duchess. On Wealthy, although the chemical had a quite variable effect, it reduced the drop percentage of each sprayed tree to less than half that of the check trees.

Cracking. By July 24, two weeks after a single application of 2,4,5-TP, severe cracking had occurred on all the Transparent-type trees. Although accurate crack records could not be obtained, it was quite obvious that at least 50 percent of the fruits of these varieties had cracked by this time. This cracking occurred freely in fruits at all stages of maturation, from the very immature M1 to the mature M4. Only a few fruits reached maturity on these trees; most of the sprayed fruits had cracked and started to break down before they became mature. Various kinds of cracks occurred, ranging from those extending ¼ inch into the cortex to the severe type in which the crack extended to the core line and the cortex separated from the core. In some cases, that portion of the apple exterior to the core line separated completely from the core and fell away, leaving the core and stem firmly attached to the spur. Such cracking, together with the effect on texture described below, caused a total loss of the crop from these trees. Many of the treated fruits, even when they were uncracked and quite immature at harvest, cracked in storage at 32° F. within two weeks. In contrast, the check trees had no cracked fruits, even at maturity, nor did any check fruits crack in storage.

No severe cracking occurred in the treated Red Duchess apples. A small percentage had narrow cracks ¼ to ½ inch long that extended only into the hypodermis or outer cortex by July 24. No cracks were found in the check Red Duchess fruits even at maturity by August 7.

Neither was there severe cracking in the sprayed Wealthy apples. Some cracks similar to those in Red Duchess occurred at various places on the surface of the Wealthy fruits, but most of the cracks were in the stem cavity. No cracks occurred in the check fruits at any degree of maturation.

Color. Some of the few treated Transparent-type fruits that neared maturity were a darker yellow than usual, having a moderate-yellow background rather than a pale-yellow, but by the time this darker yellow became readily evident, the fruits had cracked or the texture had become quite mealy, or both.

2,4,5-TP definitely increased the rate and amount of red color development in Red Duchess, but the texture of the fruits turned quite soft by the time this increase became great enough to be of importance. The background and flesh colors were still yellow green when the flesh became soft. During ripening in storage the apples turned quite dull compared with the mature check fruits, on which the red color remained bright.

The treated Wealthy fruits also developed a redder-than-usual color, but they were quite dull compared with the mature check fruits, which were bright red. Even though the treated fruits were soft enough to necessitate harvesting, their background and flesh colors were still greenish yellow rather than the pale yellow that is characteristic of normal, mature fruits.

Treated Wealthy apples showed variable amounts of red pigment in the hypodermis and outer cortex, a condition not present in the check fruits. This provided additional evidence of the power of 2,4,5-TP to induce red pigment development in this variety. However, the red color of treated Wealthies was too dull to be attractive, and in storage at 32° F. this dullness became more pronounced and less like the bright red color retained by the check fruits.

Maturation. The maturation of apples is manifested by readily detectable changes in texture, flavor, and color of skin and flesh. At maturity, the fruits of every variety have a characteristic combination of these three factors. It follows then that if a production treatment causes one of these characteristics to progress to that stage which is

associated with the mature fruit without inducing a similar change in the other two characteristics, maturation cannot be considered normal nor the fruit mature. The descriptions of the samples in Tables 1 and 2 show that 2,4,5-TP induced an abnormal type of maturation in all the varieties considered here, and that no fruits of normal maturity could be harvested from the treated trees. Although the treated Wealthy apples were much nearer to normal than those of the other varieties, their abnormal softening during maturation prevented them from attaining normal maturity.

Table 1. — Effect of Preharvest Sprays of 2,4,5-TP on the Maturation of Transparent, Giant Transparent, Lodi, and Red Duchess Apples, 1951

(All samples were picked on July 24, except Sample 12, which was picked on August 7)

Sample number and variety	Treatment and date of application	Degree of maturation	Color	Texture	Varietal aroma
1 Transparent	20 p.p.m. July 9	M3.0	Skin light greenish yellow; flesh pale greenish yellow	Moderately soft, mealy, dry	Little or none
2 Transparent	Check	M3.0	Skin light greenish yellow; flesh pale greenish yellow	Firm, crisp, juicy	Little
3 Giant Transparent	20 p.p.m. July 9	M3.5	Skin pale greenish yellow; flesh pale greenish yellow	Soft, mealy, dry	Little
4 Giant Transparent	Check	M3.5	Skin pale greenish yellow; flesh pale greenish yellow	Moderately firm, crisp, juicy	Moderate
5 Lodi	20 p.p.m. July 9	M2.5	Skin moderate greenish yellow; flesh pale yellow green	Moderately firm, semi-mealy, dry	None
6 Lodi	Check	M2.5	Skin moderate greenish yellow; flesh pale yellow green	Firm, crisp, juicy	Little
7 Lodi	20 p.p.m. July 9	M3.5	Skin pale greenish yellow; flesh pale greenish yellow	Soft, mealy, dry	Little
8 Lodi	Check	M3.5	Skin pale greenish yellow; flesh pale greenish yellow	Moderately firm, moderately crisp, moderately juicy	Moderate
9 Red Duchess	20 p.p.m. July 9	M2.5	Background light yellow green; covered 50 to 75% with moderate red stripes; flesh pale yellow green	Soft, mealy, dry	None
10 Red Duchess	Check	M2.0 Average maturation of checks	Background moderate yellow green; covered 5% with light red stripes; flesh light yellow green	Hard, crisp, juicy	None
11 Red Duchess	Check	M3.0 Check fruit with most red color	Background light greenish yellow; covered 30% with moderate red stripes; flesh pale greenish yellow	Firm to hard, crisp, juicy	Little
12 Red Duchess	Check	M4.0 Typical mature Duchess	Background pale yellow; covered 45 to 60% with bright moderate red; flesh pale yellow	Firm, crisp, juicy	Moderate

