THE EFFECT OF GROWTH REGULATORS ON BLOSSOM THINNING WITH SPECIAL REFERENCE TO APPLES AND PEACHES

By

CLARENCE ANTON LANGER

A THESIS

Submitted to the School of Graduate Studies of Michigan
State College of Agriculture and Applied Science
in partial fulfillment of the requirements
for the degree of

DOCTOR OF PHILOSOPHY

Department of Horticulture

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ABSTRACT

Fruit-thinning by hand has been practiced in the commercial orchards for many years. Recently fruit thinning with growth regulators has shown promise with apples and peaches. The experimental work with growth regulators presented in this study was begun in 1946 to determine the usefulness of these materials to orchardists and to determine the underlying principles involved.

Naphthaleneacetic acid was tested at concentrations of 5 to 100 ppm, maleic hydrazide was tested at concentrations of 50 to 500 ppm, and sodium thiozole and "clark" were each tested at concentrations of 20 to 100 ppm on apples and peaches at full bloom and at calyx time.

Growth regulators were tested by spraying several complete trees at different concentrations; also, by spraying several limbs of the same tree each with a different concentration and also spraying individually marked spurs with several concentrations. Some trees were sprayed with naphthaleneacetic acid at 20 ppm and 100 ppm and random samples of spurs were removed and analyzed for reducing sugars, non reducing sugars, starch and nitrogen content compared to control spurs.

Naphthaleneacetic acid has been shown to be effective as a blossom-thinning spray for apples in Michigan. Such factors as climate, variety, soil, nutrition, physiology, spray concentration, and time of application influenced the degree of thinning.

A direct relationship was found between spur size and the degree of thinning, large spurs (4 mm. in diameter) thinning with greater difficulty than smaller spurs (2-3 mm. in diameter).

Although there were visible responses of the apple to applications of NAA as indicated by leaf curvatures, defloration, and persistance of certain floral parts, there was no apparent affect upon chemical composition as measured by content of nitrogen, starch, and sugars. It is concluded that any chemical alterations are minute in quantity, and of the nature of growth regulators, enzymes, or vitamins; which are not determined by gross chemical analysis.

Other regulating sprays tested for thinning action on apples were either ineffective, such as maleic hydrazide, sodium thiozole, and "clark", or they caused excessive visual damage to the tree and fruit as did 2,4-dichlorophenoxyacetic acid.

More visual wilting and petiole curvature from spraying at full bloom in comparison to later sprays was noted on Oldenburg variety than on Wealthy variety.

Chas Hamner

Naphthaleneacetic acid sprays were undesirable for thinning peaches, and is considered still in the experimental stage.

Maleic hydrazide was found to thin peaches quite well at 500 ppm during the seasons of 1950 and 1951, although the set of fruit was still too heavy in 1951 after thinning. No visable injury was observed from the use of maleic hydrazide on peaches at concentrations up to and including 500 ppm.

Thinning peaches with maleic hydrazide appears promising, but must be considered still in the experimental stage.

Chas Hammer

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INTRODUCTION

Fruit-thinning has been practiced in one form or another ever since fruit has been grown. Heavy crops necessitate hand thinning, a slow and expensive operation even when labor is plentiful.

Within the past decade chemical sprays have been discovered that will reduce fruit set by destroying some of the flowers, thus permitting a smaller, more evenly spaced crop to develop. Recently, plant-growth regulators in low concentrations have proved effective in blossom-thinning of apples and pears. The experimental work with growth regulators reported in this thesis was begun in 1946 to determine the usefulness of these materials to orchardists and to determine the underlying principles involved.

REVIEW OF LITERATURE

Early History of Hormone Development

The father of plant hormones, Darwin (7), showed as early as 1850 that some influence moves from the upper to the lower part of the coleoptile of grass seedlings when they are exposed to illumination from one side.

Fitting (8, 9) was one of the very first to determine the nature of growth regulators. He used orchid pollen and found it caused swelling of the ovary when the pollen was brought in contact with the stigma. Fitting discontinued his work in the early 1900's. If he had continued his work, the development of growth regulators might have been much more rapid. However, there were reasons for discontinuance of the work. Necessary techniques had not yet been developed, and the isolation of the active growth-regulating substance could not supersede necessary physiological procedures.

In 1919 Paal (28) showed that the active substance was produced in the tip and moved downward in the stem. Went (39) collected the active substance from tips removed from the coleoptile and placed on gelatin blocks. Then by placing the blocks on the side of a coleoptile, from which the tip had been removed, the gelatin block containing growth substance caused the coleoptile to bend, proving that the auxin had moved out of the coleoptile tips into the gelatin blocks. Improvements in methods of testing for auxin-like substances were continually being developed. The use of the Avena test speeded up the procedure for growth-substance isolation from plants. Indole-acetic acid was isolated from urine extraction by Kögl and Haagen-Smit (19) of Holland. After Kögl's and Haagen-Smit's work, Thimann (37) in the United States isolated indoleacetic acid from Rhizopus suinus.

Following the discovery of indoleacetic acid in urine and fungi, it was thought for some time that auxin was only present in lower forms of plants. This was substantiated by Kögl and Kostermans (20) with yeast, and Thimann (37) with Rhizopus suinus. However, it was later found in wheat (3, 13) and in immature corn (14). It is now known that indoleacetic acid occurs in many different parts of the plant, but mostly at the growing points. It is also found in flowers, buds, pollen, leaves, and even secreted by aphids and perhaps many other insects.

It is interesting to note that according to Larson (21) and Van Overbeek (27) auxin movement in the plant is correlated with temperature. As the temperature increases from 0° C. to 30° C., each 10° C. rise increases the production of indoleacetic acid three times. Auxins are thought to be deactivated by ultraviolet rays, certain enzymes, and various environmental conditions.

Indoleacetic acid stimulates cell division and may be the controlling mechanism in meristematic activity.

Growth Regulators and Fruit Set

Early in the 1900's there were several scientists--namely, Fitting (8, 9), Hartley (15), Winge (40), Yasuda (45) and Massart (23)--who were interested in producing seedless fruits. By using various pollens and extracts of pollen they were able to produce seedless fruits in some species of plants.

The production of parthenocarpic tomato fruits attracted the attention of a large number of workers using several growth regulators. Although Gustafson (12), Wong (44), Schroeder (32), Zimmerman and Hitchcock (48, 49), Luckwill (22), and Hey and Hopf (17) were interested primarily in parthenocarpic tomatoes, they also worked with such other crops as melons, squash, cucumbers, pineapple, apple, and pear. Growth regulators used and the means of application varied a great deal, but the results were quite encouraging from the several materials regardless of the methods used in application. The materials were applied in lanolin paste on the ovaries as a spray, aerosol and dust to the buds and flowers. These methods of application were used in the greenhouse with excellent results. The following materials have shown promise for the production of parthenocarpic fruit: Indoleacetic acid, indolebutyric acid, and beta-naphthoxyacetic acid, alpha-naphtaleneacetic acid, and 2,4-dichlorophenoxyacetic acid (2,4-D). Wittwer (41) in 1949 used a vibrating apparatus plus weekly sprays of a hormone solution containing beta-naphthoxyacetic acid at 4 ppm and para-chlorophenoxyacetic acid at 10 ppm. Wittwer applied his spray to the flower clusters with a hand sprayer. An increase in fruit set resulted both in the spring and fall crop of greenhouse tomatoes.

Inasmuch as regulators were so beneficial for increasing the set of the early blooms of tomatoes in the greenhouse, as well as overcoming the problem of self-sterility in greenhouse tomato production, they were considered by investigators to have possibilities in the field. Paddock (29), working in Texas, found adverse conditions from spraying with growth-regulating sprays on the set of tomatoes in the field. The sprayed plots picked less fruits than the untreated. It was later determined that the night temperature range is too high in Texas and does not favor the use of hormone sprays for fruit set. Zalik, Hobbs, and Leopold (46) found that they could induce parthenocarpic fruit by application of para-chlorophenoxyacetic acid at several locations on the flower; namely, stigma, side of ovary, and the abscission layer of the pedicel. Singletary and Warren (33) found that hormones aided in the set of early tomatoes when night temperatures were low, but as the season progressed and night temperatures increased, no definite value could be attributed to the hormone sprays. Wittwer and Schmidt (42) stated that night temperatures below 59°F. are not conducive to good fruit set of early tomatoes. This low night temperature can be overcome by the use of growth regulators. Wittwer and Schmidt (42), testing fourteen varieties of tomatoes of various ripening dates, showed an increase in all varieties of the early crop over the controls.

Hey and Hopf (17) have been interested in the interreaction of growth-regulating substances as they enter the plant, and the function of these parts. They have been concerned with fruit set and frost damage prevention by combining vitamins and hormones. They have found that plants containing Vitamin K respond to 2,4-D in herbicidal concentrations much more readily than do those not containing Vitamin K. They have concluded that vitamins of different kinds undoubtedly are necessary for the reaction of hormones. If there are sufficient vitamins in the plants, an addition of vitamins will not improve the effect of the hormone spray. This has been determined by the use of Arbormone C which is a material combining Vitamin K with certain hormones. Hey and Hopf (17) have tried other co-reactants such as para-aminobenzoic acid plus aryl thiorea derivatives and nicotinic acid plus halogenated quinoline derivatives. They have hinted that there are probably any number of these co-reactants in the plant kingdom which, if discovered, might lead to the answer to some of the complex physiological problems still not answered in fruit set, abscission of fruits and blossoms, and frost resistance of various plants and their parts.

Use of Growth Regulators in Preventing Abscission of Plant Parts

The original work on fruit abscission of apples by Gardner, Marth, and Batjer (10), of the U. S. Horticulture Station, Beltsville, Maryland, stood for thirteen years without much change. Their work showed that concentrations of 5 and 10 ppm were effective in delaying the abscission of most varieties of apples. Their findings on timing of the spray are still practiced as far as naphthaleneacetic acid (NAA) and its related substances are concerned. Generally, they found the McIntosh variety to be less affected by the spray than the other apple varieties. Most varieties were affected for two or three weeks, but McIntosh very seldom was affected for longer than eight or nine days. The effect of coverage and spray placement found by Gardner in his original work has been substantiated by many workers.

The greatest effect from naphthaleneacetic acid sprays is at the point of application. Accordingly, a thorough wetting of the fruit and the fruit stem is necessary if one is to secure the maximum results from the spray of NAA. It is believed that the effects of the NAA spray are not translocated in the plant, as is 2,4-D. There apparently was little or no effect from NAA abscission-inhibiting sprays on the respiration of the apple trees for the foliage of the sprayed trees was dropped at the same time as the control trees. Burkholder and McCown (4), Batjer (2), Murneek (26), and many others have substantiated the work of Gardner, Marth, and Batjer (10) and added varietal characteristics and worthwhile suggestions as to the possible working mechanism of the growth regulators in preventing of the abscission of the fruits at harvest time. Batjer and Thompson (1), in search for a better material than NAA, have tried 2,4-D, along with other substances, on several varieties of apples, including the Winesap. The effects of 2,4-D on Winesap were outstanding. It increased the effective period much beyond that of NAA, but it did not take effect quite as rapidly as NAA. The effects were so outstanding on the Winesap variety that it was tried on all commercial varieties and at various concentrations, but apparently 2,4-D as an abscission-inhibiting spray is as selective in variety of apples as it is in killing weeds. The only varieties effectively influenced belong to the Winesap group, such as Stayman and Turley.

A new material which was introduced by the Dow Chemical Company (5) in 1950, under strict research conditions--as an abscission-inhibiting apple spray--was released for commercial use during the 1951 harvest season. It appears to be superior to any abscission-delaying spray yet discovered for all the standard commercial varieties of apples. It is marketed under the name of "Color-Set" and chemically is alpha-2,4,5-trichlorophenoxypropionic acid. It apparently is a better inhibitor of the maturation of the abscission layer than NAA. Its value lies in a longer effective period of inhibition of abscission plus the fact that it can be applied before the fruit begins to drop. Whether or not it remains superior to NAA will depend on its effect on storage life of the fruit, residual tree effects such as delayed blossoming or an upset of annual bearing. It is believed that unlike NAA, 2,4-D and "Color-Set" can transmit their effects over much greater distances from point of application. The ability to affect abscission by transmission over considerable distance within the plant tissues is a desirable characteristic for any abscission inhibitor.

Fruit-thinning

Thinning of most varieties of apples and peaches is necessary to obtain increased fruit size, color and quality. Thinning by hand is becoming obsolete because of the tremendous costs involved and the scarcity of skilled labor to cope with the task. Hand thinning is undoubtedly one of the most expensive operations of fruit production in the West and would be in the Central West and East if proper thinning of fruit was practiced as it is in the West. Hand thinning is not usually early enough to prevent alternate bearing, especially with varieties having strong biennial bearing characteristics, as Wealthy, Golden Delicious, Grimes Golden, Duchess, and Yellow Transparent. The size of fruits is correlated with the earliness and thoroughness of the fruit-thinning procedure.

According to Tukey and Einset (38), thinning of peaches resulted in an increase in size of fruit regardless of the time of thinning. The greatest benefit, however, was secured from hand thinning of blossoms or hand thinning of fruit during Stage I of peach development. In fact, this is the first record of blossom-thinning of peaches. Over the three-year peiod that this thinning was carried on, the trees thinned early responded with stronger growth and better annual bearing. Many other early investigations on thinning of both apples and peaches showed similar results.

The discovery that the growth regulator, NAA, was effective in the thinning of apples shifted attention immediately in the direction of thinning sprays. Murneek (24) has set forth the advantages of spray thinning over hand or pole thinning by saying: (1) "It is fast." In other words, thinning can be accomplished per tree as fast as a thorough scab spray could be applied to the same tree. (2) "It is less expensive." To hand thin a 20-bushel tree with labor available today would cost several dollars at the best and then the tree would not likely be thinned enough. On the other hand, spray thinning of the same tree would cost about 30 cents. (3) "Permits trees to carry a heavier load of good fruit." This aspect is easily conceivable in that the excess load of fruit is removed before it takes from the tree its supply of available nutrients. It has been found in the western states, as well as in the Midwest, that apples thinned at calyxtime can carry and mature from 10 to 25 per cent more apples than can hand-thinned trees in June. (4) "It preserves the tree's growth." By removal of the fruits at calyxtime, the strength and food that would normally be consumed by the excess fruits can be used in the development of strong terminal and spur growth. (5) "It will help to break alternate bearing." Through research and careful observation on this phase of apple tree behavior, it has been noted that removal of fruits early after they have been set tends to bring about more consistent annual bearing.

Schneider and Enzie (30, 31) showed in chemical thinning that concentrations between 100 and 300 ppm applied during the full bloom period practically destroyed all fruit set on Delicious and Gano apple trees. There was visual evidence of leaf- and petiole-curling for several weeks after the spray application. The blossoming the following spring was apparently about the same on the control as on the sprayed trees.

Greene (11), using NAA dissolved in a 0.1 per cent polyvinyl alcohol-water solution, sprayed the Starking variety of apple at concentrations of 10 to 100 ppm during the bloom period. The apples were thinned at all concentrations, with the greatest thinning being at the higher concentrations. He also used indolebutyric acid dissolved in the same alcohol-water solvent at concentrations varying from 10 to 50 ppm on the same variety of apple with no significant results.

Davidson, Hammer, Reimer, and Dutton (6), in their earliest work in apple-thinning, incorporated NAA at 10 ppm, along with the regular insecticide and fungicide sprays on several varieties of apples in 1945. Similar plots of the same varieties of apples were only given their regular spray treatment which did not include NAA. No methods were established for obtaining records on thinning rates, as the plot was not for that purpose. However, as harvest time grew nearer, it was quite evident that there were less fruits per tree on those receiving the NAA along with the regulator spray treatment over those not receiving NAA. Tree counts were made at harvest, and there were significantly less fruits on the trees receiving NAA spray.

Since this early work, Davidson <u>et</u> <u>al</u>. (6) have worked with this apple-thinning growth regulator each year. A good deal of emphasis was placed on the sodium salt of NAA for thinning during 1942-4. Favorable results in thinning were obtained on the standard Michigan varieties at concentrations varying for the most part from 10 to 20 ppm. Sprays were applied separately and in conjunction with insecticides and fungicides with good results in all cases. Sprays were applied in full bloom, when 75 per cent of petals were off, and two weeks after all petals were off, with satisfactory thinning. It was found that a corresponding higher concentration was necessary to give the same degree of thinning as the stage of blossom period progressed. No thinning occurred when spraying was done at four weeks after calyxtime with concentrations mentioned above. Varieties did not all respond the same in these trials, and the same variety did not always respond the same each year, especially when it was in a different environment. Varieties vary in their reaction to the NAA sprays as regards wilting, petiole curvature, and curling of leaves. The time of the spray application seems to be a factor governing this affect on the foliage.

Timing of Thinning Sprays

The investigations that have been carried out in the past several years on the thinning of apples have been for the most part carried out when petals were 75 per cent off, or very near to this stage of fruit development. Some investigators have found that apples will thin satisfactorily later than this. A few of these workers are Hoffman, Southwick, and Edgerton (18), Southwick and Weeks (36), and Davidson _et_ _al_. (6).

According to the findings of Batjer (2), the earlier one can safely thin the fruit, the larger and better quality one can expect at harvest. He also feels that early thinning will more successfully create a favorable condition for a more desirable annual bearing habit. Batjer (2) considers that it is risky to thin in blossom, or even after 75 per cent of petals have fallen. He feels frost may create a problem in many of the apple-producing sections of the United States. As long as NAA will thin apples as late as two weeks after calyxtime, this is the better commercial practice to follow. It is pointed out that in 1949 many apple areas were frosted quite severely when most of the petals were off; but some of the frosted areas, especially in Michigan, needed thinning. Some were thinned successfully at two weeks after the calyxtime with NAA spray. This later time of spraying (2) is an aid in preventing wilting and curling of the leaves, which is quite prevalent when some varieties are sprayed in full bloom. Batjer believes that the cause for less distortion of the foliage is that the spur leaves are older and probably coated with cuticle so the entrance of NAA is not accomplished as easily. He has also observed that weather conditions and varietal difference are factors which influenced this leaf-dwarfing, curling, and wilting. Cool, damp, and cloudy weather during blossom period was more likely to bring about more severe dwarfing, curling, and wilting of the foliage than when the weather had been bright and warm. An explanation of this was that the unfavorable weather delayed leaf maturity. The varieties that have appeared most susceptible to the dwarfing of foliage are Duchess, Yellow Transparent, Early McIntosh, Delicious, and Winesap. The more tolerant varieties to leaf-dwarfing and wilting are Wealthy, Jonathan, Grimes, Baldwin, and Golden Delicious.

