ENVIRONMENTAL STUDIES ON MATURATION OF THE McINTOSH APPLE

Thesis for the Degree of Ph. D.

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Adnan M. Badran

1963

THESIS

This is to certify that the

thesis entitled

ENVIRONMENTAL STUDIES ON MATURATION

OF THE McINTOSH APPLE

presented by

Adnan M. Badran

has been accepted towards fulfillment
of the requirements for

Ph D degree in Horticulture

Major professor

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ENVIRONMENTAL STUDIES ON MATURATION OF THE McINTOSH APPLE

By

Adnan M. Badran

AN ABSTRACT

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

DOCTOR OF PHILOSOPHY

Department of Horticulture

1963

ABSTRACT

ENVIRONMENTAL STUDIES ON MATURATION
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by Adnan M. Badran

The influence of the post bloom environment on the maturation period of McIntosh apples was investigated. The environmental factors experimentally varied were night temperature, light intensity and day length. Natural environmental variations were obtained by selecting orchards with a wide range of microclimates over a three year period. Observations of growth, cell division, starch accumulation, physiological maturity and storage quality of fruits from trees on seedling and East Malling rootstocks were obtained.

High night temperatures during the first month following bloom increased the rate of vegetative and fruit growth and hastened maturity. Low light intensity enhanced vegetative growth, suppressed fruit growth and delayed maturity. High night temperatures overcame the suppressing effect of low light intensity on fruit growth. Day lengths three hours shorter or longer than the ambient had no marked effect on fruit growth. Trees which received low light intensities or a short day underwent a secondary flush of terminal growth.

Net accumulation of starch was observed in fruits about one month after full bloom and occurred within two

days of the time it was first detected. Temperatures following bloom did not markedly affect the interval from full bloom to starch accumulation whereas low light intensity lengthened the interval by about one week. The onset of starch accumulation coincided with the cessation of cell division, cessation of shoot and leaf growth and the June drop of fruits in 1962, while in 1963, shoot and leaf growth continued after starch accumulation commenced. The onset of starch accumulation appears to be the turning point in the growing season when photosynthetic capacity exceeds growth requirements.

No relationships were discernible between the post bloom environments and the interval from full bloom to starch accumulation. The length of this interval bore no relationship to the length of the interval from full bloom to physiological maturity. The premise that starch accumulation may serve as a physiological parameter of the influence of the early growing season environment on fruit maturity was thereby invalidated.

The interval from full bloom to maturity was shortened in proportion to heat unit accumulation during the first two weeks following bloom. High night as well as high day temperatures were effective in advancing maturity. However, high night temperatures during the third and fourth weeks following bloom had a delaying effect on maturity.

Predicting fruit maturity by heat unit summation

methods developing in other apple production areas was not satisfactory for environmental conditions experienced in Michigan in 1961, 1962 or 1963.

The interval from full bloom to maturity was inversely proportional to the date of full bloom. This may be related to generally warmer post bloom temperatures which prevail in areas of late bloom.

The rate of change in red coloration, ground color, flesh firmness or soluble solids over a three week harvesting period was of little value in determining the proper harvest date for storage. The values of these characteristics varied considerably for fruits of the same physiological maturity from different locations in a single season.

Fruits from the harvests closest to the preclimacteric respiratory minimum rated highest in quality following five months storage in air or eight months storage in controlled atmospheres. No relationship was observed between maturity at harvest and the incidence of scald on fruits from CA storage or on fruits from various locations after air storage. However, immature fruits from trees grown on a number of East Malling rootstocks at the same location generally scalded more severely after air storage than the more mature fruits. Flesh and core browning was not related to maturity of the fruit at harvest.

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TABLE OF CONTENTS

	Page
INTRODUCTION	1
REVIEW OF LITERATURE	3
Introduction	3
I. Growth, Maturation and Ripening	3
A. Physical changes	3
B. Chemical changes	6
C. Physiological changes	11
D. Environmental modification	13
II. Maturity Indices	14
A. Physical	14
B. Chemical	17
C. Physiological	20
D. Environmental	21
MATERIALS AND METHODS	25
I. Modified Temperature Environmental Study, 1961	25
II. Modified Environmental Study, 1962	29
III. Natural Environment Study, 1962	31
IV. Post-Storage Quality Evaluation	34
RESULTS	35
I. Modified Environmental Study, 1961	35
A. The environment	35
B. Vegetative growth	35
C. Fruit growth	39

TABLE OF CONTENTS CONT'D

		Page
	D. Starch accumulation	39
	E. Fruit maturity	39
II.	Modified Environmental Study, 1962 . . .	43
	A. The environment	43
	B. Vegetative growth	43
	C. Fruit growth	45
	D. Starch accumulation and cell division	49
	E. Fruit maturity	49
III.	Natural Environment Study, 1962	53
	A. The environment	53
	B. Starch accumulation	56
	C. Fruit maturity	61
	1. Physical characteristics	61
	2. Respiratory climacteric	64
	3. Storage quality	68
IV.	EM Rootstock Study, 1962	77
	A. The environment	77
	B. Starch accumulation	77
	C. Fruit maturity	81
	1. Physical characteristics	81
	2. Respiratory climacteric	81
	3. Storage quality	86
V.	Predicting McIntosh Maturity	93