(Table 1 concluded on next page)

Texture. Other than cracking, the most outstanding effect from the use of 2,4,5-TP was abnormal softening of the fruit. Treated fruits not only developed a much softer texture than that typical of mature fruits of these varieties, but they attained this texture when their background color, flesh color, and flavor were still in a stage characteristic of quite immature fruits.

All the sprayed Transparent-type fruits became quite mealy, even though they were not mature. No juice could be squeezed from them for the determination of soluble solids and acid. The severely cracked fruits had a texture similar to that of a baked potato. The uncracked, treated fruits, when dropped from a height of about 6 inches, landed with a dull thud and had little or no bounce, whereas the check fruits

Table 1. — Concluded

Sample number and variety	Quality	Starch	Pressure (lb.)	Fresh-weight percentages of the flesh				
				Dextrose	Levulose	Sucrose	Total sugars	Dry matter
1 Transparent	Very poor; not acceptable	Absent	8.2	.97	4.83	2.18	7.98	13.10
2 Transparent	Poor; not acceptable	Moderate	10.2	.80	4.70	1.84	7.34	13.10
3 Giant Transparent	Poor to fair; not acceptable	Absent	5.6	1.00	4.31	2.57	7.88	11.75
4 Giant Transparent	Fair to good; barely acceptable	Light	8.8	.95	4.54	2.71	8.20	12.80
5 Lodi	Very poor; not acceptable	Absent	17.9	1.21	4.33	2.02	7.56	11.20
6 Lodi	Very poor; not acceptable	Moderate	18.7	.93	4.37	1.99	7.29	11.50
7 Lodi	Poor; not acceptable	Absent	4.1	1.08	4.54	2.72	8.34	11.80
8 Lodi	Fair to good; barely acceptable	Light	7.9	.94	4.46	2.49	7.89	11.90
9 Red Duchess	Very poor; not acceptable	Absent	8.1	1.13	4.25	2.32	7.70	12.20
10 Red Duchess	Very poor; not acceptable	Abundant	19.9	.64	4.01	.67	5.32	12.80
11 Red Duchess	Poor to fair; not acceptable	Abundant	18.6	.70	4.24	1.08	6.02	13.40
12 Red Duchess	Good; acceptable	Moderate	17.6	.78	4.85	1.54	7.17	13.25

associated with the mature fruit without inducing a similar change in the other two characteristics, maturation cannot be considered normal nor the fruit mature. The descriptions of the samples in Tables 1 and 2 show that 2,4,5-TP induced an abnormal type of maturation in all the varieties considered here, and that no fruits of normal maturity could be harvested from the treated trees. Although the treated Wealthy apples were much nearer to normal than those of the other varieties, their abnormal softening during maturation prevented them from attaining normal maturity.

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2 Transparent	Check	M3.0	Skin light greenish yellow; flesh pale greenish yellow	Firm, crisp, juicy	Little
3 Giant Transparent	20 p.p.m. July 9	M3.5	Skin pale greenish yellow; flesh pale greenish yellow	Soft, mealy, dry	Little
4 Giant Transparent	Check	M3.5	Skin pale greenish yellow; flesh pale greenish yellow	Moderately firm, crisp, juicy	Moderate
5 Lodi	20 p.p.m. July 9	M2.5	Skin moderate greenish yellow; flesh pale yellow green	Moderately firm, semi-mealy, dry	None
6 Lodi	Check	M2.5	Skin moderate greenish yellow; flesh pale yellow green	Firm, crisp, juicy	Little
7 Lodi	20 p.p.m. July 9	M3.5	Skin pale greenish yellow; flesh pale greenish yellow	Soft, mealy, dry	Little
8 Lodi	Check	M3.5	Skin pale greenish yellow; flesh pale greenish yellow	Moderately firm, moderately crisp, moderately juicy	Moderate
9 Red Duchess	20 p.p.m. July 9	M2.5	Background light yellow green; covered 50 to 75% with moderate red stripes; flesh pale yellow green	Soft, mealy, dry	None
10 Red Duchess	Check	M2.0 Average maturation of checks	Background moderate yellow green; covered 5% with light red stripes; flesh light yellow green	Hard, crisp, juicy	None
11 Red Duchess	Check	M3.0 Check fruit with most red color	Background light greenish yellow; covered 30% with moderate red stripes; flesh pale greenish yellow	Firm to hard, crisp, juicy	Little
12 Red Duchess	Check	M4.0 Typical mature Duchess	Background pale yellow; covered 45 to 60% with bright moderate red; flesh pale yellow	Firm, crisp, juicy	Moderate

