MORPHOLOGICAL STUDIES ON THE TOMATO PLANT FOR PREDICTING ONCE-OVER HARVEST

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MORPHOLOGICAL STUDIES ON THE TOMATO PLANT FOR PREDICTING ONCE-OVER HARVEST

By

Max E. Austin

AN ABSTRACT OF A THESIS

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ABSTRACT

MORPHOLOGICAL STUDIES ON THE TOMATO PLANT FOR PREDICTING ONCE-OVER HARVEST

By Max E. Austin

The high cost of harvesting processing tomatoes and the difficulty of obtaining labor have increased the interest of farmers, universities and machinery manufacturers in developing mechanical harvesters and tomato varieties suitable for once-over harvests. Machines capable of harvesting tomatoes mechanically, and new varieties with concentrated fruit maturity have brought to focus the need for obtaining a method for predicting the date of harvest (earliest once-over maximum yield of ripe fruit) with the highest possible quality.

Temperature, evaporation, solar radiation, minutes of sunshine and combinations of these factors were evaluated but were unsatisfactory for measuring the interval between various morphological characteristics and harvest.

Studies of the growth and development of the tomato plant indicated that one stage of growth (when the base of the stem stopped enlarging) and one stage of flowering (when the fifteenth inflorescence showed color) were significantly correlated with the date of the earliest once-over maximum yield. Time, expressed as number of calendar days, appeared to be the most reliable and efficient criterion for measuring the interval between these potential indices and once-over maximum yield.

Three systems were evaluated for scheduling plantings in order to obtain a sequence of once-over harvests. When plantings were arbitrarily spaced approximately eleven days apart, the harvest dates between

plantings averaged seven, five and eight days apart respectively, for Fireball, C-52 and H-1370.

Two experimental planting systems were also used. One was based on planting when 564°F of the daily minimum temperatures accumulated from a previous planting. This method resulted in planting dates spaced 10 days apart for each variety and harvest dates spaced 9 days apart for Fireball and C-52 and 10 days for H-1370. Plantings in the other experimental system were made when the diameter of the main stem of the previous planting began rapid enlargement. This resulted in planting dates spaced eight days apart for each variety and harvest dates between plantings of seven days for Fireball and C-52 and five days apart for H-1370. Both experimental systems resulted in a usable sequence of harvests.

Successive stem diameter measurements indicated that the stem enlargement approximated a sigmoid curve. To obtain the date that the stem stopped enlarging, a line was fitted to that portion of the curve which showed a linear response and another line was drawn through the average recordings of the maximum diameter. The point of intersection of these two lines was considered as the date the stem stopped enlarging and this procedure was designated as the stem-growth intercept method.

The reliability of cessation of stem enlargement and 15 inflorescences for predicting the date of the once-over maximum yield was tested by processing companies in four midwestern states. The date of cessation of stem enlargement was an effective index (within six days of harvest) in 12 out of 14 plantings. There was a great deal of variation between locations in the interval from 15 inflorescences to the once-over maximum yield.

The influence of different irrigation, fertilizer and spacing treatments and the removal of vegetative and reproductive structures were studied in relation to stem enlargement. Spacing in the row was the only factor that altered the enlargement of the stem. The closer the plants were spaced, the earlier the stem stopped enlarging.

The cessation of stem enlargement, the development of 15 inflorescences and the transplanting date were compared as methods of predicting the harvest date in 62 plantings over a three-year period. The date of cessation of stem enlargement was the best index to predict the date of once-over maximum yield for a mechanical tomato harvester.

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INTRODUCTION

One of the outstanding challenges for horticulturists has been to develop techniques for predicting harvest maturities. Numerous indices for predicting harvest dates of annual crops such as peas, sweet corn and beans have been formulated and some success has been experienced in correlating various climatic factors and morphological characteristics with maturity. However, no successful method has been found for predicting the earliest once-over maximum yield of ripe tomato fruit[1].

With the advent of mechanical tomato harvesters, a means for predicting the harvest date became more critical. The mechanical harvesting of processing tomatoes was stimulated by the high harvesting cost of the relatively low value per acre crop and by the difficulty of obtaining labor for hand harvest (2, 4, 5, 20, 72).

Several machinery manufacturers and two universities have developed experimental machines capable of mechanically harvesting tomatoes. Although the principle of operation and details of construction are different for each machine, all are based on a "once-over" principle in which tomato plants are cut near the soil surface and elevated to a separating unit where the fruit is shaken from the plant and elevated again, sorted and placed in containers.

Workers in several states (3, 36, 70, 76, 77) are attempting to develop varieties with features more suitable for a once-over machine harvest. Desirable characteristics include: concentrated fruit set,

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[1] Since the phrase, "earliest once-over maximum yield of ripe tomato fruit" is awkward to use, it will be referred to as harvest date or once-over maximum yield.

firm flesh, uniform red color, and jointless character, i.e., tomatoes free of stems. Also, varieties with different maturity dates are needed to extend harvest operations over a four to five-week period.

The objectives of this research were to study the growth, development and fruiting habit of the determinate-type tomato plant; to attempt to correlate at least one factor with once-over maximum yield; and to develop an objective method for predicting the harvest date for a once-over mechanical harvest. Also, the successful prediction of the harvest date early in the growing season would aid in planning harvesting schedules for uniform deliveries to the processing plants.

In 1961 many morphological and fruiting characteristics of three determinate tomato varieties were observed and attempts were made to correlate these with the once-over maximum yield using time and/or climatic conditions. Studies were expanded in 1962 and 1963 to evaluate two potential indices for predicting the harvest date.

The influence of direct-seeding and transplanting dates on earliest once-over maximum yield was studied. Miscellaneous experiments were conducted in which the rate of growth was altered. The development of various vegetative and reproductive structures were related to each other.

LITERATURE REVIEW

Growth and Development of the Tomato Plant

The tomato plant (Lycopersicum esculentum) exhibits two distinct patterns of growth. Both types result from a sympodial pattern of development. Gray (22) and Hayward (26) defined sympodial growth as a stem made up of a series of superposed branches that resembles a simple axis and is terminated in an inflorescence. One type of growth, referred to as indeterminate, develops a new axis or branch from an axillary bud located in the axil of the leaf on the opposite side of an inflorescence. The vigorous growth of the axillary bud forces the adjacent inflorescence to one side: the branch bears its leaves and is terminated like its predecessor with an inflorescence. This mode of development may be repeated many times until the axis is several feet long, bearing inflorescences throughout its length. The determinate type of sympodial growth consists of the axillary bud being suppressed while the main axis develops one to two inflorescences and then terminates in an inflorescence. Additional vegetative growth may occur from other axillary buds which, in turn, produce one to two inflorescences before termination and the process repeats itself many times.

It is frequently desirable to express quantitatively the amount of growth during a given period of time. The principal indices which have been employed for this purpose are (a) elongation of the stem, root or other organ of the plant (35, 40, 52, 85, 90); (b) increase in leaf area (16, 66, 91); (c) increase in flowers and fruits (39, 65, 91); (d) dry weight increment (13, 41, 71, 86, 91); (e) fresh weight increment (66, 71) and (f) increase in stem diameter (65, 66, 67).

Generally, the growth rate of a plant or any portion is relatively slow initially, increases rapidly to a maximum, and finally decreases until it ceases. When the rate of growth is plotted against time, a typical sigmoid curve is obtained.

A number of methods of expressing growth rate have been devised for the mathematical expression of the growth curves of plants. A complete literature review of all contributions pertaining to this subject would be too voluminous for this thesis. However, the citations that follow are considered essential.

Robertson (64) proposed that the rate of growth is a monomolecular autocatalytic reaction. This reaction is one capable of self-catalysis, one product of the reaction acting as a catalytic reagent. A reaction of this type presents a typically sigmoid-shaped curve. According to Miller (48), Robertson proposed that growth is an autocatalytic reaction where an enzyme governs the growth rate. Reed (58) and Murneek (50) reported that the rate of growth follows approximately that of an autocatalytic reaction. They found a similarity between the observed and calculated growth values and concluded that the rate of growth is goverened by constant internal factors rather than by external factors.

The growth rates of many annual plants, at least in their early stages, follows approximately the compound-interest law (9). A formula to calculate the rate of growth by using the relationship between leaf area and increase in dry weight to express the compound-interest law was developed by Briggs, Kidd and West (13). Using the formula developed by Briggs, Kidd and West (13), Luckwill (41) reported that the rate of growth of tomato plants, as measured by dry weight, increased up to fifteen weeks after seeding and after that time showed a steady decline.

During the pre-flowering period of the life cycle of the tomato plant, Ashby (7) found that leaf number increased in a linear manner with time. This relationship of leaf number with time was found by Luckwill (41) to be an exponential function during the period of flowering and linear during the pre-flowering period. This difference is explained on the basis of the occurrence of branches at the time the first inflorescence is formed; hence, from that time onward the increase in leaf number becomes an exponential function with time because of the increase in the number of branches.

A few studies have been made on the structural development of the tomato plant. The growth rate of different internal tissues is not the same. For example, the vascular cylinder enlarges faster, the pith increases in cross-sectional area at the same rate and the cortex develops more slowly than the diameter of the stem (29). Venning (81) concluded that expansion and vacuolation of pith and cortical cells contribute to the increase in diameter of young stems, although cell divisions in these tissues also play an important part. He considered that primary growth ceased upon the development of a lignified cylinder in the axis and attributed secondary increase in diameter to radial divisions of cells in secondary xylem, cambium, pericycle, starch sheath and cortex, rather than to cells formed tangentially from faces of the cambium.

Morphological measurements were made at weekly intervals on selected internodes by Thompson and Heimch (78). The fourth internode from the base of the plant was the lowest internode they studied. After initial elongation of an internode, maximum length was attained and no further changes occurred. The internodes in the lower region of the plant increased in length over a longer period than higher internodes,

but the higher internodes were distinctly longer.

Factors Affecting Growth and Development of the Tomato Plant

Many factors influence the growth and development of plants, but only findings pertinent to this study will be discussed.

Growth is generally considered a function of two variables. The first is the genetic constitution of the individual, and the second is environment (57).

Powers, Locke and Garrett (55) have reported that the interval from seeding to tomato maturity is governed by three different groups of genes. These authors reported that one group of three genes affects the interval from seeding to first bloom, another group of three genes affects the interval from first bloom to first fruit set, and a third set of genes governs the interval from first fruit set to first fruit maturity. They reported that the effects of these genes are cumulative.

Griffing (23) analyzed tomato yield components in terms of genotypic and environmental effects and reported a positive correlation between the number of inflorescences and number of fruits per inflorescence. He stated that this positive correlation represented different manifestations of essentially the same set of genes and interpreted it to mean that the genes act in essentially the same fashion on both the number of inflorescences and number of fruits. These genes evidently determine the number of reproductive structures.

Murneek (51, 52) reported that the morphological characteristics of a tomato plant is determined not only by its genetic constitution and the nature and intensity of environmental factors, but likewise by the relationship of the vegetative development and fruiting of the plant.

When tomato plants were deflorated or the fruits were removed as rapidly as they set, the plants continued to grow vegetatively. If, however, the fruits were allowed to remain on the plant and enlarge, vegetative development and the formation of flowers gradually slowed down as more fruits began to develop. The effects of fruit on the growing points could be localized to one half or part of a tomato plant. He found that the vegetative development of plants low in nitrogen was inhibited by a single fruit but when the fruit was removed the plant grew normally, flowered and set fruit. However, plants with abundant nitrogen required as many as 30 fruit to inhibit vegetative development. Murneek stressed the negative correlation between vegetative development (as measured by increments of height) and fruit set and development He pointed out that nitrogen was an immediate limiting factor affecting these influences of correlation. Similar results were reported by Lachman (37) and Nicklow and Minges (53). Arnon and Hoagland (6) found that no negative correlation existed between growth and fruit set. On the other hand, flowering and fruiting was reduced in tomato plants when the vegetative growth was very vigorous (16).

The growth and development of plants is influenced by many climatic factors. However, according to McLean (47) most of the early investigations in this field have been attempts to correlate growth and development generally with only temperature and rainfall. Blackman (10) stated that of the climatic factors which influence the distribution of plants, water supply was most important followed in order by temperature and light.

Abbe (1) reported that one of the earliest works on the study of the relation of temperature to the growth phenomenon in higher plants

was that of Réaumur (56) in 1734. He made comparisons of different quantities of heat required to grow a plant up to a given stage of maturity.

Nightingale (54) studied the effect of temperature on the development of the tomato plant and explained the results in terms of its effect on the net daily increment of photosynthate. Plants were grown in sand nutrient solutions of low, medium and high nitrogen concentrations. After six weeks of nutrient treatment, the plants were placed under continuous temperatures of 55, 70 and 95°F. Plants at 55°F accumulated carbohydrates in large quantities, indicating that daily photosynthesis exceeded daily respiration. At 95°F with the low and medium nitrogen treatments, the carbohydrate content of plants decreased rapidly, indicating that daily respiration exceeded daily photosynthesis. Accompanying the decrease in carbohydrates there was an acceleration in growth for a few days which was followed by death of the plants. At 70°F low nitrogen plants were not as high in carbohydrates as similar plants at 55°F. Nitrogen absorption was instantaneous and translocation was slightly more rapid at 70°F than at 55°F.

Numerous studies have been conducted to study the effect of temperature on carbohydrate translocation and it has been established that a Q_{10} of more than one results with increasing temperatures up to 30°C (11, 12, 18, 28, 31, 74, 75). However, there have been a few papers reporting a Q_{10} of less than one with increasing temperatures in the tomato plant. Went (85, 86) and Went and Engelsberg (87) reported that the rate of translocation is increased at lower temperatures. Hewitt and Curtis (28) criticized the interpretation that translocation was faster at lower temperatures. They stated that respiration is

increased at higher temperatures and hence, transport at the source is lessened since the reserves are expended.

Later Went and Hull (88) and Hull (30) indicated that carbohydrates are translocated independently of temperature, or even that transport is inhibited at higher temperatures. Hull measured the rate of translocation through an area of tomato stem chilled to between one and three degrees Centigrade by use of labeled C^{14} sucrose. He found that at lower temperatures translocation was equal to or greater than at higher temperatures. On the other hand, Böhning, Kendall and Linck (12) reported that translocation in the tomato plant is retarded by low temperature and accelerated by high temperature. They measured the rate of leaf elongation of tomato plants in the dark as associated with the movement of a 0.4 M sucrose solution through petioles jacketed to give temperatures of 12, 18, 24 and 30°C. They found the greatest leaf elongation through the 24°C petiole and therefore concluded that this was the optimum temperature for carbohydrate translocation in the tomato plant.

Went (84) has shown that the tomato plant is thermoperiodic, that is, the growth rate of the plants was markedly influenced by the pattern of the temperature cycle to which they were subjected. He found that, when grown under a constant temperature, the maximum rate of elongation of the tomato stems was more than 40 centimeters high and it occurred at 26.5°C, but that elongation was still more rapid if the plants were exposed to a 26.5°C daytime temperature alternating with a 17 to 20°C night temperature. Went (85) also pointed out that optimum temperature for different physiological processes may change with the age of the plant.

The daylength or photoperiod is very important for the vegetative

development of the tomato plant. The rate of stem elongation decreased sharply at less than four hours of light per day. Beyond this photoperiod Went (86) found increasing dry weight production and stem elongation by increasing the length of the photoperiod. In later publications (89, 90) he reported that the rate of stem elongation of tomato plants was more dependent upon the temperature in the dark period than in the light period, and the optimum night temperature decreased with increasing size of the plants. He stated that 80 to 90 percent of the growth occurred during darkness under natural conditions. These findings were qualified by Kristoffersen (35) studying the interactions of photoperiod and temperature in the growth and development of young tomato plants approximately five centimeters high. By exposing young plants to various light-dark cycles at 20°C, and then in continuous light for 24 hours, he found that elongation (followed by the use of a millimeter ruler and a special auxanmeter) started at a relatively low rate at the beginning of the first light period, increasing gradually, and varied between seven and 13 units per hour during the light period. As soon as the light was turned off, there was a great increase in the rate of elongation. This increase started usually five to ten minutes after the beginning of the dark period. Later, the rate decreased rapidly, and when the dark period exceeded four hours, the final rate was lower than in the light. When the light was turned on again the rate increased, and after a couple of hours the rate of elongation was more or less stabilized.

Ketellapper (32) found that reductions in the growth of tomato plants caused by unfavorable temperature can be prevented to a certain extent by adjusting the length of the light-dark cycle under which the plants are grown. The cycle length which rpodeuced optimal growth was

27 to 30 hours at 14°C, 22 hours at 23°C and 20 hours at 30°C. He concluded that peanut and tomato plants, grown under controlled conditions, possess an endogenous, time-measuring mechanism, which is slightly temperature dependent, and that for optimal development the external period must be synchronized with the endogenous period of the plant.