TABLE OF CONTENTS CONT'D

	Page
DISCUSSION	99
SUMMARY	106
LITERATURE CITED	109
APPENDIX	119

LIST OF TABLES

TABLE		Page
1	Characteristics of natural environment locations in 1962	31
2	Average weekly temperature (°F) regimes obtained for five weeks following petal fall in 1961 at the M.S.U. Horticulture Farm, East Lansing	36
3	Summation of maturity characteristics for McIntosh under modified environmental treatments, 1961	41
4	Average temperature (°F) regimes obtained for five weeks following petal fall in 1962 at the M.S.U. Horticulture Farm, East Lansing.	44
5	Influence of modified environments on the maturation of McIntosh at East Lansing in 1962	50
6	The relationship between the date of the cessation of cell division in fruits, cessation of shoot elongation, June drop and starch accumulation in fruits of McIntosh from trees subjected to modified environments at East Lansing in 1962	51
7	Relationship between post-bloom temperatures and the elapsed interval from full bloom to starch accumulation and the preclimacteric minimum for McIntosh fruits from ten locations in 1962	54
8	Relationship between post-bloom temperatures and the elapsed interval from full bloom to starch accumulation and the preclimacteric minimum for McIntosh fruits from ten locations in 1962	55
9	Relationship between post-bloom temperatures and the elapsed interval from full bloom to starch accumulation and the preclimacteric minimum for McIntosh fruits grown at three locations for the 1961, 1962, and 1963 seasons	58

LIST OF TABLES CONT'D

TABLE		Page
10	Relationship between post-bloom temperatures and the elapsed interval from full bloom to starch accumulation and the preclimacteric minimum for McIntosh fruits grown at three locations for the 1961, 1962 and 1963 seasons	59
11	Hourly and daily changes in starch content in McIntosh apples during initial stage of accumulation in 1962	60
12	The relationship between the date of full bloom, starch accumulation and harvest of several apple varieties at East Lansing in 1962	62
13	Physical characteristics of McIntosh fruits from ten locations at the onset of the respiratory climacteric	63
14	Evaluation of red coloration (%) of McIntosh fruits from seven harvests at ten locations in 1962	66
15	Harvest and post-storage evaluation of ground color rating of McIntosh fruits from seven harvests at ten locations in 1962. The fruits were stored in air for five months or CA storage for eight months	69
16	Harvest and post-storage evaluation of flesh firmness (lbs.) of McIntosh fruits from seven harvests at ten locations in 1962. The fruits were stored in air for five months or CA storage for eight months	70
17	Harvest and post-storage evaluation of soluble solids (%) of McIntosh fruits from seven harvests at ten locations in 1962. The fruits were stored in air for five months or CA storage for eight months	72
18	Appearance rating of post-storage McIntosh fruits from seven harvests at ten locations in 1962. The fruits were stored in air for five months or CA storage for eight months .	73

LIST OF TABLES CONT'D

TABLE		Page
19	Eating quality rating of post-storage McIntosh fruits from seven harvests at ten locations in 1962. The fruits were stored in air for five months or CA storage for eight months	74
20	Summation of maturity characteristics for McIntosh from ten locations in 1962 . . .	75
21	Post-storage evaluation of scald (%) on McIntosh fruits from seven harvests at ten locations in 1962. The fruits were stored in air for five months or CA storage for eight months	76
22	Post-storage evaluation of core browning (%) of McIntosh fruits from seven harvests at ten locations in 1962. The fruits were stored in air for five months or CA storage for eight months	78
23	Post-storage evaluation of flesh browning (%) of McIntosh fruits from seven harvests at ten locations in 1962. The fruits were stored in air for five months or CA storage for eight months	79
24	Summation of maturity characteristics for McIntosh grown on East Malling rootstocks in 1962	80
25	Physical characteristics of McIntosh fruits grown on seven East Malling rootstocks at the onset of the respiratory climacteric .	82
26	Evaluation of red coloration (%) of McIntosh fruits from seven harvests from trees on seven EM rootstocks in 1962. The fruits were stored in air for five months or CA storage for eight months	84
27	Harvest and post-storage evaluation of ground color rating of McIntosh fruits from seven harvests from trees on seven EM rootstocks in 1962. The fruits were stored in air for five months or CA storage for eight months	87

TABLE		Page
28	Harvest and post-storage evaluation of flesh firmness (lbs.) of McIntosh fruits from seven harvests from trees on seven EM rootstocks in 1962. The fruits were stored in air for five months or CA storage for eight months	89
29	Harvest and post-storage evaluation of soluble solids (%) of McIntosh fruits from seven harvests from trees on seven EM rootstocks in 1962. The fruits were stored in air for five months or CA storage for eight months .	90
30	Appearance rating of post-storage McIntosh fruits from seven harvests from trees on seven EM rootstocks in 1962. The fruits were stored in air for five months or CA storage for eight months	91
31	Eating quality rating of post-storage McIntosh fruits from seven harvests from trees on seven EM rootstocks in 1962. The fruits were stored in air for five months or CA storage for eight months	92
32	Post-storage evaluation of scald (%) on McIntosh fruits from seven harvests from trees on seven EM rootstocks in 1962. The fruits were stored in air for five months or CA storage for eight months	94
33	Post-storage evaluation of core browning (%) of McIntosh fruits from seven harvests from trees on seven EM rootstocks in 1962. The fruits were stored in air for five months or CA storage for eight months	95
34	Post-storage evaluation of flesh browning (%) of McIntosh fruits from seven harvests from trees on seven EM rootstocks in 1962. The fruits were stored in air for five months or CA storage for eight months	96