(Table 1 concluded on next page)

Texture. Other than cracking, the most outstanding effect from the use of 2,4,5-TP was abnormal softening of the fruit. Treated fruits not only developed a much softer texture than that typical of mature fruits of these varieties, but they attained this texture when their background color, flesh color, and flavor were still in a stage characteristic of quite immature fruits.

All the sprayed Transparent-type fruits became quite mealy, even though they were not mature. No juice could be squeezed from them for the determination of soluble solids and acid. The severely cracked fruits had a texture similar to that of a baked potato. The uncracked, treated fruits, when dropped from a height of about 6 inches, landed with a dull thud and had little or no bounce, whereas the check fruits

Table 1. — Concluded

Sample number and variety	Quality	Starch	Pressure (lb.)	Fresh-weight percentages of the flesh				
				Dextrose	Levulose	Sucrose	Total sugars	Dry matter
1 Transparent	Very poor; not acceptable	Absent	8.2	.97	4.83	2.18	7.98	13.10
2 Transparent	Poor; not acceptable	Moderate	10.2	.80	4.70	1.84	7.34	13.10
3 Giant Transparent	Poor to fair; not acceptable	Absent	5.6	1.00	4.31	2.57	7.88	11.75
4 Giant Transparent	Fair to good; barely acceptable	Light	8.8	.95	4.54	2.71	8.20	12.80
5 Lodi	Very poor; not acceptable	Absent	17.9	1.21	4.33	2.02	7.56	11.20
6 Lodi	Very poor; not acceptable	Moderate	18.7	.93	4.37	1.99	7.29	11.50
7 Lodi	Poor; not acceptable	Absent	4.1	1.08	4.54	2.72	8.34	11.80
8 Lodi	Fair to good; barely acceptable	Light	7.9	.94	4.46	2.49	7.89	11.90
9 Red Duchess	Very poor; not acceptable	Absent	8.1	1.13	4.25	2.32	7.70	12.20
10 Red Duchess	Very poor; not acceptable	Abundant	19.9	.64	4.01	.67	5.32	12.80
11 Red Duchess	Poor to fair; not acceptable	Abundant	18.6	.70	4.24	1.08	6.02	13.40
12 Red Duchess	Good; acceptable	Moderate	17.6	.78	4.85	1.54	7.17	13.25

Table 2. — Effect of Preharvest Sprays of 2,4,5-TP on the Maturation of Wealthy Apples, 1951

Sample number	Treatment and date of application	Date of picking	Degree of maturation	Color	Texture	Varietal aroma
1[a]	20 p.p.m. July 9	Aug. 7	M3.0	Background dull moderate greenish yellow; covered 60 to 75% with dull moderate red; flesh pale yellow green	Moderately firm, semi-mealy, moderately juicy	Moderate but somewhat flat
2[a]	Check	Aug. 7	M2.0 Most advanced maturation of checks	Background moderate yellow green; covered 30 to 45% with light-to-moderate red stripes; flesh light yellow green	Hard, crisp, juicy	Little or none
3	10 p.p.m. July 30	Aug. 27	M3.5	Background moderate greenish yellow; covered 75 to 80% with dull moderate red; flesh pale greenish yellow	Moderately firm, moderately crisp, moderately juicy	Little to moderate
4	10 p.p.m. July 30 Aug. 10	Aug. 27	M3.5	Background moderate greenish yellow; covered 70 to 90% with dull moderate-to-dark red; flesh pale greenish yellow	Moderately firm, moderately crisp, moderately juicy	Moderate
5	20 p.p.m. July 30	Aug. 27	M3.5	Background moderate greenish yellow; covered 70 to 90% with dull moderate-to-dark red; flesh pale greenish yellow	Moderately firm, moderately crisp, moderately juicy	Moderate
6	20 p.p.m. July 30 Aug. 10	Aug. 27	M3.5	Background moderate greenish yellow; covered 70 to 90% with dull moderate-to-dark red; flesh pale greenish yellow	Moderately firm, moderately crisp, moderately juicy	Moderate
7	Check	Aug. 27	M2.5 Average maturation of checks	Background moderate yellow green; covered 30 to 45% with bright light-to-moderate red; flesh pale yellow green	Hard, crisp, juicy	Little
8	Check	Aug. 27	M3.0 Most advanced maturation of checks	Background moderate greenish yellow; covered 50 to 75% with bright moderate-to-dark red; flesh pale greenish yellow	Firm to hard, crisp, juicy	Moderate; typical flavor for this stage of maturation
9	Check	Sept. 6	M3.0 Average maturation of checks	Background moderate greenish yellow; covered 60 to 80% with bright moderate-to-dark red; flesh pale greenish yellow	Firm to hard, crisp, juicy	Moderate; typical for this stage of maturation
10	Check	Sept. 18	M3.5 Check fruits with least red color	Background pale greenish yellow; covered 40 to 60% with bright moderate-to-dark red; flesh pale yellow	Firm, crisp, juicy	Moderate plus; typical for this stage of maturation
11	Check	Sept. 18	M4.0 Average maturation of checks	Background pale yellow; covered 55 to 65% with bright moderate-to-dark red; flesh pale yellow	Firm, crisp, juicy	Abundant; typical for this stage of maturation