It has been observed that the abscission of apples will take place more easily before June drop than after. There is not too much information available on the effect of materials on apple abscission after June drop, but what there is provides information that it would be uneconomical and perhaps injurious to the trees and fruit to thin apples with NAA after the June drop, as it would be necessary to go into quite high concentrations in order to be effective.

Batjer (2) continues with his observations, and states that still there is no one who has been able to prove how NAA reduces the set of fruit. There has been work done to indicate that tree vigor plays a part. Southwick and Weeks (36) observed that the smaller, weaker wood in the interior of a thick tree thinned more readily than the rest of the tree. They also showed dormant Wealthy buds, 4.7 mm and smaller, thinned more easily than buds 4.8 mm and larger.

Heincke (16), working just with apple wood of several varieties of apples and of various degrees of vigor, concluded that a certain degree of vigor was necessary for the storage of sufficient nutrients to bring about a good set of fruit.

Smock and Gross (34), in their investigations of abscission-inhibiting sprays of NAA, found an increase in respiration for several days after spraying. If this increased respiration should occur when applying NAA as a thinning spray, it may partly aid in the answer to how it thins. For instance, if respiration was increased then the food normally used by the young apple would be depleted and the apples on the weaker spurs would be removed first. Regardless of the cause, it appears that the less desirable fruits are removed first by the NAA thinning sprays.

Concentration of Naphthaleneacetic Acid for Thinning

Batjer (2) feels that for the most part, 5 to 20 ppm of NAA is the concentration that will meet most conditions of apple-thinning year after year, for most commercial varieties. He is quick to point out that the concentration will depend on variety, stage of blossom, or fruit development, and of course, on the many environmental factors. The degree of thinning is undoubtedly affected by concentration, ability of the variety to absorb NAA, and the susceptibility of the fruit or blossom to abscission.

Environmental Factors Affecting Thinning

Batjer (2) sums up these factors as follows:

1. In the case of adverse climatic conditions which are conducive to poor fruit set generally, but in a well managed orchard, there may be a good set, but the apples will only contain two or three seeds. It has been determined that under conditions of low seed count per apple, the NAA sprays will more easily thin than when the seed count is high, and preceeded by good cross-pollination weather.

2. It has also been observed, under uniform conditions of pollination and seed fertilization, orchards on well-drained sites are much more difficult to thin than those on wet, cold, poorly drained locations. Quite often in commercial plantings the apples are overthinned by as little as 10 ppm of NAA on the poorly drained site.

3. The factor of food reserves and its correlation with the degree of thinning with NAA has been pointed out by various workers. It has been observed that trees lacking in nitrogen seldom need to be thinned. If trees are deficient in nitrogen to the point where growth is not as vigorous as it should be, they are very likely to be overthinned by NAA treatment. It is wise to consider all factors that might reduce the leaf area of a tree during the previous growing season, as it very likely could be a factor in the ease of thinning the following season.

4. It is continually questionable whether thinning sprays should be used in combination with the regular fungicide and insecticide sprays around calyxtime, or other cover sprays. It is thought better to apply the thinning spray separately, in that the regular spray compounds are likely to contain wetting agents and cause excessive runoff, or may react with the NAA

compound and cause it to be less effective, or affect its make-up in such a way as to cut down the absorption by the tree and its parts. In other words, other limiting factors are added when the thinning spray is mixed with a regular fungicidal and insecticidal spray.

Growth-Regulator Thinning Sprays for Peaches

The literature on the thinning of peaches with growth regulators is limited. The investigations carried out on the thinning of peaches with NAA during the bloom period have yielded no positive results. Southwick, Edgerton, and Hoffman (35), using NAA on Valiant and Elberta peaches, found negative thinning effect at full bloom, calyxtime, or a week after petals were off. Murneek and Hibbard (25), using only the Elberta variety, obtained the same results. In 1950 Murneek found that peaches sprayed approximately thirty days after full bloom were thinned at June drop. He obtained fair thinning results with 15 ppm NAA on Golden Jubilee, 20 ppm on Raritan Rose, and 30 ppm on Halehaven. It apparently was not consistent, as no further work has been published on peach-thinning with NAA which improves or substantiates this work.

It is certainly plausible to expect that the results may vary from year to year for a given variety because of the complex environmental conditions above and below the ground.

No investigational work on peach-thinning with maleic hydrazide has appeared in the literature to the best of the writer's knowledge. However, according to Wittwer and Sharma (43), the sprouting of onions was inhibited by foliage sprays of maleic hydrazide. It is generally considered a growth regulator of the inhibiting type.

MATERIALS AND METHODS

Description of Orchards, Soil, Tree Vigor, and Pollination

The fourteen orchards concerned in this thesis will be described in numerical order so as to furnish an accessible means of reference for the investigation.

Orchard I is located on the Horticulture Farm, Michigan State College, East Lansing, Michigan. The orchard has been growing under sod culture method since 1937, when it was seeded to Kentucy bluegrass. This soil is a heavy Hillsdale loam, which is an ideal fruit soil. Hillsdale soil is mainly characterized by the reddish brown clay layer about 3 1/2 to 4 feet below the surface. This layer may vary from 2 inches to several feet in depth. The orchard consists of some fifteen to twenty varieties of apples. The general vigor of the McIntosh trees used in 1949 and Wagener trees used in 1950 was excellent. They were all moderately pruned annually, and exhibited terminal growth of nine to twelve inches on the lower half of the tree, and ten to eighteen inches on the upper half of the tree.

Orchard II is located in the north central portion of the "Old Mission Peninsula," Grand Traverse County. The Old Mission Peninsula extends north (fifteen miles) into Lake Michigan, forming the east and west Grand Traverse bays. Each bay is several miles across. All the soil on this peninsula is a Coloma type of sand. These Wealthy trees are located on top of a flat hill which is higher than any of the surrounding orchards. The orchard has been growing under a system of sod culture since 1944. Each tree has been fertilized each spring with four pounds of ammonium nitrate applied in a ring at the outer periphery of the limbs. The Kentucky bluegrass cover was light. The trees were severely pruned in 1948 and again in 1949. The orchard in which the Wealthy trees were located consisted of four other compatible pollination varieties.

Orchard III includes both apples and peaches. It is located in Newaygo County, five miles west and one mile south of Fremont. This area is not considered one of the best fruit counties, but there are several comparatively small localities which rate among the best orchard sites in Michigan, of which Orchard III is one. This site is one of the two highest elevations in the county. In addition, it has a rolling topography.

The apple orchard was fifteen years old and the peach orchard was ten in 1951. The soil is a very fertile Isabella sandy loam. The apples were managed under a trash cultivation system their first twelve years, and converted to a sod and straw mulch system in 1948. The peaches have been continually under trash cultivation. Complete fertilizers have been used almost exclusively for the life of the orchard. Three hundred pounds of 0-20-20 have been applied in the fall each year since 1948, and in the spring from three to five pounds of ammonium nitrate per tree depending on size and need. The apple orchard cover is dense and consists mostly of bluegrass. The trees are large for their age and have never been pruned heavily. Lateral branches are numerous, and pruning has been the "Thin Wood Method." The single row of Wealthy trees in this orchard is bordered on both sides with compatible pollination varieties. The peaches are annually pruned, and are in a vigorous state of growth. The space between the peach rows is well cultivated until July, when weeds and grass are again allowed to grow.

Orchard IV is located in Oakland County. The county is fast becoming a suburban residential community. It was at one time one of the leading apple-growing counties of the State.

There are some excellent sites in this county. Orchard IV is located on one of these, situated about four miles north and one mile west of Rochester. A rolling topography with a superior elevation gives it good air and soil drainage. The soil is a heavy type of Hillsdale sandy loam, which has been under a sod culture since 1939. The sod is fertilized with four hundred pounds of 4-16-4 per acre every third year, and four to six pounds of ammonium nitrate per tree every year. The 4-16-4 fertilizer is applied broadcast late in the fall for the benefit of the sod cover. The last application was in 1948. The nitrogen is applied in a ring at the periphery of the trees. Pruning in one of the two blocks of Jonathan variety was very heavy. The other block of Jonathan was in need of pruning, being very brushy. These will be referred to as Jonathan (A) and Jonathan (B) of Orchard IV. The Northern Spy trees were pruned very lightly. The pollination conditions were ideal for the Northern Spy apples, with compatible varieties on all four sides. The Jonathan (A), on the other hand, were bordered on one side by a woods, the other side, by Northern Spy trees. One end was bordered by McIntosh, and the other end, by young Northern Spy trees. Jonathan (B) were interplanted with three compatible pollination varieties.

Orchard V is located in Oakland County near the city limits of Birmingham. The orchard soil is a heavy Hillsdale sandy loam. The site is quite rolling, but the elevation is not quite as high as some neighboring sites. However, this site is higher than some of the neighboring sites, which affords good air and soil drainage. This peach orchard is ten years old, and is in an excellent physical condition. The trees are growing vigorously, ten to fifteen inches of terminal growth a year. It has set heavy crops in 1948 through 1951. The trees have been grown under a system of clean cultivation and cover crop the first six years, then switched to a trash cultivation. The fertilizer program of horse manure with plenty of straw was used in the 1951 season. This was applied practically as a two-inch straw mulch over the entire orchard and then chopped up with the disk. Prior to 1951, the program was one of complete fertilizer 10-10-10 applied in the spring and cultivated into the soil. The orchard has been pruned lightly every year, and needs to be headed back quite severely in order to allow for better air circulation during harvest time. Varieties used in this orchard were Redhaven, Halehaven, and Kalhaven during the years 1950 and 1951.

Orchard VI is located in Berrien County, three miles south and two miles east of Benton Harbor. This orchard is situated on a plateau and is generally higher than the neighboring land expanse, which gradually tapers off to the Saint Joseph River Valley, one and one-half miles away. The soil is an average Coloma sand which has been clean cultivated and cover croped with rye for the past 10 years since the trees were planted. Before that, it was part of the home grounds and barnyard. The trees have been fertilized annually with a 10-6-4 fertilizer in the spring. Each tree has received from five to ten pounds of 10-6-4 annually during the years 1949, 1950, and 1951, depending on size and vigor of the tree. The trees have always been pruned on the heavy side since they were five years old. The trees are vigorous and free of any cankers. They are a solid block of Redhaven variety, surrounded by many other varieties, and near the bee yard.

Orchard VII is located in Genesee County, four miles south of Linden. Genesee County can not be considered one of the good peach-growing counties of Michigan, but, on the other hand, there are two locations that have lost but one peach crop by winter freeze or spring frost since 1920. This is one of the two really favorable peach locations of Genesee County. The orchard is situated on a high ridge that is bordered on both sides by broad, deep valleys of several miles in extent. There are numerous inland lakes in the valleys. The soil is a rich Hillsdale sandy loam that has been fertilized and cover cropped for the past eight years since the peach trees have been planted. Complete fertilizer has been used in the form of three hundred pounds of 0-20-20 applied with cover crop in the fall, and two to four pounds of ammonium nitrate per tree each year in the spring. Trees in this orchard are not grown quite as vigorously as in the other peach orchards. Terminal growth of five to eight inches is the goal of this grower. The trees are moderately pruned each year, with most attention being placed on removing those limbs that have been dwarfed by a lateral outgrowing it. This orchard consists of Early Halehaven, Redhaven, and Elberta varieties.

Orchard VIII is located on the Old Mission Peninsula in Grand Traverse County. The general description of this location and soil has been given under Orchard II. This apple site is at the very north end of the peninsula and has been clean cultivated with cover crops from 1939 through 1951. This twelve-year period represents the age of the McIntosh and Jonathan trees. The orchard is interplanted with peaches which are seven years old. The McIntosh variety has been pruned moderately during the years 1949, 1950, and 1951. The Jonathan trees have not been pruned since 1949, except for the removal of broken limbs. The apples have been fertilized with a complete fertilizer (10-10-10) in the spring, since they were five years old. The spring of 1951 they received three pounds of 10-10-10 per tree. Both varieties are bordered on both sides by a compatible and suitable pollinating variety of apple.

Orchard IX is located eight miles east of Lake Michigan on the west side of U. S. Highway 31, halfway between Hart and Shelby. The soil is a light type of Isabella sandy loam. The orchard is on very rolling ground, but is for the most part, a side hill and valley. The orchard has been growing under a sod culture for seven years prior to the year 1946, at which time this investigational work started. The sod cover is sparse, except the area under the trees. All fertilizer treatments were applied broadcast under the spread of the trees. Ammonium sulphate was used in the spring at the rate of two to three pounds per tree. During the two years that records were taken at this orchard, no other form of fertilizer was used. The orchard is a ten-acre block of solid Wealthy apples. Many swarms of bees are employed for pollintion on this farm, but none are placed in this orchard. The general vigor of the trees is slightly below average for Michigan, and about average for Oceana County. The Wealthy trees do not grow very large from Oceana County north, except for an occasional location. Terminal growth will average about six to eight inches on bearing trees. Heavy pruning is needed to stimulate vigorous bearing wood, and it is not uncommon to see the open head or clover-leaf type of pruning in the Wealthy orchards in Oceana County.

Orchard X is located seven miles south of Saint Joseph and six miles east of Lake Michigan. The soil is a Miami clay loam. The orchard site is flat, and the surrounding area is rather level, with an occasional knob or hill. The orchard was maintained, for the ten years prior to this research in 1948, under the sod culture method. The soil is fertile and the trees vigorous and large for twenty-year-old Wealthy trees. The trees were forty feet apart and alternately planted in rows of Jonathan, McIntosh, and Wealthy varieties. The orchard received barnyard manure until it was fifteen years of age, but since 1942, only nitrogen has been applied in the spring. This nitrogen was either in the form of ammonium sulphate or ammonium nitrate. The trees received five pounds of ammonium nitrate the spring this work was done. The sod is a heavy Kentucky bluegrass, and was cut twice during 1948.

Orchard XI is located at the very northern tip of the lower peninsula, eight miles east of Cheboygan, on the banks of the Black River. The soil is a very light sand which can be termed a Coloma type of sandy loam. This orchard soil has been managed under the clean cultivation method until 1945, when it was seeded to Chewings fescue. The grass was spotted and short. The grass cover was fertilized with three hundred pounds of 0-20-20 when it was seeded. The trees were fertilized every year with ammonium sulphate. The spring of 1946, the trees received three pounds of ammonium sulphate per tree. Trees in this section of the state are not large, and are not forced as they are farther south. Trees are moderately pruned, and, as a result, are moderately vigorous. Most good apples are grown on three to five-year-old wood. This orchard is a ten-acre solid block of Wealthy apples, but the block is surrounded by other compatible pollination varieties. Two swarms of bees were used per acre during bloom.

Orchard XII is located in Cass County, six miles northwest of Dowagiac on a three-mile flat plateau above Indian Lake. This soil is a rich Fox loam. The apple trees that were twenty years old in 1946 were in need of cutting back from the sides and top. The trees were planted 36 feet on the square. The McIntosh trees were vigorous, making twelve to eighteen inches of terminal growth during the year 1945. Of course, all of southwestern Michigan was frozen out in 1945. This orchard has excellent cross pollination, with Delicious and Jonathan bordering the four rows of McIntosh. This orchard has been growing under sod cover for twelve years prior to 1945. Complete fertilizer has not been necessary for this orchard, but nitrogen has been applied some years. The year 1946, the McIntosh trees received no fertilizer.

Orchard XIII is located in Oceana County, four miles west of Shelby on a rolling, sandy site about four miles east of Lake Michigan. Soil is a Coloma sandy loam which has been under sod culture since 1937. The cover is mostly quack grass with some Kentucky bluegrass mixed in. The cover was thin and short, and was not clipped in 1947. Trees were moderately vigorous and heavily pruned. Terminal growth of the 1946 season was eight to ten inches, average. These Wealthy trees were not adjacent to any good pollination block, but there was dispersed in the orchard one McIntosh tree for every ten Wealthy trees.

Orchard XIV is located in Jackson County on a gently rolling topography. The elevation of the site is satisfactory, especially concerning air and soil drainage. The soil is a heavy Hillsdale sandy loam which has been under sod culture for nine years prior to 1947. The cover is a mixture of Kentucky bluegrass and quack grass which is very heavy, and was clipped twice in 1947. The orchard has been fertilized in the past with barnyard manure, but during the five years prior to 1947, it received only nitrogen in the spring. The trees received five pounds of ammonium nitrate in the spring of 1947, spread in a ring at the periphery of the tree. The trees are vigorous, showing as much as 24 inches of terminal growth in the tops of the trees. These Yellow Transparent apples were well pollinated by four compatible varieties which were interplanted. Trees were in need of pruning. None had been done for three years.

Environmental Factors

Weather at blossom time. Weather conditions during blossom time in 1946 in Orchard XII were rainy and cool. There were no killing frosts in any of the three orchards, IX, XI, or XII. Orchard XI had plenty of sunshine, but the temperature barely reached 70° F. at noon on two of the eight days of the bloom period. Every night the temperature would fall to 40° F., and on three nights the temperatures were 33° to 34° F. Orchard IX had similar weather to Orchard XI. In 1947, Orchards IX, XIII, and XIV had several days of sunshiny weather during bloom, and temperatures above 70° F. before, during, and after spraying.