Bandurski et. al. (8) reported that tomato plants grown under varied day and night temperatures differ in growth habit, anatomical structure and leaf color. Leaf color increased when the night temperature was held constant at 17°C and the day temperature increased from 4 to 30°C. The concentration of carotenes increased 13-fold and chlorophylls 260-fold. Decreased leaf color associated with increased night temperatures was not similarly associated with pigment concentration.

Recently Haun (24, 25) reported on the relative influence of temperature, available soil moisture, solar radiation and daylength on the rate of leaf development of corn, kenaf (an experimental fiber crop), crambe (a potential source of valuable industrial oil), and tephrosia (under study as a source of the insecticide rotenone). A mathematical equation was developed to predict the rate at which a plant will grow in terms of the relative contribution of each environmental factor during any month of the season. A new method was employed for making a daily record of plant growth by observing the structural changes in a leaf as it unfolds and recording in tenths of the total process of leaf unfolding. Multiple regression analyses provided data that showed the influence each environmental factor had every day on each crop. In addition, the statistical analyses provided a measure of the influence of each environmental factor for 1, 2, 3, 4 and 5 days previous to a specified day of recorded plant growth rate. The analyses also accounted for the amount of lag between influence and plant

response for the entire growing season. To test the accuracy of the equation, the expected development of kenaf was plotted for June, July, August and September. Then the actual growth rate of test plants was recorded on a simple linear graph. The two lines were significantly correlated.

Several investigators have reported on the effect of tomato transplant age on yield of ripe fruit. Kitchin (33) pricked out tomato plants of the Rutgers variety two and four weeks after seeding and transplanted in the field from each pricking out series six, seven eight and nine weeks after seeding. It was concluded that pricking out two weeks after seeding and transplanting four weeks later, gave better performance than any other combination. Sayre (68) reported that there was no advantage in either early or total yield from transplanting tomato plants of the John Baer variety more than eight or nine weeks old. He also stated that 6 or 7-week-old plants may give as large or larger yields. Casseres (15) compared 7, 11, and 15-week-old transplants of the Earliana variety and concluded that both early and total yield favored sowing the seed seven weeks prior to transplanting. Similar results were shown by Nicklow and Minges (53) with the variety Fireball. As the age of transplants increased from three to nine weeks before setting in the field, yield and fruit size decreased. They concluded that the yield appeared to be dependent on the physiological age and not the chronological age, of the transplant. On the other hand, fruit size was directly related to the chronological age as young transplants produced larger fruits than older ones regardless of the physiological stage of development.

Interval Between Stages in Vegetative Development, Flowering, Fruit Setting and Fruit Production

Tomato seedlings which were exposed to night temperatures of 80°F and a 16-hour photoperiod from emergence until pricking out produced ripe fruit approximately ten days earlier than those for the same duration at 60°F with the same photoperiod or those at 80°F with a 10-hour photoperiod in greenhouse experiments by Learner and Wittwer (38). They concluded that a 16-hour photoperiod promoted earliness and larger total yields. Also, temperatures of 80°F during the cotyledon stage only promoted earliness.

Wittwer (93, 94) reported that the time of the first flush of tomatoes on the fresh market in Michigan is determined by night temperatures favorable to fruit setting. He has reported that 45 to 50 days are normally required for fruit to ripen after it is set. Wittwer's research with growth regulators indicated success in increasing early yield and size of fruit for tomatoes which bloom during unfavorable temperature periods; but, when night temperatures were favorable, little or no response was observed except that fruits were slightly larger.

The interval between transplanting and first harvest of tomatoes of the Rutgers variety has been measured by Kitchin (33). The interval was measured in calendar days and degree days above 50 and 60°F. He concluded that degree-day accumulations above 50°F appeared to be the most consistent; however, none of these gave an accurate and reliable index from which to predict harvest date at transplanting time. In another experiment, Kitchin (34) also measured the length of the interval from anthesis to fruit maturity with calendar days and degree days above 50 and 60°F. He found no difference in the reliability of

measuring the interval in degree-day accumulations or calendar days. The length of the interval varied with anthesis date. An average of 54, 57 and 63 days elapsed between anthesis and fruit maturity for flowers which bloomed in June, July and August, respectively.

During the years 1937 and 1938 Stier (71) calculated heat units above base temperatures of 40, 45, 50, 55 and 60°F for three physiological periods of growth of tomato plants of the Marglobe variety for five or six planting dates. The first four transplanting dates in 1937 were at approximately two-week intervals between May 8 and June 20. For these four plantings, heat unit summations above 55°F gave him the lowest standard deviation for the interval from transplanting to anthesis of the first blossom. The later the transplant date, the more heat units were required. For the intervals from anthesis of the first blossom to fruit maturity and from transplanting to maturity of the first fruit, heat units above 60°F gave the lowest standard deviations. The number of calendar days between anthesis of the first flower and fruit maturity for the two years ranged from 35 to 47, with the greatest concentration between 41 and 45 days. Stier concluded that under natural conditions in Maryland, 45 days were required from anthesis to fruit maturity.

Unger and Fabig (80) have shown that the time from transplanting to the first ripe fruit of the variety Quedlinburger Frühe Liebe varied from 50 to 68 days in the years 1947 to 1952, and in the case of the variety Rheinlands Ruhm from 71 to 88 days. The interval showed no satisfactory agreement between temperature sums or heat units in different years. They did find that early ripening varieties can be distinguished in that they may reach their optimum vegetative development at relatively low night temperatures, whereas the night temperatures for optimum

development of later ripening varieties were appreciably higher. They concluded that the period from transplanting to blossom appeared to be of particular importance for the total fruit yield.

Molenaar and Vincent (49) found that the date of maturity of tomatoes of the Stokesdale variety could be altered slightly by the amount of water applied by sprinkler irrigation. Plants which received heavy applications of water matured their fruit slightly later than plants which received less water.

Wright, Pentzer and Whiteman (97) tagged freshly opened flowers of the varieties Marglobe and Globe periodically between July 8 and August 31. Their study was concerned primarily with the effects of various temperatures on the ripening and storage of tomatoes after harvest; however, they did report that 42 days after blooming, fruit showed a whitening about the blossom end but no pink or red color was apparent.

Estimating Potential Yield of Tomato Fruit

Reeder (59) reported two systems for estimating the yield of ripe tomatoes. Fields were classified as good, fair or poor and estimates were made on this basis. In the pre-harvest period, fruit one inch and over in diameter were counted at weekly intervals. One-fifth of a ton of tomatoes per acre was estimated for every one inch fruit counted. Reeder stated that the size of yield and the date of harvest could be predicted 42 to 45 days after the one inch fruit count. Yield estimates were also made during the harvest period. The average number of fruit per vine that will be ripe the following week divided by three gave an estimate of the tons per acre of tomatoes to be harvested the following week.

Similarly, the Campbell Soup Company (19) and Marlowe and Brown (42) counted the number of fruit present on several plants in each of many fields, and by an arithmetic formula involving size of fruits and number of plants per acre, estimated tons of ripe fruit per acre. Reeve _et_. _al_. (61) reported that an estimated potential tomato yield was calculated using the means for total number of inflorescences per acre on August 14, fruit per inflorescence and fruit size. August 14 was 81, 91 and 99 days respectively from three transplant dates. It was assumed that all fruit set by August 14 would mature before frost. The mean killing frost date in the area where the experiment was located was October 15. The data indicated that only one third of the calculated yield was harvested.

Kitchin (34) in seeking a method of predicting the potential yield of tomatoes, indicated that inforescence development was a practical index to use. His data showed quite conclusively that fruit production over a four-year period was correlated with reproductive structures that had been developed four to six weeks after transplanting.

Wang (83) proposed that the size of tomato yield could be explained by using graphical methods for analysis of environmental and crop data. He stated that temperature and rainfall were found to be the two most crucial factors responsible for tomato yields. It was found that low yields were correlated primarily with four climatic conditions; the frequency of warm or cold spells, the relative maximum rainfall, the relative minimum rainfall and the total high or low rainfall during the blossoming period. Wang defined relative maximum and minimum rainfall as the highest and lowest accumulation of rainfall during a given period of weeks in the growing season. These two periods were the wettest and the driest relative to the entire season, provided that

rainfall was a measure of moisture. High or normal yeilds were correlated with temperature and rainfall that were near optimum or balanced out during the blossoming period. However, Wang did not use these data to predict the size of yield.

The effects of different water-regimes on the yield of tomato plants grown under glass were studied by Salter (67). He indicated that when plants were grown in a sandy loam at field capacity, further applications of water to the plants before they fruited reduced the final yield of fruit. After fruiting had started, maximum yield was obtained from plants growing in soil maintained near field capacity.

Carolus (14) has shown that to obtain a high tomato yield in the field when the seasonal rate of evaporation was high, it was necessary to maintain a higher level of soil moisture by irrigation than when the seasonal rate of evaporation was low.

The size of tomato yield has been correlated also with solar radiation and sunlight. Wittwer (92) grew tomato plants in the greenhouse during the spring and fall seasons and observed lower yields in the fall. The variation in yield was attributed to differences in solar radiation since all other apparent environmental conditions were similar for both seasons. Similar results were obtained by Hemphill and Murneek (27) when they compared yields of four crops of field tomatoes with the amounts of sunlight available each year.

Recently Wittwer and Robb (95, 96) stated that extra carbon dioxide (800 to 2000 ppm) partially compensated for a lack of sunlight when sunlight was a limiting factor during the winter. With carbon dioxide enriched greenhouse atmosphere, the yield of fruit was greater by increasing fruit set and individual fruit size at the expense of vegetative

growth. However, plants grown in the increased concentration of atmospheric carbon dioxide required temperatures five to 10°F higher than normal, and larger quantities of fertilizer and water must be applied earlier in the growing season.

Predicting the Time of Harvest

The need for a mechanical harvesting schedule in order to obtain a sequence of once-over harvests had been recognized by Ries and Stout (62), Younkin (98) and Zoebisch (99).

In 1959, Ries and Stout (62) evaluated the potential of ten tomato varieties for a once-over mechanical tomato harvester. They recognized that a decision had to be made on when to harvest to obtain a once-over maximum yield. The best criteron that they observed was to harvest when one or two fruit per plant started to deteriorate.

Work was initiated in 1959 by Massey and Peck (43) to ascertain to optimum time for harvesting tomatoes machanically. A determinate breeding line, No. 2657, was used, but the planting date was not given. A once-over harvest of all fruit, followed by storage ripening of the unripe fruit, was compared to weekly pickings of only the fully ripened fruit. Seven weekly harvests were made between August 26 and October 9. Yields were reported as percent of various maturity classes based on the total of accumulated pickings of ripe fruit as 100 percent. The yield of ripe fruit from the once-over harvest increased from about 20 percent on August 26 to a peak of 75 percent on September 9. Subsequent harvests exhibited a decrease in ripe fruit as a result of over-ripe fruit.

Zoebisch (99) stated that some varieties which have a concentrated fruit maturity tend to ripen about the same time, even if planted a week earlier or a week later. In some locations, direct-seeding could shift maturity from ten to 14 days from that of transplanting.

Teubner and Waddington (76, 82) recognized the problem of proper planting times for successive fields so that the once-over mechanical harvest of tomato fields would provide a uniform flow of fruit to the processor. For this purpose, the dwarf variety Epoch was direct-seeded on April 14, April 23, May 7 and May 28. Two rows were planted on each date and one of these was sprayed with N-m-tolylphthalamic acid when the plants were three to four inches high and then again, one week later. The sprays were applied to increase the number of flowers in the first and second inflorescences. The probable harvest date was predicted on the basis of information obtained on growth rates from studies under controlled environment conditions, but this information was not given. Also, there was no mention as to the number and frequency of once-over harvests made but only that once-over harvests were made when the rate of rotting was estimated to be near the rate of ripening. These authors presented data showing that the harvest date of non-treated plants was predicted with considerable accuracy for all but one seeding date. The number of days from each of the four seeding dates to a maximum yield of ripe fruit was 138, 137, 142, 123 respectively. They also reported that the dates of direct-seeding in the field were scheduled for a sequence of maximum fruit production, using a 50°F base temperature and 3,000 degree days. It was found that the chemical treatment increased the yield but the harvest was delayed for two days to three weeks.

Tomes, Johnson and Stevenson (79) direct-seeded the varieties Epoch and Tecumseh to determine whether a peak harvest could be scheduled. There were four seeding dates and it was found that both varieties yielded progressively less the later the seeding date. Harvests were made on each of four dates and a peak yield was obtained on the third and fourth harvest dates. Considering the four seeding dates of the Epoch variety, the date of the peak harvest was shifted. One hundred and twelve to 114 days elapsed from seeding to peak harvest for each planting.

Massey _et_. _al_. (44, 45, 46) working with the varieties Fireball, Red Jacket and Glamour, presented data showing that once-over harvest yields increased with increased time from planting. Certain trends were apparent in total acid, pH, soluble solids and color between fruit of differing once-over harvest dates, however these differences were minor. Similar work was reported by Ries _et_. _al_. (63) using uniform plantings of the varieties Fireball and Libby C-52 which were divided into 15 plots each and assigned five harvest dates with three replicates each. On these dates a simulated mechanical harvest was made by hand and the total amount of ripe, green and deteriorated fruit determined. Samples of ripe fruit were taken and processed for each variety at each harvest date. Both varieties responded similarly in that a peak yield was obtained 97 days after transplanting and did not change for three harvests over an 11-day period. Although the yield of ripe fruit did not decrease, juice yield and total acid decreased. The pH increased and the soluble solids did not change during the 11-day period.

Recently, Marlowe and Brown (42) proposed a system from several methods tried to predict the date for maximum harvest of tomatoes for processing. Six once-over harvests and the conventional multiple harvest were made using three planting dates of three varieties. Orthogonal regression comparisons were used to determine peak harvest dates. Data

were presented comparing the date of cessation of stem diameter enlargement, one-half and one inch fruit counts, calendar days, heat summations for three phenological events at eleven base temperatures, and the proposed method -- fruit size intercept. This latter method utilizes the one-half and one inch fruit count plotted against time. The number of days from the date of the intercept of these count lines was found to be in the reliability range as the cessation of stem enlargement. The time interval to the peak harvest date from the date the fruit size intercepted was greater than the interval from the date of cessation of stem elargement and as stated earlier, fruit counts provide a means to predict the size of yield. It was found that the fruit size intercept method granted 40 days to the first commercially important harvest and 55 days to a peak harvest.

Plant growth and yield of ripe fruit are influenced by both genetic and environmental factors. The rate of plant growth and development has been correlated with many environmental factors. However, this information was not applicable for determining the time of once-over harvest. The interval from various stages of plant growth and development to the first ripe fruit has been observed by many researchers. Attempts were made to estimate yield using development of reproductive parts or climatic factors, however tomato yields still cannot be predicted with accuracy. Also, though some contributions have been made on predicting the time to harvest, there was no evidence prior to 1960 relating morphological changes to the occurrence of the earliest maximum yield.

PROCEDURES AND RESULTS

General Cultural Practices

Cultural practices for tomato plants were similar throughout the study. There were two sources for transplants. Plants grown at East Lansing are designated East Lansing transplants. Others provided by processing companies and grown in southern areas. These are designated as southern-grown transplants. The varieties were Fireball, Libby C-52, Heinz 1350, Heinz 1370 and Campbell 1327. The latter will hereafter be referred to as C-52, H-1350, H-1370 and C-1327, respectively.

Seeding was either direct in the field or in flats in the greenhouse for the majority of the plantings. The greenhouse seedlings were pricked out two weeks after seeding and transplanted in the field approximately four weeks later. Southern-grown transplants were set within 24 hours after delivery in most cases. The seeding, pricking out, and transplanting dates for all plantings at East Lansing, Michigan for the three seasons are given in Table 1. The initials D.S. designates direct-seeded and T.P., transplanted.

Plantings were either on a Hillsdale or Wauseon sandy loam at the Michigan State University Horticulture Research Farm or on unknown soil types in three other midwestern states.

Rows were five feet apart with plants 12 inches apart where direct-seeded and 16 to 18 inches apart for transplants.

Standard pest control, cultivation, fertilizer, and irrigation practices were followed throughout.

Weather Observations

Temperature records in 1961 for both day (sunrise to sunset) and

Table 1. Varieties and dates for seeding, pricking out and transplanting for three seasons at East Lansing, Michigan.

