THE EFFECT OF SOME ENVIRONMENTAL FACTORS ON BLOTCHY RIPENING OF THE TOMATO

Thesis for the Degree of M. S.

MICHIGAN STATE UNIVERSITY

Otho Sylvester Wells

1963

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By

Otho Sylvester Wells

AN ABSTRACT OF A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE

Department of Horticulture

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Blotchy ripening of the tomato was studied on the basis that this disorder is a result of a critical energy stress in the fruit. Experiments were set up to produce such energy alterations in the plant and thus within the fruit. Nutrition and variety were also included in some phases of the study.

Variety resulted in differences in both yield and the incidence of blotchiness; however, there was no correlation between yield and blotchiness from the data of eight varieties. Glamour, a low yielding variety, was very susceptible to blotchy ripening.

At low, medium, and high levels of fertility, no differences in blotchiness were found. Between blotchy and non-blotchy tissue, there were no differences in mineral composition or in percent dry weight; however, soluble solids were lower in blotchy tissue. High humidity and high soil moisture were non-effective in inducing blotchiness.

Treatments of shade, mist, mist plus shade, straw mulch, and a wind barrier were designed to either decrease transpiration or increase respiration to produce a high energy demand in rapidly developing fruits or a critical

energy depletion in rapidly respiring plants. However, an unforeseen variable, early blight, intervened soon after treatment began and modified the effect of the treatments. The shade and mist plus shade treatments reduced blotchiness through their influence on reducing early blight. The more severe the early blight, the more defoliation, and, in turn, the more blotchy ripening.

It was concluded that the theory of a critical energy stress in the latter stages of fruit development is valid, and that blotchy ripening will occur when a sufficient deficiency of reserve food materials occurs. This deficiency is thought to be most acute about the time of the second harvest of heavy-fruiting plants.

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ACKNOWLEDGMENTS

The author expresses his thanks to Dr. R. L. Carolus for his advice and assistance during the course of this study; to Drs. S. T. Dexter, R. R. Dedolph, and D. P. Watson for their counsel and guidance in the preparation of the manuscript; and to Dr. A. L. Kenworthy for his assistance in the chemical analyses appearing in this thesis.

Appreciation is also expressed to Mr. David A. Gilbart for his valuable assistance in much of the research.

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INTRODUCTION

Blotchy ripening of the tomato is a physiological-pathological disorder characterized by the absence of normal red pigment, lycopene, in localized areas of the fruit wall. Underlying the blotchy tissue there may appear a necrosis of the parenchyma tissue adjacent to the vascular bundles. Low levels of total solids, soluble solids, and organic acids are associated with blotchy tissues (19, 47, 48).

The physiological cause of blotchy ripening is probably related to either adverse climatic, cultural, and/or nutritional conditions. Tobacco mosaic virus may have a secondary influence in enhancing this physiological abnormality. Because the biosynthesis of lycopene requires a high level of available energy (30), influences resulting in a low accumulation of food reserves in the fruit are suspected.

The exact environmental conditions which will result in blotchy ripening are not known. However, the results of much research indicate that certain environmental conditions or combinations of these conditions may induce the disorder (14, 19, 44). This study was concerned primarily with environmental and cultural factors. Nutritional and varietal factors were, however, introduced in some phases of the study.

REVIEW OF LITERATURE

Since 1921, when blotchy ripening was first studied (11, 14), it has continued to be of considerable import. Varied concepts of the nature of the disorder have elicited numerous suggestions concerning its cause and control. Hypotheses as to causation are generally based on the nutritional status, environmental conditions, or viral infections (tobacco mosaic virus) of the plant and fruit. Some hypotheses may embrace the possibility of two or more of the above causation complexes interacting to produce the malady.

Nutritional Aspects

Bewley and White (2) were the first to use the term blotchy ripening and described it as hard green or waxy areas on the ripening fruit. They indicated that the blotchiness was due to low soil potassium and nitrogen, especially potassium. The uneven coloring was often accompanied by a necrosis of the fruit vascular tissue and a breakdown of the adjacent tissue with the subsequent formation of canals. Their nutritional investigation showed that the incidence of blotchy ripening could be reduced to less than 1 percent by suitable application of sulfates of ammonia and potash. As they increased the application of nitrogen, potassium, and phosphorous, the percentage of blotchy ripening decreased. They proposed that climatic factors modified nutritional effects.

Kidson and Stanton's work (27) with "cloud," a local name for blotchy ripening, showed that glucose increased cloud; but if potassium were added, the effects of glucose were counteracted. The omission of nitrogen from standard fertilizer increased cloud, but when high nitrogen was used, there was a marked reduction of the disorder. The high nitrogen also reduced the cloud-inducing effects of heavy watering. The application of calcium chloride essentially prevented cloud and reduced the incidence in plants treated with glucose.

Winsor, et al. (45, 46), in tests with different concentrations of nutrients, found that fruit quality improved up to a nutrient concentration of 225 ppm of nitrogen (potassium nitrate and ammonium sulfate) and 394 ppm of K_2O (potassium nitrate), but there was a slight reduction in total yield and a reduction in weight per fruit.

The concentration of fertilizer salts in the soil solution has been shown to have an indirect effect on the incidence of blotchy ripening. Clay and Hudson (9) found that blossom-end rot was pronounced when the soil salinity was increased by the addition of potassium and magnesium sulfates, and that blotchy ripening was highest in non-saline soil. Water was taken up most rapidly when salinity was the lowest. The highest yields of best quality fruit were produced at moderate levels of salinity. In Florida, Geraldson (20) found that the incidence and severity of blotchy ripening was higher when plants were grown in nutrient cultures with low nutrient concentrations and low nitrate/chloride ratios. Belik (1), in a study of the influence of moisture level on plant growth, found that tomatoes produced the highest yields of largest fruit when soil moisture was 60-70 percent as compared with either 40-50 percent or 80-90 percent of field capacity.

Environmental Associations

With reference to Bewley and White's work (2), Seaton and Gray (33) made a histological study of tissue from blotchy ripening greenhouse fruit and noted that the vascular necrosis of the fruit was not actually a necrosis of the vascular bundles, but a collapse of parenchymatous tissue adjacent to the bundles and anastomosing veins. As the blotchy ripening area was viewed through the epidermis, it appeared that the vascular bundles were affected, due to bands of discolored cellular material lying between the epidermis and the bundles. Gigante (21) agreed with the above observations and, in addition, found that the epidermis of a ripened fruit was often underlain with white spongy tissues, which, in some cases, extended throughout the wall.

Both Seaton and Gray (33) and Gigante (21) contradicted Bewley and White's (2) nutritional hypothesis and related blotchy ripening to conditions which prevented the translocation of elaborated food materials and water from the bundles to the outlying cells. Seaton and Gray (33) proposed that the primary condition was a withdrawal of water from the fruits during periods of excessive transpiration, occurring two to five days before the fruit ripened. Gigante (21) went further and said that the environmental water imbalance occurred when a dry spell immediately followed a wet spell. Under these conditions the fruit experienced a rapid uptake of water followed by a rapid loss of water through transpiration. A Danish report (44) also showed evidence that blotchy ripening was probably the result of rapid evaporation of water from the plants.