During the blossom period in 1948, the weather was cool and damp before spraying, with very few hours of temperatures of 70° F. during the entire ten-day blossom period for Orchard X. Orchard I in 1949 had temperatures above 70° F. for 48 hours prior to spraying in full bloom. Few petals of the center blossom were falling. One night, two days after treatment, temperatures dropped to freezing in low areas of the orchard. The McIntosh on top of the ridge were unharmed. In Orchard II, in 1949, temperatures of 70° F. and above occurred for 72 daylight hours before being treated, when 95 per cent of the petals were off. No lower temperature than 40° F. was recorded during or after blossoming. During 1950 and 1951 seasons, no frost was experienced for any of the orchard locations, and temperatures were 70° to 80° F. for most of the blossom period for both peaches and apples.

Rainfall. The rainfall during the period from 1946 through 1951 over an area from Berrien County east to Detroit and north to Cheboygan, was above normal, with the following exception. In 1946 and 1947, during peach harvest in Berrien County, lack of rain became serious on the light sand just prior to Redhaven peach harvest. This was remedied, however, by several good rains before Halehaven harvest. In other words, moisture has not been a limiting factor during this six-year period.

Mechanical and chemical practices. The spraying practice for the control of insects and diseases in the orchards, and especially the trees which were used for investigational work, was exceptionally good. Scab control was held to less than 10 per cent on apples, and all diseases including brown rot on peaches were held to less than 0.1 per cent. Control of red banded leaf roller, curculio, codling moth, oriental peach moth, peach tree borer, mites, and other minor insects was better than 95 per cent.

Choosing and Marking of Experimental Trees and Limbs

Orchards IX, XI, and XII in 1946; IX, XIII, and XIV in 1947; and X in 1948, were all arranged so that complete trees were sprayed with each concentration of fruit-thinning spray, and similar trees in every way were used for control trees. Several limbs were used to obtain records which will be described further in detail in the following:

Orchards V, VII, and VIII in 1951, and III, IV, V, and VI in 1950 were all similarly arranged, using limbs at various locations on the tree for the several concentrations of one material. Limbs were chosen only after careful consideration of location on the tree; diameter and age of the limb; whether the limb was growing downward, horizontally, or at a vertical angle; and whether each limb selected possessed a similar number of fruit buds. Enough limbs were chosen to correspond to the number of concentrations or combinations that were to be tested. Enough trees were then picked so that each concentration would be located at each of the several positions on the tree as north, south, east, and west. This was necessary to alternate every spray material combination and limb position on the tree at least once (Fig. 3, page 47).

In the case of the apples, the blossom spurs were counted, and in the case of the peaches, the fruit buds were counted. Counting was always started at the terminal end of the branch and proceeded to two-, three-, four-, five-, and six-year-old wood. No older than six-year-old wood has been used in gathering these data. Limbs were marked with colored wax pencils, and a marked, weatherproof tag was fastened at that spot with strong cord.

Choosing, Measuring, and Tagging of Apple Spurs

Orchards I, II, III, and IV, and varieties McIntosh, Wealthy, Wagener, Jonathan, and Northern Spy were used in this phase of fruit-thinning research. On each of three trees of each variety chosen for this work, it was necessary to divide the tree into three segments; one for check, and one each for the two different concentrations tested. The segments were alternated so that the check would be in each of the three divisions. This plan is shown in graphic form on page 45, Figure 1. Twelve fruit spurs of each size, 2 mm., 3 mm., and 4 mm. in diameter, were distributed from the very low limbs to those twenty feet from the ground, for each of the three segments of each tree. Each spur was measured with calipers which were calibrated to 0.1 millimeter. The spurs were measured just below the flower and leaf cluster base. The reason that this particular part of the spur was used rather than the blossom bud was that by measuring buds and last year's spur growth at intervals throughout the spring dormant season, it was found that the bud size was a less reliable index measure of tree vigor. The bud continually differentiates, and is more affected by dehydration and moisture absorption than the spur growth. Late spring measurements are necessary to be certain that buds being measured are fruit buds. The correlation of bud size to tree vigor in late spring is less reliable than it would be in winter dormancy. Measurements were made on last year's fruit spur growth at intervals from December through full bloom, with no change taking place in the diameter of last year's spur growth.

Each spur, when it was measured, was tagged with a small wood tag with fine wire. Tags for each size were of a different color to make it easier to find them later in the season.

Thinning Sprays, Concentrations, and Application

Orchards IX, XI, and XII in 1946; IX, XIII, and XIV in 1947; and Orchard X in 1948 were all treated with napthalene-acetic acid at concentrations of from 5 to 20 ppm. In Orchard X, on the varieties Wealthy and Winesap, 2,4-dichlorophenoxy-acetic acid were sprayed at concentrations of 2.5 to 10 ppm. These plots were all sprayed with power sprayers of the high pressure type. To all varieties in all orchards mentioned above, the number of gallons per tree applied for the blossom-thinning spray is the regular amount applied for scab and insect control at this very same time of apple-blossom development. In Orchard X in 1948, the quantity of spray per tree was doubled, using a concentration of 10 ppm.

In Orchards I, II, III, and IV, naphthaleneacetic acid was used at concentrations of 10 to 40 ppm. This work in 1949 and 1950 required spraying of individual marked spurs. A knapsack sprayer was used with a very fine nozzle. Each tagged spur was thoroughly sprayed. Every spur on each tree of each variety tagged to be sprayed with a certain concentration was sprayed before changing to a new concentration.

In Orchard I in 1950, the Wagener variety used for chemical analysis of the spurs was sprayed with 20 and 100 ppm of naphthaleneacetic acid, using a power sprayer equipped with a 35-gallon-a-minute pump, and spray distributed with a multiple-gun spray mast. These 25-year-old trees received spray from all sides as they were circled with the sprayer continually forcing spray through the tree. Trees were dripping spray from all limbs, leaves, and blossoms.

In 1950 in two orchards, namely III and IV, four apple varieties, Northern Spy, Wealthy, Jonathan, and Wagener, were treated with three hormones, sodium thiozole at 20 and 100 ppm, "clark"[1] at 20 and 100 ppm, and maleic hydrazide at 50 and 500

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[1] A commercial sulfhydryl product obtained from the B. F. Goodrich Chemical Company.

ppm. The same year, in three peach orchards, namely III, V, and VI, Redhaven, Halehaven, and Kalhaven varieties were treated with naphthaleneacetic acid at 20, 60, and 100 ppm; with Clark at 20, 60, and 100 ppm; and with maleic hydrazide at 50, 100, and 500 ppm. In 1951, in two orchards, V and VII, Redhaven and Halehaven varieties were treated with only maleic hydrazide at 100, 200, 300, 400, and 500 ppm. In 1951, in apple Orchard VIII, Jonathan and McIntosh varieties were treated with 5, 15, and 30 ppm of naphthaleneacetic acid, and each naphthaleneacetic acid concentration was also combined with 5, 10, 100, and 1000 ppm of Vitamin K.

All thinning research since and including 1949 was done on a limb basis, as earlier explained. The spraying of these limbs was done by using a knapsack sprayer. The limb was well wetted, and every precaution was taken to prevent drift to other tagged limbs. Each limb on all trees in the orchard that received the same concentration was sprayed from the one mixture.

Spray treatments were applied in full bloom or at calyx-time for the most part. A full bloom spray will be considered in this thesis as the time when the center blossom petals would fall when jarred. The calyx spray will be thought of when 75 per cent or more petals have fallen. There was one series of thinning sprays applied to Redhaven peaches in 1950, Orchard VI, when the fruits were nearing the end of the first phase of fruit development. There were several intermediate spraying positions between full bloom and calyxtime since 1949. However, these are clearly described in other portions of this thesis when and where they appear of importance.

Per Cent Set, Fruits per One Hundred Blossom Spurs or Buds

In all orchards except I, II, III, and IV which dealt with spur size, the tagged limbs were carefully examined, and the apples and peaches that continued to mature after the June drop were recorded. The limbs were all re-examined for fruit counts again when fruit was half grown, and a final count was made just prior to harvest. The total fruits were used in calculating fruits per one hundred blossom spurs. In those apple orchards dealing with spur size, the number of spurs to set fruit were counted and recorded according to size of spur. Number of spurs to set fruit divided by number of spurs measured and sprayed gave the per cent set of each spur size.

Collection and Treatment of Spurs in Preparation for Chemical Analysis

In Orchard I, in 1950, using the apple variety Wagener, random spurs were gathered in one hundred-spur samples. Four samples were taken immediately prior to spraying. Each of four samples was taken by a random picking of spurs from all trees in the experiment. Forty-eight hours after spraying, four samples were taken in the same random manner, but this time from each of the three divisions: check, sprayed 20 ppm, and sprayed 100 ppm. After seven days, the same manner of spur-sampling was carried out. Immediately after gathering the spur samples, they were separated into two parts; the leaves and cluster bases made up one part, and peduncles and flowers or fruits made up the other part. Care was taken to not discard any portion of the 1950 season spur growth. As soon as the samples were divided and weighed, they were frozen at -20° F. They remained in this frozen condition until all samples were taken; then they were dried and each sample weighed, ground, and thoroughly mixed. Ten-gram samples were used for the chemical analysis of the spurs for nitrogen, reducing sugars, nonreducing sugars, and starch.

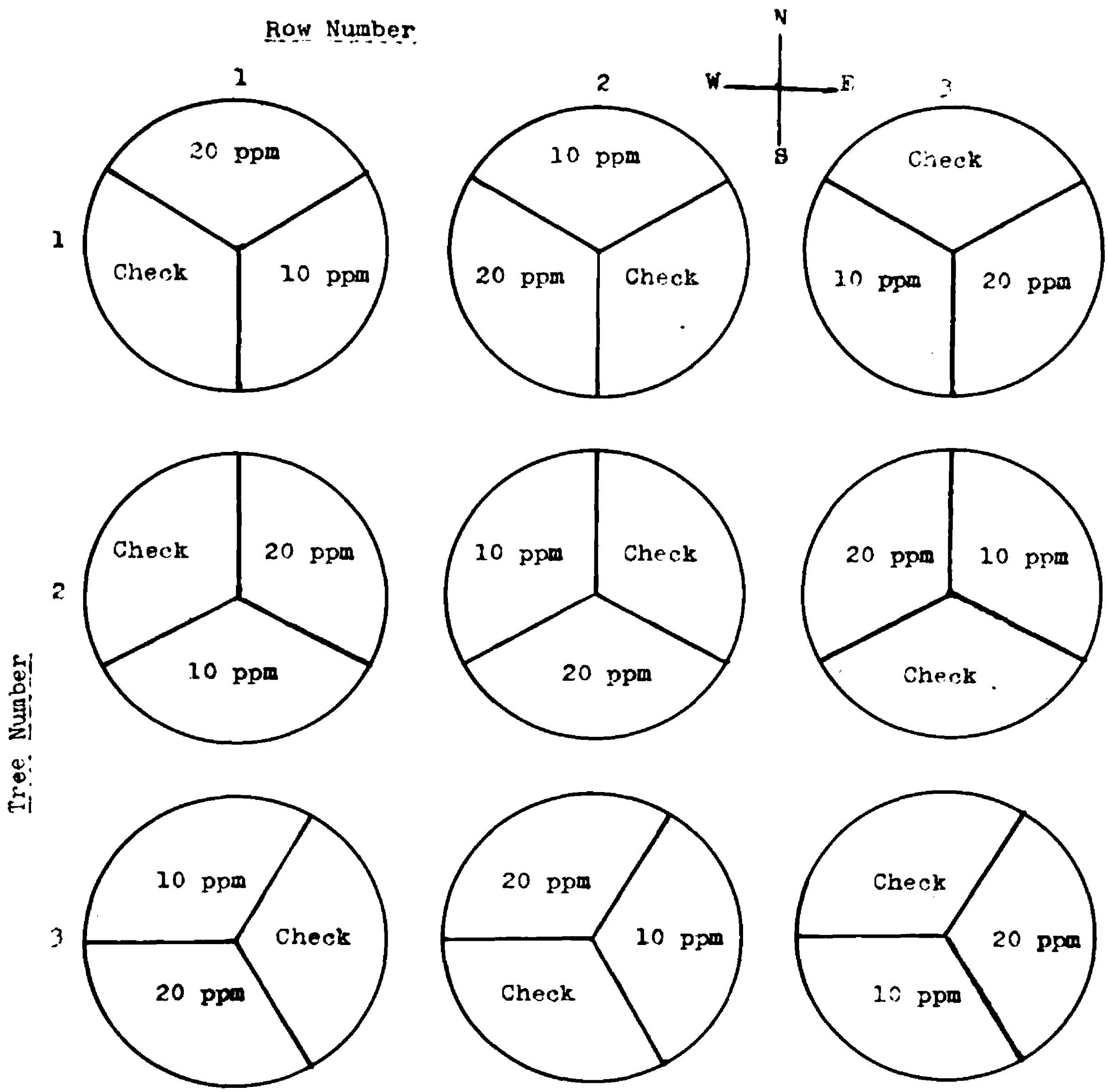


Figure 1. Plot layout of segment treatments for testing of blossom thinning sprays in relation to size of blossom spurs. Naphthaleneacetic acid applied at calyx time at concentrations indicated. Thirty-six blossom spurs selected at random from (a) high limbs, (b) low limbs, made up of three sizes - 2 mm.; 3 mm.; and 4 mm.

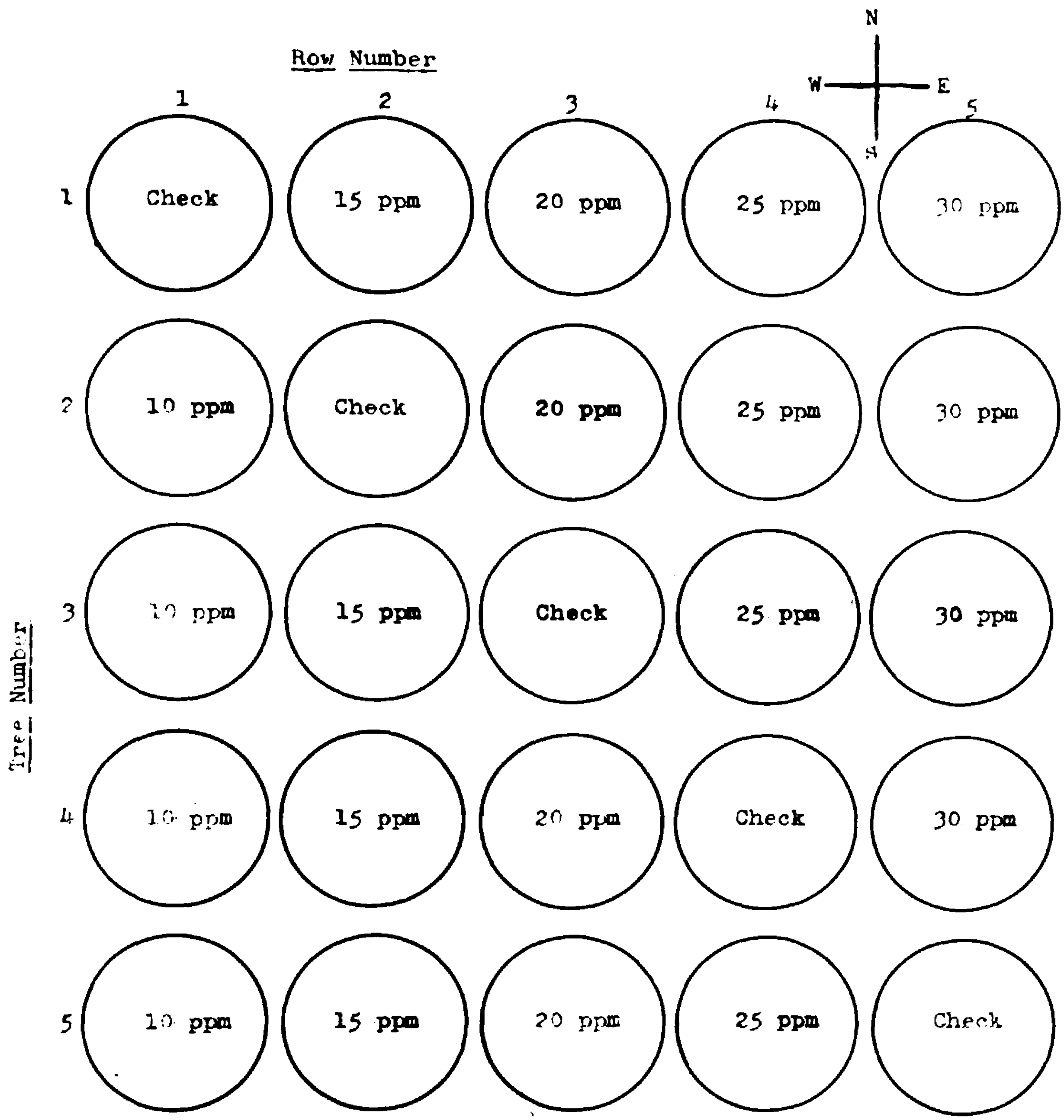


Figure 2. Plot layout of "entire tree" treatment used in testing naphthaleneacetic acid and thiozole as blossom-thinning sprays at concentrations noted; "Clark" at 20, 60, 100 ppm.; and maleic hydrazide at 50, 100, 200, 300, 400, and 500 ppm.