Season	Variety[1]	Planting[2]	Date Seeded	Pricked out	Transplanted
1961	1,2,5	D.S.	5/4	-	-
	1,2,5	D.S.	5/17	-	-
	1,2,5	T.P.	4/4	4/18	5/22
	1,2,5	T.P.	4/18	5/2	6/2
	1,2,5	T.P.	5/3	5/17	6/14
1962	2	T.P.[3]	-	-	5/14
	4,5	T.P.[3]	-	-	5/18
	2	T.P.[3]	-	-	5/21
	3,4,5	T.P.[3]	-	-	5/24
	4,5	T.P.[3]	-	-	5/28
	1,2,5	D.S.	5/4	-	-
	1,2,5	D.S.	5/17	-	-
	1,2,5	T.P.	4/3	4/17	5/15
	1,2,5	T.P.	4/13	4/27	5/21
	1,2,5	T.P.	4/13	4/27	5/25
	1,2,5	T.P.	4/23	5/7	6/1
	1,2,5	T.P.	4/23	5/7	6/4
	1,2,5	T.P.[4]	4/27	5/11	6/5
1963	3,4,5	T.P.[5]	-	-	5/24
	3,4,5	T.P.[3]	-	-	5/27
	1,2,5	T.P.[6]	4/12	4/26	5/27
	4	T.P.[7]	4/16	4/29	5/31

[1] Variety - 1 = Fireball, 2 = C-1327, 4 = H-1350 and 5 = H-1370.

[2] Planting - D.S. = direct-seeded, T.P. = transplanted.

[3] Southern-grown transplants.

[4] East Lansing transplants used in an environmental study.

[5] Southern-grown transplants used both in large plantings and in the study of plant structure removal on the growth of the tomato stem and time of harvest.

[6] East Lansing transplants used in growth rate study.

[7] East Lansing transplants used in an arithmetic spacing design.

night were derived from Ryan thermographs. Only maximum-minimum thermometers were used in 1962 and 1963. These instruments were housed three to six inches from the soil surface in United States Weather Bureau small-sized shelters.

Records of precipitation, solar radiation, evaporation and wind velocity were available from an official United States Weather Station within 200 yards of the tomato fields.

The 1961 weather conditions were favorable during the growing season. The average 1961 temperatures for the months June, July, and August were within a degree of the 50-year average. The September average was six degrees higher than the 50-year average. The average 24-hour maximum and minimum temperatures for the harvest period were 80°F and 58°F, respectively. However, the harvest period of August 11 to September 28 was generally moist. During the 48-day harvest period, there were 17 days of precipitation totaling 7.0 inches. Also, there were four days in which a trace of precipitation was recorded. This amount of precipitation was 1.5 inches for the month of August and one inch for September more than the annual average.

The weather was generally cool and dry during the transplanting period of May 14 to June 4, 1962. During the 21-day planting period, only 0.2 inch of rain fell. Temperature and precipitation were normal during the growing season, however, several cool nights occurred in August and September.

The 1963 growing season generally was unfavorable. At East Lansing the minimum temperature dropped to 26°F on May 23 and to 32°F on May 24 approximately 20 hours after transplanting. The average maximum temperature for the month of June was 7.6° above normal. The total precipitation

was a normal 4.1 inches, with 4.0 inches falling between June 7 and 10. The average monthly temperature for July was normal; August was 1.8° below normal. The precipitation for these two months was 1.8 and 0.4 inches above the normal respectively. The last rainfall was recorded on September 12.

Frankfort, Indiana was hot and very dry, with only 2.0 inches of precipitation for June, 1963. On the other hand, mean temperatures for July and August were 3.6° and 5.3° below normal, and precipitation was 2.5 and 0.7 inches above normal respectively. The last rainfall was recorded on August 28, 1963. At Waterman, Illinois, a frost was reported three days after transplanting in the field.

Statistical Techniques

Successive measurements of stem diameter indicated that the growth measurements with time approximated a sigmoid curve for each variety at each planting date. The methods of Blackman (9), Briggs, Kidd and West (13) and Haun (24) were too complex to obtain objectively, the approximate date that the stem stopped enlarging. Therefore, a line was fitted to that portion of the curve which showed a linear response and another line was drawn through the average recordings of the maximum diameter (**Figure 1**). The date where these two lines intersected was calculated using the formula for single regression, $x = \frac{y - a}{b}$ where y is the mean maximum diameter, a is the intercept of the fitted line and b is the slope of the fitted line. Hereafter this procedure will be referred to as the "stem-growth intercept" method.

The stem diameter measurements were made at the base of the main

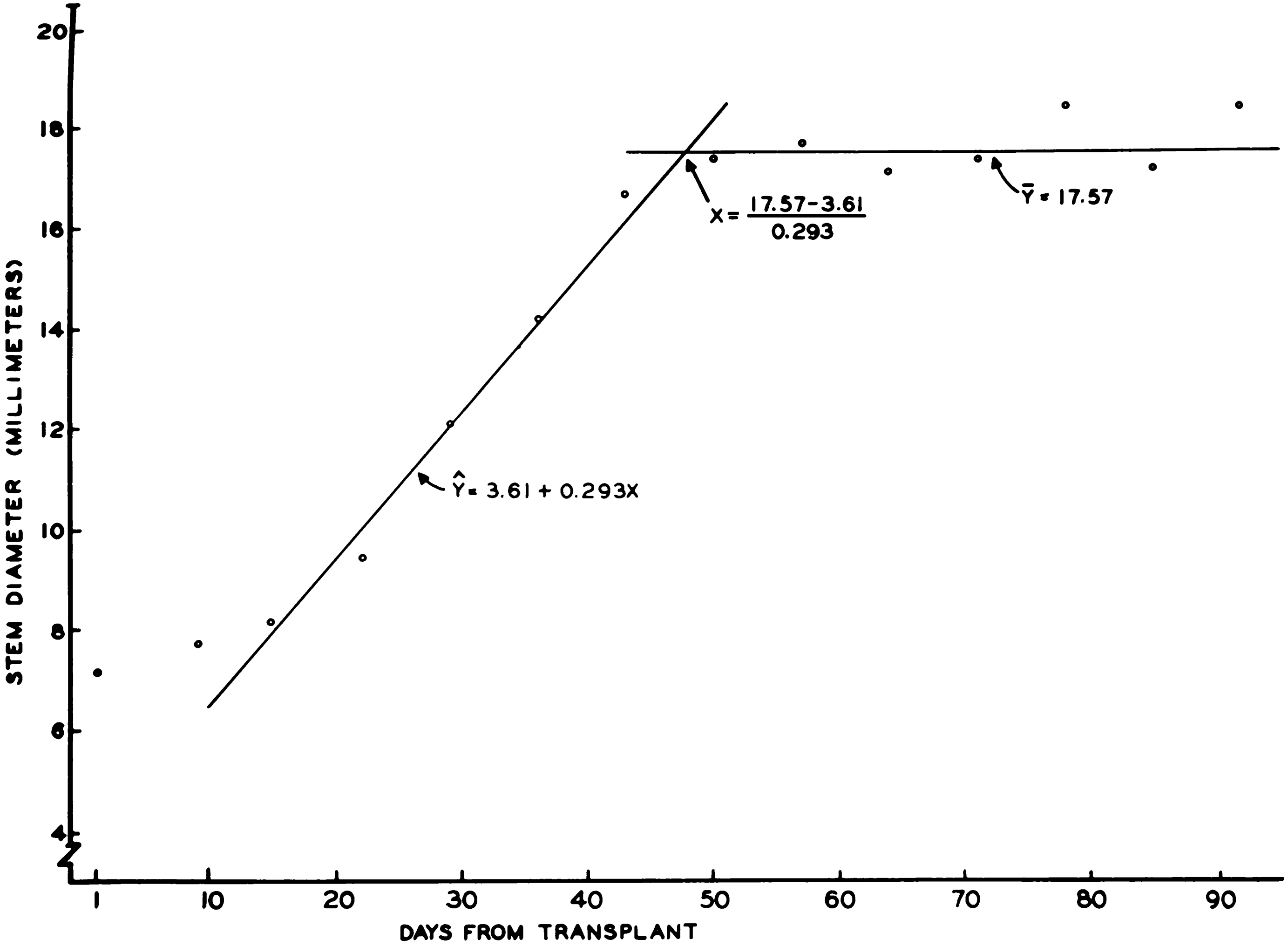

Figure 1. Method for determining the cessation of stem enlargement by the stem-growth intercept method with C-52 planted May 22, 1961.

stem with a direct-reading caliper gage[1] graduated to 0.1 millimeter. To determine the variation in the actual measurement, each of ten plants was measured ten times in one day at a marked point at the base of the stem. In 1962 measurements for determining variation were made with the C-1327 and H-1350 varieties at 53 and 55 days after transplanting, respectively. A similar test was repeated in 1963 using H-1370 at 28 and 58 days after transplanting.

Differences between the largest and smallest recordings for 200 measurements averaged 0.75 millimeter in 1962. Standard deviations were calculated for each of ten plants and averaged 0.26 millimeter for the same measurements (Appendix Table 1). The maximum variation was only 0.17 millimeter when measurements were made 28 days after transplanting in 1963. Thirty days later, the variation in the actual measurement averaged 0.5 millimeter (Appendix Table 2).

The variation in a plant population was determined after the cessation of stem enlargement, in blocks of approximately 2000 plants of each variety. Standard deviations were calculated four times for 5, 10, 20, 30, 40, 50 and 75 plants. Following procedures outlined by Snedecor (69), the number of plant stems that had to be measured was calculated to determine when the average stem stopped enlarging.

The diameter of the stem varied approximately 15 percent for C-1327, 13 percent for H-1350 and 12 percent for H-1370. At East Lansing in 1963 when plants were randomly selected at each measuring

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[1] Federal Products Corporation, Providence, Rhode Island. Model 49P-172-R1.

date and when the variation was limited to 0.8 millimeter or to the error in making a measurement, 38 plants of C-1327, 28 of H-1350 and 26 of H-1370 were needed to make an accurate prediction.

The number of days from transplanting to the cessation of stem enlargement and the number of inflorescences per plant in the arithmetic spacing study 46 days after transplanting were statistically evaluated by analysis of variance. Mean differences were compared by the Duncan's multiple range test. In the irrigation, fertilizer and spacing study, the variance was analyzed for all factors with single degrees for freedom.

At each harvest, the weights of green, ripe and deteriorated fruit were obtained. Any fruit that was not fully red in color was considered a green fruit. The weights of ripe fruit were expressed as percent of total fruit harvested and the analysis of variance was used with both weight and percent. Duncan's multiple range test was used to determine the maximum weight and maximum percent of ripe fruit that did not differ for each planting of each variety. The analysis of variance was also used with each processing quality determination in 1961. This thesis is concerned only with the time that the once-over maximum yield could be obtained and only the percent of ripe fruit is presented in the tables.

Time of Planting and Harvest Studies

The first experiments in 1961 were designed to determine if there were one or more morphological characteristics observable in the growing season which could be correlated with the earliest once-over maximum yield.

A split-plot design with four replicates was used in 1961. The

order of randomization was the three varieties (Fireball, C-52 and H-1370) and seven harvest dates. The three transplantings and two direct seedings were not randomized. East Lansing transplants were set in 20-foot rows. After the majority of fruit were set, the guard plants at the end of each row were removed.

Observations on growth and development were continued on the same three varieties in 1962. In addition, this study was made to develop an objective schedule of transplanting in order that a sequence of harvests could be obtained. The field layout was a split-plot design with four replicates randomized for seven planting dates and five dates of harvest. The three varieties were not randomized.

Observation on Growth and Development -- Four plants per replicate of each variety were randomly selected, tagged and observed at seven-day intervals for (a) plant height, (b) the size of the plant in and between rows, (c) the widest diameter of the main stem at soil level, (d) the number of inflorescences, having one flower showing color, (e) the number of flowers that were showing color, (f) the number of plants with one or more flowers showing color, (g) the number of "fruit set," (h) the number of ½ and 1-inch fruit until the first fruit turning color appeared, (i) the number of fruit turning color, (j) the number of red fruit and (k) the number of deteriorated fruit. For the direct-seeded plantings, observations were started when the seedlings approximated the size of the field transplants at planting time.

The stem diameter measurements were made on the base of the main stem. The site of measurement was marked on two opposing sides at soil level with a felt pen. This prevented the observer from moving the point

of measurement during the course of the growing season. For example, moving up the stem would yield a much later date for the cessation of growth. If plants are not measured carefully, stem injury might cause secondary thickening and abnormally extend the period of growth.

The growth of several plant structures was observed in 1963 with the varieties Fireball, C-52 and H-1370. Measurements or counts were made on two plants in each of four replications at weekly intervals for the first six weeks after transplanting for Fireball and C-52 and the first seven weeks for H-1370, after which observations were made every three or four days. Observations were recorded on stem diameter, leaf, branch and inflorencence number. The aerial portion of plants were harvested and weighed fresh and after drying at 120°F until dry. The date that the stem stopped enlarging was determined by the stem-growth intercept method described earlier.

When the development of all plant structures for each variety was plotted with time, typical sigmoid-shaped curves resulted. Varieties Fireball and C-52 completed their growth within a 64-day period from transplanting. Most of the structures on H-1370 were actively growing 67 days after transplanting. Nevertheless, the pattern of growth of the same structure of each of the three varieties was similar (Appendix Table 3), therefore, only C-52 will be discussed.

The rate of growth of all structures except branches was initially slow, then gradually became more rapid until a point of maximum rate was reached (Figure 2). This period of growth is represented by a straight line. The number of branches increased rapidly soon after their initial development. Later this linear rate of growth ceased.

Inflorescence formation (cluster number), fresh weight and dry weight

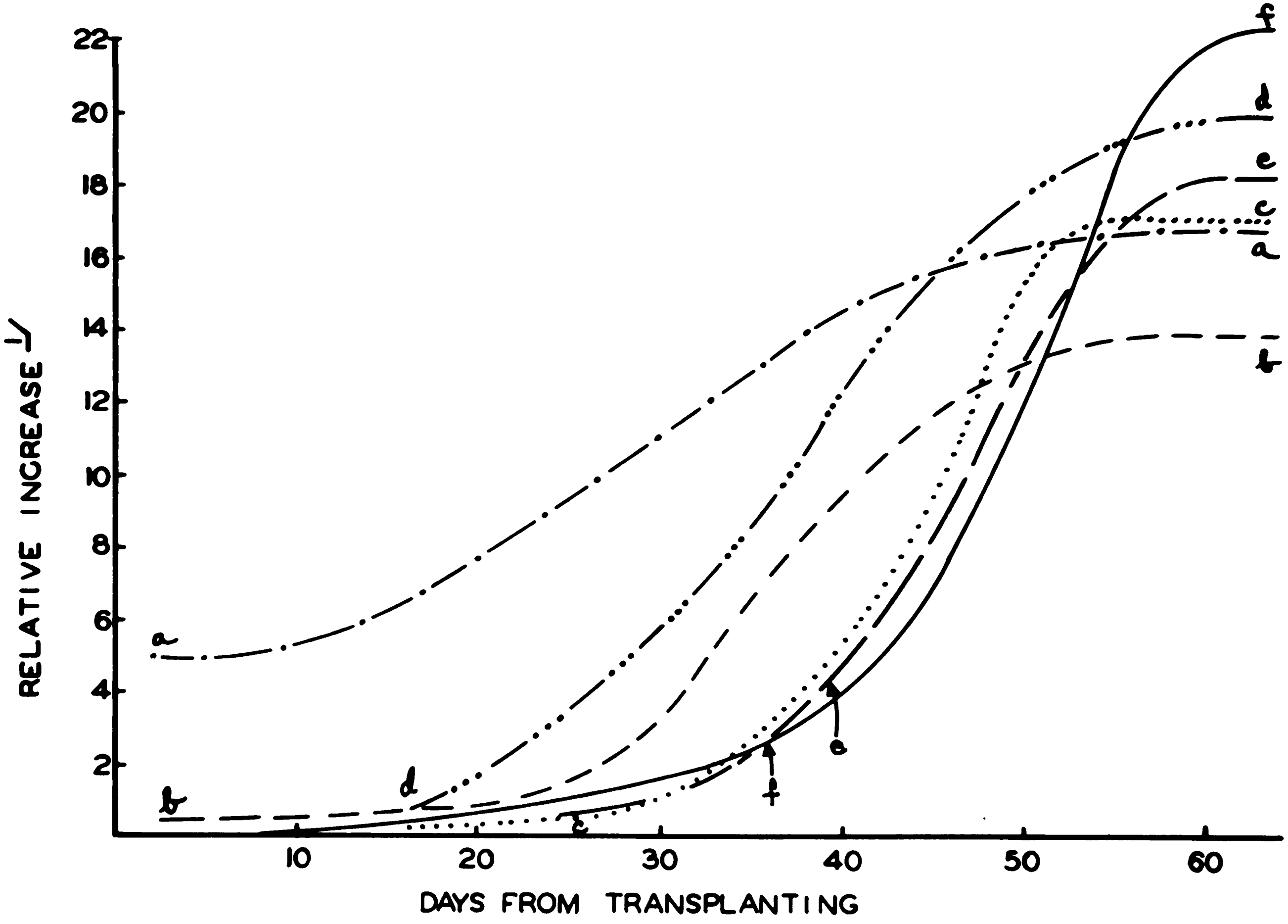

Figure 2. Growth curves for several plant parts of variety C-52 transplanted May 27, 1963[2].