Lorenz and Knott (29) identified a different type of outer wall disorder, "graywall," which was found only in mature green fruit. Fruits having the disorder were thin-walled on the side exposed to the sun. Another report (40) indicated that "graywall" fruits were watery and thin-walled, and that this condition was due to excessive nitrogen and water. On the other hand, Lorenz and Knott (29) ascribed the trouble to excess heat on the exposed side of the fruit. As the fruit warmed, the water distilled from the warm side to the cooler or shaded side of the fruit. They concluded that if young, immature cells were exposed to high light intensity, and thus higher temperatures, they would not have the turgor capacity to enlarge, hence thin walls. On this basis they recommended the planting of thick foliaged varieties which would provide adequate shade.

Conover (10) reported that in Florida the first evidence of blotchy ripening, which he called internal browning, appeared in 1927. In the winter season of 1948-1949, the tomatoes in Dade County, Florida, were again severely affected with blotchy ripening. No definite cause could be cited, but the disorder was found to the greatest extent where there was luxuriant vine growth and heavily shaded fruits. Stoner and Hogan (42) made observations similar to Conover's, and on the basis of field and laboratory study, they concluded that blotchy ripening was due to some physiological factor, neither nutritional nor viral.

Haenseler (22) found blotchy ripening on several varieties in New Jersey and postulated a possible three-way interaction between variety, environment, and virus infection. He observed that the plant tended to recover as the season progressed, for only the second and third harvests of several harvests were seriously affected in the observational year, 1949.

Kidson and Stanton (27), as well as Ells (19), found blotchy ripening to be worse on the lower clusters of heavily fruiting plants. On some plants the uneven coloring persisted throughout the season and in such cases, the incidence of blotchy fruit was higher at early and late harvests. Ells (19) reported that blotchy ripening seldom occurred on fruits from the upper clusters. Kidson and Stanton (27) found that steam sterilization of the soil increased blotchiness along with substantial increases in growth and yield. Even though they found that the most susceptible plants were those having luxuriant growth, they also found evidence that heavy defoliation would increase the disorder. The latter finding contradicts the first but might be explained in the findings of Davies (13) who observed that severe defoliation resulted in better grade fruit and reduced the proportion of irregularly colored ones, but at the expense of marked yield reduction.

Hall and Dennison (23) set up experiments to observe the effects of shade, moisture, soil compaction, and cool temperatures on the incidence of blotchy ripening. Although shade and mist separately produced blotchy ripening, a combination of the two was more effective than either alone. Soil compaction was noticeably effective, but appeared to be insignificant when combined with shade or mist. Cool night temperature increased the disorder, but its effect was much greater when combined with mist or mist and shade. It may be that the mist intensified the shade and was thus responsible for increased blotchiness, or the mist may have been an important water source, since the mist nozzles operated continuously during the treatment. If the latter is the case, it would be in agreement with Kidson and Stanton's (27) and Ells' (19) results which showed that heavy watering increased the incidence of blotchiness.

Cooper (13, 14, 15) and Jones (25) worked with the specific factors, shade, temperature, and water and their relationship to the incidence of blotchy ripening. These workers concluded that blotchiness was increased with shade, high day temperatures, and a high moisture regime.

Other work by Cooper (12) showed that the percentage of uniformly colored fruit increased when greenhouse plants were widely spaced(6 x 6 feet) and when the axillary shoots were retained. He increased yield and the number of fruits per plant, but at the expense of reduced mean fruit weight. At closer spacings, the retention of axillary shoots decreased yield per unit area and the number of fruits per plant, and in that case also, there was a higher percentage of even colored fruit. The mean fruit weight also increased.

These results are not in agreement with the findings of other workers (19, 27), who found that high yielding plants tended to produce more blotchiness. Ells (19) found that as the ratio between fruit weight and green plant weight increased, blotchy ripening increased. Cooper (16) also found that when tomatoes were grown in 8-3/4-inch containers, in contrast to being grown in ground beds, and at 60°F. night temperature, rather than at 55°F., the proportion of uniformly colored fruit increased. Under the same conditions, early yield was increased, but total yield was not.

Tobacco Mosaic Infection

A recent report (35) on the association of virus with ripening disorders made a distinction between graywall and internal browning. Murakishi (35) reported that internal browning was caused by a strain(s) of tobacco mosaic virus (TMV) and could be seen in either mature green or ripe fruit. On the other hand, graywall was restricted to green to mature green fruits. Blotchy ripening was the same as graywall except that the former appeared on unevenly colored ripe fruit.

Before Murakishi (35) proposed his classification, workers were relating the internal browning condition of tomato fruit to virus infection. Holmes (24) was probably the first person to propose a definite relationship between strains of TMV and internal browning, even though previously, Selman (39) and Broadbent (8) reported virus infections in tomatoes grown in English glasshouses. Holmes further showed that there was a close association between infected tomato plants and mosaic infected Plantago sp., which grew near tomato fields.

Raychaudhuri (36) found, and Boyle (5) confirmed, that the TMV strain that was associated with internal browning was not the same as the ordinary strain of TMV.

Boyle (4) and Boyle and Wharton (7) showed that internal browning could be reproduced in fruits by inoculating large, fruit-bearing plants with tobacco mosaic virus that had been isolated from internally-browned fruits and from foliage of plants that had produced such fruit, but that the inoculation of young plants did not result in internal browning. Internal browning was interpreted as a "shock reaction" resulting from virus invasion and accumulation and a hypersensitive response of the host.

While Boyle and Wharton (7) could not find any relationship between internal browning and the rate of fertilizer application, other work has shown that nutrition significantly influences the incidence of internal browning. Selman (39) found evidence of differing responses of potassium application to blotchy fruit production on virus-infected plants. High potassium reduced blotchy ripening in infected plants. However, it appears that the same quantity of potassium applied to control plants resulted in an increase of blotchy ripening. Rich (37) found that high potash could alleviate internal browning in virus-inoculated plants. Cotter (17) reported that high nitrogen, low potassium, and low boron generally favored blotchy ripening and internal browning; however, Taylor (43) could not relate the deficiency of boron in plants producing internal browning to the incidence of the disorder.

Murakishi (32, 33, 34) showed that graywall and internal browning could be induced in TMV-free plants by low light intensity or shading.

Along with external factors which affect the incidence of blotchy ripening are internal conditions associated with the disorder. The composition of the tomato fruit and of the plant has been studied and definite relationships between blotchy and non-blotchy fruit have been found. Winsor et al. (47, 48) found blotchy ripened fruit to be lower in total solids, sugars, and acidity. Ells (19) found that blotchy ripened tissue was lower in dry matter, soluble solids, and reducing sugars than was normal fruit.

EXPERIMENTAL

Field Investigations--1961

Experiments were conducted during the summer of 1961 to measure the influence of environment, nutrition, and variety on blotchy ripening.

Ells (19) suggested that a primary cause of blotchy ripening was a carbohydrate stress in the fruit at some critical period during development. Accordingly, a high ratio of fruit to plant weight might impose a carbohydrate stress and the incidence of the disorder might then increase. Thus, yield differences within the same variety but with different treatments might alter plant weight-fruit weight ratios and afford a test of this hypothesis.