[a] See discussion on page 22.

(Table 2 concluded on next page)

Table 2. — Concluded

Sample number	Quality	Starch	Percent in juice of—		Pressure (lb.)	Fresh-weight percentages of the flesh				
			Soluble solids	Acid		Dextrose	Levulose	Sucrose	Total sugars	Dry matter
1[a]	Fair to good; barely acceptable	Absent	9.5	.58	11.1	1.28	5.14	1.70	8.12	11.95
2[a]	Poor; not acceptable	Abundant	9.2	.85	16.0	1.04	5.49	1.20	7.73	13.30
3	Fair to good; barely acceptable	Absent	10.6	.53	9.3	1.15	5.46	2.95	9.56	13.20
4	Good; acceptable	Absent	10.9	.59	11.4	1.24	5.71	2.85	9.80	13.50
5	Good; acceptable	Absent	11.8	.62	10.8	1.08	6.10	3.19	10.37	14.60
6	Good; acceptable	Absent	10.8	.60	10.9	.95	5.52	2.84	9.31	13.30
7	Poor; not acceptable	Abundant	10.8	.78	15.7	1.01	5.92	2.48	9.41	14.10
8	Good; acceptable	Moderate	10.8	.63	13.8	1.03	6.24	2.78	10.05	14.10
9	Good; acceptable	Moderate	11.2	.60	12.8	1.01	6.12	2.97	10.10	14.20
10	Good to very good; acceptable to satisfactory	Moderate	12.0	.68	12.5	1.02	5.85	3.53	10.40	14.70
11	Very good; satisfactory	Light to moderate	12.2	.65	12.0	1.00	6.09	4.03	11.12	15.00

[a] See discussion on page 22.

had the bounce and sound normally expected of such apples. The sprayed Red Duchess fruits were mealy and easily bruised and in general had a texture similar to the Transparent-type varieties but less extreme. Like the Transparent-type fruits, no juice could be squeezed from them.

The Wealthy apples from the treated trees were moderately firm but softer than the mature check fruits, even though the sprayed fruits had not yet developed mature background color, flesh color, and flavor at harvest. The sprayed fruits were also less juicy than the check fruits at the same stage of maturation.

Flavor.[a] None of the treated apples developed the flavor characteristic of mature fruits of the variety, nor did any of them have the degree of flavor that the check fruits had at the same stage of maturation. In the fruits of the Transparent-type varieties and in Red Duchess, this deficiency in flavor was due largely to the failure of the treated fruits to develop an *aroma* characteristic of the degree of softening of the samples. As shown in Table 1, these Transparent-type and Red Duchess apples were all very low in aroma, most of them having the aroma characteristic of quite immature apples — usually called "green apple smell." The check fruits had the aroma usual for their stages of maturation.

The taste of the sprayed fruits of these varieties was about normal for the degrees of maturation shown by the M designations in Table 1. This was also true for the check fruits.

2,4,5-TP had the same effect on the aroma of Wealthy apples as it had on the other varieties, but to a much less marked degree. The differences between the treated and check Wealthies, although quite definite, were consequently not nearly so great as the differences between the treated and check fruits of the other varieties. 2,4,5-TP did not greatly affect taste in Wealthy, as shown by the sugar and acid data in Table 2.

Measured Effects

Measured effects are shown in Tables 1 and 2.

Firmness. The pressure data and sample descriptions in the tables show the effect that 2,4,5-TP had on texture. While the pressure tester as a means of measuring apple texture leaves much to be desired, differences of the magnitude shown leave little doubt that 2,4,5-TP

[a] The meanings of the terms as used here should be reviewed on page 5.

decreased firmness. It should be noticed particularly that the pressure required by the *mature* check Red Duchess (Sample 12) was more than twice that required by the treated Red Duchess (Sample 9), even though the treated Red Duchess, on the basis of background color, flesh color, and flavor, was far from mature.

The pressure data for Wealthy failed to show the degree of difference in texture between treated and check fruits that could be readily detected by cutting or chewing the fruit — a fact that emphasizes the inadequacy of the pressure tester as a means of measuring apple texture.

Soluble solids. Since no juice could be extracted from the treated Transparent-type and Red Duchess fruits, the percentage of soluble solids could be determined only for Wealthy. The generally lower percentages in the juice from the treated samples in comparison with the check sample (Sample 10, Table 2) at the same stage of maturation constitute further evidence of abnormal maturation induced by the spray material.