[1] Relative increase - each digit represents the following:

a) stem diameter - one millimeter
b) leaf number - 10 leaves
c) cluster number - 4 clusters
d) branch number - one branch
e) fresh weight - 100 grams
f) dry weight - 10 grams

[2] Each point is an average of eight plants.

exhibited a similar growth pattern. Leaf number and stem diameter had similar rates of development. Stem diameter initiated its maximum rate of development earlier than other structures.

Best Criterion between Planting Time and Yield -- Degree days were calculated in two ways, above a constant 50°F base, and above base temperatures that were arbitrarily selected at weekly intervals from transplanting to harvest date (earliest once-over maximum yield of ripe fruit) in both 1961 and 1962. The variable base temperatures used were one degree intervals from 42 through 50°F and two-degree intervals from 50 through 60°F.

Table 2 shows standard deviations and coefficients of variation for calendar days, degree-days above a 50°F base, and degree-days above the variable base temperatures. There was less variation between plantings using the variable base temperature for the varieties C-52 and H-1370, but the constant 50° base was best for Fireball.

The use of degree-day accumulations showed little advantage over calendar days when the ease of calculation for calendar days was considered. Calendar-day measurements appeared to be more practical and more reliable than the other measurements used.

Best Criterion between Morphological Observations and Harvest Date -- To find an objective method to determine early in the growing season when the maximum yield of ripe fruit would occur, several criteria related to climate were used to measure the interval from the harvest date back to many growth characteristics of each variety. The criteria compared were: days, summations of the differences between the daily maximum and minimum temperatures, summations of each night temperature above a 50°F base, total amount of evaporation from an open pan, daily solar radiation,

Table 2. Number of degree days and calendar days from the date of transplanting to the harvest date.

	Variety								
	Fireball			Libby C-52			Heinz 1370		
Planting	50°[1]	S.B.[2]	Days	50°[1]	S.B.[2]	Days	50°[1]	S.B.[2]	Days
1961									
May 22	1696	1724	94	2040	1928	108	2209	2027	115
June 2	1887	1948	94	2070	2060	101	2219	2110	111
June 14	1888	1970	92	-	-	-	-	-	-
1962									
May 15	1884	1896	97	2012	1964	101	2172	2044	115
May 21	1853	1862	95	1928	1907	102	2018	1976	113
May 25	1864	1884	98	1974	1934	102	2093	1984	112
June 1	1849	1893	94	1914	1912	98	2028	1957	109
June 4	1857	1909	95	1887	1909	99	2012	1954	109
Mean	1847	1886	95	1975	1945	102	2107	2007	112
Std. dev.	63.1	74.1	1.9	68.7	54.5	3.2	91.8	56.5	2.5
Coef. var.	3.4%	3.9%	2.0%	3.5%	2.8%	3.2%	4.4%	2.8%	1.4%

1/ Degree days above 50°F.

2/ S.B. - shifting base - The base temperature changed weekly from transplanting to the harvest date in the following order: one-degree intervals from 42 through 50°F and two-degree intervals from 50 to 60°F. The 60°F was used from the 14th week to the harvest date.

minutes of daily sunshine, the product of daily sunshine and the average day temperature and the product of the length of night and the corresponding average night temperature.

These relationships of the climate and time are summarized in Appendix Table 4 through 10. The climatic values were not consistent among

plantings and further analyses were not conducted. The variations in the accumulations of the various climatic factors suggest that: (a) these factors measured alone are not the limiting factors determining the rate of development, and/or (b) some other combination of factors should be tried -- perhaps the multiple regression technique described by Haun (24).

The best criterion to measure intervals between the dates of various stages of plant development and once-over maximum yield was calendar days.

The coefficient of variation was used to compare the intervals between the dates of various stages of plant development and once-over maximum yield because intervals of various lengths could be compared directly. The statistic was calculated by dividing the standard deviation of each morphological character by its respective average number of days and multiplying this figure by 100.

As indicated in Table 3 with low coefficients of variation, both the date that the fifteenth inflorescence showed color and the date that the stem stopped enlarging were good criteria for estimating the time when the earliest once-over maximum yield occurred. Both of these features differed for the varieties tested in 1961. However, the relationship of these morphological characteristics with days to harvest was more uniform between plantings than any other characteristic.

The stage of plant growth when 15 inflorescences were recorded is presented in Table 4. These data indicated that generally, the later in the season that 15 inflorescences developed, the fewer the number of flowers formed and less fruit set, even though the plant size was not appreciably different in the later plantings.

There was an approximate 1:1 ratio of one-half inch and one inch fruit on the same date that the plant had 15 inflorescences for only four

Table 3. Average number of days and the coefficient of variation for several plantings from harvest date back to several stages of plant development.

Morphological character	Fireball[1/] Av. days (No.)	Fireball[1/] Coef. of var. (%)	C-52[2/] Av. days (No.)	C-52[2/] Coef. of var. (%)	H-1370[2/] Av. days (No.)	H-1370[2/] Coef. of var. (%)	Av. coef. of var. (%)
First flower	75	8.2	80	8.8	89	9.7	8.9
First fruit set	68	8.2	73	11.0	80	13.8	11.0
First 1/2" fruit	59	9.4	65	8.6	71	15.1	11.0
First turning fruit	25	14.6	28	12.4	28	40.8	22.6
First ripe fruit	20	18.3	24	14.8	23	44.1	25.7
15 clusters	59	4.8	66	6.1	70	6.7	5.9
Flowering peak	49	9.6	58	9.6	59	11.9	10.4
Stem-growth intercept	53	3.8	57	6.1	59	7.4	5.8
Growing peak of stem	73	13.9	74	6.9	87	8.0	9.6
Decreased plant height	35	13.4	37	4.7	43	9.5	9.2
1:1 ratio 1/2:1" fruit	55	5.4	58	12.4	73	15.1	11.0

[1/] Based on five plantings
[2/] Based on three plantings

Table 4. Several stages of growth of three tomato varieties when they had approximately 15 inflorescences[1/].

Variety and planting	Date of 15 inflor.	Vine (inches)			Stem dia.	Average number per plant			
		Length	Width	Height	(mm)	Flowers	Fruit set	1/2" fruit	1" fruit
Fireball									
May 22, T.P.	6/26	10.4	8.3	13.7	13.5	17.7	11.0	1.3	1.2
June 2, T.P.	7/3	15.2	15.4	15.5	14.8	16.3	7.7	2.0	3.1
June 14, T.P.	7/17	18.5	18.5	16.0	13.7	7.5	6.6	3.6	2.4
May 4, D.S.	7/13	13.5	13.3	14.4	13.3	11.2	2.6	1.3	1.2
May 17, D.S	7/21	15.8	18.5	14.3	12.5	9.1	1.8	---	---
C-52									
May 22, T.P.	6/29	13.5	14.1	15.5	15.2	15.8	10.6	1.9	1.6
June 2, T.P.	7/7	15.0	17.3	17.7	15.6	11.1	5.7	3.2	0.9
June 14, T.P.	7/16	17.8	18.0	15.2	14.5	8.6	8.6	2.0	0.1
May 4, D.S.	7/14	14.2	17.8	18.6	14.0	5.6	1.7	1.0	---
May 17, D.S.	7/23	20.0	23.0	17.8	14.7	4.1	1.8	---	---
H-1370									
May 22, T.P.	7/4	14.4	16.3	16.7	14.4	9.8	8.2	1.6	1.6
June 2, T.P.	7/9	18.2	20.2	17.8	14.9	2.5	---	1.5	2.3
June 14, T.P.	7/21	20.4	22.9	17.4	14.6	3.5	2.5	2.0	0.6
May 4, D.S.	7/18	14.0	15.5	16.2	12.7	5.7	2.2	0.1	---
May 17, D.S.	7/30	16.0	23.5	20.5	14.1	---	---	2.2	0.9

[1/] An average of 16 plants.

plantings -- the May 22 transplanting of each variety and the May 4 direct-seeding of Fireball. No similar correlations were found in the other plantings. Therefore, the date of 1:1 fruit ratio was not as reliable an index for maturity as the date of 15 inflorescences.

The size and development of a tomato plant when the stem stopped enlarging for the varieties Fireball, C-52 and H-1370 are presented in Table 5. Fireball was smaller and had a smaller number of clusters than C-52 and H-1370. Although plants of C-52 and H-1370 were about the same size, plants of C-52 had more clusters at this time. The ratio of one-half inch and one inch fruit at the time the stem stopped enlarging was approximately 1:1 in the two direct-seedings of Fireball, the first transplanting and the first direct-seeding of C-52, and in one of the H-1370 plantings. Consequently, the date of 1:1 fruit ratio was as good an index as the date of cessation of stem enlargement for only part of the time.

The rapid development of inflorescences had just begun in Fireball whereas it had approached a peak in C-52 and H-1370 at the time the stem stopped enlarging.

Predicting Date of Planting and Harvest -- A study was made in 1962 to develop an objective schedule of transplanting to obtain a sequence of once-over harvests. After the initial transplanting (May 15) of the varieties Fireball, C-52 and H-1370, two planting systems were used. The first consisted of transplanting on the date when 564 degrees of the daily minimum temperature, which was the average summations between the dates of the earliest once-over maximum yield for any two successive 1961 plantings of the same variety, had accumulated from the previous planting. The second system was based on the growth of the stem. A new

Table 5. Several stages of growth of three tomato varieties when the stem diameter ceased to enlarge[1].

Variety and planting	Date stem stopped	Vine (inches)			Stem dia.	Average number per plant		
		Length	Width	Height	(mm)	Clusters	1/2" fruit	1" fruit
Fireball								
May 22, T.P.	7/4	15.0	16.4	15.6	14.8	19.2	4.6	9.2
June 2, T.P.	7/12	19.0	23.0	17.3	15.4	26.1	6.8	8.5
June 14, T.P.	7/24	25.6	27.6	16.0	15.2	18.6	5.9	8.2
May 4, D.S.	7/17	15.7	20.0	16.0	14.2	17.1	2.9	2.4
May 17, D.S.	7/24	18.8	25.1	17.5	13.5	17.0	2.2	2.6
C-52								
May 22, T.P.	7/8	19.4	23.0	19.7	14.0	30.7	4.7	4.3
June 2, T.P.	7/16	22.6	33.0	24.4	17.5	37.0	8.4	8.0
June 14, T.P.	7/29	20.5	31.0	21.0	17.5	30.1	6.2	7.8
May 4, D.S.	7/22	18.8	30.2	19.8	16.0	29.0	3.7	3.6
May 17, D.S.	8/3	22.3	32.1	21.0	17.9	33.8	5.0	20.7
H-1370								
May 22, T.P.	7/15	22.2	29.5	18.1	17.0	28.0	1.6	4.2
June 2, T.P.	7/21	19.4	23.2	16.4	17.0	28.6	2.9	5.3
June 14, T.P.	8/2	20.9	31.5	21.2	17.2	23.9	5.8	17.2
May 4, D.S.	7/29	18.7	28.9	22.7	16.0	26.5	3.7	7.9
May 17, D.S.	8/5	18.1	31.0	25.0	15.2	21.8	3.4	2.5

[1] An average of 16 plants.

planting was made when the average stem diameter of the previous planting increased one or more millimeters within a three or four-day period. There were two plantings for each system.

The dates of harvests for each variety were regulated in accordance to the 1961 findings, assuming that the best harvest date would occur a fixed number of days after the cessation of stem enlargement. The predicted harvest date was bracketed on both sides with two selected harvest dates at three or four-day intervals.

Planting dates of each variety were ten days apart when the accumulation of 564 degrees was used as a criterion to schedule planting dates (Figure 3). The number of days that the stem continued to enlarge decreased with later plantings of Fireball and H-1370 and remained about the same for C-52. The harvest dates for various plantings occurred eleven and seven days apart for Fireball and C-52 and seven and 14 days apart for H-1370.

When the transplanting date was governed by the growth of the stem in the previous planting, the second planting was transplanted six days after the first and the third planting was transplanted eleven days after the second (Figure 3). Also, the number of days that the stem continued to enlarge decreased with later plantings of Fireball and remained the same for C-52 and H-1370. The harvest dates were spaced four and ten days apart for Fireball, seven days for both plantings of C-52 and four and seven days for H-1370.

From the data it appears that a sequence of harvests could be obtained if transplantings were spaced about ten days apart. However, if conditions were adverse during planting time, a system based on the establishment of plants and initiation of new growth, such as a rapid increase

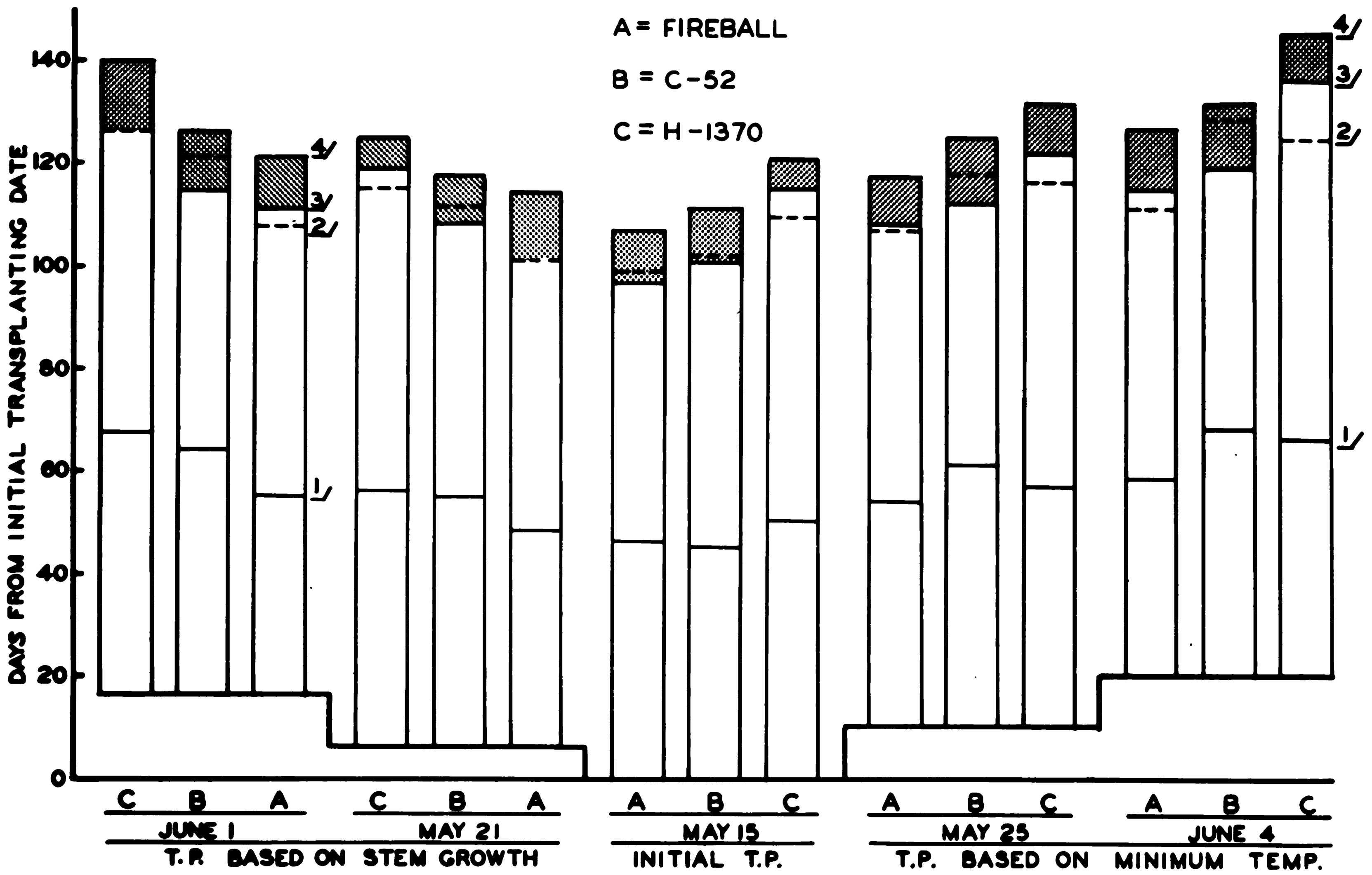

Figure 3. The relationship of the growth of the stem to harvest when transplanted on two planting systems in 1962.