Though Ells (19) found no distinct association between nutrient levels and the incidence of this disorder, further consideration of potassium and phosphorus nutrition was made in this study.

Procedure

The influences of fertility levels, variety, and harvest date, on yield and the incidence of blotchy ripening in eight varieties (Glamour, Cardinal, Morton Hybrid, Burpee Hybrid, N3266A, Indian River, Big Boy, and Big Early Hybrid) were investigated. Plants used were transplanted June 1 to the field location with 3 x 5 foot spacing.

The differential fertilizer treatments were: (1) control, (2) 120 pounds P_2O_5 plus 160 pounds K_2O per acre, (3) 24 pounds P_2O_5 plus 32 pounds K_2O, and (4) 120 pounds P_2O_5 plus 113 pounds K_2O. All plots were fertilized with 60 pounds per acre of NH_4NO_3. The soil tested 66 pounds of available phosphorus and 39 pounds of available potassium by the Spurway test (41).

Only the fruits of the last two harvests were weighed and graded. Yield and percent blotchy ripening data were summarized by analysis of variance. Difference between means were delineated by Duncan's multiple range test.

Soluble solids, percent dry weight, and mineral composition values were determined for blotchy and non-blotchy wall tissue from blotchy fruit. Tissue samples were dried at 46°C. for 72 hours and analyzed for nitrogen by the Kjeldahl procedure and for potassium with the Beckman Model B flame spectrophotometer. A direct reading photoelectric spectrometer, a "Quantograph," was used for the determination of phosphorus, sodium, calcium, magnesium, manganese, iron, copper, boron, zinc, molybdenum, and aluminum (26). A Zeiss hand refractometer was used for estimating soluble solids.

For observational purposes several non-blotchy and blotchy fruits from three successive harvests were uniformly arranged and stored at 65°F. for a period of one week. Many of the blotchy areas were outlined with ink to determine if they would ripen and to determine the pattern of such ripening.

Results

Neither yield nor the incidence of blotchy ripening was influenced by either fertilizer or the interactions of fertilizer with variety or of fertilizer with harvest date (Table 1). The September 19 harvest was generally over twice as large as the September 27 harvest, but the later, lighter harvest had a higher incidence of blotchy ripening than the earlier harvest (Table 1). A correlation analysis further showed that there was no correlation between yield and percent blotchy ripening within a given date or between dates.

Yield and percent blotchy ripening were influenced by variety and date. For the September 19 harvest, the yield of Indian River and Big Boy were similar (Table 2), and there was no significant difference in percent blotchy ripening. However, for the September 27 harvest, the yields of Indian River and Big Boy represented the highest and lowest values, respectively, but each showed the same proportion of blotchy fruit. Indian River, N3266A, and Big Boy produced the highest yields, and Big Early Hybrid and Morton Hybrid produced the lowest yields. Glamour, a relatively low-yielding variety, was markedly affected with blotchy ripening, while Indian River and Big Boy were only mildly affected (Table 2).

Soluble solids content was higher in non-blotchy wall tissue (3.8%) than in blotchy wall tissue (3.4%) in all varieties (odds 19:1). Percent dry weights in the two types of tissue did not materially differ. No differences in mineral composition were found between the two tissue types (Table 3).

TABLE 1. The influence of fertility levels and harvest dates on the average yield and average incidence of blotchy ripening of eight varieties of tomatoes.

Date	Control	HP-HK[a]	LP-LK	HP-MK	Average
(a)	Yield (Tons per Acre)				
September 19	8.8	9.6	9.5	9.7	9.4
September 27	4.1	3.4	3.5	5.3	4.1
Total	12.9	13.0	13.0	15.0	13.5
(b)	Blotchy Ripening (% by Weight)				
September 19	20.5	22.2	21.7	21.9	22.1
September 27	23.9	30.5	29.8	34.5	29.7
Average	22.2	26.4	25.8	28.2	25.9

[a]HP--High phosphorus
HK--High potassium
L--Low
M--Medium

TABLE 2. Influence of variety and harvest date on yield and on percent blotchy ripening of marketable tomatoes.[a]

Yield (Tons per Acre)

September 19		September 27		Total	
Variety	Mean Yield	Variety	Mean Yield	Variety	Mean Yield
Big Early Hybrid	5.1 a	Big Boy	2.9 a	Big Early Hybrid	8.4 a
Morton Hybrid	7.8 b	Burpee Hybrid	3.1 a	Morton Hybrid	11.5 b
Glamour	8.4 b	Big Early Hybrid	3.3 a	Glamour	12.5 b
Cardinal	9.0 bc	Morton Hybrid	3.7 a	Burpee Hybrid	12.5 bc
Burpee Hybrid	9.4 bc	Glamour	4.1 a	Cardinal	13.5 cd
N3266A	11.2 cd	Cardinal	4.5 a	Big Boy	14.9 de
Big Boy	12.0 d	N3266A	4.5 ab	N3266A	15.8 e
Indian River	12.2 d	Indian River	6.3 b	Indian River	18.5 f

Percent Blotchy Ripening (by Weight)

					Average
Big Boy	15.6 a	Indian River	18.0 a	Big Boy	16.1 a
Big Early Hybrid	17.8 a	Big Boy	18.0 a	Big Early Hybrid	20.4 ab
Morton Hybrid	17.9 a	N3266A	24.3 ab	Indian River	20.9 ab
Burpee Hybrid	20.2 ab	Big Early Hybrid	24.5 ab	Burpee Hybrid	23.0 ab
Indian River	22.3 ab	Burpee Hybrid	31.6 abc	Morton Hybrid	23.6 ab
Cardinal	23.5 ab	Morton Hybrid	35.5 bc	N3266A	24.3 ab
N3266A	24.6 ab	Cardinal	39.2 bc	Cardinal	28.9 bc
Glamour	34.5 b	Glamour	46.3 c	Glamour	36.3 c

[a]Mean yields or percent blotchy ripening within a column which are not followed by the same letter differ at odds of 99:1.

TABLE 3. Mineral composition of non-blotchy and blotchy wall tissue of blotchy tomato fruit.[a]

	Percent of Dry Weight	
Element	Non-Blotchy	Blotchy
Nitrogen	2.54	2.77
Potassium	4.19	4.52
Phosphorus	0.479	0.554
Calcium	0.28	0.41
Magnesium	0.21	0.21
	PPM, Dry Weight Basis	
Sodium	160.0	211.0
Manganese	20.0	23.0
Iron	309.0	394.0
Copper	11.0	15.3
Boron	23.2	25.0
Zinc	30.0	32.0
Molybdenum	1.3	1.5
Aluminum	47.0	48.0

[a]Averages of 15, 10-fruit samples.

Observations, after a seven-day storage period of field-harvest blotchy fruit, indicated that all of the blotchy areas developed uniform color with the exception of those areas that were underlain with necrotic vascular tissue. These areas remained non-uniformly colored in relation to the severity of the necrosis.