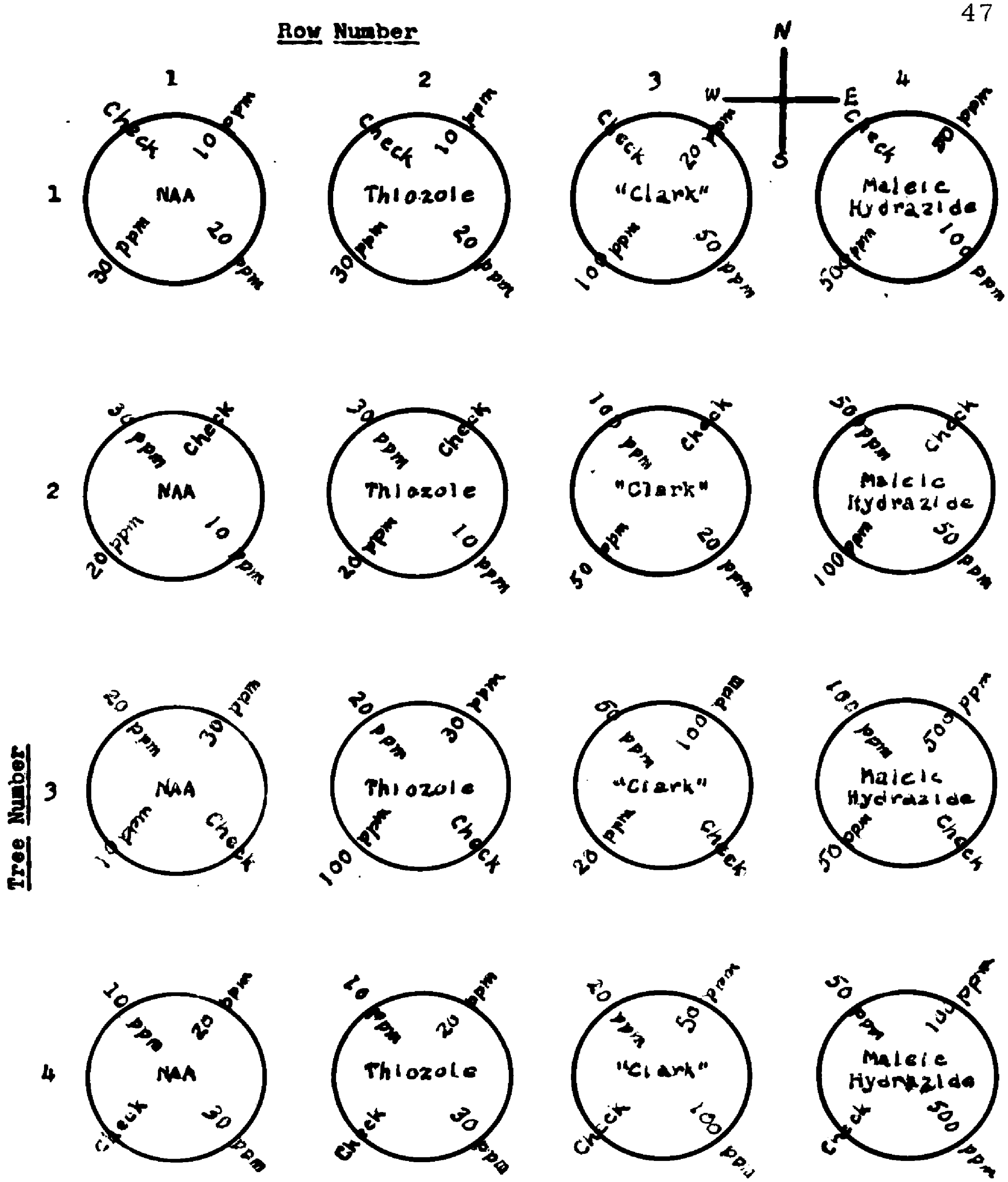


Figure 3. Plot layout of limb treatments for testing of growth regulator materials and their concentrations, as indicated.

Figure 4. Branch of Wagener apple tree showing tags used to identify the spur sizes of 2, 3, and 4 mm. Fruit has been removed by thinning sprays.

RESULTS

The results gathered on fruit-thinning during the six-year period, starting in 1946, are presented in the form of tables, graphs, and pictures.

Spur Size in Relation to Blossom-thinning

Data gathered during the years 1949 and 1950, with respect to the correlation of fruit spur size of several apple varieties with the concentration of naphthaleneacetic acid (NAA) necessary to decrease the set of fruit, are presented in Table I. Spurs 2 millimeters in diameter were consistently thinned the most, and those 4 millimeters in diameter were thinned the least, regardless of variety, year, stage of floral development, and weather conditions. On the other hand, there were no apparent differences in thinning of spurs located on the lower branches of the tree as compared with those on upper branches. Nor were there any apparent differences with respect to the side of the tree upon which the spurs were located.

The effect of invigorating pruning on fruit-thinning is reflected in the Wealthy variety in Orchards II and III, as shown in Table I and Figures 6 and 7. In the case of Orchard II in 1949, the Wealthy trees were exceptionally vigorous, due partly to severe pruning in the winter of 1947 and to the ideal growing season of 1948. The fruit spurs were not only larger, but undoubtedly stronger than average Wealthy fruit spurs of other years. On the other hand, in Orchard III, the pruning in years past has been very light. The trees were quite brushy, and the fruit spur size was generally smaller. As shown in Table I and Figure 6, the improved vigor in Orchard III was reflected in a higher percentage set.

The question whether age of a tree is a factor in thinning depends upon the criteria that are used for age; that is, chronological age or physiological age. Generally speaking, older trees twenty years or more of age thin more readily than younger trees. This is borne out by the results here reported. Thus, in Table I, the ages of the trees vary from 14 to 35 years of age; yet, the trends in thinning appear similar. Since thinning results as shown in Table I were based upon the size of spur, which is a measure of vigor, the data are really comparisons of physiological age, and not chronological age. Even a young tree may be low in vigor and older physiologically than an older tree of high vigor.

Pollination and fertilization also bear some relation to the effectiveness of thinning sprays. Thus, in Jonathan Orchard IV and Figure 9, there was a lack of good pollinating varieties, and the set was accordingly low. Jonathan was thinned more severely than Northern Spy when blossoms were sprayed with NAA at 10 ppm. Ordinarily, the Northern Spy variety thins more easily than does the Jonathan. There may be a correlation between number of ovules fertilized and the ease of thinning.

There is also a difference between varieties. As seen in Table I, blossom applications of NAA at 10 ppm eliminated nearly all fruits from the 2-millimeter spurs of McIntosh, Jonathan, and Northern Spy varieties, and reduced the set between 25 and 95 per cent on 3- and 4-millimeter spurs of these varieties. Applications of NAA at 20 ppm thinned these same varieties excessively. On the other hand, applications of NAA at 20 ppm to blossoms of the Wealthy and Wagener varieties resulted in thinning of most of the 2-millimeter spurs, and reduced the set of 3- and 4-millimeter spurs as much as 50 per cent. During the 1949 and 1950 seasons, 20 ppm of NAA was a suitable concentration for thinning of these varieties in Orchards II and III. It is of some interest to point out that when the concentration of 40 ppm of NAA was used on Wealthy blossoms in the vigorous orchard (Orchard II), it did not overthin as it did in Orchard III the following year. In Orchard IV with the Jonathan variety, application of 20 ppm of NAA completely eliminated fruit on all spurs measured and tagged, and similar results were obtained with Northern Spy variety in the same orchard. The results with Jonathan may be traced to poor pollination. However, in the case of Northern Spy, the facility for thinning undoubtedly is due to a varietal characteristic, as this tendency has been observed many times under commercial thinning procedures.

Effectiveness of Maleic Hydrazide, Sodium Thiozole, and "Clark"

Three relatively new materials were tried in 1950 for their effectiveness as blossom-thinning agents; namely, maleic hydrazide, sodium thiozole, and "clark." The last-named material is a commercial product obtained from the B. F. Goodrich Chemical Company. It is a sulfhydryl compound. Results with four varieties in two orchards are shown in Table II. The materials were not effective as blossom-thinning agents. On the contrary, maleic hydrazide seemed to increase the set on Northern Spy, Jonathan, and Wagener trees, but did reduce fruit set to some degree with Wealthy. Applications of maleic hydrazide and ''clark'' produced no evident injury to foliage, fruit, or tree, either immediately after application or at any time during the growing season.

The performance of ''clark'' as a fruit-thinning spray was inconsistent; it showed more indication of thinning at 20 ppm on Jonathan and Wealthy than it did at 100 ppm. The material failed to thin Wageners at either concentration, and thinned Northern Spy mostly at the higher concentrations. Sodium thiozole appeared quite effective on Jonathan and Northern Spy, but on Wealthy and Wagener, it was less effective. Sodium thiozole, unlike ''clark'' and maleic hydrazide, did cause visual damage to the foliage at 100 ppm. Edges of the leaves were burned and curled slightly inward. Abscission of flowers was inhibited, and the green color was retained until the time of the June drop, when these flowers dropped along with other partially developed fruits.

Relation of Vitamin K to Blossom-thinning

It has been postulated by some of the English workers that the response of a variety to a blossom-thinning material such as NAA may be related to certain materials present in variable amounts in the variety (17). Among these is Vitamin K. Accordingly, Vitamin K was applied in combination with several concentrations of NAA, with the results shown in Table III. The Jonathan trees were sprayed when just past full bloom with 5, 15, and 30 ppm of NAA in combination with 5, 10, 100, and 1000 ppm of Vitamin K. The sprays of NAA without the addition of Vitamin K increased thinning as concentrations rose. Because the orchard was young and in good vigor, the effectiveness of NAA was not as great as has been shown in orchards of lower vigor.

The addition of Vitamin K to the sprays of NAA appeared to decrease thinning at the 100-ppm level of Vitamin K for the Jonathan variety. However, at 1000 ppm of Vitamin K. there appeared to be an increase in the thinning, as compared to NAA alone. This can be partially explained by the fact that on nearly every limb that was sprayed with 1000 ppm of Vitamin K, slight foliage-burning was observed, as well as some injury to pistils. The McIntosh block of Orchard VIII was treated exactly as the

Jonathan, except that it was sprayed when about 70 per cent of the petals were off. The results were quite similar to those obtained in the Jonathan block, except that Vitamin K at 1000 ppm seemed to counteract the effectiveness of NAA at 30 ppm. This can possibly be explained by the fact that more of the blossoms had been already fertilized before they were sprayed, so that the slight burning damage did not affect the set. Nevertheless, there appeared to be some countering action of Vitamin K on NAA thinning sprays during the 1951 season on two varieties, as shown in Table III.

Thinning with Naphthaleneacetic Acid on the Tree Basis

Data on thinning apples with naphthaleneacetic acid over a three-year period are presented in Table IV. The Wealthy variety was used each of the three years; and in addition, Jonathan, McIntosh, and Yellow Transparent were used one year each.

In 1946, in Orchard IX, blossoms from Wealthy trees sprayed with NAA at 10 ppm set 17 per cent, compared with 26 per cent for the controls. In 1947, blossoms from the same trees set 36 per cent on the checks, as compared to 15 per cent set when sprayed with NAA at 15 ppm, and 6 per cent when sprayed with NAA at 30 ppm. In 1946, there were no frosts, but the temperatures were cool, and weather rainy, during Wealthy bloom, and the orchard is a solid block of one variety. In 1947, the weather was much more favorable for pollination and fertilization.

Wealthy Orchard XIII is located on a neighboring farm, and is quite similar to Orchard IX. Blossoms from check trees in this orchard set more fruit than in Orchard IX. However, when the blossoms were sprayed with NAA at a concentration of 15 ppm, set was reduced to 16 per cent, as compared to 15 per cent in Orchard IX with the same treatment. This appears to be an excellent comparison of the materials, procedure, weather, personal observations, and choice of trees.

Wealthy blossoms in Orchard XI set fruit fairly well in spite of cool weather during bloom, and when sprayed with NAA, were thinned sufficiently for the type of trees grown in the Cheboygan area, which are small and heavily pruned.

Wealthy blossoms in Orchard X showed an increasing gradation in thinning with increasing concentrations of NAA. It so happened that in Orchard X, no thinning was necessary because of the poor set due to cold, rainy weather throughout the bloom period.

Blossom set in Jonathan Orchard XI was low, due to cool weather and low vigor. Most of the set was on the large, 4-millimeter spurs which ordinarily do not thin as readily as do blossoms on small- and medium-sized spurs. The 17 per cent set caused from the sprays of NAA was about the correct percentage for a good crop.

The blossoms in the McIntosh Orchard XII were thinned sufficiently when sprayed with NAA at 5 ppm in 1946. The ease of thinning in this orchard in 1946 was undoubtedly due to weather conditions during blossoming. A 27 per cent set of blossoms was a little high for the very heavy bloom which prevailed, but on the other hand, 12 per cent was a little low. Too many three-inch McIntosh fruits developed on the overthinned trees, and reduced the production a little more than is considered economical for most years.

Yellow Transparent blossoms in Orchard XIV were thinned satisfactorily when sprayed with NAA at 15 ppm. Applications of NAA at 10 ppm did not thin blossoms sufficiently, whereas at 20 ppm, far too much thinning occurred for an economical orchard practice. It appears that during the seasons of 1946, 1947, and 1948, the cool weather which prevailed at blossom time in all sections where investigations were carried out was conducive to the ease of thinning.

Chemical Analysis of Apple Spurs Following Application of NAA as Thinning Sprays

Observation of numerous blocks of various varieties of apples which were thinned with NAA sprays during full bloom or at calyxtime exhibited wilting 24 to 48 hours after the treatment. Retardation of spur growth occurred for several weeks on several varieties when spray thinned at full bloom, and occasionally, this happened when the spraying was done at calyx-time. Some slight twisting of the leaf petioles occasionally accompanied the wilting.

With the above observations in mind, the NAA spray-thinned Wagener apple spurs were analyzed for nitrogen, total sugars, reducing and nonreducing sugars, and starch. The results of the analysis are on a dry unit weight basis, and given in Tables V, VI, and VII. Examination of Table V shows no definite trend of the effect of NAA calyx sprays on the nitrogen and carbohydrate content in Wagener apple blossoms, spurs, and leaves. There was a slight proportional increase in the reducing sugars in the check spurs collected seven days after treatment over the treated spurs. The amount of difference does not appear to be significant, as the variation in the replicate samples could account for part of the difference. Considering the uniformity of the analyses in Table V, it can be concluded that any seeming injury to leaves, petioles, or cluster bases is not sufficient to affect the composition of the materials for which the analyses were made.

Table VI shows the results of analysis of the flower parts and young apples for the same constituents as in Table V. Again the table is quite uniform in reference to the analysis of nitrogen, sugars, and starch for the 48-hour period. There was an increase in dry weight of the check spurs seven days after treatment, due to the growth of the apples which were not removed by the NAA spray. The treated spurs had very few fruits remaining, as they were thinned severely at 20 ppm. The additional fruits could also be the reason for the slight increase in nitrogen and reducing sugar as shown in Table VI.

Table VII shows results of the analysis of the entire fruiting spur. No definite trend seems established. Minor fluctuations may be partly due to errors in sampling. As a whole, the results again indicate no serious effect on the composition of the parts analyzed. Further, the sprayed trees bore a full crop of apples the following year, and required thinning.

Peach-thinning Trials in 1950

The thinning investigational work on peaches with "clark," sodium thiozole, maleic hydrazide, and naphthaleneacetic acid at pH 2.5 was carried out with Halehaven, Redhaven, and Kelhaven varieties, at three distinctly different geographical areas.

The results are given in Table VIII. NAA did not reduce the set of fruit in Orchards III or V on either the Halehaven and Kalhaven varieties. However, in Orchard VI, an excellent range of thinning was accomplished on Redhaven peaches. This thinning occurred after fruit was approaching the end of Stage I of fruit development. This thinning was accompanied by excessive damage at all concentrations used at this stage of fruit development. However, the same sprays used at an early bloom stage caused no damage, although they also resulted in no thinning. The injury in Orchard VI was a very severe leaf-burning, and at the high concentrations, removed practically all the leaves.

Applications at 20 ppm resulted in severe damage, but the fruit matured to a fair quality. However, at the higher concentrations, fruits failed to mature.

With "clark" there was no definite indication of thinning in Orchards III, V, or VI. Similar results were obtained with sodium thiozole. "Clark" did not affect the foliage, blossoms, or fruits at any stage of growth. Sodium thiozole, on the other hand, did burn foliage at high concentrations in Orchard VI, but gave very little injury, if any, where the spray was applied in bloom. Also, those limbs sprayed with sodium thiozole could be located very easily by the presence of adhering "shucks," which remained characteristically green and continued to grow until the time of the June drop. Sodium thiozole and "clark" were discarded from further trial.

Maleic hydrazide, as shown in Table VIII, caused very distinct thinning in all stages of bloom, but had no effect after peaches were 3/4 inch in diameter. Thinning was effected at concentrations of 100 and 500 ppm. The reduction in set in Orchard V on Halehaven variety when sprayed at 90 per cent of full bloom was 64 per cent. In Orchard V, on the Kalhaven variety, which was sprayed when in 70 per cent of full bloom, the set was reduced by 83 per cent. Twenty-seven fruits remained for each one hundred fruit buds in Orchard V on the Halehaven variety, which was too many for these vigorous ten-year-old trees to carry. Seventeen fruits left for each one hundred buds in Orchard III did not reduce the total yield per tree, since the increase in size of fruit compensated for the slight overthinning, the supply of fruit buds being light in this orchard. On the other hand, nine fruits per one hundred fruit buds was slightly too much thinning on the Kalhaven trees of Orchard V. The most desirable number of fruits per hundred fruit buds will vary some with age, size, vigor, pruning, and variety of peach, but the accepted range is from twelve to twenty.

The effective period during which maleic hydrazide apparently thinned the fruits is a promising suggestion for further investigation. It appears from the results shown in Table VIII that this material will thin peaches when applied from 70 per cent of full bloom to calyxtime. Thus, in the 1950 season, as shown in Table VIII, maleic hydrazide did no damage. The foliage a week after spraying, at June drop, at harvest time, and also the following year, showed no ill effects from the material whatsoever. In fact, the foliage on the limbs sprayed with 500 ppm was actually larger and more luxurient than on the rest of the tree. This condition was undoubtedly brought about by the early removal of the heavy load of fruit that was taxing the tree. This is illustrated in Figure 13.

Peach-thinning with Maleic Hydrazide, 1951

Maleic hydrazide was used again during the season of 1951 on the Halehaven and Redhaven varieties. Table IX shows clearly the same definite trend as that observed in 1950, although the reduction in set was less in 1951 than in 1950. It is evident that the concentration of maleic hydrazide desired for thinning must be in the neighborhood of 500 ppm. The number of fruits to set per hundred fruit buds on the unsprayed trees was much lower in 1951 (Tables VIII and IX). The thinning in Orchard VII on both varieties was not sufficient even at 500 ppm. Although the per cent reduction of set was significant for the Halehaven peaches of Orchard VII, there were still too many fruits set per hundred fruit buds. The situation was similar for the Redhaven variety, although the number of fruits set per hundred fruit buds was within the limits acceptable for a commercial crop.