LIST OF FIGURES

Figure		Page
1	Technique employed to obtain night temperature control	26
2	Photomicrographs of apple starch granules at the initial stage of accumulation . .	28
3	The influence of night temperatures on McIntosh shoot elongation at East Lansing in 1961	37
4	Influence of night temperature on McIntosh leaf growth at East Lansing in 1961 . . .	38
5	Influence of night temperature on McIntosh fruit growth at East Lansing in 1961 . .	40
6	Respiratory climacteric of McIntosh fruits from modified temperature treatments at East Lansing in 1961	42
7	Influence of night temperatures, light intensity and day length on McIntosh shoot elongation at East Lansing in 1962 . . .	46
8	Influence of night temperature, light intensity and day length on McIntosh leaf growth at East Lansing in 1962	47
9	Influence of night temperature, light intensity and day length on McIntosh fruit growth at East Lansing in 1962	48
10	Respiratory climacteric of McIntosh fruits from modified environmental treatments at East Lansing in 1962	52
11	Change in red coloration, ground color, flesh firmness and soluble solids of McIntosh fruits over a sequence of seven harvests at ten locations in 1962	65
12	Respiratory behavior of McIntosh fruits from seven harvests at ten locations in Michigan in 1962. Fruits were harvested at 3-day intervals	67

LIST OF FIGURES CONT'D

Figure		Page
13	Change in red coloration, ground color, flesh firmness and soluble solids of McIntosh fruits over a sequence of seven harvests from seven EM rootstocks in 1962	83
14	Respiratory behavior of McIntosh apples grown on seven EM rootstocks in 1962. Fruits were taken from seven harvests at 3-day intervals	85

INTRODUCTION

During the past 50 years the merchandising period for fresh apples has expanded from a few months to the entire year. The departure from a harvest season surplus to year around availability has been made possible through the application of refrigeration and more recently controlled atmosphere storage. Fruit quality after long periods under optimum storage conditions is strongly dependent upon the maturity of the fruit at harvest. Immature fruits are subject to excessive shrivelling, physiological disorders associated with immaturity and are generally of low dessert quality as they fail to ripen properly during storage. Overmature fruits are subject to several physiological disorders associated with senescence and are of low dessert quality after an extended period in storage. Determining the proper harvest maturity becomes more critical as the length of the intended storage season increases and is one of the most important annual decisions made in the apple industry.

The elapsed interval from full bloom to maturity varies according to the growing season environment, particularly during the first month following bloom. The first month is important in terms of fruit development since total fruit cell number is determined during this period. Starch accumulation in developing fruits begins approximately one month after full bloom. The elapsed interval from full bloom

to the onset of starch accumulation may be related to the cessation of cell division and hence be related to environment during this period. This thesis was based on the hypothesis that the onset of starch accumulation in the developing fruits may serve as a physiological parameter of the influence of the post bloom environment and hence a new basis for predicting fruit maturity.

REVIEW OF LITERATURE

Introduction

The problem of fruit maturity has been studied for several decades and many methods for predicting and estimating maturity have evolved. Methods used with some success in one apple production area are often not successful in other areas. Maturity indices based on physical characteristics of the fruit are generally quite subjective in nature but are commonly employed. Predicting methods are generally based on records of past seasons for a particular area and may not be applicable to other areas. The following review of literature contains some of the methods currently in use and provides the basis for the importance of the early growing season environment on fruit growth and development.

I. Growth, Maturation and Ripening

A. Physical changes

The physiology of growth in apple fruits has been studied extensively in recent years by a group of Australian investigators under the direction of Dr. R. N. Robertson. Their initial studies (Bain and Robertson, 1951) confirmed the observations of other investigators (Tetley, 1930, 1931; Tukey and Young, 1942; Smith, 1950) that cell division in developing apple fruits ceased within four weeks after fertilization and subsequent growth was due to cell enlargment. Variation in size of fruit at maturity was shown by Bain and

Robertson (1951) to be due primarily to variations in cell number and to a small extent by mean cell size. Their conclusions were at variance with observations by Smith (1950) that either or both cell size and cell number may be the determining factor in fruit size in any given season. Smith (1950) has shown that the characteristic varietal size was determined primarily by the cell number and that variations in degree of cell enlargement were of secondary importance. Cell enlargement continued in a linear manner as long as the fruit remained attached to the tree while intercellular air space increased at a decreasing rate over the same period (Bain and Robertson, 1951).