Discussion

Heavy fruiting varieties are thought to be more susceptible to the blotchy disorder (19, 27), but in this study there was no such relationship. The fact that the high producing variety, Indian River, was mildly affected with blotchiness may be partially accounted for by its being a variety that is known to show appreciable resistance to the disorder. Although Glamour was a relatively low yielding variety, it showed very marked susceptibility to blotchiness. N3266A, a selection for resistance to TMV, was a relatively high yielding variety which had a high incidence of blotchiness. Since there was no correlation between yield and blotchy ripening, it appears that yield in this experiment did not alter the carbohydrate levels enough to influence blotchiness. Thus, the relationship between yield and the incidence of the disorder is explained on the basis of plant vigor. Generally, most of the varieties were at their peak of production at the earlier harvest, and the resulting heavy yield apparently utilized any available reserve food materials that may have accumulated during optimum conditions for photosynthesis. The heavier yield at the earlier harvest predisposed the fruits of the later harvest to develop on temporarily weakened plants. Also, at this time the metabolic functions of the plant were in a state of decline due to cooler weather and an onslaught of late diseases.

If, then, there is a close association between higher yields and increased blotchiness, it must be that these plants were not producing heavily enough to create the necessary stress on carbohydrate availability to the fruits.

Since the fertility levels exerted no significant influence on either yield or blotchiness, it may be assumed that for the quantity of fruit produced, the original fertility status of the soil was adequate.

The results of the analysis of non-blotchy and blotchy tissue are not in complete agreement with other research. Although there was a significant difference in soluble solids between blotchy and non-blotchy tissue, there was no difference in percent dry weight or in mineral composition. Apparently, a lower value for each of these is not always a true indication of blotchy tissue.

Field Investigations--1962

The purpose of the field experiment of 1962 was to determine if certain environmental factors would induce blotchy ripening, and if so, to what extent. Treatments were chosen which would in some cases reduce transpiration and in others increase respiration. With a hypothesis that restriction of transpiration would result in a rapid enlargement of the fruit and, in turn, create a critical demand for energy, treatments were set up to induce these effects. High rates of respiration are known to rapidly deplete reserve food materials; therefore, treatments which would increase the respiratory activity were also initiated. Hall and Dennison (23) worked with shade, mist, and a combination of the two to determine the effect on blotchy ripening. This experiment involved similar considerations.

Procedure

Seed of Fireball variety were sown on April 4 and on May 26 the plants were transplanted into the field. The field soil had been fertilized with 300 pounds of 5-20-20 and 40 tons per acre of manure. On July 2 a sidedressing of 100 pounds per acre of ammonium nitrate was applied. Six treatments of double-row, eight-plant plots were replicated three times, each plant being spaced 2-1/2 x 4 feet. The treatments were: check, shade, wind barrier, straw mulch, mist, and mist plus shade. To facilitate mechanical adaptations, the mist and mist plus shade treatments were staggered across replications and down the field. All other treatments were randomized within each replicate.

The purposes of the shade treatment were primarily to reduce light intensity and increase the temperature, thereby, increasing respiration. The shade material, Lumite saran shade fabric (Chicopee Manufacturing Corporation, Cornelia, Georgia) covered the whole plot and reduced the light intensity by 72 percent as measured by a Weston Illumination Meter, Model 756, with a quartz filter. The shade fabric was suspended two feet above ground level or approximately six inches above the tops of the plants.

The wind barriers were to serve as a means of reducing transpiration during windy weather and to increase the temperature on a calm day, thus increasing respiration. White, two-mil polyethylene plastic, 2-1/2 feet high, surrounded the plot.

In the straw mulch treatments, wheat straw was placed under and around the plants with some of the straw lightly covering the plants. The purpose was to reduce light intensity and to decrease transpiration.

The mist was used to reduce transpiration. A mist system was set up so that the foliage was kept continuously wet. The misting cycle was regulated by a solenoid valve and a Mist-A-Matic-Model B control system (E. C. Geiger, North Wales, Pennsylvania). This type of system is based on the principle of the weight of water. When adequate water falls on a fine-mesh, stainless steel screen, the screen moves downward and depresses a lever throwing a mercury switch, closing the solenoid valve, shutting off the mist. As the water evaporates from the screen, the same as from the plants, the screen tilts up, actuating the mercury switch, opening the solenoid, actuating a new mist cycle.

The mist plus shade treatment was to reduce transpiration and light intensity. The same shade material as was used for shade alone was used, and the mist system was the same as for the mist alone.

All treatments were set up on July 30 (after harvesting the first ripened fruits) and were not removed until after the last harvest on August 30.

All the area in the experiment was kept free of grass and weeds, excepting slight sprouting of volunteer wheat in the latter part of the harvest season. Irrigation supplemented normal rainfall so that the plants did not experience drought conditions. Weekly soil moisture readings showed that the moisture content never fell below 45 percent of field capacity. Neither were there times when the moisture level was above field capacity for extended periods of time.

The fruits for which records were kept were harvested from August 4 through August 30. Before August 4, only a few scattered fruits were harvested, and after August 30, there were few fruit remaining. Only the red, mature fruits were harvested for each harvest date.

After harvest, the fruits from each treatment in each replicate were separated into four classes: (1) normal (fruits showing no external appearances of blotchy ripening), (2) mild yellow blotch (fruits in which 1 to 25 percent of a fruit was covered by yellow blotchiness), (3) severe yellow blotch (fruits in which over 25 percent of a fruit was covered by yellow blotchiness), and (4) green blotch (fruits showing any amount of green blotchiness; however, this type usually covered more than 25 percent of a fruit). Within each class and for each treatment, the yield was recorded by number and by weight of the fruit. An estimate of soluble solids in a representative sample of fruit in each class was made by selecting from each sample two fruits of similar size, maturity, and blotchiness. It was found that soluble solids values for normal fruit and fruit from the mild blotchy class (having 10-15 percent blotchiness) were only very slightly variable (2-3 percent) and that this variability was very inconsistent. Therefore, a blotchy sample having 5-10 percent blotchiness was used for both the normal and the mild classes. For the severe class, samples having from 40-50 percent blotchiness were taken. In this way there were noticeable and consistent differences in the soluble solids estimates. Samples from the green blotch class showed from 25-40 percent green area.

The data were summarized by analysis of variance, and differences between means delineated with Duncan's multiple range test.

Results

Treatment had no effect on total yield; however, within each of the fruit classes, except green blotch, treatment was effective in altering the proportions of total yield in the various classes (Table 4a and 4b). The distribution of total yield among the four classes showed that the seasonal yield of severe yellow blotch was higher than the combined yield of the other three classes (Figure 1). Normal fruit yield was low, accounting for only 6.4 percent of the total yield (Table 4b).

The differences in yield, within each class, due to treatment are shown in Table 5. A significant trend was

TABLE 4. The influence of treatment on total yield, proportional yield, and soluble solids of four classes of ripe Fireball tomato fruit.