It should be explained that the heavy set in 1951 was due to a combination of factors. First, the trees were heavier with buds than in previous years. Second, no pruning was done in 1951, so that there was a larger producing area. The per cent reduction of set, the number of fruits to set per hundred fruit buds, and the pruning practices in Orchard V on both Halehaven and Redhaven varieties were all similar to Orchard VII. Even with a 16 and 13 per cent set respectively, it was necessary to do some hand thinning.

There was no visual damage to any part of the tree or to the fruit. The luxurient growth of the thinned limbs in 1950 was, however, not evident in 1951. This can probably be explained by the fact that the reduction in set was not as great in any case as it was in 1950. Also, the trees were pruned in 1950 and not in 1951; pruning would help improve the general vigor of the entire tree.

An additional consideration is the fact that all three of the varieties used responded similarly, indicating that maleic hydrazide may have a wide varietal range of usefulness.

Table I. Thinning effect of naphthaleneacetic acid sprays in relation to size of spurs of McIntosh, Wealthy, Wagener, Jonathan, and Northern Spy apples during late bloom in several areas in Michigan.

No. of Spurs	Size of Spurs* (mm.)	Spray Concentration (ppm)	No. of Spurs to Set Fruit	Set (per cent)	Conditions of Blossoms at Time of Spraying
		McIntosh Orchard I, 1949			
31	2	Check	2	6.45	Full bloom, only few center, blossoms dropping petals; temperatures above 70° F. during the daylight hours for 48 hours prior to spraying; one night frost in low areas.
31	3	Check	13	41.93	
32	4	Check	17	53.12	
32	2	10	0	6.45	
33	3	10	6	18.18	
33	4	10	12	36.36	
36	2	20	0	0.00	
34	3	20	3	9.00	
36	4	20	9	25.00	
		Wealthy Orchard II, 1949			
34	2	Check	3	9.00	Late bloom, 95 per cent petals off; temperatures 70° F. or above during the daylight hours for 3 days prior to spraying; temperatures 40-50° F. for 48 hours following sprays.
35	3	Check	11	31.43	
34	4	Check	25	73.53	
31	2	20	0	0.00	
32	3	20	8	25.00	
36	4	20	16	44.44	
32	2	40	0	0.00	
35	3	40	7	20.00	
34	4	40	14	41.18	

Table I (Continued)

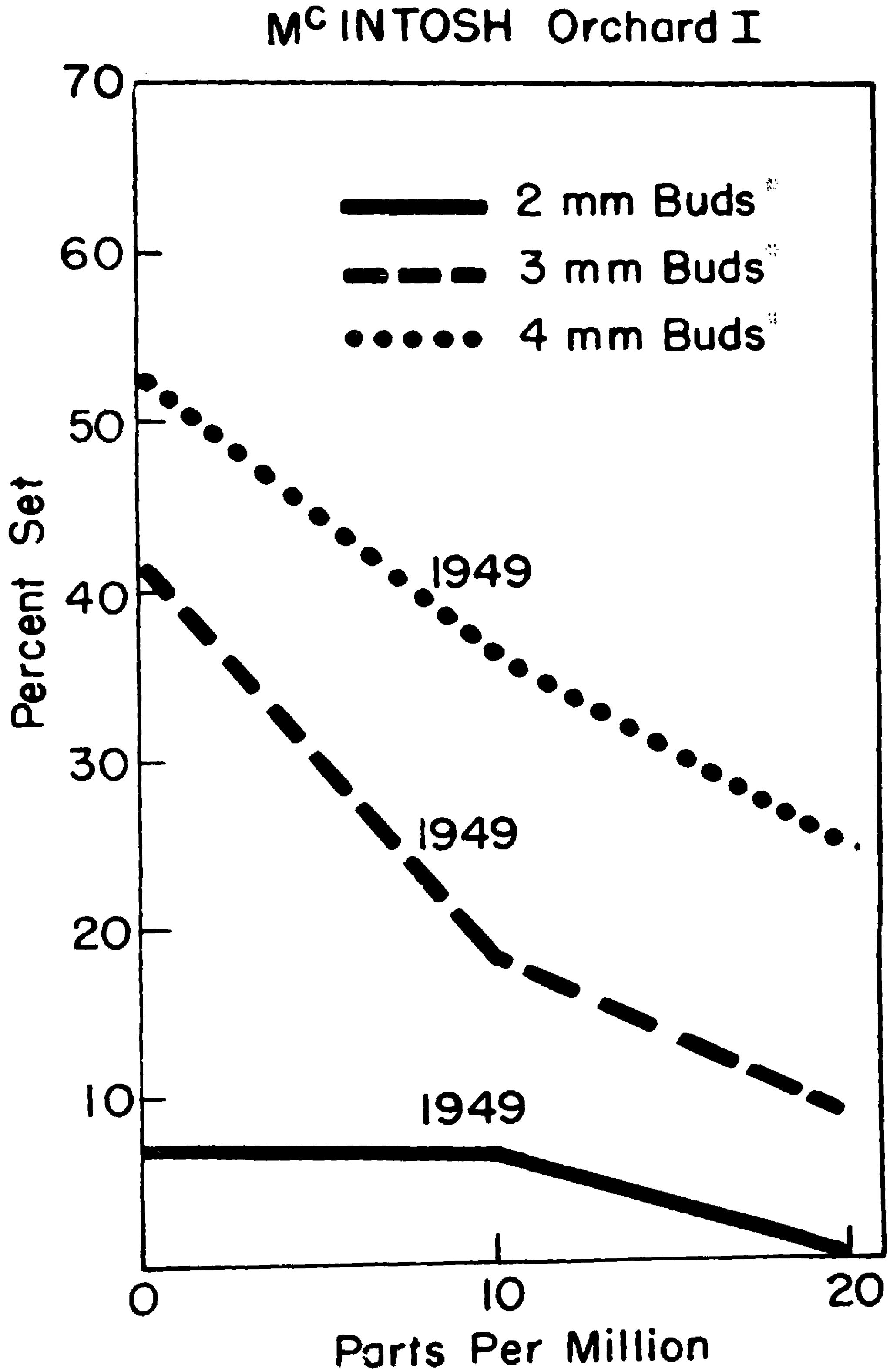
No. of Spurs	Size of Spurs* (mm.)	Spray Concentration (ppm)	No. of Spurs to Set Fruit	Set (per cent)	Conditions of Blossoms at Time of Spraying
		Wealthy Orchard III, 1949			
36	2	Check	14	38.88	Late bloom, 85 per cent petals off; temperatures above 70° F. during the daylight hours for 72 hours prior to spraying; 60 per cent center blossoms already fertilized.
36	3	Check	28	77.77	
36	4	Check	35	94.44	
36	2	20	7	19.44	
36	3	20	7	19.44	
36	4	20	14	38.88	
36	2	40	0	0.00	
36	3	40	3	5.55	
36	4	40	3	8.34	
		Wagener Orchard III, 1950			
36	2	Check	5	14.00	Late bloom, 95 per cent petals off and 65 per cent of center blossoms fertilized; temperatures 70° F. during daylight hours for 72 hours prior to spraying.
36	3	Check	16	44.44	
36	4	Check	32	88.88	
36	2	20	1	2.80	
36	3	20	5	14.00	
36	4	20	10	28.00	
36	2	40	0	0.00	
36	3	40	2	5.55	
36	4	40	7	19.44	

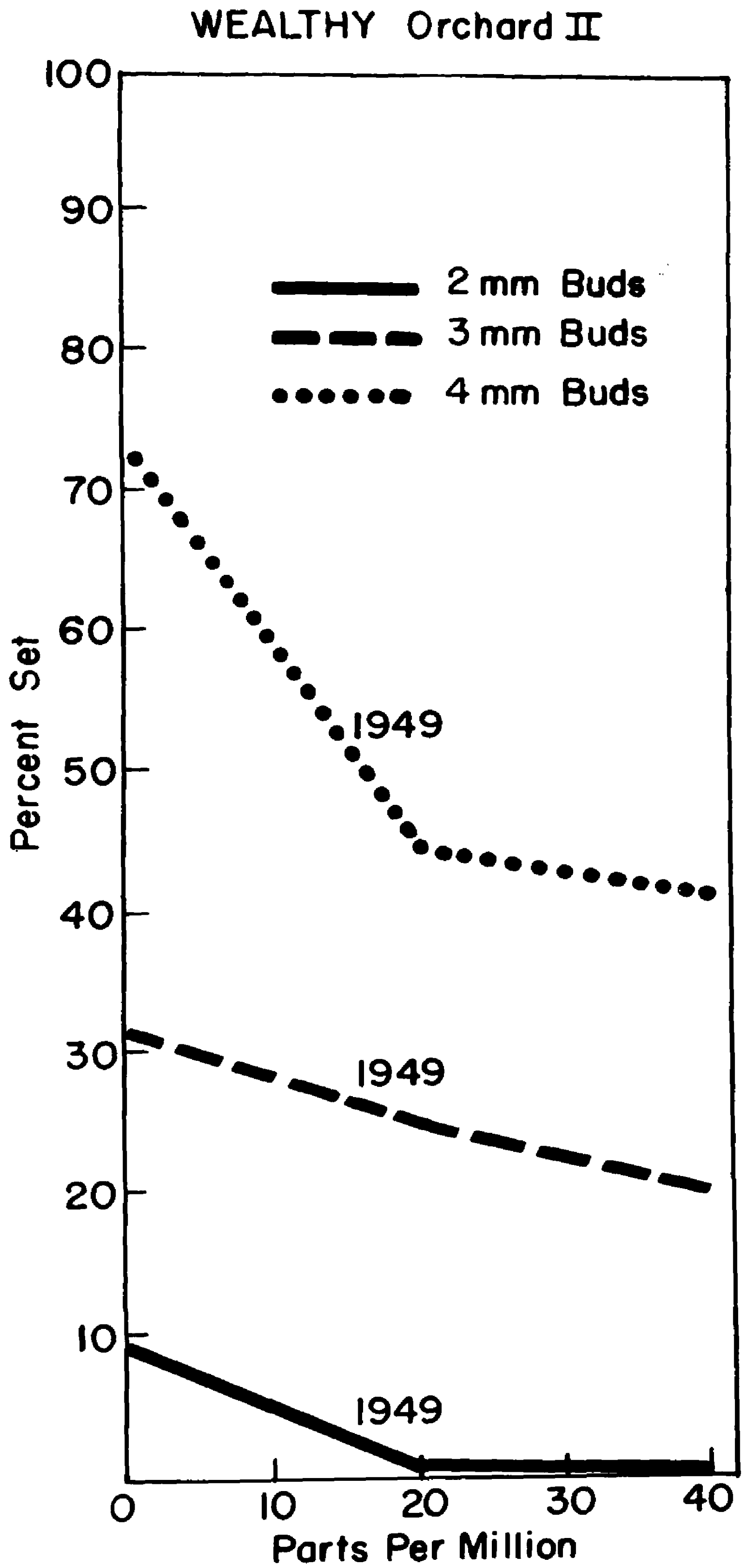
Table I (Continued)

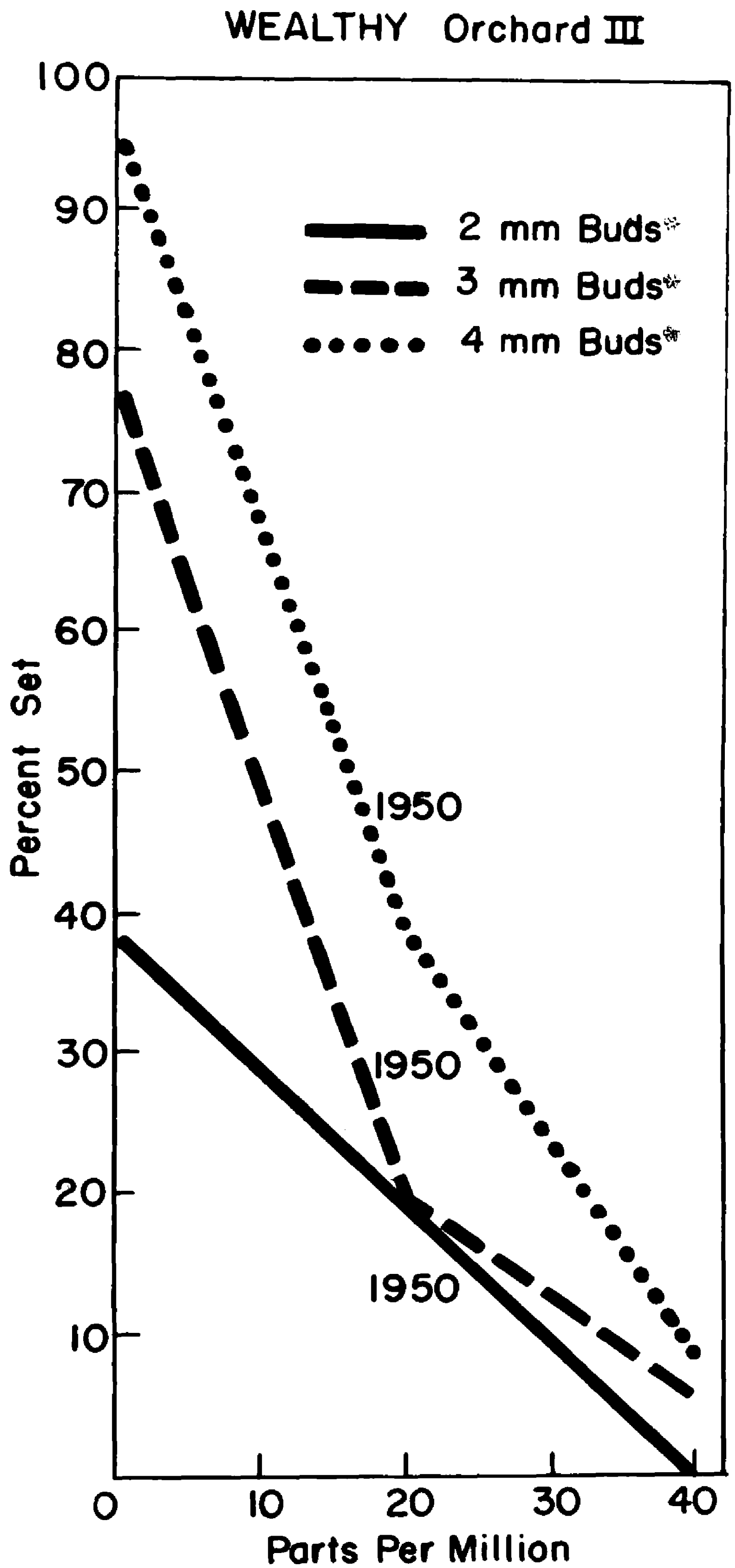
No. of Spurs	Size of Spurs* (mm.)	Spray Concentration (ppm)	No. of Spurs to Set Fruit	Set (per cent)	Conditions of Blossoms at Time of Spraying
		Jonathan Orchard IV, 1950			
36	2	Check	7	19.44	Late bloom, 50
36	3	Check	13	36.11	per cent of
36	4	Check	12	33.34	center blossoms
					fertilized; 75
36	2	10	0	0.00	per cent of
36	3	10	6	16.67	petals off; tem-
36	4	10	6	16.67	peratures 70°
					F. or above
36	2	20	0	0.00	during day-
36	3	20	0	0.00	light hours of
36	4	20	0	0.00	the blossom
					period.
		Northern Spy Orchard IV, 1950			
36	2	Check	4	11.10	Full bloom, 25
36	3	Check	7	19.44	per cent of
36	4	Check	16	44.44	center blossoms
					fertilized; tem-
36	2	10	2	5.55	perature above
36	3	10	5	14.00	75° F. during
36	4	10	12	33.67	the daylight
					hours for 2
36	2	20	0	0.00	days prior to
36	3	20	0	0.00	spraying.
36	4	20	0	0.00	

* Diameters of the previous year's growth.