Acidity. For the reason given above, only Wealthy juice was available for the determination of acidity. The titratable acid percentages from the treated Wealthy fruits were consistently lower than those of check fruits at the same stage of maturation.

Dry matter. Table 1 shows that in Transparent and Lodi there was no important difference between treated and check fruits in the percentages of dry matter. The higher dry-matter content of the check sample of Giant Transparent in comparison with the treated sample is presumably related to the higher content of sugars and starch and the firmer texture of the check fruits.

The lower dry-matter content in the treated Red Duchess apples, in spite of their higher sugar content, is further evidence of the abnormal metabolism induced by 2,4,5-TP. Absence of starch and abnormal softening indicate that the higher sugar content was due to the hydrolysis of starch and some of the cell-wall carbohydrates, or that normal deposition and storage of these materials were prevented. An accelerated respiration rate may have also contributed to the lower dry-matter content.

In Wealthy the trend of dry-matter percentage was definitely lower in the treated fruits, except for Sample 5, which had a more nearly normal maturation than the other treated samples. This was further evidence of abnormal carbohydrate metabolism.

Sugars. The data in Table 1 on the Transparent-type varieties show that the differences in sugar percentages between treated and check samples at the same stage of maturation were probably not significant. However, the absence of starch and the softer texture in the treated fruits show that abnormalities in the carbohydrate metabolism and the cell-wall structure resulted from the use of 2,4,5-TP.

The higher percentages of sucrose and total sugars in the treated Red Duchess sample than in the mature sample (even though the quality of the treated Red Duchess was much lower and the color was that of immature fruits) emphasize the abnormal carbohydrate metabolism induced by 2,4,5-TP. The absence of starch and the mealy texture provided additional evidence of this abnormality.

The sugar data on the Wealthy check samples (Table 2) show the expected changes in sugar percentages during maturation. It is noteworthy that the treated fruits had a consistently lower sucrose content than check fruits at the same stage of maturation, M3.5. In general this difference also occurred in total sugar content, except for the treated fruits in Sample 5 which, as mentioned earlier, had a more nearly normal type of maturation than the treated fruits in the other samples. The absence of starch and the softer texture in the treated fruits, coupled with generally lower sugar content, again showed an abnormal carbohydrate metabolism during maturation from the use of 2,4,5-TP.

At this point it should be explained why Sample 1 in Table 2 was both treated and picked earlier than the other samples. This sample, growing on a single Wealthy tree, was sprayed on July 9 — the same day the Transparent-type fruits were sprayed — in order to empty the spray tank and to satisfy a curiosity concerning how apples so far from normal maturity (in this case 8 weeks) would respond to an application of 2,4,5-TP. The apples making up the sample were picked on August 7 because they were softer than normal, even though their background and flesh colors were characteristic of immature fruits. Their flavor was flat and somewhat characteristic of Wealthy fruits in a state of senescence. A cooking test showed that an acceptable sauce could be made from these apples, but that the sauce was far from *satisfactory.*

When the sample was taken, there was wide variability in the stage of development of the fruits on this tree. Approximately half of them were similar to the sample. About 25 percent were at a stage very much like that of the check fruits at this time, showing little or no red color and a moderate yellow-green background. These immature fruits

occurred frequently on spurs adjacent to those with the most red color. The remaining apples were at all stages of development between the reddest and the greenest. Nearly all the fruits on this tree eventually became similar to the fruits of Sample 1. The lower content of sucrose, total sugars, dry matter, and soluble solids in the Sample 1 fruits in comparison with those of the check fruits of Sample 9, which were at the same stage of maturation, shows the undesirable effects from 2,4,5-TP when applied very early to Wealthy.

Sample 2, chosen as a check to compare with Sample 1, was made up of fruits with the most red color on nearby check trees. The comparison of these samples shows that the effects from the 2,4,5-TP were earlier development of red color, earlier softening, lower acid content, lower dry-matter percentage, and absence of starch, all of which add up to abnormal maturation.

Effects in 1952

On July 10, 1952, the same lot of Color-Set that was used in these 1951 investigations was applied to Transparent trees at concentrations of 5, 10, and 20 p.p.m. (parts per million), and the fruit harvested on July 23. Though detailed records could not be obtained, all three concentrations were obviously effective in reducing drop. The estimated drop percentages, based on the number of bushels of dropped and picked fruit at harvest, were: check — 20 percent; treated fruits — 5 p.p.m., 10 percent; 10 p.p.m., 6 percent; 20 p.p.m., 6 percent. The fruits that had received the concentration of 5 p.p.m. separated from the spurs much more readily than the fruits that had received the higher concentrations, even though only a small percentage of them were mature.

These concentrations produced comparatively little cracking in the fruits, and none of the severe type of cracking so prevalent in 1951. However, at all three concentrations, by the time the apples reached a stage of maturation suitable for commercial picking, the fruits were softer than the check fruits at the same stage of maturation. Softening was particularly noticeable on fruits that developed the darker-than-normal background color.