(a) Yield

Treatment	Total Yield			Normal			Mild Yellow			Severe Yellow			Green Blotch		
	No.[a]	Wt.[b]	A.W.[c]	No.	Wt.	A.W.	No.	Wt.	A.W.	No.	Wt.	A.W.	No.	Wt.	A.W.
Check	1695	41.2	.27	62	1.4	.24	359	8.5	.26	1008	24.3	.27	266	7.0	.29
Wind Barrier	1610	40.9	.28	74	1.7	.26	325	8.1	.27	975	24.9	.28	236	6.2	.29
Mulch	1719	42.5	.27	79	2.0	.28	256	6.1	.26	1239	30.3	.27	145	3.6	.28
Mist	1743	44.3	.28	70	1.6	.25	295	7.5	.23	1087	27.8	.28	296	7.4	.28
Shade	1670	42.9	.23	191	4.6	.27	438	11.8	.30	761	19.3	.28	230	7.2	.28
Mist-Shade	1513	36.1	.26	163	3.7	.25	383	9.2	.27	742	17.9	.27	225	5.3	.26
Average	1659	41.3	.27	107	2.5	.26[d]	343	8.5	.27	969	24.2	.28	241	6.1	.28
Significant Difference[e]	NS	NS	NS	**	**	*	*	*	NS	**	**	NS	NS	NS	NS

(b) Proportional Yield and Soluble Solids

Treatment	Normal		Mild		Severe		Green Blotch	
	% of Total[f]	S. Sol.	% of Total	S. Sol.	% of Total	S. Sol.	% of Total	S. Sol.
Check	3.3	4.5	21.5	4.5	59.7	4.6	18.0	4.3
Wind Barrier	4.0	4.3	20.2	4.3	61.5	4.5	15.6	3.9
Mulch	4.8	4.2	14.5	4.2	72.5	4.2	10.1	3.8
Mist	3.6	4.4	17.3	4.4	62.9	4.2	17.0	3.9
Shade	10.9	4.2	27.6	4.2	45.6	4.4	19.0	3.9
Mist-Shade	11.5	4.1	25.7	4.1	49.8	4.1	16.9	3.7
Average	6.4	4.3[g]	21.1	4.3	58.7	4.3	16.1	3.9
Significant Difference[e]	**	*	**	*	**	**	NS	**

[a]Number of fruit from 24 plants.
[b]Weight in tons per acre (ave. of 3 plots).
[c]Weight in pounds per fruit.
[d]The average weight of normal fruit is signif. lower (at 1%) than green blotch.
[e]*Significant at 5%.
**Significant at 1%.
[f]% of total weight in tons per acre.
[g]Signif. higher at 1% than green blotch.

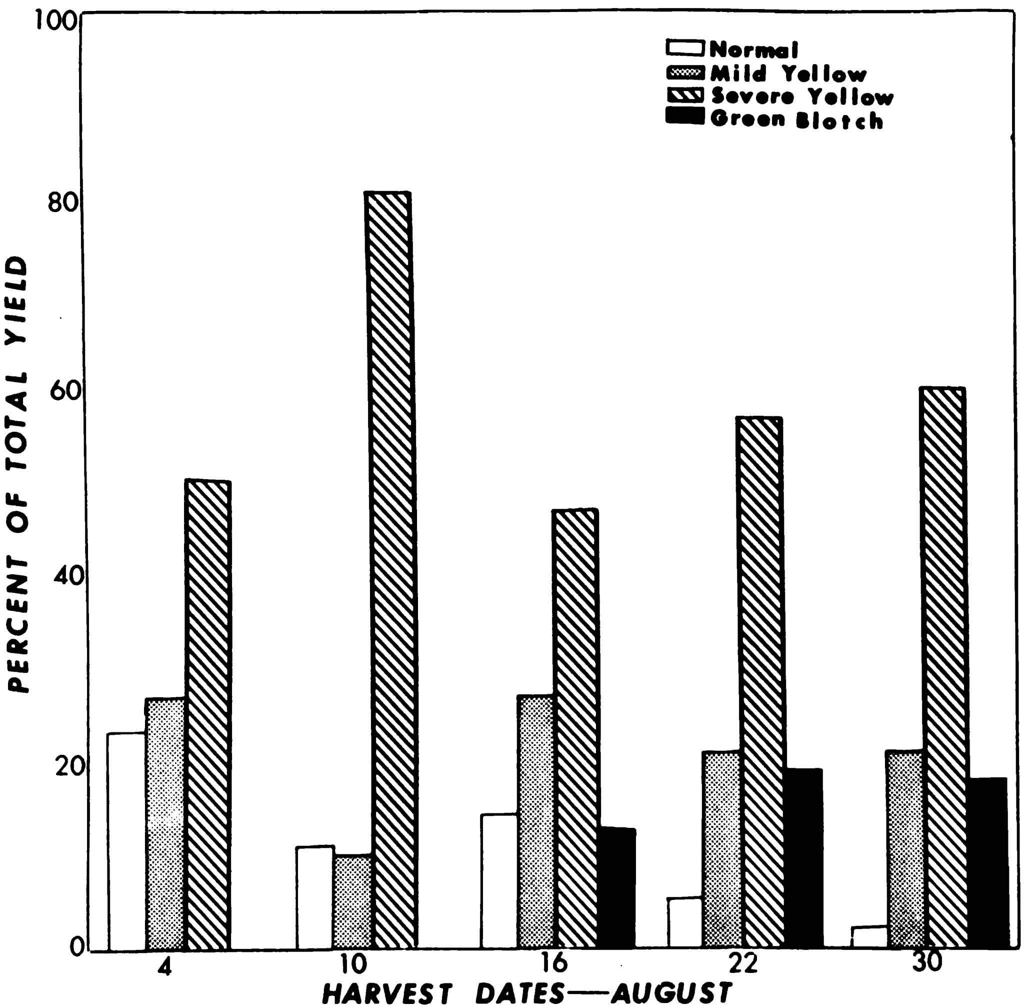

Fig. 1. The proportion of total fruit yield occurring in each class for each harvest.

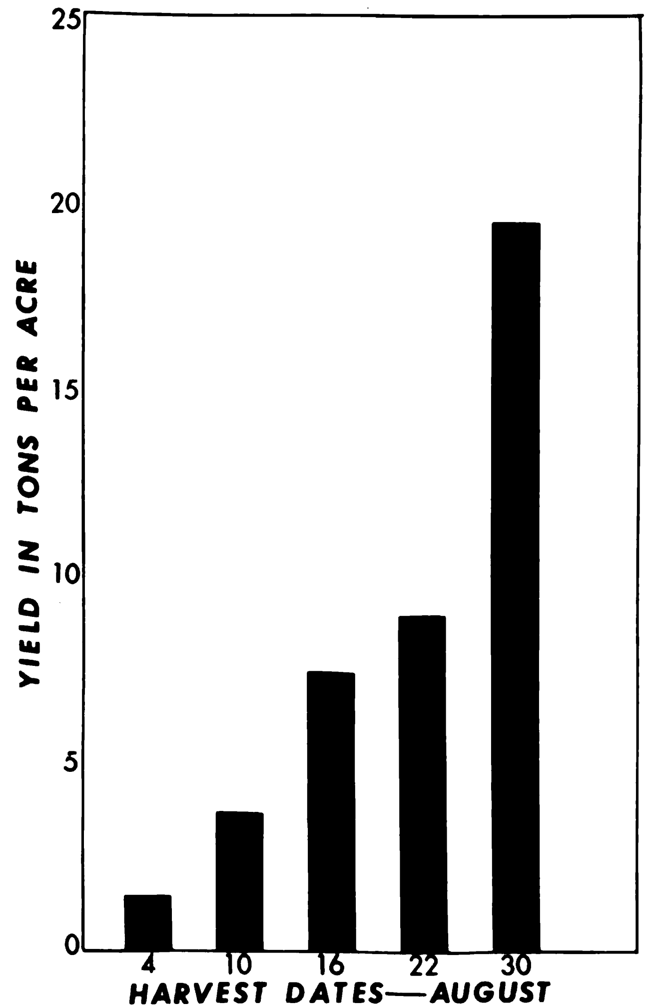

Fig. 2. Total yield for each harvest.