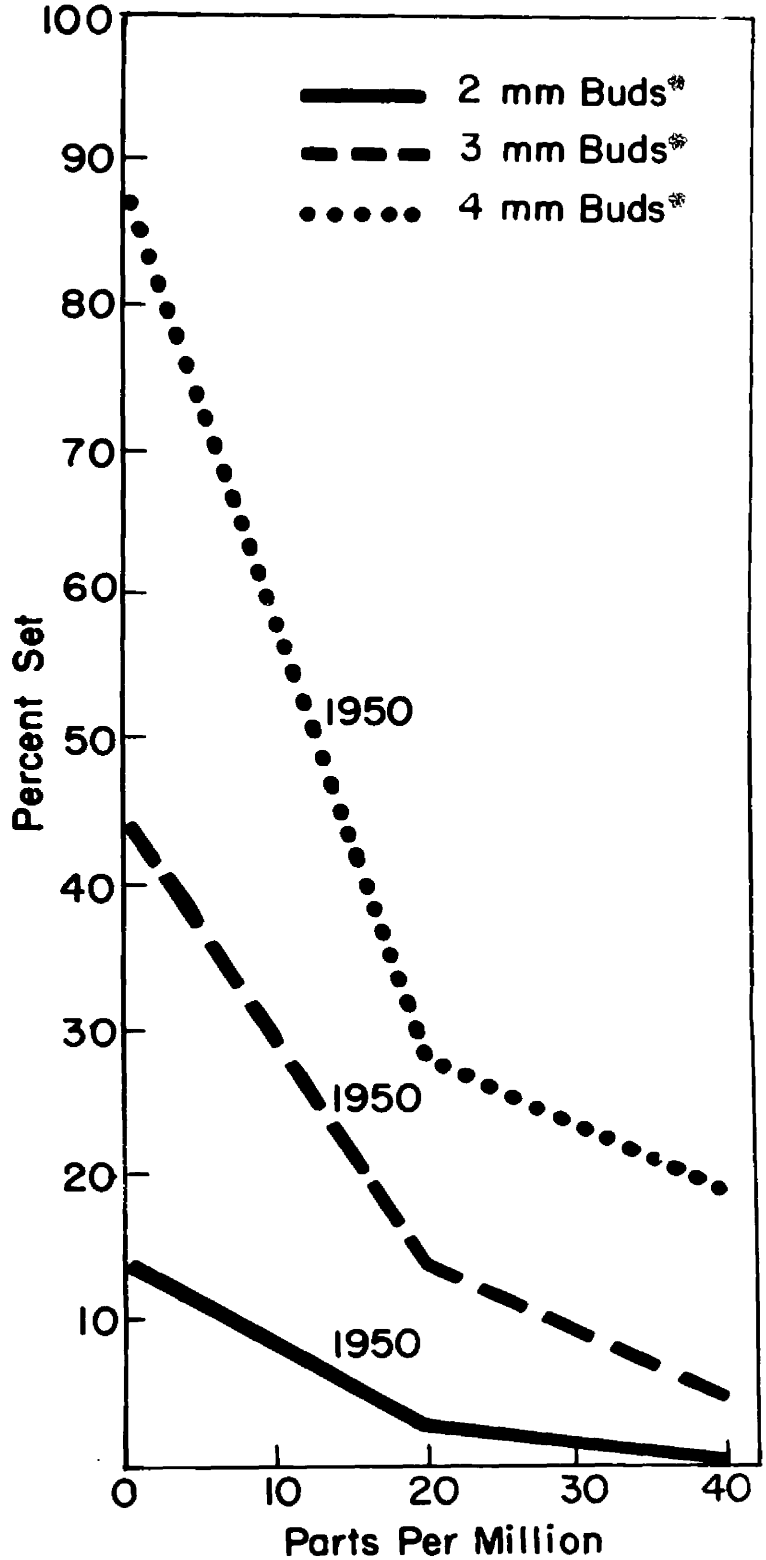
Orchard No. I - Ingham County
Orchard No. II - Grand Traverse County
Orchard No. III - Newaygo County
Orchard No. IV - Oakland County

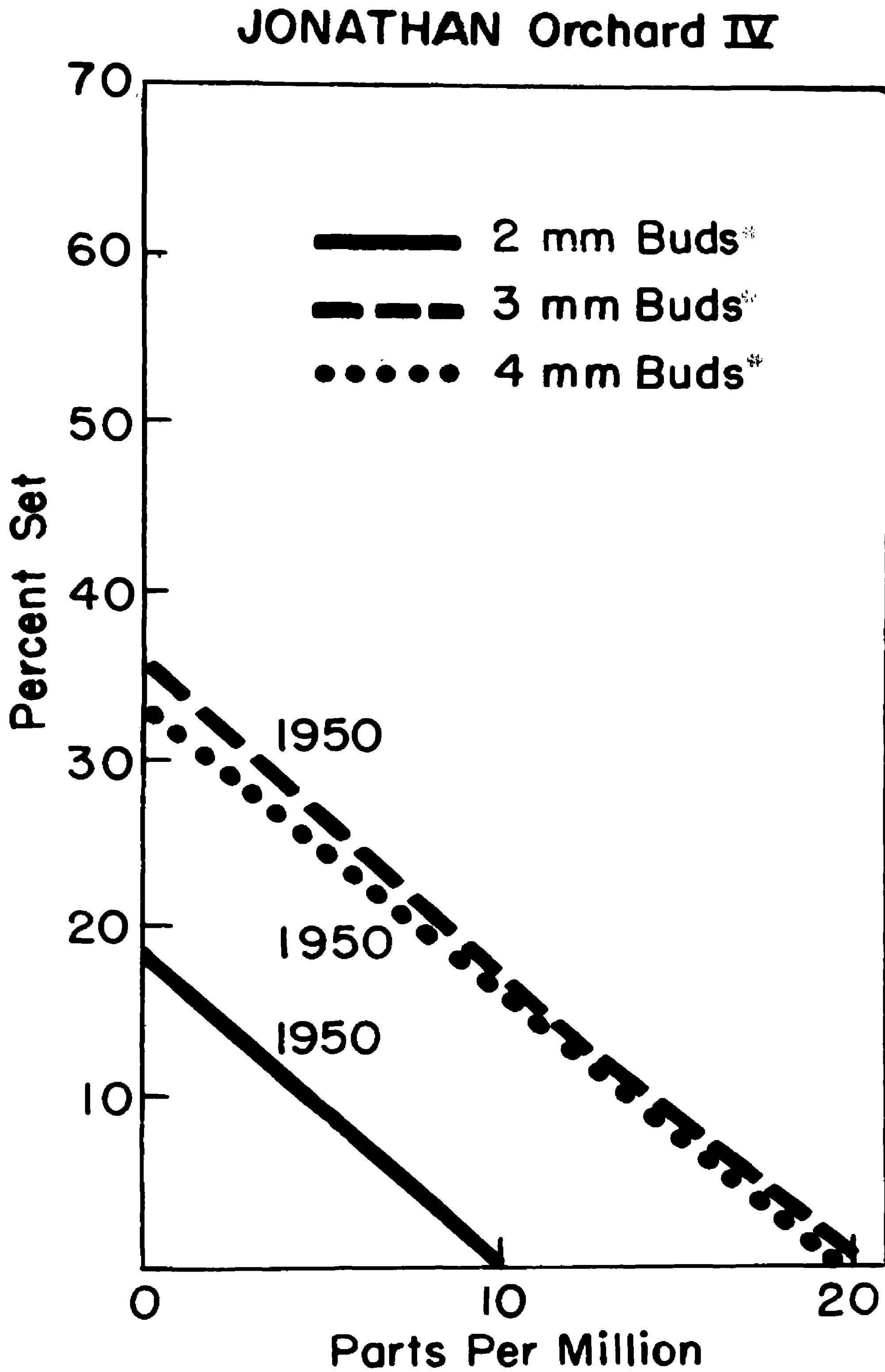

Mc INTOSH Orchard I
70
60
50
40
30
20
10
0
10
20
Percent Set
Parts Per Million
2 mm Buds*
3 mm Buds*
4 mm Buds*
1949
1949
1949


WEALTHY Orchard II
2 mm Buds
3 mm Buds
4 mm Buds
1949
1949
1949
Percent Set
Parts Per Million
0
10
20
30
40
50
60
70
80
90
100


WEALTHY Orchard III
2 mm Buds*
3 mm Buds*
4 mm Buds*
1950
1950
1950
Percent Set
Parts Per Million
100
90
80
70
60
50
40
30
20
10
0
10
20
30
40

WAGENER Orchard III




JONATHAN Orchard IV
2 mm Buds*
3 mm Buds*
4 mm Buds*
1950
1950
1950
70
60
50
40
30
20
10
Percent Set
0
10
20
Parts Per Million

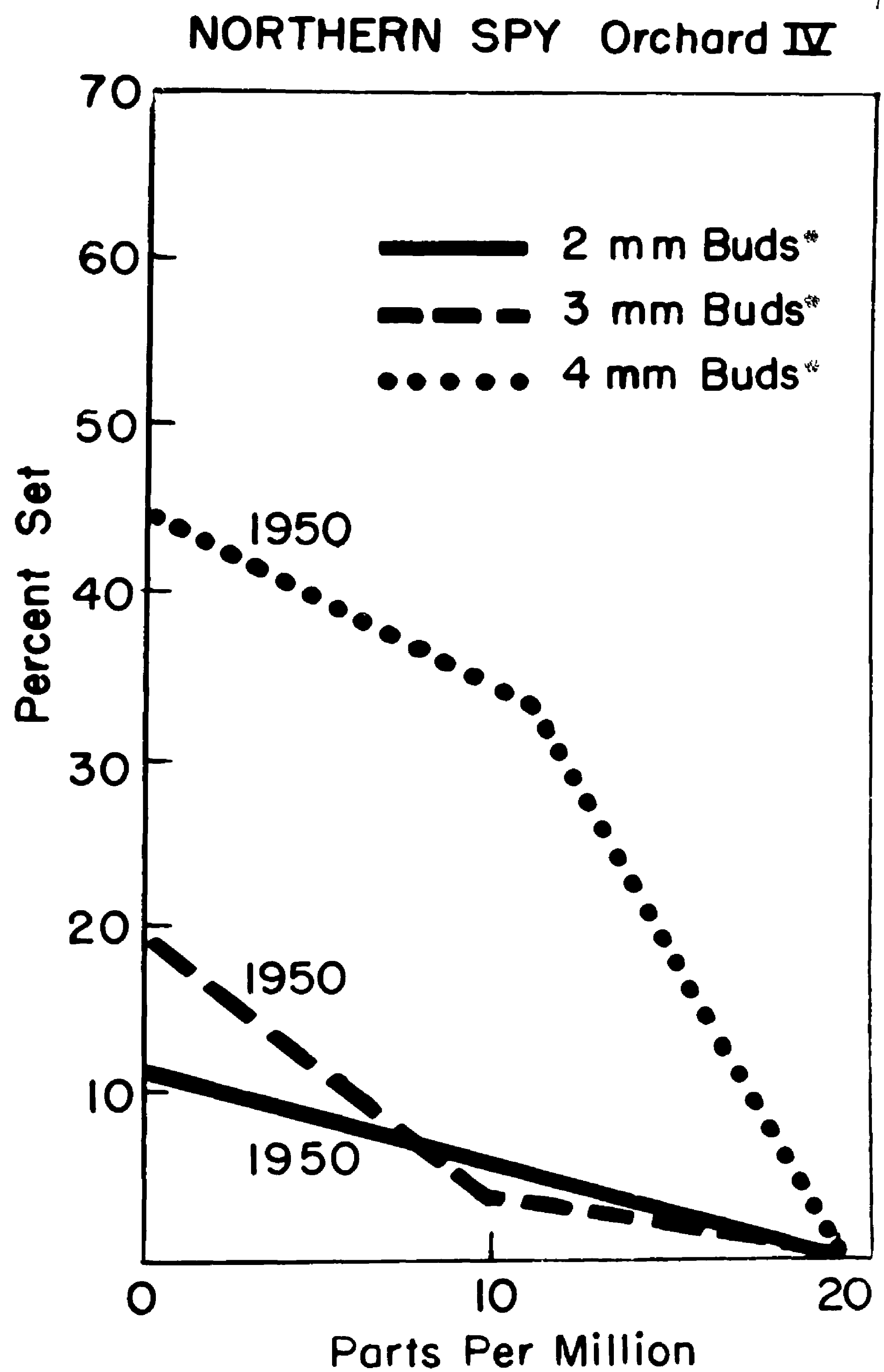

NORTHERN SPY Orchard IV
70
60
50
40
30
20
10
Percent Set
2 mm Buds*
3 mm Buds*
4 mm Buds*
1950
1950
1950
0
10
20
Parts Per Million

Table II. Thinning effect of maleic hydrazide, thiozole, and ''clark'' on Northern Spy, Jonathan, Wealthy, and Wagener apples.

Treatment	Fruits per 100 Blossoming Spurs	Stage of Blossoms when Sprayed
Northern Spy Orchard IV, 1950		
Check	45	Blossom petals 25 per cent off; center blossom fertilized.
20 ppm ''clark''	40	
100 ppm ''clark''	32	
Check	44	
20 ppm thiozole	32	
100 ppm thiozole	29	
Check	41	
50 ppm maleic hydrazide	47	
500 ppm maleic hydrazide	47	
Jonathan Orchard IV, 1950		
Check	72	Blossom petals 90 per cent off; 75 per cent of center blossoms fertilized.
20 ppm ''clark''	57	
100 ppm ''clark''	58	
Check	68	
20 ppm thiozole	50	
100 ppm thiozole	37	
Check	64	
50 ppm maleic hydrazide	56	
500 ppm maleic hydrazide	86	

Table II (Continued)

Treatment	Fruits per 100 Blossoming Spurs	Stage of Blossoms when Sprayed
Wealthy Orchard III, 1950		
Check	56	
20 ppm "clark"	50	
100 ppm "clark"	53	
		Blossom petals 85 per cent off; 65 per cent of center blossoms fertilized.
Check	55	
20 ppm thiozole	60	
100 ppm thiozole	60	
Check	49	
50 ppm maleic hydrazide	39	
500 ppm maleic hydrazide	47	
Wagener Orchard III, 1950		
Check	51	
20 ppm "clark"	60	
100 ppm "clark"	66	
		Blossom petals 95 per cent off; 75 per cent of center blossoms fertilized.
Check	52	
20 ppm thiozole	60	
100 ppm thiozole	59	
Check	50	
50 ppm maleic hydrazide	45	
500 ppm maleic hydrazide	58	

Orchard IV - Oakland County
Orchard III - Newaygo County

"Clark" = sulfhydryl compound
Thiozole = sodium thiozole
M. H. = maleic hydrazide

Table III. Thinning effect of naphthaleneacetic acid in combination with Vitamin K on two varieties of apples during blossomtime.

Naphthalene-acetic Acid (ppm)	Vitamin K (ppm)	Fruits per 100 Blossom Spurs	Conditions of Blossoms at Spraying Time
	Jonathan Orchard VIII, 1951		
5	0	48	
5	0	30	
5	5	31	
5	10	29	
5	100	45	
5	1,000	30	
0	0	45	
15	0	26	30 per cent petals off, 85° F., dry, clear.
15	5	25	
15	10	31	
15	100	33	
15	1,000	28	
0	0	46	
30	0	15	
30	5	11	
30	10	20	
30	100	27	
30	1,000	15	

Table III (Continued)

Naphthalene-acetic Acid (ppm)	Vitamin K (ppm)	Fruits per 100 Blossom Spurs	Conditions of Blossoms at Spraying Time
McIntosh Orchard VIII, 1951			
0	0	55	
5	0	32	
5	5	31	
5	10	34	
5	100	36	
5	1,000	22	
0	0	52	
15	0	23	70 per cent
15	5	19	petals off,
15	10	19	80° F., dry,
15	100	28	clear.
15	1,000	19	
0	0	57	
30	0	9	
30	5	12	
30	10	16	
30	100	23	
30	1,000	33	

Orchard VIII - Grand Traverse County

Table IV. Thinning effect of naphthaleneacetic acid sprays on Wealthy, Jonathan, McIntosh, and Yellow Transparent apples at several locations in Michigan.

Spray Concentration (ppm)	Fruits per 100 Blossom Spurs	Reduction in Fruit Set (per cent)	Condition of Blossoms at Time of Spraying
	Wealthy Orchard IX, 1946		
Check	26	--	Full bloom
10	17	35	Full bloom
	Wealthy Orchard XI, 1946		
Check	41	--	"Calyxtime"
10	27	34	"Calyxtime"
15	24	42	"Calyxtime"
	Wealthy Orchard XIII, 1947		
Check	44	--	"Calyxtime"
10	25	43	"Calyxtime"
15	16	64	"Calyxtime"
20	3	93	"Calyxtime"
	Wealthy Orchard IX, 1947		
Check	36	--	"Calyxtime"
10	18	50	"Calyxtime"
15	15	60	"Calyxtime"
20	6	83	"Calyxtime"
	Wealthy Orchard X, 1948		
Check	23	--	Full bloom
10	11	52	Full bloom
10*	7	70	Full bloom
15	6	74	Full bloom
20	3	87	Full bloom

Table IV (Continued)

Spray Concentration (ppm)	Fruits per 100 Blossom Spurs	Reduction in Fruit Set (per cent)	Condition of Blossoms at Time of Spraying
Jonathan Orchard XI, 1946			
Check	17	--	"Calyxtime"
10	14	18	"Calyxtime"
15	10	41	"Calyxtime"
McIntosh Orchard XII, 1946			
Check	39	--	Full bloom
5	27	31	Full bloom
10	12	70	Full bloom
Yellow Transparent Orchard XIV, 1947			
Check	45	--	"Calyxtime"
10	32	29	"Calyxtime"
15	18	60	"Calyxtime"
20	6	86	"Calyxtime"

* Twice as many gallons per tree.

Orchard IX - Oceana County
Orchard X - Berrien County
Orchard XI - Cheboygan County
Orchard XII - Cass County
Orchard XIII - Oceana County
Orchard XIV - Jackson County

Table V. Effect of naphthaleneacetic acid sprays on the nitrogen and carbohydrate content of Wagener apple-blossom spur leaves, petioles, and cluster bases. (Applications made at "calyxtime," Orchard I, 1950.)

Sample	Treatment	Dry Wt. of 100 Blossom Spur Leaves, Petioles and Cluster Bases	Grams per Spur Leaves, Petioles and Cluster Bases				
			Nitrogen	Total Sugar	Reducing Sugar	Non-reducing	Starch
5	Checks, 48	22.1	.0071	.0110	.0066	.0044	.0033
6	hours after	21.0	.0069	.0101	.0058	.0043	.0046
7	treatment	21.7	.0067	.0107	.0062	.0045	.0036
8		20.6	.0066	.0087	.0056	.0031	.0033
		Av. 21.4	.0066	.0101	.0060	.0041	.0037
9	20 ppm 48	23.8	.0078	.0107	.0055	.0052	.0048
10	hours after	23.5	.0080	.0105	.0047	.0058	.0050
11	treatment	21.8	.0074	.0093	.0049	.0044	.0038
12		24.3	.0082	.0103	.0051	.0052	.0043
		Av. 23.4	.0079	.0102	.0051	.0051	.0045
13	100 ppm 48	20.7	.0066	.0069	.0038	.0031	.0019
14	hours after	19.8	.0069	.0073	.0030	.0043	.0021
15	treatment	24.9	.0082	.0082	.0047	.0035	.0025
16		23.4	.0073	.0087	.0057	.0030	.0024
		Av. 22.2	.0073	.0078	.0043	.0035	.0022

Table V (Continued)

Sample	Treatment	Dry Wt. of 100 Blossom Spur Leaves, Petioles and Cluster Bases	Grams per Spur Leaves, Petioles and Cluster Bases				
			Nitrogen	Total Sugar	Reducing Sugar	Non-reducing Sugar	Starch
45	Check 7	25.6	.0074	.0137	.0094	.0043	.0020
46	days after	20.0	.0060	.0090	.0051	.0039	.0020
47	treatment	25.0	.0072	.0104	.0059	.0045	.0026
48		19.7	.0059	.0114	.0048	.0066	.0021
		Av. 22.6	.0066	.0111	.0063	.0048	.0022
49	20 ppm 7	29.6	.0089	.0126	.0071	.0055	.0028
50	days after	30.0	.0090	.0133	.0078	.0055	.0037
51	treatment	23.4	.0070	.0115	.0072	.0043	.0020
52		25.4	.0079	.0121	.0080	.0041	.0023
		Av. 27.1	.0082	.0124	.0075	.0049	.0027
53	100 ppm 7	26.2	.0084	.0113	.0068	.0055	.0016
54	days after	26.6	.0083	.0123	.0088	.0035	.0026
55	treatment	22.7	.0070	.0115	.0073	.0042	.0022
56		23.1	.0072	.0107	.0067	.0040	.0024
		Av. 24.7	.0077	.0115	.0072	.0043	.0022

Analysis made by Dr. E. J. Benne, Agriculture Chemistry Department, Michigan State College.