Color in apple fruits is a varietal characteristic, but the rate of development can be hastened or delayed by environmental conditions. The pigment responsible for color in the red varieties was found to be the anthocyanin, idaein (3-$\mathcal{L}$-galactosidylcyanidin) (Sando, 1937; Duncan and Dustman, 1936). A precursor of this anthocyanin is synthesized in the leaves and moves to the fruits in the same manner as sugars (Cnslow, 1925). Light is required for the development of red color (Overholser, 1917; Schrader and Marth, 1931) and the ideal temperature required for color development was found by Magness (1928) to be warm days for maximum photosynthesis and cool nights during the latter part of the ripening season. Seigleman and Hendricks (1958) demonstrated the photocontrol of anthocyanin formation in the apple skin and found two distinct radiation-dependent phases. The first phase was

an induction period while the second phase was the anthocyanin formation which was a linear function of time of irradiation at constant irradiance. The action spectrum of the two phases was in the region of 6000 to 7500 A°. They concluded that the photoreceptor was probably a flavoprotein similar to acyl coenzyme A dehydrogenase, which was later termed "Phytochrome." Most of the red pigment was found in the hypodermis with some in the epidermis; and in some varieties, anthocyanin was found in the flesh particularly in the over-ripe fruits (Smock and Neubert, 1950).

The underlying green color of apple fades out when fruits approach maturity due to chlorophyll destruction in the chloroplasts of the cell, while xanthophyll and carotenoid pigments remain relatively constant and are responsible for the yellow ground color of apples (Biale and Young, 1962). Ground color development was influenced by the leaf-fruit ratio with fewer leaves per fruit resulting in greener fruits (Haller and Magness, 1925).

As the apple matures, the cortical tissue becomes softer and the cells become less firmly cemented together as protopectin is enzymatically hydrolyzed into soluble pectin (Griffin and Kertesz, 1946). Increase in cell size, intercellular spaces and water content were among the important factors which affect the texture (Blumann, 1959).

The specific gravity of the apple decreased throughout the period of fruit development (Simpson, 1953) and was primarily the result of the increase in the volume of

intercellular spaces. Decrease of juice viscosity also followed a similar pattern (Rasmussen, 1962; Truscott and Wickson, 1954).

B. Chemical changes

Mineral composition of apple fruit has been reviewed adequately by Askew (1935) and Smock and Neubert (1950). In general, the mineral content of the apple flesh increased during the first six weeks after full bloom (Brown, 1926). The total nitrogen in apple fruits increased during fruit development (Gourley and Hopkins, 1929). English workers led by Dr. A. C. Hulme (1936) have shown that total nitrogen per fruit increased rapidly during the first six weeks.

The organic acid fraction of the fruit is of interest because it affects the eating quality of the apple. The organic acids increased steadily as the fruit enlarged on the tree until just before harvest when there was a slight decline (Hulme, 1936). The titratable acidity steadily decreased as the fruit matured on the tree (Caldwell, 1928; Lopez, 1958). The pH rose steadily as the fruit developed and remained unchanged for several weeks and dropped to a lower value just before harvest (Heimlich, 1953; Powrie and Asselberges, 1956). Comin and Sullivan (1953, 1954) have shown that the degree of dissociation of acids in the Rome Beauty apple increased rapidly throughout apple development, and rapidly decreased two weeks before picking maturity. Accumulation of cations, mainly potassium, may account for the increased dissociation of the acids with a

concommitant increase in the pH (Richmond, 1963). Malic acid was found to be the dominant organic acid in the apple by many workers (Bigelow and Dunbar, 1917; Krotkov and Helson, 1946; Thimann and Bonner, 1950). Since the development of ion exchange and paper chromatography analytical techniques, several investigators (Hulme, 1958; Krotkov et al., 1951) have shown that malic acid was not the dominant acid during the early stage of development. Quinic acid was found to be the dominant acid in the early stage of development of the young fruit (Hulme 1958).

The relationship between acid and carbohydrate metabolism was studied by Krotkov et al. (1951). They found that organic acids did not contribute to the increase in sugars during the climacteric and were not formed during the decrease in sugars in the postclimacteric period. Acidity of the apple fruits was high in years when climatic conditions were favorable for carbohydrate accumulation (Haller and Magness, 1926; Brown, 1926). Robertson and Turner (1951) suggested that organic acids are formed in the leaves and transported to the fruits in the same proportion as they are formed. Hulme (1954b; 1958) has shown that citramalic acid appears only at maturity in the peel tissues, and quinic and shikimic acids may have a possible role as precursors of aromatic ring compounds.

An extensive study on the changes in the nitrogenous compounds of apples during growth and ripening was conducted by Hulme (1958), Archbold (1932), Askew (1935), Robertson

and Turner (1951), and Pearson and Robertson (1953). Hulme (1958) summarized the amino acids which he and others identified by chromatographic methods. Joslyn and Stepka (1949) were the first to identify asparagine, aspartic and serine by paper chromatography.

Robertson and Turner (1951) found that protein in Granny Smith apples increased per apple and per cell at a steady rate until about 135 days from full bloom after which the rate was slower.

Studies on the lipids from the peel of Granny Smith apples were conducted by Huelin and Gallop (1951). They found that oil content increased with maturity, and the iodine number of the oil increased with oil concentration.