On July 10, the same lot of Color-Set was also applied to Duchess trees (Red Duchess were not available at this time) in concentrations of 5, 10, and 20 p.p.m., and the fruits harvested on August 5. A heavy windstorm on the night of August 4 blew several bushels of apples from these treated trees, and although a detailed record was not obtained, the drop from the check trees was obviously much greater

than from any of the treated trees, even though the general degree of maturation of the check fruits was somewhat less than that of the fruits on the sprayed trees. Cracking was of minor importance and, when it did occur, was of the same general type found in 1951 in Red Duchess.

All three concentrations stimulated the development of red color on Duchess, but the effect was confined largely to the fruits hanging on the outside of the trees, even though the spray had thoroughly penetrated all parts of the trees. The development of red color was directly related to the firmness of the fruit: the greater the amount of red color, the softer was the fruit. Those fruits that on the basis of background and flesh colors could be considered at a stage of maturation suitable for commercial picking were too soft for any but specialized handling, and their quality was definitely inferior to that of the check fruits at the same degree of maturation.

Most of the inside fruits on the treated Duchess trees failed to show an inducement of red color, and seemed unaffected in any way by 2,4,5-TP. In 1951 with Red Duchess this situation was not so evident, but was quite common with Wealthy receiving the concentration of 10 p.p.m.

DISCUSSION

These results show that 2,4,5-TP had some profound effects upon the metabolism of the fruits of the varieties discussed, and that these effects can be considered collectively as abnormal maturation — an outstanding feature of which was decreased quality.

Manifestations of abnormal maturation in the treated fruits were:

1. The occurrence of light to severe cracking in the Transparent-type fruits at all degrees of maturation, with minor cracks in Red Duchess and Wealthy, but none in check fruits.

2. The rapid development of a soft, mealy texture in Transparent-type and Red Duchess fruits while on the basis of color and flavor they were still immature. This texture development was equivalent to the fruits' passing from the hard, crisp, juicy texture at the time 2,4,5-TP was applied, to a texture typical of senescent fruits of these varieties when the samples were collected two weeks later. Wealthy fruits developed a similar texture while still immature, though at a slower rate and to a lesser degree. On the basis of firmness alone, they passed from an immature stage to post-maturity in one week, but on the basis of color and flavor they were still immature.

3. The deficiency of juiciness, which in the Transparent-type and Red Duchess fruits was so severe that, unlike the check fruits, no juice could be extracted from them. Treated Wealthy fruits were less juicy than check fruits at the same degree of maturation.

4. The lower flavor of all varieties than that of the check fruits at the same degree of maturation, an effect much less marked in Wealthy than in the other varieties. The flavor deficiency was due primarily to the lack of development of normal aroma. Differences in sugar and acid content were not great enough to affect taste significantly, but the deficiency in aroma decreased quality seriously.

5. The background color that, as the fruits became almost mature, turned duller and darker than that of the check fruits. On the red varieties, the overlying red color, rather than being the bright red characteristic of the check fruits, was dull and senescent-looking.

6. The occurrence of an unbalanced carbohydrate metabolism as shown by absence of starch and abnormal softening.

These effects can hardly be attributed to tree location. Transparent trees growing in three different locations and soil types in the University orchards were given the same spray treatments as those used for the samples. The fruits on all of them made the same type of response in regard to color, cracking, maturation, texture, and flavor as those already described. Similar results on Transparent were reported by Illinois fruit growers from different parts of the state.

Also, at the same time, some Duchess trees more than a half-mile away responded in the same fashion as the Red Duchess to 2,4,5-TP. This was to be expected since Duchess and Red Duchess are, except for color, genetically similar. Illinois growers reported the same effect on Duchess, as well as losses from extreme softening on Wealthy.

Neither can abnormal maturation be attributed to seasonal differences. As already described, the Transparent and Duchess fruits gave the same type of response in 1952 as in 1951, except that in 1952 no serious cracking occurred in Transparent. This lack of cracking may have been due to the abnormally dry weather during the 1952 maturation period. The 1951 season, from the standpoint of temperature, rainfall, and humidity, was normal.

Other Investigations With 2,4,5-TP

The results of other investigations, though otherwise interpreted, have indicated that some varieties of apples maturate abnormally when treated with 2,4,5-TP. Only Lott,[17] it appears, has considered the re-

sults indicative of abnormal maturation. The decreased firmness of fruits treated with 2,4,5-TP has usually been interpreted as evidence of an increased rate of maturation, and no attention apparently has been given to the effects of 2,4,5-TP on quality.

The results from the use of 2,4,5-TP on Jonathan and Golden Delicious in 1950 led the senior author to issue a warning[17] that this material may cause unusual softening and other manifestations of abnormal maturation. He pointed out that, at different degrees of maturation, the treated fruits of both varieties were softer in texture and lower in the content of sugars, acid, and dry matter than check fruits.