Table VI. Effect of naphthaleneacetic acid sprays on the nitrogen and carbohydrate content in Wagener apple-blossom spur flowers, young fruits, and peduncles. (Applications made at "calyxtime," Orchard I, 1950.)

Sample	Treatment	Dry Wt. of 100 Blossom Spur Blooms, Fruits, and Peduncles	Grams per Spur Blossoms, Fruits, and Peduncles				
			Nitrogen	Total Sugar	Reducing Sugar	Non-reducing Sugar	Starch
5	Checks 48	11.7	.0047	.0036	.0028	.0008	.0008
6	hours after	11.0	.0044	.0037	.0027	.0010	.0005
7	treatment	10.5	.0040	.0048	.0037	.0011	.0005
8		11.2	.0045	.0028	.0015	.0013	.0005
		Av. 11.1	.0044	.0037	.0027	.0010	.0006
9	20 ppm 48	9.9	.0042	.0043	.0034	.0009	.0006
10	hours after	9.4	.0038	.0027	.0024	.0003	.0006
11	treatment	9.8	.0039	.0028	.0015	.0013	.0009
12		9.7	.0039	.0032	.0023	.0009	.0002
		Av. 9.7	.0039	.0033	.0024	.0009	.0006
13	100 ppm 48	9.2	.0039	.0020	.0015	.0005	.0003
14	hours after	9.9	.0041	.0030	.0022	.0008	.0003
15	treatment	9.3	.0039	.0035	.0025	.0010	.0003
16		9.5	.0038	.0047	.0042	.0005	.0003
		Av. 9.5	.0039	.0033	.0026	.0007	.0003

Table VI (Continued)

Sample	Treatment	Dry Wt. of 100 Blossom Spur Blooms, Fruits, and Peduncles	Grams per Spur Blossoms, Fruits, and Peduncles				
			Nitrogen	Total Sugar	Reducing Sugar	Non-reducing Sugar	Starch
45	Check 7 days	13.7	.0049	.0072	.0058	.0014	.0007
46	after treat-	13.1	.0049	.0054	.0047	.0007	.0008
47	ment	15.1	.0056	.0071	.0046	.0025	.0009
48		12.8	.0049	.0036	.0026	.0010	.0007
		Av. 13.7	.0051	.0058	.0044	.0014	.0008
49	20 ppm 7	9.6	.0038	.0057	.0046	.0011	.0001
50	days after	9.6	.0039	.0032	.0017	.0015	.0002
51	treatment	9.1	.0036	.0040	.0030	.0010	.0001
52		9.8	.0039	.0034	.0020	.0014	.0001
		Av. 9.5	.0038	.0041	.0028	.0013	.0001
53	100 ppm 7	10.0	.0041	.0043	.0034	.0009	.0003
54	days after	9.9	.0043	.0034	.0030	.0004	.0003
55	treatment	8.2	.0035	.0021	.0016	.0005	.0002
56		9.9	.0042	.0041	.0036	.0005	.0001
		Av. 9.5	.0040	.0035	.0029	.0006	.0002

Analysis made by Dr. E. J. Benne, Agriculture Chemistry Department, Michigan State College.

Table VII. Effect of naphthaleneacetic acid sprays on the nitrogen and carbohydrate content of entire Wagener apple-blossom spurs. (Applications made at "calyxtime," Orchard I, 1950.)

Sample	Treatment	Dry Wt. of 100 Complete Blossom Spurs	Grams per Complete Blossom Spur				
			Nitrogen	Total Sugar	Reducing Sugar	Non-reducing Sugar	Starch
5	Checks 48	33.8	.0118	.0146	.0094	.0052	.0041
6	hours after	32.0	.0113	.0138	.0085	.0053	.0051
7	treatment	32.2	.0107	.0155	.0099	.0056	.0041
8		21.8	.0111	.0115	.0071	.0044	.0038
		Av. 32.5	.0112	.0139	.0088	.0051	.0043
9	20 ppm 48	33.7	.0120	.0150	.0089	.0061	.0054
10	hours after	32.9	.0118	.0132	.0071	.0061	.0056
11	treatment	31.6	.0113	.0121	.0064	.0057	.0047
12		34.0	.0121	.0135	.0074	.0061	.0045
		Av. 33.1	.0118	.0135	.0075	.0060	.0051
13	100 ppm 48	29.9	.0105	.0089	.0053	.0036	.0022
14	hours after	29.7	.0110	.0103	.0052	.0051	.0024
15	treatment	34.2	.0121	.0117	.0072	.0045	.0028
16		32.9	.0111	.0134	.0099	.0035	.0027
		Av. 31.7	.0112	.0111	.0069	.0042	.0025

Table VII (Continued)

Sample	Treatment	Dry Wt. of 100 Complete Blossom Spurs	Grams per Complete Blossom Spur: Nitrogen	Total Sugar	Reducing Sugar	Non-reducing Sugar	Starch
45	Checks 7	29.3	.0123	.0209	.0152	.0057	.0027
46	days after	33.1	.0109	.0144	.0098	.0046	.0028
47	treatment	40.1	.0128	.0175	.0105	.0070	.0035
48		32.5	.0108	.0150	.0074	.0076	.0028
		Av. 33.8	.0117	.0168	.0107	.0061	.0030
49	20 ppm 7	39.2	.0127	.0183	.0117	.0066	.0029
50	days after	39.6	.0129	.0165	.0095	.0070	.0039
51	treatment	32.5	.0106	.0155	.0102	.0053	.0021
52		35.2	.0118	.0155	.0100	.0055	.0024
		Av. 36.6	.0120	.0165	.0105	.0060	.0026
53	100 ppm 7	36.2	.0125	.0156	.0092	.0064	.0019
54	days after	36.5	.0126	.0157	.0118	.0039	.0029
55	treatment	30.9	.0105	.0136	.0089	.0047	.0024
56		33.0	.0114	.0148	.0103	.0045	.0025
		Av. 34.2	.0118	.0149	.0101	.0048	.0024

Analyses made by Dr. E. J. Benne, Agriculture Chemistry Department, Michigan State College.

Table VIII. Thinning effect of naphthaleneacetic acid, "clark," thiozole, and maleic hydrazide on Halehaven, Redhaven, and Kalhaven peaches when sprayed at different stages of bloom and fruit development.

Treatment		Concentration (ppm)	Fruits per 100 Blossom Buds	Condition of Blossoms at Time of Spraying
Halehaven Orchard III, 1950				
NAA	pH 2.5	Check	84	All petals were off three days prior to spraying. Had daytime temperatures averaging above 70° F.
NAA	pH 2.5	20	74	
NAA	pH 2.5	60	79	
NAA	pH 2.5	100	75	
"Clark"		Check	85	
"Clark"		20	78	
"Clark"		60	67	
"Clark"		100	70	
Thiozole		Check	77	
Thiozole		20	68	
Thiozole		60	61	
Thiozole		100	65	
Maleic hydrazide		Check	77	
Maleic hydrazide		50	71	
Maleic hydrazide		100	78	
Maleic hydrazide		500	17	

Table VIII (Continued)

Treatment		Concentration (ppm)	Fruits per 100 Blossom Buds	Condition of Blossoms at Time of Spraying
Halehaven Orchard V, 1950				
NAA	pH 2.5	Check	73	90 per cent of
NAA	pH 2.5	20	69	blossoms open.
NAA	pH 2.5	60	78	Temperatures
NAA	pH 2.5	100	78	before and after
				spraying for a
"Clark"		Check	74	three-day period
"Clark"		20	78	averaged above
"Clark"		60	75	70° F. during
"Clark"		100	80	daylight hours.
Thiozole		Check	76	
Thiozole		20	76	
Thiozole		60	81	
Thiozole		100	75	
Maleic hydrazide		Check	75	
Maleic hydrazide		50	70	
Maleic hydrazide		100	62	
Maleic hydrazide		500	27	

Table VIII (Continued)

Treatment		Concentration (ppm)	Fruits per 100 Blossom Buds	Condition of Blossoms at Time of Spraying
Kalhaven Orchard V, 1950				
NAA	pH 2.5	Check	48	70 per cent of
NAA	pH 2.5	20	47	blossoms open;
NAA	pH 2.5	100	51	temperatures in
				the daytime av-
"Clark"		Check	48	eraged above
"Clark"		20	43	70° F. for 3
"Clark"		100	41	days prior to
				spraying and for
Thiozole		Check	50	2 days after
Thiozole		20	51	spraying.
Thiozole		100	63	
Maleic hydrazide		Check	52	
Maleic hydrazide		50	51	
Maleic hydrazide		500	9	

Table VIII (Continued)

Treatment		Concentration (ppm)	Fruits per 100 Blossom Buds	Condition of Blossoms at Time of Spraying
Redhaven Orchard VI, 1950				
NAA	pH 2.5	Check	57	Peaches were 3/4'' long and 1/2'' in diameter; temperature 83° F., bright, sunny day when sprayed.
NAA	pH 2.5	20	29	
NAA	pH 2.5	60	8	
NAA	pH 2.5	100	6	
''Clark''		Check	64	
''Clark''		20	52	
''Clark''		60	63	
''Clark''		100	56	
Thiozole		Check	64	
Thiozole		20	48	
Thiozole		60	59	
Thiozole		100	53	
Maleic hydrazide		Check	59	
Maleic hydrazide		50	47	
Maleic hydrazide		100	48	
Maleic hydrazide		500	65	

Orchard V - Oakland County
Orchard VI - Berrien County
Orchard III - Newaygo County

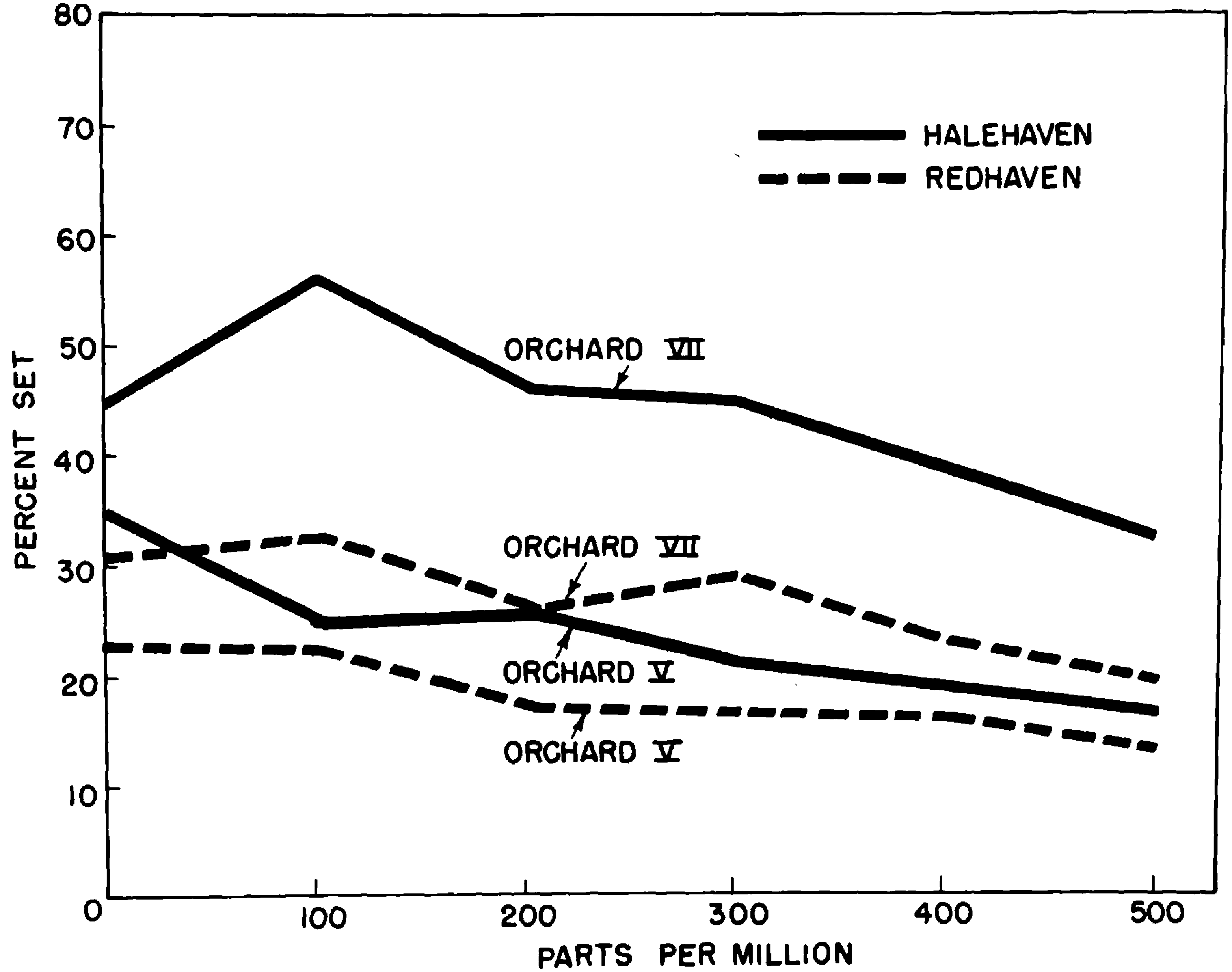

HALEHAVEN
REDHAVEN
ORCHARD VII
ORCHARD VII
ORCHARD V
ORCHARD V
PERCENT SET
80
70
60
50
40
30
20
10
0
100
200
300
400
500
PARTS PER MILLION

Table IX. Thinning effect of maleic hydrazide on Redhaven and Halehaven peaches sprayed during blossoming at two locations in 1951.

Spray Concentration (ppm)	Fruits per 100 Blossom Buds	Condition of Blossoms at Time of Spraying
Halehaven Orchard VII, 1951		
Check	45	90 per cent of blossoms open.
100	46	
200	46	
300	45	
400	39	
500	32	
Redhaven Orchard VII, 1951		
Check	34	All blossoms open; some petals already off.
100	33	
200	26	
300	29	
400	23	
500	19	

Table IX (Continued)

Spray Concen- tration (ppm)	Fruits per 100 Blossom Buds	Condition of Blossoms at Time of Spraying
Halehaven Orchard V, 1951		
Check	35	90 per cent of blos- soms open.
100	25	
200	26	
300	21	
400	19	
500	16	
Redhaven Orchard V, 1951		
Check	33	All blossoms open; some blossoms in the ''calyx'' stage.
100	22	
200	17	
300	16	
400	16	
500	13	

Orchard V - Oakland County
Orchard VII - Genesee County

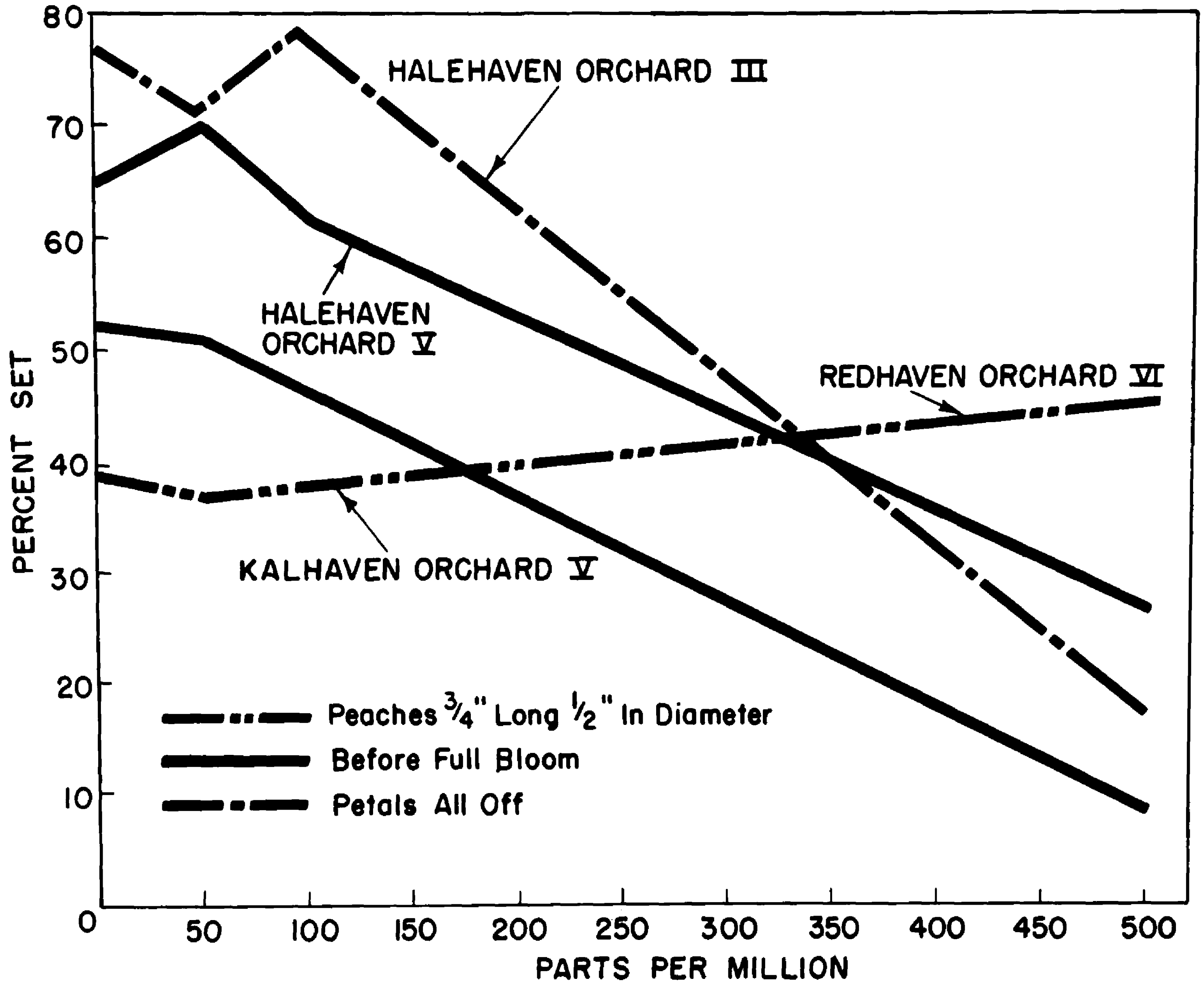

HALEHAVEN ORCHARD III
HALEHAVEN ORCHARD V
REDHAVEN ORCHARD VI
KALHAVEN ORCHARD V
Peaches 3/4" Long 1/2" In Diameter
Before Full Bloom
Petals All Off
PERCENT SET
PARTS PER MILLION
0
10
20
30
40
50
60
70
80
50
100
150
200
250
300
350
400
450
500

Figure 13. Tagged limb showing more vigorous foliage on limb of Halehaven peach thinned heavily in 1950 with maleic hydrazide at 500 ppm.