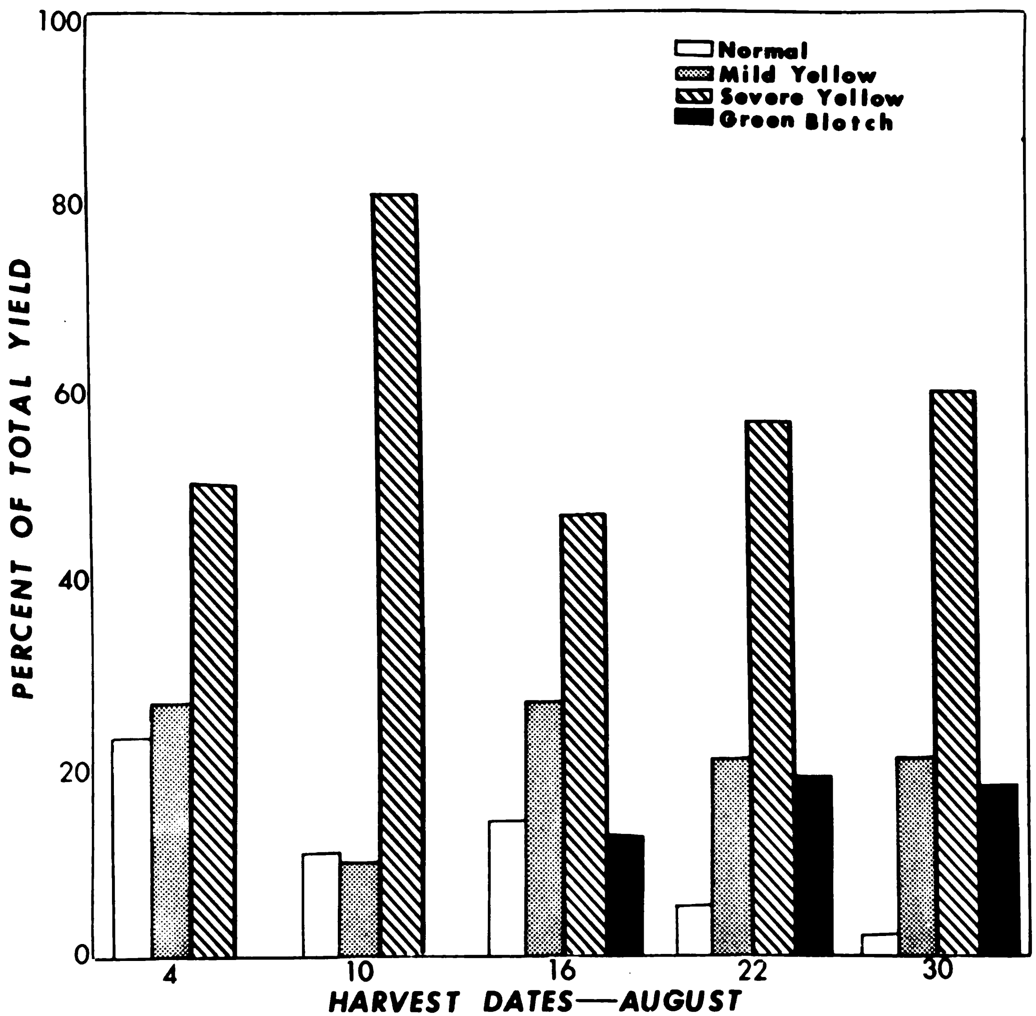

Fig. 1. The proportion of total fruit yield occurring in each class for each harvest.

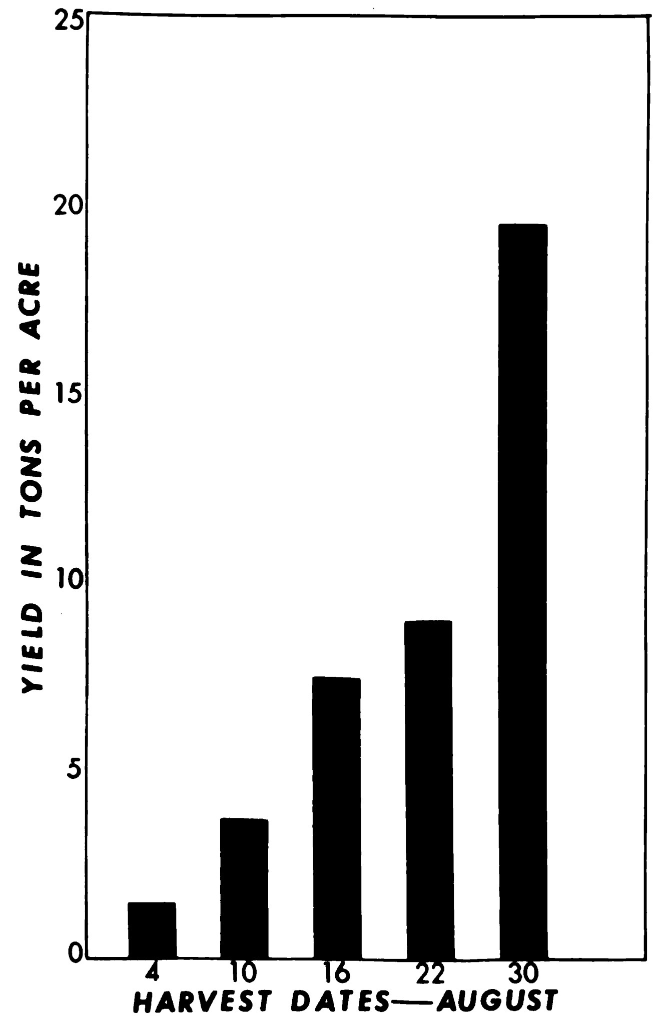

Fig. 2. Total yield for each harvest.

TABLE 5. The influence of treatment on yield of fruit displaying various degrees of blotchiness.[a]

Weight[b] per Treatment		Class	Percentage of Total Weight[c]	
Treatment	Weight	Normal	Treatment	Percent
Check	1.4 a		Check	3.3 a
Mist	1.6 a		Mist	3.6 a
Wind Barrier	1.7 a		Wind Barrier	4.0 a
Mulch	2.0 a		Mulch	4.8 a
Mist-Shade	3.7 b		Shade	10.9 b
Shade	4.6 c		Mist-Shade	11.5 b
		Mild Yellow Blotch		
Mulch	6.1 a		Mulch	14.5 a
Mist	7.5 b		Mist	17.3 a
Wind Barrier	8.1 b		Wind Barrier	20.2 a
Check	8.5 bc		Check	21.5 ab
Mist-Shade	9.2 c		Mist-Shade	25.7 b
Shade	11.8 d		Shade	27.6 b
		Severe Yellow Blotch		
Mist-Shade	17.9 a		Shade	45.6 a
Shade	19.3 a		Mist-Shade	49.8 ab
Check	24.3 b		Check	59.7 bc
Wind Barrier	24.9 b		Wind Barrier	61.5 bc
Mist	27.8 c		Mist	62.9 bc
Mulch	30.8 d		Mulch	72.5 c

[a]Weight or percent within a column which are not followed by the same letter differ at odds of 99:1.