Thompson[25] reported that 2,4,5-TP, applied at a concentration of 20 p.p.m., markedly softened Williams, a summer-maturing variety. Eighteen days after the material was applied, a large percentage of the fruit was unmarketable. Apparently, Thompson used softness as the criterion of maturation, since he did not mention background color, flesh color, or flavor.

In a later publication,[26] Thompson stated that 2,4,5-TP, applied at concentrations of 20 p.p.m. on three consecutive dates with intervals of five and six days, had no effect on the firmness of Williams compared with NAA at 10 p.p.m. as the check. The only method he mentioned for determining the degree of maturation was the "maturity of the apples as measured by a Magness and Taylor pressure tester." Time of picking was apparently based on the rate of red color development in the apples. Duchess fruits sprayed with 2,4,5-TP two to four weeks before normal harvest at a concentration of 20 p.p.m., became too soft to handle when as little as 30 percent of the apple surface was covered with red color — a clear indication of abnormal maturation. Here again the background color, flesh color, and flavor were not mentioned.

Smock *et al.*[23] reported that 2,4,5-TP, applied at a concentration of 5 p.p.m. to Williams Early Red 10 days before harvest, resulted in significantly softer fruit at harvest, and that a concentration of 20 p.p.m. increased softening markedly. The measure of the degree of maturation was not stated, but it seems to have been a combination of background color and degree of softness. Their data on background color indicate that all samples were immature at harvest. The softer texture and the greater amount of red color in the treated fruits would then add up to abnormal maturation. Flesh color and flavor were not mentioned.

In another experiment, they sprayed single limbs of three Duchess trees with 2,4,5-TP at a concentration of 10 p.p.m. Fruits were

harvested 13 days later, and a second picking (from one tree only) was made 22 days after the application. They stated that "firmness data on the two picking dates indicated that the 2,4,5-TP treatment had advanced maturity on the tree about 5 days over the control." No criterion of maturity other than firmness was mentioned; firmness alone was apparently considered sufficient.

More specificity in published reports regarding the degree of maturation of the samples and the means by which the degree of maturation was determined or estimated would lead to more nearly accurate evaluation of results. As has been emphasized in this bulletin, decreased firmness alone cannot correctly be considered as evidence of maturity or post-maturity in apples. Decreased firmness is only one of the maturation changes in apples, and unless accompanied by the normal changes in background color, flesh color, and flavor which are characteristic of maturation, decreased firmness should be considered as evidence of abnormal maturation.

EVALUATION OF RESULTS

As is well known, the addition of any practice in the production of fruit is desirable only when its advantages definitely outweigh its disadvantages; and because any additional orchard practice increases the cost of production, the results must more than defray the cost of the practice if it is to be widely accepted. In evaluating 2,4,5-TP from this viewpoint, the purpose for which it was introduced is considered first and its economic effects later.

2,4,5-TP was developed for use as a spray to inhibit apple drop. As has been pointed out, 2,4,5-TP was very effective in reducing drop in the varieties discussed in this bulletin; therefore 2,4,5-TP as a drop-inhibitor offers a very definite advantage. However, Transparent-type, Red Duchess, and Duchess apples are usually harvested in Illinois without the necessity for drop-inhibiting sprays. When fruit growers have felt that such a spray was needed on these varieties, they have controlled drop very satisfactorily with applications of NAA. Sprays of NAA have been generally satisfactory for Wealthy trees since they inhibited drop without adversely affecting quality. Consequently, in Illinois at least, a new drop-inhibiting material was not needed for these varieties.

It is generally assumed that early maturity of apples leads to a higher market price and consequently to greater net returns per pro-

duction unit. In considering the question of earlier maturity from the use of 2,4,5-TP, the data which have been presented show clearly that Wealthy was the only variety in which the maturation of the treated fruits even approached normal, and that 2,4,5-TP had a distinct softening effect on the fruit of all the varieties used, an effect that became significant while the fruits were still definitely immature.

Another disadvantage equally as great as the softening effect was the definite reduction in flavor of all varieties from the use of 2,4,5-TP. This flavor deficiency is very important because consumers prefer fruits of high quality or, at least, the maximum quality attainable by the variety. Flavor deficiency is especially important in Transparent-type, Red Duchess, and Duchess fruits because even under the best production conditions their genetic make-up prevents them from attaining high quality.

It is quite obvious then that the use of 2,4,5-TP to hasten the maturity of these varieties is undesirable because of the abnormally soft texture and poor flavor that result.

As to the beneficial effect of 2,4,5-TP on fruit color, which is implied in some of the trade names under which it is sold — Color-Set, Stikcol, and others — the darker yellow skin color induced by 2,4,5-TP on Transparent-type fruits did not occur in a large enough percentage of fruits to be of much significance; and in every apple examined in which that color did occur the fruit was cracked or quite soft, or both.