1/ Cessation of stem enlargement.

2/ Predicted harvest.

3/ First harvest of once-over maximum yield.

4/ Last harvest of once-over maximum yield.

in stem diameter, would be more advantageous in obtaining a sequence of harvests.

Regardless of the planting system, the stems stopped enlarging by variety in the following order: Fireball, C-52 and H-1370.

The once-over maximum yield extended from two to five harvests for all plantings (Figure 3). The once-over maximum yield in 1962 was obtained 60 percent of the time based on predictions from the 1961 information. However, the average predicted date was only three days earlier than the harvest date for Fireball and five days for H-1370. The once-over maximum yield was obtained on all predicted dates for all plantings of C-52.

After the last plant harvest in 1963, 12 plants (spaced 48 inches apart in the row) remained in each replicate. These plants were used to obtain once-over yields. The harvest date for each variety was predicted on the assumption that the once-over maximum yield would be obtained in a fixed number of days from the cessation of stem enlargement. The first four plants in each replicate of each variety were harvested one week prior to the predicted date, the next four plants on the predicted date and the last four one week later.

The harvest dates and the average percent of ripe fruit per harvest are shown in Table 6. The harvest date was accurately predicted for both Fireball and C-52. The once-over maximum yield was not accurately predicted for H-1370 because of an error in estimating the date the stem stopped enlarging.

<u>Yield Records</u> -- Five plantings of the varieties Fireball, C-52 and H-1370 were made in 1961 so that there would be a sequence in once-over maximum yields obtained. On every Monday and Thursday, starting with the time when the first commercial hand-harvest probably would have been made,

Table 6. Percent of ripe fruit per harvest when the harvest date was predicted using stem diameter measurements in 1963.

Variety	Harvest date	% ripe fruit harvested[1]
Fireball	8/28	25a
	9/4	60 b[2]
	9/11	67 b
C-52	9/10	38a
	9/17	56 b[2]
	9/24	45 c
H-1370	9/13	13a
	9/19	25 b[2]
	9/26	40 c

[1] Means followed by different subscripts differ at odds of 19:1.

[2] Predicted harvest date by stem diameter.

harvests were made for a total of seven harvests for each of five plantings of three varieties. The plants were cut at the soil surface at each harvest date and placed on the Michigan State University tomato plot harvester (72).

The seven harvests made of each variety at each 1961 planting resulted in obtaining once-over maximum yields (expressed as percent ripe fruit) for at least two harvests for all varieties and planting dates, except the June 14 transplantings and May 17 direct-seedings of the varieties C-52 and H-1370 (Tables 7, 8 and 9). Once the maximum yields were attained, they did not decrease for the remainder of harvests for the varieties C-52 and H-1370.

Fireball was the only variety which decreased in once-over maximum yield prior to the end of the seven harvests and this occurred only in the two direct-seeded plantings (Table 7). It is significant under the

Table 7. Average percent of ripe fruit from seven harvests of each of five plantings of Fireball in 1961.

Harvest date	Transplanting dates			Direct-seeding dates	
	May 22	June 2	June 14	May 4	May 17
			(Percent ripe fruit)		
8/11	19				
8/15	24				
8/18	27	17			
8/21	24	21			
8/24	41 1/	33			
8/28	35	32			
8/31	42	43	28	21	
9/4		57	32	34	
9/7		66	53	56	28
9/11			53	68	40
9/14			63	75	58 1/
9/18			65	59	67
9/21			63	51	68
9/26					57
9/28					56

1/ Means adjacent to the same line are not significantly different for the maximum yield at odds of 19:1.

conditions studied in 1961 that neither the yield nor quality of the varieties C-52 or H-1370 decreased after the peak yields were attained in any one planting (Tables 8 and 9).

The average of the once-over maximum yield for all harvests of all varieties and plantings was 17 tons per acre for Fireball, 22 for C-52 and 27 for H-1370.

The beginning of the once-over maximum yield period with Fireball for those plants seeded in the greenhouse on May 3, and transplanted on June 14, differs only four days from the once-over maximum yield of the same variety of the May 4 field seeding. The once-over maximum yield of Fireball differed only about two tons which indicates that the chronological

Table 8. Average percent of ripe fruit from seven harvests of each of five plantings of C-52 in 1961.

Harvest dates	Transplanting dates			Direct-seeding dated	
	May 22	June 2	June 14	May 4	May 17
	(Percent ripe fruit)				
8/18	15				
8/21	10				
8/24	19	11			
8/28	24	20			
8/31	28	20			
9/4	56 1/	34		18	
9/7	68	53	26	36	
9/11		64	34	58	32
9/14		72	46	66	42
9/18			54	71	46 1/
9/21			46	66	54
9/26			48		57
9/28			59		54

1/ Means adjacent to the same line are not significantly different for the maximum yield at odds of 19:1.

and physiological ages were similar.

The percent of ripe fruit, as shown in Tables 7, 8, and 9, for most harvests in 1961 was low compared to the percent of ripe fruit obtained in 1960 (62). There was little difference between varieties in maximum percentage of ripe fruit obtained. In the first and third transplanting and the second direct-seeding, none of the varieties ever matured 70 percent ripe fruit in the harvests taken.

In 1962, there were five transplantings of the three varieties mentioned earlier and two direct-seedings planted in blocks randomized for planting date. The harvesting scheme was described earlier in predicting date of planting and harvest study.

Good growing weather and an excellent location produced an outstanding

Table 9. Average percent of ripe fruit from seven harvests of each of five plantings of H-1370 in 1961.

Harvest date	Transplanting dates			Direct-seeding dates	
	May 22	June 2	June 14	May 4	May 17
	(Percent ripe fruit)				
8/31	8				
9/4	16				
9/7	31				
9/11	48 1/	29			
9/14	55	45			
9/18	65	59	32	44	16
9/21	68	69	46	63	26
9/26		76	54	66	28
9/28		70	51	59	42 1/

1/ Means adjacent to the same line are not significantly different for the maximum yield at odds of 19:1.

tomato yield (Tables 10, 11 and 12). The variety C-52 was the only one which decreased in percent of ripe fruit prior to the end of the five harvests and this occurred only in the May 4 direct-seeded planting.

The average of the once-over maximum yield for all harvests of varieties and plantings was 26 tons per acre for Fireball, 30 for C-52 and 33 for H-1370. Compared to the average yields obtained in 1961, these are 53 percent, 36 percent and 22 percent increases, respectively. The percent of ripe fruit for most harvests was higher than the 1961 harvests. The average yields of Fireball, C-52 and H-1370 had matured 70, 73, and 66 percent ripe fruit, respectively.

Much of this difference in seasonal response is believed to be due to environmental differences in the two years. That weather conditions were better for growing tomatoes in 1962 is evidenced by the average tomato yields for Michigan for two seasons. It was 12.5 tons per acre

Table 10. Average percent of ripe fruit from five harvests of each of seven plantings of Fireball in 1962.

Harvest date	Transplanting dates					Direct-seeding dates	
	May 15	May 21	May 25	June 1	June 4	May 4	May 17
	(Percent ripe fruit)						
8/17	44						
8/20	55[1]						
8/23	66						
8/24		50					
8/27	60						
8/28		56	50				
8/30	60						
8/31		69	74	52		59	
9/3		67	69	65		68	
9/6		68	71	72		77	
9/7					67		63[1]
9/10			75	77	75	78	73
9/13				79	77	79	74
9/17					80		82
9/19					73		
9/20							75

[1] Means adjacent to the same line are not significantly different for the maximum yield at odds of 19:1.

in 1961 and 13.8 tons per acre in 1962 (17).

A consideration is that generally the later in the season that a planting is made, the smaller the yields obtained. It was clearly demonstrated with the variety H-1370 for two years, with a sequence of planting dates, that later transplanting reduced yields. This agrees with Younkin (98) that there is an optimum date for direct-seeding and transplanting for highest yields. If plantings are made either before or after this date, yields would be reduced because of reduced seedling survival, increased disease incidence, or reduced fruit setting.

Inadequate field observations are available to determine which

Table 11. Average percent of ripe fruit from five harvests of each of seven plantings of C-52 in 1962.

Harvest date	Transplanting dates					Direct-seeding dates	
	May 15	May 21	May 25	June 1	June 4	May 4	May 17
	(Percent ripe fruit)						
8/24	55[1]						
8/27	60						
8/28		48					
8/29	68						
8/31	75	76					
9/3	77	79					
9/4			67				
9/6		80					
9/7			75	74		70	
9/10		83	77			74	
9/11				76	72		
9/13						78	
9/14			75	78	77		59[1]
9/17			73	78		79	63
9/18					74		
9/19				73		67	65
9/21					77		67
9/24					75		64

[1] Means adjacent to the same line are not significantly different for the maximum yield at odds of 19:1.

inflorescences contribute to the once-over maximum yield. However, observations at harvest time showed that plants had deteriorated fruit on an average of three to four fruiting branches. Approximately 33 fruits were harvested from one plant at one simulated mechanical harvest, so if each inflorescence contributed three fruit to the maximum yield, eleven inflorescences would be required for the maximum fruit maturation. This may explain why the date that the fifteenth inflorescence showed color appeared to be an index for the harvest date since the once-over maximum yield is composed of only red fruit.

Table 12. Average percent of ripe fruit from five harvests of each of seven plantings of H-1370 in 1962.

Harvest date	Transplanting dates					Direct-seeding dates	
	May 15	May 21	May 25	June 1	June 4	May 4	May 17
	(Percent ripe fruit)						
8/31	63						
9/4	69	61					
9/7	77 [1]	72					
9/10	81						
9/11		77					
9/13	79						
9/14		80	66				
9/17		77	67				
9/18				56		58	
9/19			68				
9/21			61	66	57	63	
9/24			68				
9/25				69	60	68	47 [1]
9/28				71	58	63	52
10/1				72	63	68	53
10/3					66		54
10/6							51

[1] Means adjacent to the same line are not significantly different for the maximum yield at odds of 19:1.

Fruit Quality -- Ripe tomato fruit from the 1961 time of planting and harvest study was processed. Replications one and two and replications three and four were composited respectively and each sample was taken to the Food Science Laboratory for processing. The following determinations were made[1]:

Juice Yield. The tomatoes were weighed, washed, drained, cut into pieces, heated to 185°F in a stainless steel kettle, transferred to a juice extracter with a 0.033-inch screen and the resulting juice was weighed.

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[1] Determinations were made by Dr. C. L. Bedford of the Food Science Department.

Viscosity. The juice was concentrated into a puree and placed in a Brookfield viscosimeter and the resulting viscosity was measured using a number 2 spindle at a speed of 60 r.p.m.

Total Solids and Soluble Solids. Ten grams of the sample were weighed into a tared aluminum dish. The sample was dried for eight hours at 70°C under 28 inches of vacuum and a slow stream of dried air. Soluble solids were determined with an Abbe refractometer.

Color. Gardner L, a and b readings were obtained using a 2 x 1½-inch sample cell with the mirrors in the "L" position. The instrument was standardized with a red porcelain plate having the values of L 24.1, al 27.4, bl 12.5.

pH and Total Acidity. These determinations were made on the juice using a Beckman glass electrode pH meter. Ten-gram samples were weighed into 250-ml. beakers and 100 ml. of distilled water added. The resulting mixture was continuously stirred using a magnetic stirrer. The results were reported as percent citric acid.

The variety H-1370 had a significantly higher percent juice yield, total solids, apparent viscosity and percent soluble solids than C-52 or Fireball. However, H-1370 had less color. There were no differences between Fireball and C-52 (Table 13). The percent juice yields, total solids, percent soluble solids and color for harvests within plantings for any variety were not different. In general, the later plantings and the later harvests in each planting resulted in lower viscosities.

The total acidity and pH was lower in Fireball than in C-52 or H-1370. There was no difference between C-52 and H-1370 (Table 13). In every case except one, the total acidity was higher in the direct-seeded plantings.

Table 13. A comparison of the quality for three varieties harvested in all 1961 plantings[1].

Quality character	Units	Variety Fireball	 C-52	 H-1370
Apparent viscosity	2/	160	142	201
color	2/	1.94	1.92	1.80
juice yield	%	76.6	77.3	78.8
total solids	%	5.24	5.27	5.56
soluble solids	%	4.9	5.0	5.2
total acidity	1/	.285	.340	.330
pH	--	4.52	4.44	4.43

1/ Any two means underscored by the same line are not significantly different at odds greater than 99:1.

2/ Apparent viscosity - expressed in centipoises
color - expressed as Gardner a/b ratio
total acidity - expressed as citric acid

The exception was that no difference existed between the direct-seeded plantings of Fireball and the transplantings made on May 22. The pH was higher in fruit from the direct-seeded plantings of Fireball, but there were no differences among plantings of C-52 and H-1370.

Predicting Harvest Dates in Large Plantings.

Observations were made in large plantings (approximately 2000 plants) of several varieties to gain further information on the use of cessation of stem enlargement and the appearance of 15 inflorescences as indices in predicting the harvest date. In 1962 stem diameter measurements and inflorescence counts were made at weekly intervals on ten transplants that

had previously been tagged in each variety block (Table 1). Each plant was randomly selected diagonally across ten 250-foot rows. The stem-growth intercept method was used to predict the harvest date in the large plantings. The number of days from the cessation of stem enlargement to the once-over maximum yield was not determined for the varieties C-1327 and H-1350 prior to this time. Therefore, since C-1327 was considered an early variety but later than Fireball, and H-1350 and C-52 as mid-season varieties, the time between the cessation of stem enlargement and once-over maximum yield was chosen to be the same as obtained for Fireball and C-52, respectively. An attempt was made to bracket the predicted harvest date, but mechanical harvesting studies interrupted the later harvests.

In 1963 there were three large plantings of each of the three varieties C-1327, H-1350 and H-1370. Two plantings were made on May 27, however one of these plantings (designated as transplant III) was planted on an one-third-acre block that had been planted on May 15 but killed by frost on May 23. The plants of C-1327 for this planting were from two lots -- one obtained on May 21 and the other on May 13. The plants of H-1350 were the remainder of those obtained for the other May 27 planting (transplant II in tables hereafter). All plants that were not transplanted within 24 hours after delivery, were stored in peat moss at 40°F.

Stem diameter measurements were made at weekly intervals for the first six weeks after transplanting and then every three or four days until the stem stopped enlarging. These measurements were made on 15 randomly chosen plants in each of five replications. Also, an attempt was made to find the date that the average plant in a variety block showed color in the fifteenth inflorescence. The harvest date was predicted using the date of cessation of stem enlargement as the index. Once-over harvests were made prior to

the date predicted for the earliest once-over maximum yield, on the predicted date, and also after that date.

In 1962 a constant stem diameter was obtained in large planting blocks of C-52 and H-1370 in the same number of days from planting as in the time of planting and harvest studies (Figure 4). A sequence of harvests was predicted and obtained with various plantings of the same variety. The average variation between the predicted and actual harvest dates was five days for all varieties.

The reliability of this system and the relationship of weather conditions and plant conditions at transplanting time is demonstrated in Figure 4. The southern-grown plants of H-1350 were not hardened like the other varieties. The H-1350 and H-1370 varieties were grown at different locations in the South. The latter variety had been pulled earlier and was in transit longer. This difference occurred because the Heinz Company, which supplied the plants, does not normally ship H-1370 plants as far North as Michigan later than early May. On the transplant date of May 24, the weather was cool and extremely windy. The maximum temperature was 67°F late in the afternoon and the wind velocity was 45 mph at planting time. These conditions impaired the growth of the plants of H-1350. The plant stems continued to enlarge for a longer period than those of a similar planting made four days later. The once-over maximum yield was predicted to occur in the May 24 planting seven days later than the May 28 planting. The once-over harvests substantiated this prediction.