[b]Weight in tons per acre.

[c]Total weight per treatment.

clearly indicated as the yield of normally pigmented fruit and the resulting percentage of total yield were highest under the shade and mist plus shade treatments. Shade treatment was effective in producing more fruit in the mild yellow class. Yield from the mist plus shade treatments followed, but was not higher than the yield from the check plots. A lower yield of severe yellow blotch was produced under shade and mist plus shade. Among the other treatments, there were no consistent differences in yield.

The relationship between harvest dates and the proportion of yield in each class and total yield is shown in Figures 1 and 2. Total yield continued to rapidly increase through the last harvest, after which there were only scattered fruits left on the vines. The greatest proportion of normal fruit came with the first harvest, August 4; and from this date there was an overall decline with the succeeding harvests. The green blotch disorder did not appear until the third harvest, August 16. Severe yellow blotch was consistently higher for each harvest than the other classes of blotchiness. The second harvest, August 10, was abnormally high (80.5 percent) with severe yellow blotch. On August 10, the remaining portion of fruit was almost equally divided between normal and mild yellow.

The average weight per fruit was not different between treatments in either the total or the classes, except in the normal class. Between classes, the average weight of normal fruit was lower than the average weight of severe yellow blotch fruit (Table 4a).

Within each class, soluble solids were different due to treatment (Table 5), but there was no definite trend indicating that fruit from any particular treatment was consistently lower or higher in soluble solids. Between classes, soluble solids were lower in green blotch fruit. The other three classes had the same value, 4.3, for soluble solids (Table 4b).

One purpose of the shade was to increase respiration by raising the temperature; however, the day temperature was 2°F. lower under the shade as compared to normal air temperature. Night temperatures under the shade were not recorded, but were probably higher due to the soil heat radiation.

Generally, the season was very windy and, therefore, the wind barrier served more to reduce wind movement than to raise the temperature.

Early blight, a fungal disease caused by *Alternaria solani*, appeared around August 10, and by August 16 the plants were from 10 to 40 percent defoliated, and by August 30 the plants were from 40 to 95 percent defoliated. In each case the lowest percentage of defoliation was found with the shaded treatments.

The yield of decayed or rotted fruit was very small, accounting for only 2 percent of the total.

Discussion

In this investigation the yield was high, which may, in part at least, be attributed to the fact that only 2 percent of the fruits were infected with decay organisms. Along with this high yield was a very high incidence of blotchy

ripening. It should be noted that even though many of the fruits classified as mild yellow could be sold on the market, these fruits were nonetheless abnormally pigmented and, therefore, were considered to be affected with blotchy ripening.

Ells (19) and Kidson and Stanton (27) found that heavy-fruiting plants tended to produce more blotchy fruit than light-fruiting plants. These workers did not specify the environmental conditions under which they found increased blotchiness with heavier production; but if the carbohydrate status of the plant is a critical factor in influencing this trouble, then it appears that certain environmental factors would cause an increase in blotchiness beyond the point of production effects. Heavy fruiting utilizes a lot of energy and if the plant is unable to synthesize and replenish the necessary metabolites, there will be a rapid weakening of the vegetative portion of the plant as well as a marked decrease in fruit quality.

In agreement with this theory was the manner in which the very high incidence of blotchiness occurred. As previously stated, early blight became an important disease during the time of the second harvest, August 10. From this date until the end of the harvest season, the severity of the disease was exemplified by a constant increase in defoliation. Consequently, as production rapidly increased (Figure 2), there was a consistent decline in normally ripened fruit (Figure 1).

Bonner (3) stated that a typical leaf is light saturated at 10 to 20 percent of full light intensity. Therefore, the upper leaves of the plants were fully light saturated even though they were receiving only 23 percent of full light intensity. However, many of the lower leaves that were capable of maximum photosynthesis were probably not receiving even 10 percent full sunlight; hence, the plants were not accumulating food reserves at a maximum rate. Therefore, it would be expected that these plants would have weaker vegetative growth than the plants in full sunlight and, in turn, fruit of lower quality. Conversely, the data well verify that the shaded plants produced significantly higher yields of normally ripened fruit and significantly less of poorly pigmented fruit. These results are most likely explained on the basis of the effect of another variable, early blight, and not on a transpiration-respiration hypothesis. This fungal disease thrives best in an environment of high temperature and high humidity.

During the day the air temperature under the shade was 2°F. lower than the normal air temperature. Therefore, early blight was less active on the shaded plants. The mist plus shade treatments also reduced the temperature; but, at the same time, the humidity was much higher. At night the temperature and humidity effects were reversed. However, the effect was the same as during the day. Under the shade (at night) the heat which radiated from the soil kept the plants dry, while the resulting evaporation of moisture from the leaves kept the plants cool. The plants not covered with shade material were cool but not dry. Therefore, the fungal growth was again less active on the shaded plants.

Total yield was not reduced as a result of the blight because fruit set and partial fruit development had taken place before early blight infection set in. Only fruit pigmentation was affected by early blight, as is seen by the incidence of blotchiness among treatments. Apparently there was enough available energy for fruit development but not enough for complete pigment development.

It may be concluded that this experiment was quite illustrative of the effect of a foliage disease on the incidence of blotchy ripening. The resultant defoliation supports the work of Kidson and Stanton (27), who found that heavy defoliation increased the disorder. On the other hand, Davies (18) found that severe defoliation resulted in better grade fruit and reduced the proportion of irregularly colored ones, but at the expense of marked yield reduction. The results of this experiment showed that even with a high yield and with severe defoliation, the incidence of blotchiness was high. Therefore, it is reasonable to propose that there is a definite critical time in the development of either the plant or the fruit, or both, when a maximum energy deficiency will cause blotchy ripening. Such a proposal is partially, at least, in agreement with the work of Boyle (4) and Boyle and Wharton (7), who showed that internal browning could be induced by inoculating large, fruit-bearing plants with tobacco mosaic virus, but the inoculation of young plants was ineffective in causing internal browning.

Since early blight became the predominate factor in this experiment, it is yet unknown if environmental factors exert their influence through transpiration-respiration activity. The effects of the treatments on fully foliated plants may result in entirely different results than the treatments on blight-infested plants.

Greenhouse Experiment--1962

During the spring of 1962, a greenhouse experiment was set up to determine if stringent treatments would markedly induce or increase the incidence of blotchy ripening of fruit from heavy-fruiting plants.