Goodwin (1952) reviewed the literature on changes in carotenoids in fruits during ripening and concluded that the carotene content increased at the time when chlorophyll destruction was taking place. The yellow color of the apple peel and flesh was due to this pigment.

Sugars are an important factor in fruit quality and storage life, and serve as the primary substrate for respiration. Sugars are synthesized in the leaves by photosynthesis and translocated to the fruits (Evans, 1928). The leaf-fruit ratio may affect the concentration of sugars in the fruits (Haller and Magness, 1926). Glucose, fructose and sucrose increase as the fruit develops on the tree. In Bramley Seedling apples, fructose content was found to be twice that

of glucose at harvest time (Archbold, 1932). Archbold and Barter (1934) reported that total sugars increased from the core to the outside and from the stem to the calyx end. Sugar content varied from season to season and by location (Evans, 1928). Extensive investigations on sugar changes during fruit development were conducted by Archbold (1932); Caldwell (1934); Krotkov and Helson (1946); Eggenberger (1949); Griffiths et al. (1950); Hulme (1950); and Robertson's group in Australia (1951). Archbold (1932) showed that the concentration of glucose remained constant during the cell division stage, and fructose remained the most abundant sugar when the apples were removed from the tree.

Hulme (1950) explained that starch synthesis and hydrolysis were not directly related to the increase or decrease in reducing sugars. Total sugars increased for a short period after harvest due to starch hydrolysis (Krotkov and Helson, 1946) and declined gradually during senescence. Haynes and Archbold (1928) reported that death of the apple followed the exhaustion of sucrose, the respirable material.

Starch is formed in the early part of the apple development primarily from the sugars transported from the leaves and partially from sugars formed in the fruits (Smock and Neubert, 1950). Gerhardt (1926) provided evidence for the presence of a small amount of starch degradation products in apples at certain stages of development. White et al. (1959) described starches as polysaccharides which serve as nutritional reservoirs in plants. The

starch itself is a mixture of a straight-chained amylose component and a branched-chained amylopectin fraction; amylose gives an intensely blue-colored complex with iodine while the color of the amylopectin-iodine compound is blue-violet, and on the basis of these color differences, the relative proportions of amylose and amylopectin in apple starch has been estimated (Hulme, 1958). Microscopic examination reveals the starch grain is a series of concentric layers of starch deposits around a hilum (Bonner, 1950), and the layering is believed due to the alteration of day and night, with the denser layer being deposited during the day. Starch deposition begins near the skin and proceeds toward the core (Archbold and Barter, 1934) and as the fruits mature, starch hydrolysis proceeds from the core outward. Determination of starch content is dependent on the ratio of amylose and amylopectin which varies with plant species (Bonner, 1950) and from season to season (Carter and Neubert, 1954).

Changes in starch content of the apple fruit during development have been studied by many workers (Haller and Magness, 1944; Haller and Smith, 1950; Kidd et al., 1950; Phillips and Poapst, 1950; Poapst et al., 1957). Hulme (1958) reported that starch may not be hydrolyzed or synthesized in the metabolizing cell by the amylase enzyme but rather by a phosphorylation process.

The pectic compounds of the developing apples are comprised of protopectin (insoluble pectin) which is the main

constituent of the middle lamella of the cell wall (Smock and Neubert, 1950). As the apple matures, protopectin is hydrolyzed by the pectinase enzyme into soluble pectinic acid and pectin (Griffin and Kertesz, 1946; Kertesz, 1943). Pectic changes in apples were influenced by different conditions and were not always constant. Kertesz (1951) has written an extensive review of pectic substances.

C. Physiological changes

Transpiration of Baldwin apples during the growing season was studied by Pieniazek (1943); transpiration was found to be rapid when fruits were small and was directly related to the surface area and the amount of epidermal hairs. Pieniazek (1943) also attributed the transpiration to the small quantity of cuticle present on young fruits. Transpiration rate dropped steadily throughout the fruit development and started to increase again at maturity. However, fruits harvested early transpired faster than more mature fruits (Smock and Neubert, 1950).

Photosynthesis is believed to occur in young fruit since chlorophyll is present in the epidermal tissue. The amount of the green pigment present in the cortical tissue is much less than that in the epidermis or in leaves. Furthermore, the fruit is not structurally adapted for photosynthesis. This may explain the limited amount of sugar synthesis in the fruits (Smock and Neubert, 1950).

The apple fruit is metabolically active throughout its development. Krotkov (1941) has shown that the

respiration rate of McIntosh apples decreased rapidly in early summer and less rapidly in late summer. The period of rapid respiration rate coincided with the period of active cell division. Kidd and West (1926) observed a rise in the respiration rate of English apples after detachment at the commercial harvesting time and referred to this phenomena as the respiratory climacteric. They showed later (1945) that the climacteric rise in respiration also occurred while the fruits were attached to the tree. They demonstrated that detached fruits had the same respiration rate for a short period of time as those attached to the tree. The respiratory climacteric was found to be a general phenomenon in fruits (Biale, 1951) and was looked upon as a transition phase between ontogeny and senescense (Biale and Young, 1962). Kidd and West (1930) attributed the onset of climacteric to protoplasmic changes. They also showed that treatment of apples with ethylene induced the climacteric. The mechanism responsible for the climacteric has been extensively investigated and has been reviewed by Hulme (1958). Hulme (1936) observed that a rise in the net protein was associated with the climacteric in apples. These findings were confirmed by Pearson and Robertson (1953, 1954). Robertson and Turner (1951) explained the climacteric in terms of phosphorylations coupled with electron transport system. Protein synthesis provides a rapid turnover of phosphate acceptors which cause a rise in respiration rate, according to the Robertson theory (1954).