The time of harvest of three plantings in 1963 of each of three varieties resulted in average once-over maximum yields for all harvests and plantings to be 19.5 tons per acre for C-1327, 24.5 for H-1350 and 33.0 for H-1370. Compared to the once-over maximum yields in 1962, the

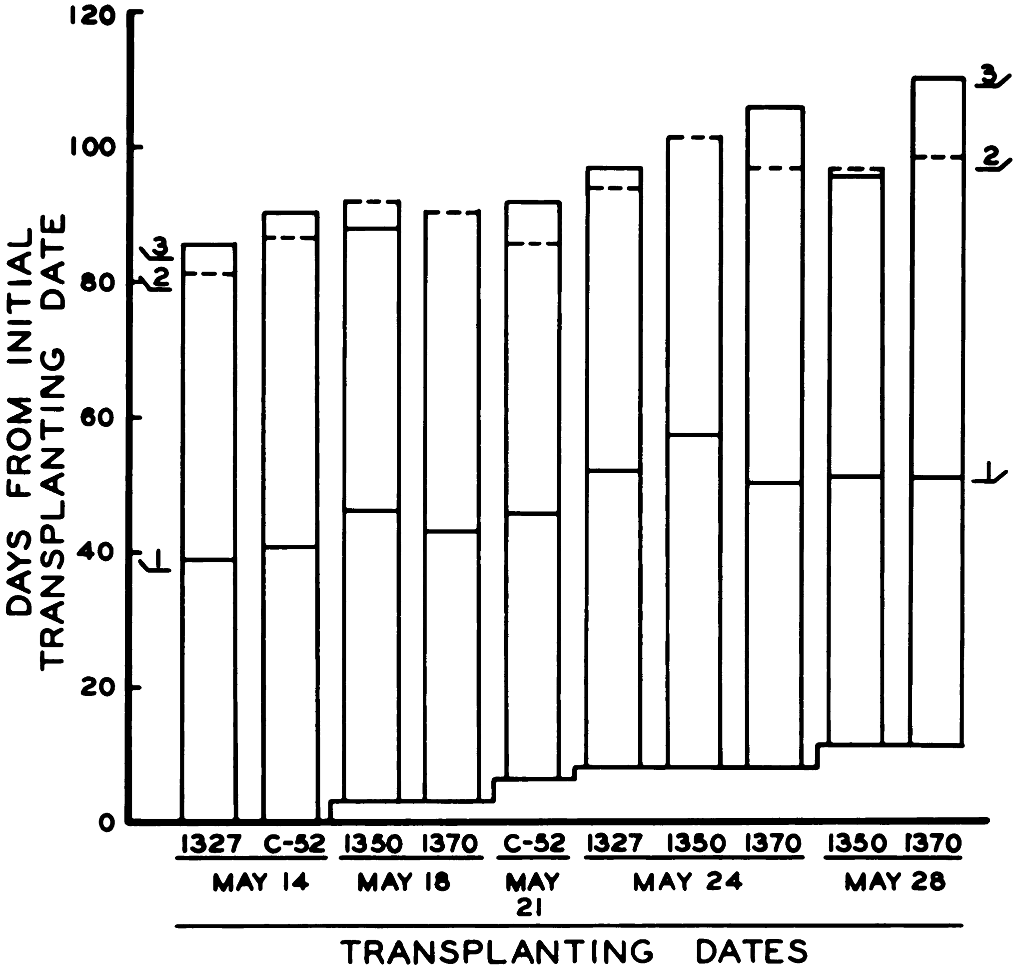

Figure 4. Relationship of cessation of stem enlargement and predicted harvest date to the date of once-over maximum yield in 1962.

1/ Cessation of stem enlargement

2/ Predicted harvest

3/ Once-over maximum yield

1963 yields for C-1327 and H-1350 were low. The yield of H-1370 was comparable to other years, but in all cases, the earliest once-over maximum yield occurred after the predicted date (Table 15).

Table 14 shows that transplant II of C-1327 is the only one where the yield did not change significantly over the harvest period. The percent of ripe fruit for most harvests was lower than in the 1962 harvests. The varieties C-1327, H-1350 and H-1370 yielded 44, 55 and 64 percent ripe fruit respectively.

The number of days from the cessation of stem enlargement to the harvest date was predicted to be 57, 54 and 61 days respectively, for the varieties C-1327, H-1350 and H-1370 (Table 15). The earliest once-over maximum yield was obtained within three days of the predicted date in three plantings of H-1350. However, the harvest date was predicted for only one planting of C-1327. Harvest dates were six and 13 days earlier than the predicted date for the other two plantings. The earliest once-over maximum yield occurred six to ten later than the predicted date for each of the three plantings of H-1370.

The dates that 15 inflorescences were noted on plants of the three varieties in the large plantings are presented in Table 16. The number of days from the date that the fifteenth inflorescence showed color to the harvest in 1963 was five days earlier for C-1327, two days later for H-1350 and 12 days later for H-1370 than was observed in 1962.

Tests with Processing Companies

To test the reliability of the two most promising indices for predicting the harvest date stem diameter measurements, inflorescence counts and yield records were obtained by processing companies (hereafter referred

Table 14. The time of harvest and the average percent of ripe fruit for three large 1963 plantings.

Variety	C-1327			H-1350			H-1370		
transplant	I	II	III	I	II	III	I	II	III
date in May	24	27	27	24	27	27	24	27	27
Harvest date				(Percent ripe fruit)					
9/6			26						
9/9	38	33		37					
9/10						28			
9/11			27						
9/13	40		28	51					
9/16		36	41		38	48	19		
9/17	47			62					
9/19									21
9/20	58 1/	32	39	57	52	54		19	
9/23	45	36	31		51				
9/24						54			
9/26							49		32
9/27		40			54	48		34	
9/30							60		49
10/4							67	54	69 1/
10/9							66	59	71
10/13								60	

1/ Means adjacent to the same line are not significantly different for the maximum yield at odds of 19:1.

to as cooperators) on the varieties C-1327, H-1350, H-1370 and C-52. These data were obtained at Leipsic and Napoleon, Ohio; Marengo, Morris and Waterman, Illinois; and Frankfort, Indiana. The cooperators followed an instructional outline and at the end of the harvest season, sent the accumulated data to Michigan State University for final analysis.

The increase in stem diameter was plotted with time. The date that the stem stopped enlarging was determined by the stem-growth intercept method and then the date of the occurrence of the once-over maximum yield was predicted using the number of days obtained from previous work for this

Table 15. Prediction dates based on stem diameter measurements and yields obtained in large 1963 plantings.

Variety and trans-planting	Stem stopped enlarging (July)	Prediction made (August)	Harvest date		Days to harvest	Yield tons / acre
			Predicted (Sept.)	Obtained		
C-1327						
5/24 -I	25	8	20	9/20	57	21.2
5/27 -II	27	19	22	9/9	44	12.1
5/27 -III	27	12	22	9/16	51	21.9
Average 1963					51	
Average 1962					57	
H-1350						
5/24 -I	22	8	14	9/17	57	25.1
5/27 -II	30	15	22	9/20	52	19.7
5/27 -III	25	12	17	9/16	53	21.4
Average 1963					54	
Average 1962					54	
H-1370						
5/24 -I	25	12	24	9/30	67	28.6
5/27 -II	29	15	28	10/4	68	33.0
5/27 -III	27	15	26	10/6	70	34.4
Average 1963					68	
Average 1962					61	

Table 16. Date of approximately 15 inflorescences and the number of days to harvest in large 1963 plantings.

	Variety					
	C-1327		H-1350		H-1370	
Trans-planting	Date of approx. 15 clusters (July)	Days to harvest	Date of approx. 15 clusters (July)	Days to harvest	Date of approx. 15 clusters (July)	Days to harvest
5/24 - I	10	72	11	68	11	81
5/27 - II	12	59	12	70	11	86
5/27 -III	13	65	13	65	13	84
Average 1963		65		68		84
Average 1962		70		66		72

observation.

Yield records generally were obtained by the cooperators at 7-day intervals starting 42 days after each cooperator was certain that the tomato stem stopped enlarging. An average of five harvests were made at each location. The method of harvest varied with cooperators. The methods were as follows: (a) counting the number of ripe, green and deteriorated fruit on each of eight plants, (b) weighing and counting each of three grades from ten plants for each harvest, (c) harvesting two plants and weighing and counting each of five grades for each harvest. The author calculated the yield as percent of ripe fruit. The highest percent of ripe fruit was selected as the once-over maximum yield.

At East Lansing, plants of C-1327, H-1350 and H-1370 transplanted on May 24 and the plants of C-52 set on May 27, 1963 were used for comparison of the data obtained by the cooperators.

In general, the harvest date could have been predicted in 12 out of

14 plantings, nine of which the once-over maximum yield occurred within three days of the predicted date (Table 17). The once-over maximum yield was obtained five and six days before the predicted date in two of the remaining three plantings and four days after in the third planting. However, the harvest interval for these three plantings was seven days and the once-over maximum yield could have occurred any time between two harvest dates.

The harvest date was not predicted accurately for C-1327 at Napoleon, Ohio. However, the once-over maximum yield occurred approximately 20 days later than the average for this variety grown at other locations. Also, the predicted harvest date of H-1370 at East Lansing, Michigan, was six days early. There is no logical explanation for this discrepancy.

The number of days from the time the fifteenth inflorescence shows color to the once-over maximum yield for six locations are shown in Table 18. Time was consistent for the varieties H-1350, H-1370 and C-52 at two locations for one season. However, in prior years, the same varieties matured earlier. The variety C-1327 had the same number of days for this observation at three locations in Illinois, but the time varied twelve days from that at East Lansing, Michigan. The 1963 data at East Lansing was similar to that observed in 1962. Inflorescence counts on H-1350 were made at Frankfort, Indiana, but the observed date of the fifteenth inflorescence showing color appeared to be about 30 days premature. The data for 1963 and 1962 inflorescence count indicate that although the period from 15 inflorescences to maturity was uniform for different plantings of the same variety, the variation between years and in some instances, between locations, probably makes this system unreliable.

Table 17. Predicted and observed dates of the once-over maximum yield for several varieties and locations in 1963.

		Date		Maximum yield			
Location	Variety	Trans-planting (May)	Stem stopped enlarging (July)	Predicted date	Date obtained	Deviation in days 1/	Harvest interval at critical period
East Lansing, Mich.	C-52	27	23	9/17	9/17	0	7
	C-1327	24	25	9/20	9/20	0	4
	H-1350	24	22	9/14	9/17	+3	4
	H-1370	24	25	9/24	9/30	+6	4
Leipsic, Ohio	C-52	17	31	9/25	9/25	0	7
	H-1350	17	24	9/17	9/18	+1	7
	H-1370	17	29	10/1	9/25	-6	7
Napoleon, Ohio	C-1327	21	27	9/17	9/30	+13	7
	H-1350	21	28	9/21	9/23	+2	7
	H-1370	21	24	9/27	9/30	+3	7
Frankfort, Indiana	H-1350	16	14	9/7	9/11	+4	7
Morris, Illinois	C-1327	13	13	9/3	8/29	+5	7
Marengo, Illinois	C-1327	24	23	9/13	9/10	-3	7
Waterman, Illinois	C-1327	20	21	9/11	9/9	-2	7

1/ Deviation in days from predicted date based on stem diameter measurements.

Table 18. Date of approximately 15 inflorescences and the number of days from this date to the once-over maximum yield in 1963.

Location	C-52		C-1327		H-1350		H-1370	
	Date of 15th cluster	Days to max. yield	Date of 15th cluster	Days to max. yield	Date of 15th cluster	Days to max. yield	Date of 15th cluster	Days to max. yield
East Lansing, Mich.	6/20	89	7/10	72	7/11	68	7/11	81
Leipsic, Ohio	7/1	86	-	-	7/9	71	7/5	82
Frankfort, Indiana	-	-	-	-	6/13[1]	90	-	-
Morris, Illinois	-	-	6/30	60	-	-	-	-
Marengo, Illinois	-	-	7/5	60	-	-	-	-
Waterman, Illinois	-	-	7/5	60	-	-	-	-
1963 Average		88		63		71		82
1962 Average		68		70		66		72
1961 Average		66		-		-		72

1/ This date is 28 days from transplanting. The average number of days for this index for H-1350 is 52 days.

Irrigation, Fertilizer and Spacing Study

The effects of several cultural factors on the growth of tomato plants were studied in the field during 1962. The varieties Fireball, C-52 and H-1370 were transplanted in 20-foot rows in a factorial experiment utilizing a split-plot. The factors in the split-plot were randomized in the following order: two levels of soil moisture, three varieties, two levels of fertility, two plant spacings in the row and two harvests. There were two replications of the main soil moisture blocks.

All blocks were fertilized on May 4 with 5-20-20 fertilizer at the rate of 488 pounds per acre. Starter solution (10-52-17) was applied with all transplants. Soil moisture was varied by irrigating two of four blocks with one inch of water per week from July 6 to August 23. One half of each variety plot was sidedressed with 12-12-12 fertilizer at the rate of 436 pounds per acre on June 15 and again on June 26 with 300 pounds per acre. The spacings within the row were nine and 18 inches. Two rows, five feet apart, were planted in each spacing plot permitting two harvests.

Stem diameter measurements were made every three or four days from the time of planting to the time that the stem stopped enlarging, and inflorescences were counted until 30 or more had developed on each plant. These observations were made on four plants per treatment in each plot. Two once-over harvests were made on each variety, four to seven days apart, based on the average cessation of stem enlargement.

Spacing was the only factor of those tested that influenced the diameter growth of the stem. The average number of days from transplanting of three varieties to the cessation of stem enlargement are presented in Table 19. Stems of plants spaced nine inches in the row

Table 19. Influence of spacing in the row on the number of days from transplanting to the cessation of stem enlargement in 1962.

Variety	Spacing (inches)	
	9	18
	(days)	
Fireball	38	45
C-52	41	49
H-1370	42	50
Average[1]	40	48

[1] F. value for comparison of 9 and 18-inch spacing is significant at odds greater than 99:1.

stopped enlarging eight days earlier than those spaced 18 inches. However, spacing did not influence the size of yield as it was obtained in this study (Table 20).

Table 20 shows that H-1370 was harvested too early in order to obtain a once-over maximum yield. The percent of ripe fruit decreased on the second harvest for both Fireball and C-52. This was due to an increase in the percent of deteriorated fruit (not shown in the table).

Arithmetic Spacing Study

A further evaluation on the effect of spacing on morphological characteristics was initiated with six-week-old transplants of H-1350, spaced at 6-, 12-, 18-, 24-, 30- and 36-inch intervals in a modified arithmetic design. The design was modified so that two rows of the same spacing were planted next to each other. The outer-most row in any direction served as a guard row. This modification placed eight guard

Table 20. The effect of cultural practices on percent of ripe fruit of three varieties in 1962.

	Irrigation							
	No fertilizer				Supplemental fertilizer			
Spacing	9"		18"		9"		18"	
harvest	1	2	1	2	1	2	1	2
Variety	(Percent ripe fruit)							
Fireball	75	68	70	68	70	70	77	66
C-52	63	63	68	58	62	56	76	68
H-1370	46	56	46	52	55	46	44	54
	No irrigation							
Fireball	79	76	76	78	70	76	69	76
C-52	74	74	80	78	75	74	73	74
H-1370	51	54	52	62	51	57	48	55
Average[1]	Fireball 73		C-52 70		H-1370 52			

[1] Means underscored by the same line are not significantly different at odds of 99:1.

plants around each record plant. The record plants were in the center of either a rectangular or square pattern. The center rows in all directions were used as guard rows. The overall design gave four identical quadrants. Each quadrant was used as a replicate for statistical analysis even though the various spacings were not distributed at random.

Stem diameter measurements and inflorescence counts were made at three- to seven-day intervals until the plants were too large and prevented walking in the plot. Once-over harvests could not be obtained due to the crowded conditions resulting from the close spacings.

The closer the plants were spaced, the earlier the stem stopped enlarging and the fewer inflorescences occurred per plant. Figure 5 shows one quadrant with the average results for all quadrants. The stem grew for a longer time in three-foot rows going East and West than those going North and South. On the other hand, direction of row had an opposite effect on inflorescence development. Additional studies are needed to confirm these effects. Temperatures of various surfaces of the tomato plant stem should also be studied.

Inflorescence and Leaf Removal Study

In an experiment to study the effects of inflorescence and leaf removal on the growth of the tomato stem and time of harvest, southern-grown transplants of the varieties C-1327, H-1350 and H-1370 were set in blocks. Each block consisted of four replications of each of six completely randomized treatments. Each treatment consisted of three rows, five feet apart, with five plants spaced 16 inches apart in the row. The type of treatment and the dates of application for each variety are presented in Table 21.

It was hypothesized that removing leaves would advance the harvest date and since the number of days from the cessation of stem enlargement to the harvest date appeared to be constant, leaf removal would advance the date that the stem would stop enlarging. Also, removing inflorescences would delay the harvest date and thereby delay the cessation of stem enlargement.

Stem diameter measurements were made at weekly intervals for the first six weeks after transplanting and then every three or four days until the stem stopped enlarging.