Figure 14. Fruits removed from spurs 2 mm and 3 mm in size of fruitful Wealthy limb by a naphthaleneacetic acid spray of 20 ppm applied at calyx time.

Figure 15. Wealthy tree spray thinned at calyx time with 10 ppm of naphthaleneacetic acid at full bloom in 1946 and again in 1947, Orchard IX.

Figure 16. Baldwin tree spray thinned at calyx with 2[illegible] [illegible] of naphthaleneacetic acid using a "Lowboy Mast".

Figure 17. Baldwin tree not thinned by spraying, but hand thinned about June drop time.

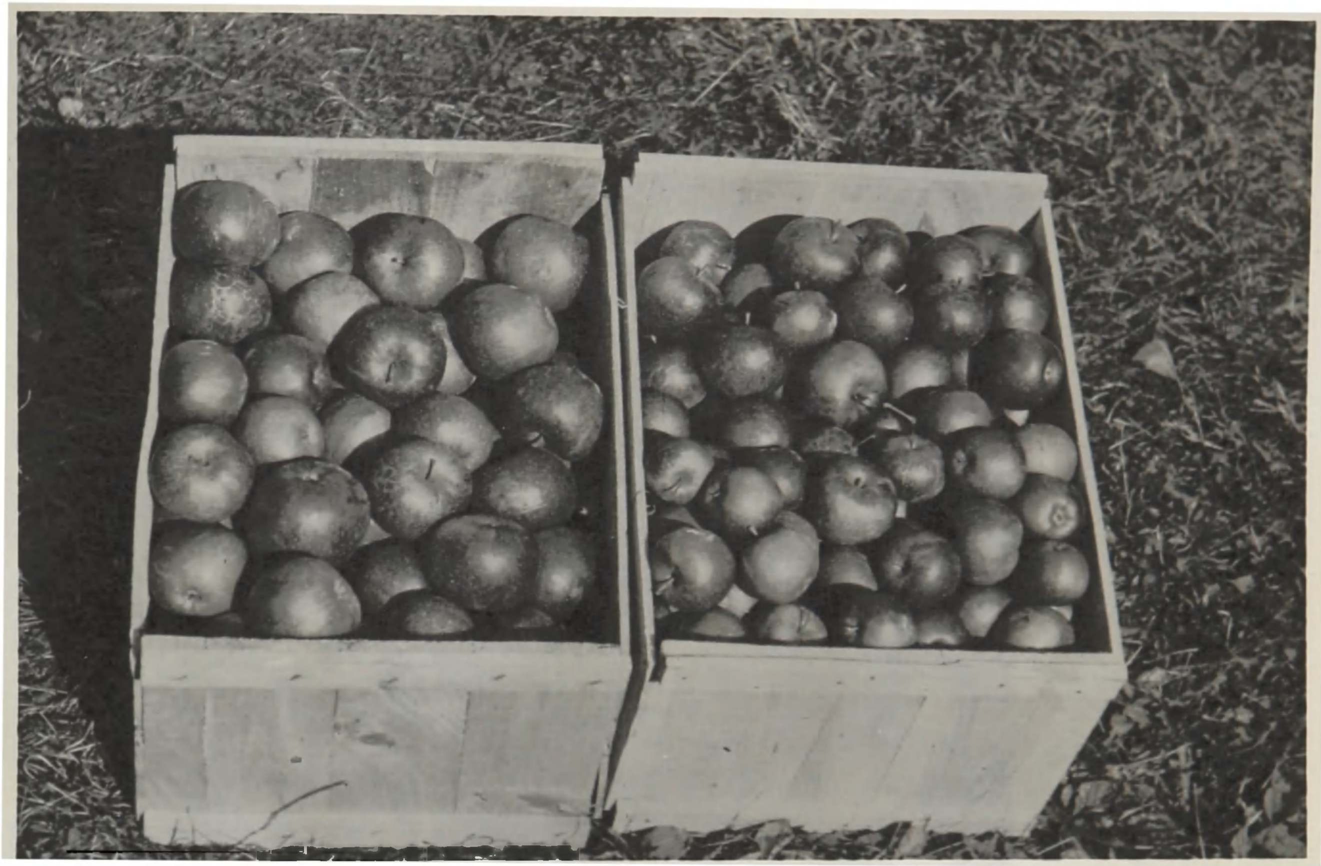


Figure 18. Left: Baldwin apples from spray thinned trees using 20 ppm of naphthaleneacetic acid at calyx time. Right: Baldwin apples from hand thinned trees -- thinning at June drop time.

Figure 19. Varietal response to naphthaleneacetic acid sprays at 20 ppm at calyx time (48 hours after application). Upper left: Wealthy control; Upper right: Wealthy sprayed; Lower left: Oldenburg sprayed; and Lower right: Oldenburg control.

Figure 20. Effect of 2,4-Dichlorophenoxyacetic acid on Stayman variety of apple. Left: Sprayed with 10 ppm at calyx time. Right: Control limb.

DISCUSSION

Spray Thinning of Apples

It seems evident that such factors as climate, soil and nutrition, physiology, variety, and economics must be considered in any problem dealing with growth-regulating substances as blossom-thinning materials for the apple and the pear.

Climatic factors. Temperature, rainfall, and sunlight can hardly be considered separately. They are certainly interrelated in their effect on set of fruit under Michigan conditions. Low temperatures (below 65° F.) are not conducive to pollination or fertilization of the flower. Anthers will not mature and discharge viable pollen until temperatures approach 65° F. Rainfall at blossomtime is invariably accompanied by a cool period of three to five days with temperatures below 60° F. Further, rain may destroy viable pollen, as pollen in water will swell and "explode" in a very short time.

Light is also a factor in fruit set. It is involved in various physiological processes, energy relationships, photoperiod, and other complex and perhaps little understood phenomena involved in plant behavior. During the six years that this investigational work has been carried on, various degrees of climatic factors have been observed to be very important. For example, temperatures below 60° F., excessive rainfall, and very little sunlight are conducive to easier thinning, often resulting in overthinning. Lower concentrations of the thinning agent, as naphthaleneacetic acid, must be used under such conditions. Batjer (2) and others have observed that well cared for orchards of certain varieties will set well, regardless of adverse weather conditions during bloom, but that poorly cared for trees may thin very easily. Inspections of fruit from easily thinned trees has shown an average of one to three seeds per fruit, compared to four to seven seeds in fruit set under favorable weather conditions.

Frost is another factor in fruit-thinning; in fact, it behaves in a manner suggestive of NAA. Thus, in the spring of 1949, observations were made of frost effects in Wealthy Orchard I. Trees located in the hollow or low spot in this orchard were frosted at different degrees of intensity at different heights on the tree. The topmost blossoms of the tree were very slightly frosted, and the bottom blossoms were very heavily damaged by frost. Some of these blossoms had been tagged according to spur diameter preparatory to spraying with NAA. Because of the frost damage, the trees were not sprayed. When the fruit was half grown, it was observed that there was an occasional apple on the upper half of the trees, and these fruits were commonly found on large spurs (4 mm. in diameter) as compared with smaller-sized spurs (2 to 3 mm.). Frost is thus also a selective thinning agent, removing the blossoms from weak spurs first.

This observation suggests that fruit growers should be less concerned about loss of a crop from frost injury following the use of thinning sprays, inasmuch as it is the weakest blossoms which are removed in either event. A confirming observation was made in an orchard in 1949. Part of the orchard had been sprayed with a thinning spray when frost forecasts were received. The remainder of the orchard was left unsprayed. Three nights of frost followed, and slight to heavy damage occurred; yet the fall harvest showed no difference in crop between the thinned and unthinned frosted trees.

Factors of soil and nutrition. Soil and nutrition are also factors in determining the effectiveness of blossom-thinning sprays.

Both of these factors, in turn, affect the vigor of the tree, and it has been shown that trees in good vigor are less easily thinned than trees in poor vigor (Table I). Well cared for orchards which receive annually sufficient fertilizer to satisfy tree requirements, and which are provided with sod covers or sod and mulch systems to preserve moisture and prevent erosion and loss of valuable top soil, develop strong vigorous fruit spurs. In the orchards included in the present study, no drainage problems were found, but according to other investigators (3), trees growing on poorly drained soil have thinned at much lower concentrations of growth-regulating sprays than trees on well-aerated soils. It is probably that soil aeration is affected under these conditions, with accompanying reduction in oxygen supply, respiration, and nutrient uptake. Reduced vigor and reduced fruit set would follow.

Physiological factors. The effect of pruning is associated with vigor, age of spurs, and productive wood of the tree. No one has explained satisfactorily the physiological effects of pruning on the set of fruit. However, a correlation has been shown in the present studies between spur size and fruit set, repeated on several varieties at several geographical locations and for different degrees of pruning. Thinning in every case was more easily attained as the size or vigor of fruit spurs decreased. The observation that weaker wood or smaller buds thin more easily than vigorous wood is substantiated by Batjer (3) and Murneek (48).

Whether young trees would thin with greater difficulty than older trees was not an important consideration in the present studies. However, it has been found that an overly vigorous, succulent young tree may, under certain conditions and with certain varieties, thin as easily as a weak tree. There is evidently much more yet to be explained as to the relation between the physiology of the tree and the responses observed from thinning with growth regulators.

It is interesting to note in the tables of chemical analysis (Tables V, VI, and VII), concerning Wagener apple spurs sprayed with 20 and 100 ppm of naphthaleneacetic acid that no significant differences appear in nitrogen, starch, or sugar content of the spurs, either 48 hours or seven days after treatment. Nevertheless, wilting and petiole curvature was evident at 48 hours, and curvatures persisted for seven days (Figure 19). It seems reasonable to postulate that naphthaleneacetic acid might alter the carbohydrate-nitrogen ratio in treated plants. Yet such does not seem to have been the case (Tables V, VI, VII). It appears that the thinning action by growth regulators is more likely associated with some sensitive mechanism in the plant such as complex hormone, enzyme, or vitamin relationships which accompany fertilization and fruit set.

The idea of such relationships prompted the use of Vitamin K in conjunction with naphthaleneacetic acid thinning sprays on two varieties in 1951, the results of which are given in Table V. While there is some indication of an antagonistic effect of Vitamin K at the higher concentrations, more research on this phase of the problem will need to be done before any conclusions can be drawn. The Wagener apple variety contains three times as much Vitamin C as the McIntosh variety of apple. The Sturmer variety contains more Vitamin C than do citrus fruits. This fact is mentioned to indicate the wide variation in content of particular constituents in the apple. It is reasonable to suggest that as wide a variation exists also with other vitamins, hormones, and enzymes in different apple varieties.

Varietal factors. It has been definitely shown that some varieties thin more easily at lower concentrations of growth-regulating sprays than do others. It is shown in Table I and in the six following graphs illustrating Table I, and also in Table VI, that Jonathan, McIntosh, and Northern Spy blossoms were thinned more heavily at lower concentrations than were Wealthy, Wagener, and Yellow Transparent. It has been noted in other parts of this thesis that there are many variations in the same variety under different conditions. All varieties tested are more susceptible to thinning and wilting and petiole-curling when sprayed at full bloom than when sprayed at calyx. However, some varieties are more resistant to wilting than others. For example, Figure 19 shows the difference between untreated Wealthy and Oldenburg branches and those sprayed with NAA. The Oldenburg variety shows much more wilting and petiole curvature than the Wealthy variety. This condition has been observed to be accentuated when spraying is done during full bloom as compared to spraying at calyxtime. Davidson (6) has made similar observations. It has also been observed that wilting and epinastic curvature are more evident in years of cool, damp blossom periods than in sunny, warm blossom periods. This may be associated with greater synthesis of other hormones, vitamins, or enzymes by the plant under conditions of sunshine and warmer weather. Riboflavin, for example, is known to inactivate indoleacetic acid in the presence of light.

The selective action of 2,4-dichlorophenoxyacetic acid is of some interest. Used at 2.5, 5, and 10 ppm, this material did not affect the McIntosh and Jonathan varieties, but on Stayman the effects were severe. The Stayman trees were not only thinned, but tree growth was seriously checked for six weeks. Figure 20 is from a photograph taken six weeks after spraying.

Economic factors. One of the features of thinning at blossomtime or soon after is the strong tendency that this treatment has to develop annual bearing. Thus, Wealthy Orchard IX has been spray thinned with growth regulators from 1946 through 1951. This orchard, not being too vigorous, has thinned excellently every year with 10 to 15 ppm, and has not missed a good crop of fruit during this six-year period (Figure 15). The Wealthy variety has a strong biennial bearing tendency, but this early thinning, before the fruit has set, has resulted in remarkable uniformity in cropping. It has been observed, however, that as this hormone thinning is continued for several years, the trees become more difficult to thin. This is because the vigor of the trees has been improved and larger diameter spurs have been found which, as is shown in Table I, are more difficult to thin than small-diameter spurs (2 to 3 mm.). The observations have also been made that spray-thinned trees carry a greater load of larger apples than do similar hand-thinned trees. Commercial growers and investigators in several sections of Michigan, and in other apple-growing areas of the United States, have reported similar experiences. Annual bearing, larger size fruit, and greater yield are significant contributions to commercial fruit-growing.

The cost of thinning has been reduced tenfold by spray thinning as compared to hand thinning. This saving in itself could easily be the difference between profit and loss in a large commercial apple orchard. In 1951 nearly one-quarter of the apple orchards of Michigan were spray thinned.

Spray Thinning of Peaches

Much less investigational work has been done in the thinning of peaches with growth regulators than with apples. Such trials as have been made have not given satisfactory results. Likewise, three of the materials reported in this thesis (NAA, sodium thiozole, and "clark") failed to give the desired results.

On the other hand, maleic hydrazide showed promise when used at 500 ppm. But there is no indication that the thinning is selective as regards vigor. Otherwise there would have been more severe thinning in 1951 of trees which had been weakened by winter injury in the latter part of November, 1950. It should be noted that the greatest thinning in 1950 was when the spray was applied before 75 per cent of the buds were open. In 1951, no spraying was done until practically all the blossoms were fertilized. It will be necessary to make more definite measurements of vigor, stage of development, concentrations of spray, climatic factors, soil factors, and perhaps complex physiological factors before it will be reasonably safe to recommend maleic hydrazide for use as a general thinning agent for peaches. It is known, and has been demonstrated, that maleic hydrazide will remove all of the blossoms from some deciduous shade trees at 1,000 ppm without apparent damage to the tree.

It may be possible to use naphthaleneacetic acid for thinning peaches if applied at the time of the June drop. Table III shows in Orchard VI that thinning was accomplished with this material although with excessive damage to foliage. However, it is felt the low pH used may have accounted for some of the burning. Further, other investigators have obtained occasional success with naphthaleneacetic acid without excessive burning. Correlation studies should be made of the length and thickness of terminal growth and stages of bud and flower development in relation to concentration of maleic hydrazide. It is felt that the limited success with maleic hydrazide reported here merits detailed study.

SUMMARY

Naphthaleneacetic acid has been shown to be effective as a blossom-thinning spray for apples in Michigan. Such factors as climate, variety, soil, nutrition, physiology, spray concentration, and time of application influenced the degree of thinning.

A direct relationship was found between spur size and the degree of thinning, large spurs (4 mm. in diameter) thinning with greater difficulty than smaller spurs (2 to 3 mm. in diameter).

Although there were visible responses of the apple to applications of NAA as indicated by leaf curvatures, defloration, and persistence of certain floral parts, there was no apparent effect upon chemical composition as measured by content of nitrogen, starch, and sugars. It is concluded that any chemical alterations are minute in quantity, and of the nature of growth regulators, enzymes, or vitamins; which are not determined by gross chemical analysis.

Other regulating sprays tested for thinning action on apples were either ineffective, such as maleic hydrazide, sodium

thiozole, and "clark," or they caused excessive visual damage to the tree and fruit as did 2,4-dichlorophenoxyacetic acid.

More visual wilting and petiole curvature from spraying at full bloom in comparison to later sprays was noted on Oldenburg variety than on Wealthy variety.

Naphthaleneacetic acid sprays were undesirable for thinning peaches, and is considered still in the experimental stage.

Maleic hydrazide was found to thin peaches quite well at 500 ppm during the seasons of 1950 and 1951, although the set of fruit was still too heavy in 1951 after thinning. No visible injury was observed from the use of maleic hydrazide on peaches at concentrations up to and including 500 ppm.

Thinning peaches with maleic hydrazide appears promising, but must be considered still in the experimental stage.

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