D. Environmental modification

In general, a high level of nitrogen nutrition resulted in larger fruits, decreased the firmness, retarded chlorophyll degradation, delayed the development of anthocyanin and a high potassium level tended to increase fruit color (Gourley and Hopkins, 1929; Overly and Overholser, 1932; Hill and Heeney, 1952; Hill, 1953, Weeks et al., 1952; Beatie, 1954; Collins, 1957). Eggert (1961) found a positive correlation between P content and firmness at harvest, and between Ca content and firmness after storage. High nitrogen reduced soluble solids content of the fruit (Smock and Boynton, 1944).

Smock and Neubert (1950) reported that water was a limiting factor in photosynthesis and fruit quality. The rate of red coloration development at the end of the growing season was diminished when moisture was limited.

Heinicke and Childers (1936) have shown that respiration during the night increased with increase in temperature. Tukey (1956) concluded that the growth of M-Intosh apples exposed to controlled night temperatures and natural day temperature for approximately a month following petal fall was stimulated mainly by high night temperature. Day temperature influenced the daily growth. Later (1960) he reported that growth was more sensitive to night and day temperature conditions prevailing for a month after petal fall than to similar conditions following this period.

Fruit growth may also be influenced by light intensity

and duration. Piringer and Downs (1959) found that vegetative growth was greatest on trees provided a 16 hour photoperiod. This conclusion was at variance with Hoyle (1955) who found that growth and flowering of Cox's Orange Pippin and Worcester Pearmin were not affected by photoperiod. She used a combination of low intensity incandescent and fluorescent lights supplementing the basic 8 hour day. Visser (1956) found greater elongation and better growth of apple seedlings grown in continuous light. Apples were found to grow more rapidly under a 10 hour day regime than with the full length of day at midsummer (Garner and Allard, 1923).

II. Maturity Indices

A. Physical

It was stated earlier that developing apples soften as they approach maturity. Magness and Taylor (1925) developed a pressure tester to indicate the flesh firmness of apple as a possible index of maturity. Firmness of a given variety varied from season to season and from one location to another (Smock and Neubert, 1950). Furthermore, the firmness varied at different locations on the same apple. In general, the red area of an apple was firmer than the non-red area. Moisture, temperature and nutrient intensity may affect fruit firmness (Haller and Magness, 1944; Smock and Boynton, 1944; Haller, 1937). The pressure tester is a better measure of fruit condition than it is a measure of fruit maturity. A marked disadvantage of the pressure

tester is that the fruit is spoiled for further use. A recent innovation in pressure testing has been the development of the "mechanical thumb" by workers in the USDA (Schomer and Olsen, 1963). It is a modification of the Magness-Taylor pressure tester to measure compression of the fruit flesh. The use of the "mechanical thumb" does not mutilate the fruit.

Surface red color of apple fruit has been studied as a maturity index, since color continues to develop as the fruit remains on the tree. However, color development is very much influenced by environmental conditions such as night temperature, sunlight and nutrition. Thus, color was not reliable as a maturity index (Smock, 1948, Blanpied, 1960).

As the apple ripens on the tree the underlying green coloration in the skin changes to yellow as a result of chlorophyll degradation and the resultant appearance of the yellow carotenoid pigments. Magness et al. (1926) and Smock (1948) prepared color charts to assist in describing the ground color. In some varieties ground color does not change markedly as the fruit matures. Ground color is influenced by the level of nitrogen nutrition which limits its usefulness as a maturity index. Smock (1948) reported that despite the ground color test limitations, it was the best useful measure for McIntosh maturity.

As fruits approach full maturity, the seeds change color from white to brown. However, the rate of seed

coloration varied from season to season which made this observation of little value as a maturity index (Haller and Magness, 1944; Smock and Neubert, 1950).

Flesh color (Yeatman et al., 1962) was studied in relation to maturity of Red and Golden Delicious apples by using the light-transmittance technique which measures optical density difference (ΔO.D.) between wave lengths of 740 - 695 mu. Low O.D. differences indicated high chlorophyll content in the apple, while high O.D. differences indicated low chlorophyll content. Low chlorophyll content was correlated with better apple quality. The light transmittance technique was studied also by Olsen and Schomer (1962) who found a good correlation between the severity of water core and light transmittance.

The ease of abscission of apple fruit from the spur has been used as an index of maturity. As the apple matures on the tree, it separates more easily from the spur, but some varieties such as McIntosh may abscise before attaining maturity. Environmental conditions markedly affect the ease of fruit abscission. Furthermore, the use of chemicals to prevent pre-harvest drop complicates the use of abscission as a maturity index (Smock, 1948; Blanpied, 1960).