→ N

feet	3.0	2.5	2.0	1.5	1.0
3.0 Population [2] Days-Stem [3] Inflor. No. [4]	4800 53a 23ab	5800 50ab 20abcd	7300 50ab 24a	9700 50ab 23ab	14,500 50ab 21abc
2.5 Population [2] Days-Stem [3] Inflor. No. [4]	5800 53a 18abcde	7000 53a 20abcd	8700 50ab 15abcde	11,600 51ab 16abcde	17,400 44cd 14abcde
2.0 Population [2] Days-Stem [3] Inflor. No. [4]	7300 51ab 20abcd	8700 49bc 17abcde	10,900 43def 23ab	14,500 43def 17abcde	21,800 39gh 16abcde
1.5 Population [2] Days-Stem [3] Inflor. No. [4]	9700 53a 13bcde	11,600 40defg 17abcde	14,500 40defg 14abcde	19,400 39gh 12cde	29,000 41efg 8e
1.0 Population [2] Days-Stem [3] Inflor. No. [4]	14,500 44cd 10e	17,400 44cd 15abcde	21,800 38gh 15abcde	29,000 38gh 14abcde	43,600 32h 10e

[1] blocks containing different letters within a parameter differ at odds of 99:1

[2] plants per acre

[3] average number of days from transplanting to the date the stem stopped enlarging

[4] average number of inflorescences per plant 46 days after transplanting

Figure 5. The growth of the tomato stem and inflorescence count of H-1350 in an arithmetic spacing design[1]

Table 21. The dates of leaf and cluster removal from three varieties in 1963.

Treatment (structures removed)	Number removed	Variety C-1327 date	H-1350 date	H-1370 date
1. Control		-	-	-
2. Leaves	5	7/11	7/12	7/12
3. Leaves	10	7/11	7/12	7/12
4. Clusters	5	6/27	6/28	6/28
5. 10 Clusters				
	5 on	6/28	6/28	6/28
	5 on	7/8	7/12	7/12
6. 15 Clusters	5 on	6/28	6/28	6/28
	10 on	7/11	7/12	7/12

The potential harvest date was predicted using the stem-growth intercept method described earlier. Three once-over harvests were obtained for each of five treatments in each variety. Two rows in the sixth treatment were harvested only once to simulate machine harvest, while one row was hand-harvested at three- or four-day intervals until the marketable yield was nil. The treatment rows were harvested in the same sequence as described in the 1963 time of planting and harvest studies mentioned earlier, that is, one row a week prior to the predicted date, one row on the predicted date and one row one week after the predicted date. In the treatment with only two harvests, one was made on the predicted date and the other, one week later.

The inforescence and leaf removal treatments had no effect on the

date that the stem stopped enlarging (Table 22). The once-over maximum yield of C-1327 occurred prior to the predicted date and did not change within a seven-day period. Therefore, the once-over maximum yield would have been obtained from all C-1327 treatments except when 15 inflorescences were removed. Harvest of the H-1350 control treatment on the predicted date was inadvertently omitted; however, in comparing the yields obtained with those from other treatments, it indicated that the prediction date was at least one week early. Removing five to 15 inflorescences from H-1350 delayed the once-over maximum yield beyond the predicted date.

Table 22 also shows that the average number of days from the time the stem stopped enlarging to harvest for all treatments on C-1327 and two treatments on H-1370 (control and 15 inflorescences removed) were within one day of the average observed in the 1963 large plantings (Table 15). This observation for all treatments on H-1350 varied five days from that obtained in the large plantings. Removing inflorescences and the control caused this variation.

Removing 15 inflorescences was the only treatment which affected the size of once-over maximum yield for both C-1327 and H-1350. However, the highest yield of C-1327 and H-1350 was only 48 and 55 percent ripe respectively. The only two treatments where H-1370 had a once-over maximum yield of ripe fruit greater than 50 percent were the control and removal of 15 inflorescences. Since the majority of the H-1350 treatments were harvested at the same time, the similarity between the yields from these two treatments cannot be explained.

Higher yields were obtained by the multiple-hand-harvest method than by the once-over simulated machine-harvest for the varieties C-1327

Table 22. Prediction dates based on stem diameter measurements and the yields obtained in the 1963 leaf and cluster removal study.

Variety	Treatment (structures removed)	Stem stopped enlarging (July)	Harvest date		Days to harvest	Yield	
			Predicted (Sept.)	Obtained (Sept.)		Tons/ acre	Percent ripe
C-1327							
	control (multiple harvest)	-	-	-	-	34.0	-
	control (once-over harvest)	22	16	9	49	21.6	46
	5 leaves " " "	19	13	13	56	22.9	44
	10 leaves " " "	18	12	6	50	18.0	39
	5 clusters " " "	19	13	13	56	25.2	48
	10 clusters " " "	25	19	12	49	20.5	41
	15 clusters " " "	21	15	9	50	17.0	31
					Av. 52		
H-1350							
	control (multiple harvest)	-	-	-	-	37.0	-
	control (once-over harvest)	13	5	13	62	27.3	54
	5 leaves " " "	20	12	12	54	27.2	51
	10 leaves " " "	20	12	12	54	27.4	55
	5 clusters " " "	18	10	17	51	26.8	55
	10 clusters " " "	21	13	20	61	29.4	53
	15 clusters " " "	25	17	24	61	22.8	46
					Av. 59		
H-1370							
	control (multiple harvest)	-	-	-	-	36.3	-
	control (once-over harvest)	24	23	30[1]	68[1]	31.9[1]	53[1]
	5 leaves " " "	23	22	[1]	[1]	[1]	[1]
	10 leaves " " "	23	22	[1]	[1]	[1]	[1]
	5 clusters " " "	24	23	[1]	[1]	[1]	[1]
	10 clusters " " "	22	21	[1]	[1]	[1]	[1]
	15 clusters " " "	25	24	30	67	33.4	53
					Av. 68		

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[1] Treatment prevented maximum yield.

and H-1350. However, similar yields were obtained for the two methods from H-1370.

Compilation of Most Successful Indices

Over a three-year period many features of growth and development were tried as potential indices for predicting a once-over harvest date. Cessation of stem enlargement and 15 inflorescences were the best indices for predicting dates of harvest. The average number of days for these indices and comparisons with days from transplanting are summarized in Table 23 for most of the plantings of five varieties. The interval between the once-over maximum yield and three stages of plant growth varied with variety. These three indices were also compared for their relative effectiveness in predicting harvest from 1961 to 1963. The only plantings not compared were those where different cultural treatments were studied.

The number of times that the individual plantings deviated from the average figure of all plantings was calculated for 1, 3, 5 and 7 days variation and expressed as percentages. The precision of these different comparisons is shown in Table 24. All three indices for determining harvest were quite effective. For example, there was not a great deal of variation in days from transplanting to harvest for the varieties Fireball and C-1327 when a deviation of three days from the average was considered. However, Fireball was grown only at one location and even though it was observed over a three-year period, the soil type and cultural practices were nearly the same. On the other hand, days from transplanting was more consistent than any other index for C-1327 which was grown at different locations with variable conditions of soil type and cultural practices.

Table 23. Average number of days between the date of the once-over maximum yield and three observations for 62 plantings.

		Observations		
Variety	No. of plantings	trans-planting	15 clusters	Cessation of stem enlargement
			(days)	
Fireball	13	96	62	55
C-52	14	108	71	56
H-1370	18	120	75	64
H-1350	9	116	69	54
C-1327	8	110	65	51

It is believed that with certain varieties such as H-1350, which is one of the most promising new varieties in this area for once-over harvest, the cessation of stem enlargement is the most reliable index for predicting harvest. The deviation from the average number of days for all H-1350 plantings was within three days 89 percent of the time and within five days 100 percent of the time. When the deviation from the average, for days from transplanting, was within five days, only 56 percent of the plantings were within this selected period.

The cessation of stem enlargement is also a reliable index for predicting harvest for the varieties Fireball and C-52. Averaging both varieties, the maximum yield occurred within a five-day deviation, 96 percent of the time.

The fact that H-1370 matured late in the season may be responsible for the difficulty in predicting harvest. In these studies, this variety did not decrease in maximum yield during any harvest season.

Table 24. The comparative effectiveness of three indices in predicting harvest on 62 plantings [1].

			Observations		
Variety	No. of plantings	Allotted deviation	Trans- plantings	15 clusters	Cessation of stem enlargement
		(Days)	(Percent deviation)		
Fireball	13	1	89	62	54
		3	33	15	31
		5	11	15	0
		7	0	0	0
C-52	14	1	82	79	64
		3	64	57	29
		5	27	28	7
		7	18	21	0
H-1370	18	1	100	94	78
		3	100	59	50
		5	73	39	28
		7	60	17	6
H-1350	9	1	78	57	89
		3	56	29	11
		5	44	0	0
		7	44	0	0
C-1327	8	1	75	88	75
		3	25	62	62
		5	12	12	38
		7	0	0	0
Average percent deviation for all varieties					
	62	1	85	76	72
		3	56	44	37
		5	33	19	15
		7	24	8	1

[1] Percent of time that the deviation from the average number of days from once-over maximum yield back to each observation was greater than the corresponding days allotted for deviation.

The cessation of stem enlargement was the most consistent index for determining once-over harvests when the variation was considered for each observation during a three-year period and with a total of 62 plantings.

SUMMARY

Various growth and fruiting characteristics of three to five tomato varieties were studied for three consecutive years to develop an objective method to predict the harvest date (earliest once-over maximum yield of ripe fruit) for mechanical harvesting.

In 1961, eleven different types of measurements on growth and development of the tomato plant were made at weekly intervals on five plantings of each of three varieties. The seven harvests made of each variety at each planting indicated that fruit quality and yield did not vary for at least one week. The intervals from the earliest date of once-over maximum yield back to various morphological characteristics were correlated with many climatic factors and time. Two characteristics appeared to be possible indices for the determination of the harvest date. These indices were: (a) when the base of the main stem ceased to enlarge and (b) when the fifteenth inflorescence had one flower showing color. Calendar days appeared to be the most practical criteria to measure intervals from these indices.

Two experimental transplanting systems, the first based on the criterion that another planting would be made when 564°F of minimum temperature accumulated and the second, when the stem diameter of the previous transplanting began rapid expansion, were evaluated and compared to an arbitrary system where plantings were spaced approximately eleven days apart. The experimental systems spaced planting dates approximately nine days apart and harvest dates averaged eight days apart. These data were similar to that obtained with the arbitrary system.

It was necessary to have an objective method for determining when

the stem stopped enlarging. Therefore, a line was fitted to the grand period of growth and another line was drawn through the average recordings of the maximun diameters. The point of intersection of these two lines was interpreted as the date that the stem stopped enlarging, and referred to as the stem-growth intercept.

The error in taking a measurement was determined at different times and with different varieties. The maximum variation (the difference between the extremes) averaged 0.8 millimeter. Also, the amount of plant variation existing between plants during growth was determined from approximately 2000 plants of each of three varieties. In 1963 at East Lansing, when the variation was not allowed to be more than 0.8 millimeter, 38 plants of C-1327, 28 of H-1350 and 26 of H-1370 had to be measured when the plants were randomly selected at each measuring date.

To evaluate two potential indices (date of 15 inflorescences and cessation of stem enlargement), seven plantings were made in 1962 and one in 1963 of the same varieties used in 1961. Observations were also made in large plantings set for bulk handling studies both in 1962 and 1963.

The growth and development of Fireball, C-52 and H-1370 varieties were similar to that observed in 1961. The number of days from the development of 15 inflorescences to the harvest date was consistent for each variety from all plantings in the same year, however, the time intervals were not similar between years.

To test the reliability of the two most promising indices, processing companies at Leipsic and Napoleon, Ohio; Marengo, Morris and Waterman, Illinois; and Frankfort, Indiana obtained stem diameter measurements,

inflorescence counts and yield records on several varieties. The results indicated that the date of the cessation of stem enlargement was an effective index (within six days of harvest) for predicting the harvest date in 12 out of 14 plantings. The interval from 15 inflorescences to the harvest date varied more with variety and location.

An attempt was made in 1962 to influence the growth and fruiting of the tomato plant by varying environmental conditions. High soil moisture and fertility levels did not influence the growth rate of the stem, however, there was an influence with spacing in the row. The base of the stem of plants of three varieties spaced nine inches in the row stopped enlarging eight days earlier than those spaced 18 inches.

The effects of spacing were studied again in 1963 using a modified arithmetic design. It was observed that, generally, the closer the plants were spaced, the earlier the stem stopped enlarging and the fewer inflorescences occurred per plant. There was a row-direction effect for stem growth and inflorescence development, but they were oriented 90 degrees from each other.

Removing five to 15 inflorescences or five to ten leaves had no effect on the date that the stem stopped enlarging, but inflorescence removal delayed harvest. Therefore, the date of once-over maximum yield was not obtained on the predicted date.

Information on the cessation of stem enlargement and the development of 15 inflorescences as indices for predicting once-over harvest for each five varieties and days from transplanting to harvest were compared for 62 plantings at different locations over a three-year period. Days from transplanting was the less consistent index for most varieties. Days

from 15 inflorescences varied with location and years; therefore is not a reliable index to predict once-over harvest. Cessation of stem enlargement was the most consistent index for predicting harvest date.

These results indicate that measurements of stem diameter during the growth of the plant may be used to predict the harvest date for once-over harvest. However, each planting of each variety must be considered individually.

It is concluded that the earliest maximum yield is 55, 56 and 54 days from the cessation of stem enlargement, respectively, for the varieties Fireball, Libby C-52 and Heinz 1350. The average number of days for the same interval with Heinz 1370 was 64 days and for Campbell 1327 was 51 days. However, further studies are recommended for these last two varieties if they are to be used in this area for mechanical harvesting.

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APPENDIX

Appendix table 1. Variation in taking a measurement of the base of tomato plant stems in 1962.

Times mea-sured	C-1327 - T.P. May 14, 1962 - 53 days later										
	Plant number										
	1	2	3	4	5	6	7	8	9	10	
	(millimeters)										
1	16.2	15.4	13.2	17.1	15.3	16.5	19.9	17.5	14.7	16.6	
2	16.2	15.4	13.3	16.9	15.0	17.3	19.2	16.8	14.7	16.4	
3	16.2	15.3	13.2	17.0	14.7	17.4	19.2	16.4	14.7	16.2	
4	16.2	14.8	13.0	17.0	14.7	16.7	19.0	16.4	14.7	16.7	
5	16.7	14.3	13.5	17.0	14.7	16.2	19.0	16.8	14.7	16.2	
6	16.3	14.6	13.6	17.1	14.7	16.5	19.3	16.6	14.8	16.2	
7	16.2	14.7	13.3	17.0	14.7	16.3	19.0	16.5	14.7	16.1	
8	16.3	14.3	14.3	17.0	15.1	16.4	19.3	16.5	14.7	16.3	
9	16.5	14.8	14.4	17.0	15.0	16.3	19.2	16.5	14.9	16.3	
10	16.3	14.8	14.4	17.0	15.1	16.2	19.1	16.5	14.6	16.3	Av.
Mean	16.3	14.8	13.6	17.0	14.9	16.6	19.2	16.6	14.7	16.3	16.0
Std. dev.	0.16	0.41	0.54	0.05	0.23	0.43	0.27	0.33	0.08	0.19	0.27
Diff. btwn. hi & lo	0.5	1.1	1.4	0.2	0.6	1.1	0.8	1.1	0.3	0.6	0.77

Times mea-sured	H-1350 - T.P. May 28, 1962 - 63 days later										
	Plant number										
	1	2	3	4	5	6	7	8	9	10	
	(millimeters)										
1	18.9	15.1	16.6	14.0	16.8	15.6	15.0	19.3	12.3	17.0	
2	18.9	15.0	16.5	14.1	16.6	15.3	14.9	19.3	12.4	16.6	
3	18.8	15.2	16.4	13.8	16.6	15.2	14.8	19.3	12.2	16.6	
4	18.6	15.6	16.2	13.9	16.3	15.0	14.4	19.2	12.3	16.6	
5	18.6	15.3	16.3	13.8	16.3	15.0	14.4	19.4	12.5	16.3	
6	18.4	14.2	16.2	13.5	16.3	15.0	14.3	19.2	12.2	16.4	
7	18.4	14.3	16.2	13.6	15.8	14.8	14.2	19.3	12.3	16.3	
8	18.2	14.7	16.2	13.5	15.8	14.8	14.3	19.3	12.5	16.3	
9	18.2	14.5	16.1	13.5	15.7	14.8	14.1	19.2	12.2	16.2	
10	18.2	14.7	16.3	13.6	15.7	14.8	14.0	19.3	12.3	16.3	Av.
Mean	18.5	14.9	16.3	13.7	16.2	15.0	14.4	19.3	12.3	16.5	15.7
Std. dev.	0.28	0.45	0.15	0.22	0.41	0.27	0.34	0.06	0.11	0.24	0.25
Diff. btwn. hi & lo	0.7	1.4	0.5	0.6	1.1	0.8	1.0	0.2	0.3	0.7	0.73

Appendix table 2. Variation in taking a measurement of the base of tomato plant stems in 1963.