The experiment was initiated on the basis of a hypothesis that fruits would enlarge more rapidly if the plant had access to an abundance of moisture, both in the soil and in the atmosphere (high humidity). Such treatment would, consequently, create a critical energy stress in the fruit, and thus cause poor pigment development. Geraldson (20) found that the incidence and severity of blotchy ripening was greater when the plants were growing in a culture solution having a low, rather than a high, nitrate/chloride ratio. Therefore, adding ammonium chloride in a water-saturated soil and atmosphere, should hypothetically result in a higher incidence of blotchiness than found in plants with only high water or high water plus high humidity. Conversely, treatment that would limit the available water should result in reduced blotchiness. One method of limiting the water supply would be to increase the osmotic concentration of the soil solution by adding a salt, such as sodium nitrate.

Procedure

From a greenhouse planting, five Michigan-Ohio Hybrid tomato plants were selected in each of two replicates. These plants were subjected to five different treatments: (1) check (having a low water regime, a regularly weekly watering), (2) high water (two gallons per day beyond normal weekly applications), (3) high water plus high humidity (by covering the plant with a clear plastic cover), (4) high water plus high humidity plus an initial two-ounce application of ammonium chloride, and (5) an initial four-ounce application of sodium nitrate in a gallon of water plus a daily two-ounce application in a pint of water. The experimental plants were separated from each other by inserting into the soil sections of six-inch corrugated aluminum lawn edging.

When treatment commenced, ten clusters of fruit had set, and the first three clusters had been harvested. The experiment was terminated when approximately the tenth cluster was harvested. Therefore, the data are composed of results of approximately seven clusters of fruit per plant.

The fruits were harvested in the red-ripe stage. For each fruit, the color was evaluated, the weight was taken, and soluble solids were estimated. Since there was variation in the number of fruit that ripened each day, the results were tabulated on the basis of four, ten-day periods: June 20-30, July 1-10, 11-20, and 21-30.

The data were summarized by analysis of variance and differences between means were compared by "Students" t-Test.

Results

Although the yield for the various periods and among treatments was quite variable, there was no significant difference in the average weight per fruit (Table 6a and 6b). Soluble solids decreased as the season progressed; however, only the values from the first and last harvest dates were significantly different. Between treatments, soluble solids values from the treatment of high water plus high humidity plus ammonium chloride were significantly higher than either high water or high water plus high humidity (Table 6b).

The incidence of poorly colored fruit reached very high percentages, but in this experiment the abnormal pigmentation was not altogether of the classical blotchy ripening type. There appeared around July 1 a light yellow mosaic pattern of blotchiness, which was found on any segment of the fruit wall, in contrast to true blotchy ripening which is very rarely found on the blossom-end section. The incidence of the mosaic blotchiness increased throughout the season and became very serious around July 21. In Table 6a is shown the relationship between season and the incidence of poor pigmentation. As soluble solids decreased, the proportion of blotchiness increased. Among treatments there was much variation in

TABLE 6. A summary of the seasonal data showing the influence of harvest date and treatment on yield, soluble solids, and color.

(a)		Harvest Dates			
Date	Number of Fruit	Total Wt.(gms)	Average Wt./Fruit	Soluble Solids[b]	% Poorly Colored Fruit[c]
June 20-30	35[a]	6389	183	4.20 a	11.43
July 1-10	62	10397	168	4.19 ab	32.26
July 11-20	17	2941	173	4.05 ab	41.18
July 21-30	43	7582	158	3.87 b	75.00
Total	162	27309			
Average	41	6827	171	4.08	41.36
Significant Difference[d]			NS	**	

(b)		Treatment			
Treatment					
High Water, High Humidity	40[e]	6025	151	3.94 a	30.00
High water	49	8693	177	3.95 a	59.18
Check	50	9075	182	4.07 ab	48.00
High Water, High Humidity, NH_4Cl	11	2055	187	4.25 b	9.09
$NaNO_3$	12	1461	122	5.03 b	8.33
Total	162	27309			
Average	32	5462	164	4.25	41.36
Significant Difference[d]			NS	**	

[a]From ten plants.
[b]Values within a column which are not followed by the same letter differ at odds of 99:1.
[c]Percent of total number per date or treatment.
[d]**Statistically significant at odds of 99:1.
[e]From two plants for all harvest periods.

blotchiness, but there was no apparent relationship with soluble solids. Fruit from treatments involving ammonium chloride and sodium nitrate were markedly lower in the percentage of poorly colored fruit.

During the latter days of the first harvest period, the plants treated with ammonium chloride died because of broken stems; and also during the same time, the plants receiving sodium nitrate died because of an excessive salt concentration in the soil solution.

Discussion

Kraus and Kraybill (28) found that in the tomato stem there is a carbohydrate-nitrogen gradient. Beginning at the base of the plant and going upward, the nitrogen content increases and the carbohydrate content decreases. If such a relationship is true for fruits also, then the soluble solids values for this experiment were in agreement; for as the season progressed and as higher clusters were harvested, there was a regular decline in soluble solids. With the check plants under normal growing conditions, it would be expected that fruit soluble solids values would be approximately equal to the average of the values by harvest period. And this was found to be true (Table 6a and 6b).

The high soluble solids values shown by the sodium nitrate treated plants is probably not entirely accurate, since these plants were dehydrating before visible symptoms of wilting appeared. The death of the plants treated with ammonium chloride was probably also a contributing factor to

the higher soluble solids in this treatment.

The low incidence of blotchy fruit on the fertilized plants is related to the fruits' ripening at a time when the seasonal incidence of poorly colored fruit was low. If the plants had survived, the values might have been higher. Consequently, the low percentage of poor fruit cannot be related to high soluble solids.

According to the initial hypothesis, an increase in fruit size was a prerequisite of increased incidence of blotchy ripening; however, since neither effect was produced, it may be concluded that this experiment was not effective in producing the results anticipated.

GENERAL DISCUSSION

The primary objective of this study was to determine if there is an association between blotchy ripening and an energy stress in the fruit during its development from the almost mature green stage to the red ripe state. The assumption was made that any factor which would create a critical energy demand in the fruit would either induce or increase blotchiness. Therefore, experiments were designed to alter both the anabolic and catabolic rates of metabolism within the plant and thus within the fruit.

Treatments were enacted, both singly and interactionally, to study the effects of reduced light intensity, reduced transpiration, increased respiration, nutrition, and variety on the incidence of blotchy ripening.

On the basis of the results of the experiments conducted, there was no conclusive evidence that blotchy ripening could be attributed to any one factor or to any definite complex of factors. Even so, the theory of energy stress was amply illustrated as a result of an unexpected variable, early blight. Since the sole source of the energy of a plant is radiant energy, it is essential to the reproductive functions of a plant that it have efficient photoreceptive organs, leaves. As a consequence of the blight-induced defoliation, the energy reserves were rapidly depleted as the fruit ripened. Apparently a small proportion of the fruit received sufficient energy, while the majority of the fruit was deprived of the necessary energy for uniform color formation.

These results indicate that the theory of energy stress is valid and that regardless of the specific physiological factors involved, any factor that tends to reduce the carbohydrate assimilation rate or reduce accumulated reserves below a minimum tends to constitute a metabolic deficiency having the visual symptoms of blotchy ripening.

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