Apple fruits increased in size as long as they remained on the tree (Magness et al., 1926; Haller and Magness, 1944). The rate of size increase may be influenced by soil moisture and by any factor which influences the photosynthetic rate. The use of size increase as a maturity index was

of limited value (Haller and Magness, 1944).

Truscott and Wickson (1954) studied juice viscosity in relation to apple maturity and suggested that changes in viscosity of fruit juice might be used as an indication of fruit maturity.

As apple fruits approach maturity, the lenticels become filled with cork cells; however, the rate of change was too gradual to make this observation a valuable index for maturity (Haller and Magness, 1944).

Flavor and eating quality are used by many persons in the apple industry as a subjective index of fruit maturity. Extreme variability between different individuals as to what constitutes good eating quality makes this observation of little general value.

The McIntosh variety has a very distinctive odor which contributes to its eating quality (Smock and Neubert, 1950). Gas chromatographic identification of the volatile components of the apple fruits was studied by USDA personnel (1962). Chemical constituents responsible for odor were esters, essential oils, and aldehydes.

Astringent materials in apples are one of the most important factors contributing to the eating quality. As fruits mature on the tree, astringency declines. Astringent materials are composed chiefly of tannin and its derivatives and flavones.

B. Chemical

The sugar content of the apple increased as the fruit

matured on the tree (Heimlich, 1953). Sugars were the main constituents of the soluble solids. Soluble solids as measured by a refractometer has been used as a maturity index (Smock, 1948; Smock and Neubert, 1950). The sugar content varied with crop load, cultural practices, and environmental conditions during the season (Caldwell, 1928; Blanpied, 1960). The change in soluble solids was too gradual to be useful as a guide to maturity (Smock, 1948).

The titratable acidity steadily decreased as the fruit matured on the tree (Bigelow and Dunbar, 1917; Caldwell, 1928). The pH rose steadily as the fruit developed, but the rise was not striking (Archbold, 1932). Smock and Neubert (1950) reported a considerable fluctuation as the fruit matured, but in general there was an increase. Acidity varied between varieties (Askew, 1935) and from one season to another (Caldwell, 1928). Statistical correlation was found between the pH and the titratable acidity. Haller and Magness (1926) reported the influence of leaf-fruit ratio on the total acidity. Sugar-acid ratio showed a continuous increase with maturity (Lopez, 1958). Reyneke and Reinecke (1939) reported that solids-acid ratio was a suitable maturity index because it more effectively reflected small changes in maturity. In general, total acidity decreased with loss of firmness, pH and soluble solids-acid ratio increased (Lopez, 1958). The sugar-acid ratio was used successfully as a maturity index for citrus fruit. Comin and Sullivan (1953, 1954) have shown that the degree of

dissociation of acids in the Rome Beauty apple increased at a rapid rate until about two weeks before picking maturity and then rapidly decreased. It was suggested that the peak of this dissociation occurred at a point in the relation between anabolic and catabolic processes where the fruits were at maximum quality standard of taste, flavor and appearance, and hence may prove useful as an index on proper maturity. Blanpied (1960) concluded that acid changes were not consistent enough to be used as a reliable maturity index.

As the apples mature on the tree, the starch gradually decreases in the fruit. Canadian workers have attempted to make use of the starch disappearance in the apple fruits as a criterion of picking maturity (Phillips and Poapst, 1950; Poapst et al., 1957). Hesse and Hitz (1939) suggested a correlation between starch disappearance and maturity of the apple fruits. Phillips and Poapst (1950) studied the starch disappearance in relation to maturity quite extensively and found the starch loss was linear, and this linearity appeared to be independent from day-to-day weather conditions but varied from season to season (Poapst et al., 1954). Poapst et al. (1959) concluded that the picking time in McIntosh apples was related to starch content and starch-iodine reaction may be used as an index. Although this test was recommended as a useful maturity index in Canada, it has not been found reliable in the United States (Smock, 1948; Blanpied, 1960). The dependence of starch conversion on

climatic and cultural conditions has diminished the importance placed on starch disappearance as a guide to maturity (Tiller, 1936; Ward, 1954; Smock, 1948; Hulme, 1958).

The pectic changes seem to vary considerably with different varieties and under different conditions. Such changes cannot be used as a good index of softening rate for maturity (Smock and Neubert, 1950).

C. Physiological

Apple fruit respiration rate varies with the age of the fruit. Kidd and West (1926) indicated that some apple varities should be picked just before the climacteric rise begins. Smock (1948) in the United States confirmed this relation with McIntosh in New York State. Some workers have raised criticism at this respiratory technique and expressed the climacteric rise as a physiological artifact resulting from the fruit detachment (Ezell and Gerhardt, 1942) but Kidd (1938) proved that attached fruits on the tree pass through the climacteric rise of respiration. It was also found that fruits after detachment had a similar respiration rate to the attached fruits for a short period (Kidd, 1935). This test is valuable, but only of experimental interest since it is not adaptable to the orchard. Hulme (1954) studied the respiration behavior of Cox's Orange Pippin apples and found the difference in time between the onset of the climacteric at 12° C. and at 15° C. varied with the picking date, but had a minimal value which varied from season to season. He suggested that this minimal gap may reflect a

definite physiological state of the fruit which could be a guide to maturity.