Times measured	H-1370 - T.P. May 27, 1963 - 28 days later										
	Plant number										
	1	2	3	4	5	6	7	8	9	10	Av.
	(millimeters)										
1	6.3	7.4	6.8	6.0	5.5	5.2	5.4	4.2	6.9	6.5	
2	6.3	7.7	6.8	6.0	5.2	5.3	5.5	4.0	6.9	6.4	
3	6.3	7.4	6.8	5.9	5.5	5.1	5.4	4.2	6.8	6.5	
4	6.3	7.5	6.8	6.0	5.2	5.4	5.3	4.3	6.8	6.5	
5	6.3	7.6	6.8	5.9	5.5	5.2	5.5	4.7	6.9	6.4	
6	6.3	7.6	6.7	6.0	5.2	5.2	5.3	4.3	6.9	6.5	
7	6.3	7.6	6.8	6.0	5.3	5.3	5.5	4.2	6.9	6.5	
8	6.3	7.6	6.8	5.9	5.5	5.0	5.3	4.2	6.9	6.5	
9	6.3	7.5	6.8	6.0	5.5	5.3	5.3	4.3	6.9	6.4	
10	6.3	7.5	6.8	5.9	5.5	5.1	5.2	4.2	6.9	6.4	
Mean	6.3	7.5	6.8	6.0	5.4	5.2	5.3	4.3	6.9	6.5	6.0
Std. dev.	-	0.01	0.03	0.05	0.14	0.12	0.11	0.18	0.04	0.08	0.08
Diff. btw. hi & lo	-	0.3	0.1	0.1	0.3	0.3	0.1	0.3	0.1	0.1	0.17

Times measured	H-1370 - T.P. May 27, 1963 - 58 days later										
	Plant number										
	1	2	3	4	5	6	7	8	9	10	Av.
	(millimeters)										
1	16.2	13.9	13.3	14.8	14.6	18.0	13.4	17.0	16.3	15.9	
2	16.3	13.8	13.6	14.7	14.3	18.2	13.4	17.2	16.3	16.1	
3	16.3	13.8	13.3	14.6	14.3	17.8	13.3	17.1	16.6	16.3	
4	16.3	13.8	13.8	14.8	14.6	18.1	13.8	16.9	16.2	16.3	
5	16.6	13.3	13.5	14.7	14.4	17.9	13.3	17.2	16.4	16.3	
6	16.3	13.3	13.4	14.7	14.7	17.8	13.4	16.9	16.0	16.1	
7	16.1	13.5	13.3	14.6	14.4	18.2	13.5	16.8	16.9	16.1	
8	16.2	13.3	13.3	14.6	14.6	18.1	13.3	17.0	15.8	16.4	
9	16.2	13.6	13.3	14.6	14.5	18.1	13.3	17.0	16.2	16.3	
10	16.2	13.3	13.3	14.6	14.5	18.2	13.3	16.9	15.8	16.3	
Mean	16.3	13.6	13.4	14.7	14.5	18.0	13.4	17.0	16.2	16.2	15.3
Std. dev.	0.13	0.25	0.17	0.08	0.14	0.16	0.16	0.13	0.32	0.15	0.17
Diff. btw. hi & lo	0.5	0.6	0.5	0.2	0.4	0.3	0.5	0.4	1.1	0.5	0.50

Appendix table 3. Successive observations of various plant structures for three varieties in 1963.

Days from trans-planting	Stem dia. (mm)	Observations				
		Number of			Fresh wt. (gms)	Dry wt. (gms)
		Leaves	Clusters	Branches		
FIREBALL						
2	4.5	4	0	0	4	0
9	5.7	5	0	0	6	1
16	6.9	8	1	1	23	3
23	8.5	12	2	3	44	5
30	10.3	30	3	7	127	15
37	12.1	53	15	8	321	35
43	14.7	95	31	11	714	87
46	15.0	82	32	10	621	78
50	14.8	97	47	11	1016	98
54	14.0	86	42	11	903	93
57	14.5	95	50	12	1012	112
60	15.0	89	47	12	1000	119
64	14.4	80	36	12	741	96
C-52						
2	5.0	4	0	0	6	1
9	4.8	6	0	0	6	1
16	6.8	8	1	1	28	4
23	8.8	12	2	4	54	6
30	10.4	30	3	6	112	15
37	14.2	77	15	12	407	43
43	13.7	97	27	13	682	84
46	15.7	126	44	18	1039	123
50	15.2	114	47	16	1293	120
54	17.0	133	68	18	1648	148
57	16.4	140	64	20	1677	158
60	17.3	136	72	19	1954	221
64	16.0	140	67	20	1712	223
H-1370						
2	4.5	4	0	0	4	0
9	4.6	6	0	0	6	1
16	7.1	7	0	1	22	3
23	9.7	12	0	3	54	6
30	12.0	36	1	7	180	21
37	13.5	59	9	11	434	44
44	15.2	104	16	12	737	92
50	15.9	122	40	16	1410	153
54	16.0	135	44	19	1686	180
57	16.2	159	52	22	2151	211
60	16.5	157	57	29	2302	235
64	18.2	180	68	26	2292	244
67	19.4	228	75	29	2767	307

Appendix table 4. Summation of degree nights above $50^{\circ}F$[1] from several observations to the harvest date in 1961.

Variety and planting	Harvest date	Observations				
		Trans-planting	15 clusters	Flowering peak	Stem-growth intercept date	Decreased plant height
			(°F)			
Fireball						
5/22, T.P.	8/24	1481	1058	832	904	580
6/22, T.P.	9/4	1676	1613	1108	1070	856
6/14, T.P.	9/14	1700	1672	974	1100	848
5/4, D.S.	9/11	----	1226	1031	1603	779
5/17, D.S.	9/14	----	1159	1100	1100	703
Mean		1619	1346	1009	1155	753
Dev. from		+81	+326	+99	+448	+95
Mean		-138	-288	-186	-251	-173
C-52						
5/22, T.P.	9/7	1824	1348	1178	1201	800
6/2, T.P.	9/11	1821	1314	1283	1177	779
5/4, D.S.	9/14	----	1281	1100	1138	848
Mean		1822	1314	1187	1172	809
Dev. from		+2	+34	+96	+29	+39
Mean		-1	-33	-87	-34	-30
H-1370						
5/22, T.P.	9/14	1998	1424	1352	1264	848
6/2, T.P.	9/21	1999	1445	1179	1238	927
5/4, D.S.	9/21	----	1276	1053	1095	927
Mean		1998	1382	1195	1199	901
Dev. from		+1	+63	+157	+65	+26
Mean		-0	-106	-142	-104	-53

[1] The average temperature between sunset and sunrise minus 50°F.

Appendix table 5. Summations of the differences between the 24-hour maximum and minimum temperatures from several observations and the harvest date in 1961.

Variety and planting	Harvest date	Observations				
		Trans- planting	15 clusters	Flowering peak	Stem-growth intercept date	Decreased Plant Height
			(°F)			
Fireball						
5/22, T.P.	8/24	2285	1407	1021	1195	671
6/2, T.P.	9/4	2240	1431	1228	1169	878
6/14, T.P.	9/14	2143	1252	952	1082	775
5/4, D.S.	9/11	----	1310	1037	1207	730
5/17, D. S.	9/14	----	1144	1082	1082	800
Mean		2223	1309	1064	1147	771
Dev. from		+62	+122	+164	+60	+107
Mean		-80	-165	-112	-65	-100
C-52						
5/22, T.P.	9/7	2553	1582	1289	1350	782
6/2, T.P.	9/11	2409	1472	1387	1245	730
5/4, D.S.	9/14	----	1334	1082	1127	775
Mean		2481	1463	1253	1241	762
Dev. from		+72	+119	+134	+109	+20
Mean		-72	-129	-171	-114	-32
H-1370						
5/22, T.P.	9/14	2696	1606	1432	1310	775
6/2, T.P.	9/21	2624	1461	1252	1314	945
5/4. D.S.	9/21	----	1393	1122	1136	945
Mean		2660	1487	1269	1253	888
Dev. from		+36	+119	+163	+61	+57
Mean		-36	-94	-147	-117	-113

Appendix table 6. Total amount of open pan evaporation between several observations to the harvest date in 1961.

Variety and planting	Harvest date	Observations				
		Trans-planting	15 clusters	Flowering peak	Stem-growth intercept	Decreased plant height
			(inches)			
Fireball						
5/22, T.P.	8/24	17.71	12.18	8.20	9.71	5.53
6/2, T.P.	9/4	19.00	11.42	9.64	9.09	6.97
6/14. T.P.	9/14	17.46	9.58	7.10	8.31	6.13
5/4, D.S.	9/11	-----	10.01	8.02	9.29	5.84
5/17, D.S.	9/14	-----	8.90	8.31	8.31	5.77
Mean		18.06	10.42	8.25	8.94	6.05
Dev. from		+.94	+1.78	+1.39	+.77	+.93
Mean		-.60	-1.50	-1.15	-.63	-.52
C-52						
5/22, T.P.	9/7	21.45	13.05	10.03	10.43	6.15
6/2, T.P.	9/11	20.05	11.39	10.69	9.54	5.84
5/4, D.S.	9/14	-----	10.22	8.31	8.69	6.13
Mean		20.75	11.55	9.68	9.55	6.04
Dev. from		+.70	+1.50	+1.01	+.88	+.11
Mean		-.70	-1.33	-1.37	-.86	-.20
H-1370						
5/22, T.P.	9/14	22.40	12.49	10.98	9.96	6.13
6/2, T.P.	9/21	21.42	12.17	9.39	9.98	7.21
5/4, D.S.	9/21	-----	10.47	8.18	8.50	7.21
Mean		21.91	11.71	9.52	9.48	6.85
Dev. from		+.49	+.78	+1.46	+.50	+.36
Mean		-.49	-1.24	-1.34	-.98	-.72

Appendix table 7. Summations of daily solar radiation between several observations and the harvest date in 1961.

		Observations				
Variety and planting	Harvest date	Trans-planting	15 clusters	Flowering peak	Stem-growth intercept	Decreased plant height
		(gm - cal./sq. cm. of horizontal surface x 10^3)				
Fireball						
5/22, T.P.	8/24	48.2	29.6	20.5	24.3	13.5
6/2, T.P.	9/4	47.9	29.4	24.7	23.5	17.8
6/14, T.P.	9/14	44.3	24.8	18.4	21.4	15.7
5/4, D.S.	9/11	----	26.3	20.8	23.2	15.1
5/17, D.S.	9/14	----	22.8	21.4	21.4	12.3
Mean		46.8	26.6	21.2	22.8	14.9
Dev. from		+1.4	+3.0	+3.5	+1.5	+2.9
Mean		-2.5	-3.8	-2.8	-1.4	-2.6
C-52						
5/22, T.P.	9/7	53.6	32.8	25.8	26.9	15.9
6/2, T.P.	9/11	50.9	29.5	27.7	23.8	15.1
5/4, D.S.	9/14	----	26.5	21.4	22.3	15.7
Mean		52.2	29.6	25.0	24.3	15.6
Dev. from		+1.4	+3.2	+2.7	+2.5	+0.3
Mean		-1.3	-3.1	-3.6	-2.0	-0.5
H-1370						
5/22, T.P.	9/14	56.1	32.2	28.3	26.0	15.7
6/2, T.P.	9/21	54.6	31.8	24.5	25.9	18.8
5/4, D.S.	9/21	----	24.3	21.6	22.4	18.8
Mean		55.3	29.4	24.8	24.8	17.8
Dev. from		+0.8	+2.8	+3.5	+1.2	+1.0
Mean		-0.7	-5.1	-3.2	-2.4	-2.1

Appendix table 8. Summations of daily sunshine between several observations and the harvest date in 1961, (minutes of sunshine x 10^3).

		Observations				
Variety and planting	Harvest date	Trans- planting	15 clusters	Flowering peak	Stem-growth intercept date	Decreased plant height
Fireball						
5/22, T.P.	8/24	57.8	35.1	24.7	29.3	16.0
6/2. T.P.	9/4	55.7	35.4	29.9	28.4	21.2
6/14, T.P.	9/14	53.4	30.1	21.8	25.8	19.8
5/4, D.S.	9/11	----	32.2	25.3	29.6	19.3
5/17, D.S.	9/14	----	27.5	25.8	25.8	15.5
Mean		55.6	32.1	25.5	27.8	18.4
Dev. from		+2.1	+3.3	+4.4	+1.8	+3.8
Mean		-2.2	-4.6	-3.7	-2.0	-2.9
C-52						
5/22. T.P.	9/7	64.2	39.2	31.1	32.4	18.4
6/2, T.P.	9/11	59.8	36.1	34.0	30.5	19.3
5/4, D.S.	9/14	----	32.4	25.8	26.9	19.8
Mean		62.0	35.9	30.3	29.9	19.2
Dev. from		+2.2	+3.3	+3.7	+2.44	+0.6
Mean		-2.2	-3.5	-4.5	-3.0	-0.8
H-1370						
5/22, T.P.	9/14	67.6	39.1	34,5	31.6	19.8
6/3, T.P.	9/21	63.9	38.5	29.4	31.1	23.4
5/4, D.S.	9/21	----	32.9	25.4	26.4	23.4
Mean		65.7	36.8	29.8	29.7	22.2
Dev. from		+1.9	+2.3	+4.7	+1.9	+1.2
Mean		-1.8	-3.9	-4.3	-3.3	-2.4

Appendix table 9. Summations of the product of the daily sunshine and the day temperature between several observations and the harvest date in 1961, (minutes of sunshine x average day temperature x 10^6)

		Observations				
Variety and planting	Harvest date	Trans-planting	15 clusters	Flowering peak	Stem-growth intercept	Decreased plant height
Fireball						
5/22, T.P.	8/24	4.22	2.58	1.99	2.15	1.19
6/2, T.P.	9/4	4.05	2.59	2.22	2.11	1.42
6/14, T.P.	9/14	3.86	2.25	1.63	1.77	1.42
5/4, D.S.	9/11	----	2.40	1.73	2.22	1.38
5/17, D.S.	9/14	----	2.06	1.77	1.77	1.12
Mean		4.04	2.38	1.87	2.00	1.31
Dev. from		+0.18	+0.21	+0.35	+0.21	+0.11
Mean		-0.18	-0.32	-0.24	-0.23	-0.19
C-52						
5/22. T.P.	9/7	4.54	2.88	2.31	2.39	1.37
6/2, T.P.	9/11	4.35	2.67	2.53	2.28	1.38
5/4, D.S.	9/14	----	2.41	1.77	2.02	1.42
Mean		4.45	2.65	2.20	2.23	1.39
Dev. from		+0.09	+0.23	+0.33	+0.16	+0.03
Mean		-0.09	-0.24	-0.43	-0.21	-0.02
H-1370						
5/22, T.P.	9/14	4.80	2.89	2.57	2.36	1.42
6/2, T.P.	9/21	4.67	2.88	2.05	2.34	1.70
5/4, D.S.	9/21	----	2.48	1.92	1.99	1.70
Mean		4.73	2.75	2.18	2.23	1.61
Dev. from		+0.06	+0.14	+0.39	+0.37	+0.09
Mean		-0.06	-0.27	-0.26	-0.24	-0.19

Appendix table 10. Summations of the product of the length of night and night temperature between several observations to the harvest date in 1961, (Length of night in minutes x average night temperature x 10^6).

Variety and planting	Harvest date	Observations				
		Trans-planting	15 clusters	Flowering peak	Stem-growth intercept	Decreased plant height
Fireball						
5/22, T.P.	8/24	3.40	2.24	1.75	1.95	1.25
6/2, T.P.	9/4	3.61	2.51	2.28	2.22	1.79
6/14, T.P.	9/14	3.64	2.54	2.01	2.28	1.74
5/4, D.S.	9/11	----	2.54	2.13	2.39	1.59
5/17, D.S.	9/14	----	2.39	2.28	2.28	1.45
Mean		3.55	2.44	2.09	2.22	1.56
Dev. from		+0.09	+0.10	+0.19	+0.17	+0.22
Mean		-0.15	-0.20	-0.34	-0.27	-0.31
C-52						
5/22, T.P.	9/7	4.08	2.81	2.43	2.49	1.65
6/22, T.P.	9/11	3.96	2.73	2.63	2.42	1.59
5/4, D.S.	9/14	----	2.65	2.28	2.35	1.74
Mean		4.02	2.73	2.44	2.42	1.66
Dev. from		+0.06	+0.08	+0.19	+0.07	+0.08
Mean		-0.06	-0.08	-0.17	-0.07	-0.07
H-1370						
5/22, T.P.	9/4	4.43	2.63	2.78	2.61	1.74
6/2, T.P.	9/21	4.40	3.11	2.57	2.69	2.04
5/4, D.S.	9/21	----	2.80	2.26	2.34	2.04
Mean		4.42	2.85	2.54	2.55	1.94
Dev. from		+0.01	+0.27	+0.24	+0.14	+0.37
Mean		-0.02	-0.22	-0.28	-0.21	-0.20