In Red Duchess the earlier development and the greater amount of red color on treated fruits would have been advantageous had the accompanying texture not been much softer than normal and the flesh immature in color and flavor. Some Illinois fruit growers reported the loss of significant quantities of Duchess apples from this softening effect, and it has been shown that Duchess responded in 1951 and 1952 quite similarly to Red Duchess.

In the treated Wealthy fruits, the earlier development and the greater amount of red color were potentially highly desirable, but the softer texture of such fruits, while not nearly so pronounced as in the other varieties, was an accompanying disadvantage. Some Illinois apple growers reported very significant losses of Wealthy fruits because of the abnormal softening that occurred while they waited for them to develop the background and flesh colors that they had learned to associate with normal, mature fruit.

It is well known that consumers prefer apples with the greatest amount and intensity of red color in the red varieties, and the predominance of yellow, rather than green, in yellow varieties. Conse-

quently any practice that enhances these colors without adversely affecting quality is desirable from the standpoint of potential economic returns. But the color responses that these varieties made to 2,4,5-TP cannot be considered an economic advantage because of the undesirable accompanying effects.

It is not assumed that results like those obtained from this investigation can be expected in all seasons. But the fact that such results did occur in 1951 and, with the exception of severe cracking, occurred again in 1952 shows that such results are potential in any season. Consequently 2,4,5-TP cannot be recommended for the Transparent-type varieties, Red Duchess, or Duchess. It can be recommended for Wealthy, but only with the reservations that the fruits be carefully watched to prevent them from becoming too soft before harvest, that picking be done rapidly, and that the apples be handled carefully to avoid bruising. 2,4,5-TP should not be used on Wealthy trees or orchards whose past history shows a tendency to produce cracked fruits.

SUMMARY AND CONCLUSIONS

Sprays of the 2,4,5 trichlorophenoxypropionic acid formulation known as Color-Set 1004 were applied on July 9, 1951, to 15-year-old trees of the Transparent, Giant Transparent, Lodi, and Red Duchess apple varieties at a concentration of 20 p.p.m. Four lots of Wealthy trees, also 15 years old, were sprayed with 2,4,5-TP, one lot being given a concentration of 10 p.p.m. on July 30, another lot 10 p.p.m. on July 30 and August 10, a third lot 20 p.p.m. on July 30, and a fourth lot 20 p.p.m. on July 30 and August 10.

Samples of treated and check fruits were collected from the Transparent-type varieties and from Red Duchess on July 24, and a sample of mature Red Duchess on August 7.

Samples of treated and check fruits were collected from Wealthy on August 27. Samples of check fruits were again collected on September 6 and at maturity on September 18.

The percentage of dropped fruits was much less from the treated trees of each variety than from the check trees.

2,4,5-TP induced abnormal maturation in all of the varieties as shown by: (1) severe fruit cracking and soft texture in the Transparent-type varieties while skin and flesh colors were still characteristic of quite immature fruits; (2) very soft texture in Red Duchess while background and flesh colors were still characteristic of quite immature fruits; (3) development in Wealthy fruits of texture soft enough to

require picking, even though background and flesh colors had not progressed to those typical of mature fruits; (4) marked reduction in juiciness in the Transparent-type and Red Duchess varieties with a less marked but important reduction in Wealthy; (5) abnormal carbohydrate metabolism in all varieties as shown by the absence of starch and the mealiness of treated fruits; and (6) lower fruit quality as shown by the lack of development of normal apple and varietal flavor.

2,4,5-TP caused Red Duchess and Wealthy apples to develop red color earlier and in a greater amount than check fruits. In both of these varieties, the red color was somewhat duller than that of the check fruits at the same degree of maturation. The advantage of greater color development in these varieties was more than offset by the abnormal softness that developed by the time the difference in red color became evident. It is concluded that the most effective way to obtain the red color desired is to use such production practices as pruning, thinning, and proper fertilization that promote its development, and not to depend on "growth-affecting" sprays.

2,4,5-TP is not recommended as a drop-inhibiting spray on Transparent, Giant Transparent, Lodi, Red Duchess, Duchess, and similar varieties maturing before September 1 in Illinois. Its use on Wealthy should be accompanied by careful observation to prevent the fruits from becoming too soft before harvest and by rapid and careful picking and handling to avoid further softening and consequent bruising. It should not be used in Wealthy orchards whose past history shows a tendency to produce cracked fruits. In general, NAA should be used instead of 2,4,5-TP on Wealthy for drop inhibition.

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Two other Illinois Agricultural Experiment Station Bulletins report investigations similar to the one reported here. These publications are:

Effect of Preharvest Sprays of 2,4,5-Trichlorophenoxypropionic Acid Upon the Maturation of Jonathan, Starking, and Golden Delicious Apples. Bulletin 589. By Richard V. Lott and Robert R. Rice. 30p. 1955.

Effect of Preharvest Sprays of 2,4,5-Trichlorophenoxypropionic Acid Upon the Ripening of Jonathan, Starking, and Golden Delicious Apples. Bulletin 590. By Richard V. Lott and Robert R. Rice. 31p. 1955.

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