Enzymatic studies on the apple fruits indicated that polyphenolase plays the most important role in darkening of apple tissues upon exposure to air. The oxidase activity of apples was found to decrease with increasing maturity on the tree (Ezell and Gerhardt, 1942). Catalase activity was found by the same authors to increase steadily with maturity within a given variety. This increase varied from one variety to another (Draine, 1926).

The biochemical changes which take place during the climacteric were studied as possible maturity criteria. Addition of malate to peel tissues caused an increase in carbon dioxide output but not in the oxygen uptake during the respiration climacteric and this resulted in an increase in the respiratory quotient (Neal and Hulme, 1958; Dilley, 1962). It was suggested that this decarboxylation process takes place at the expense of some Kreb cycle acids and does not require oxygen (Neal and Hulme, 1958; Pearson and Robertson, 1954). The net increase in protein, which occurred during the climacteric, was interpreted as a result of malic enzyme development which was required in the reaction.

D. Environmental

Smock (1948) reported that harvesting by calendar date proved to be a more reliable index of fruit maturity than elapsed days from full bloom. Blanpied (1960) studied the optimum picking dates for a 10 year period, and found

that for seven years out of ten the optimum harvest date was within three calendar days, and concluded that the calendar date may serve as a rough guide though not a very accurate one.

It is well known that different varieties of apples have different lengths of growing season. Tukey (1942) made a comparison of different varieties and different seasons and found that the interval between full bloom and maturity differed slightly due to seasonal variations, while Haller (1942) concluded from three years experiments that regardless of locality and seasonal variations, the number of days from bloom to maturity was rather constant, and was a more reliable index than others studied. The average number of days from full bloom to maturity was given by other workers in the areas of uniform growing conditions (Haller and Magness, 1944; Haller and Smith, 1950; Ellenwood, 1941; Ryall et al., 1941).

Date of full bloom was studied as a basis for predicting maturity. Magness et al. (1926) and Blanpied (1960) reported a fairly close relationship between the time of full bloom in different varieties and the picking date.

The validity of the elapsed days from bloom to maturity is questionable because of the seasonal environmental variations. When heat units were calculated with a 45° F base temperature, a better prediction of harvest was made (Brooks, 1945). Osterwalder (1949) reported the importance

of temperature distribution through the season in addition to heat unit accumulation. Haller and Smith (1950) found an inverse relationship between the early growing season temperature and the growth rate. High night temperatures were found to decrease the number of days from full bloom to harvest (Baker and Brooks, 1944). Gunnaway and Cremin (1959) developed a means of forecasting maturity of Elberta peaches by a method based on maximum daily temperatures from full bloom until the beginning of July. It was found (Radu et al., 1960) that the temperature sum during the first 10 days after fruit set was the main factor in determining the apple growth and length of time from bloom to harvest. Eggert (1960) summarized the results of eight years and concluded that the temperature prevailing during the early part of the growing season exerted a greater influence on time of maturity than the temperature during the latter part of the growing season. He found that the variability in heat units accumulated during the 40 days after petal fall accounted for 95% of the variability found in the total elapsed days from petal fall to harvest, and that accumulation of heat units immediately prior to harvest did not markedly influence maturity.

Tukey and Young (1942) and others (Smith, 1950; Bain and Robertson, 1951) reported that cell division ceased within four weeks after full bloom. Several investigators (Krotkov and Helson, 1946; Archbold, 1932; Robertson and Turner, 1951; Pearson and Robertson, 1954) have observed

that starch accumulation commences approximately one month after full bloom.

MATERIALS AND METHODS

I. Modified Temperature Environmental Study, 1961.

Eight five-year-old McIntosh trees were selected for study from a rootstock-variety orchard at the Horticulture Farm at East Lansing. Four of the trees were grown on East Malling II rootstocks while the remaining four were on East Malling VII. Wooden pole frame and electrical conduit structures were built over two trees on each rootstock. The remaining four trees were left uncovered to serve as controls. A white nylon parachute with white canvas affixed to the periphery was fastened to the frame structure and served as an easily removed canopy enclosing the tree (Fig. 1).

Portable electric heaters with auxillary fans were placed under the canopy to provide a source of heat. The two trees, one each of EM II and VII, receiving the 75° F night temperature were supplied with heaters totalling 1650 watts while the two receiving the 65 F night temperature were supplied with 1300 watts. The heaters were wired for control through a Fenwal thermostat located in the center of each tree. Thermocouples were placed at three elevations within the heated and control trees and the temperatures were monitored at four minute intervals during the night by a recording potentiometer.

Commencing on May 19, 1961, four days after full bloom, the trees receiving the modified night temperatures

Figure 1 Technique employed to obtain night temperature control.

were covered with the parachute canopies and heated during the night. The canopies were placed over the trees at about 7:00 p.m. when the heaters and recorder were turned on and were removed at 6:00 a.m. the following morning. This schedule continued for about 30 days following full bloom or until starch accumulation was observed in the developing fruits.

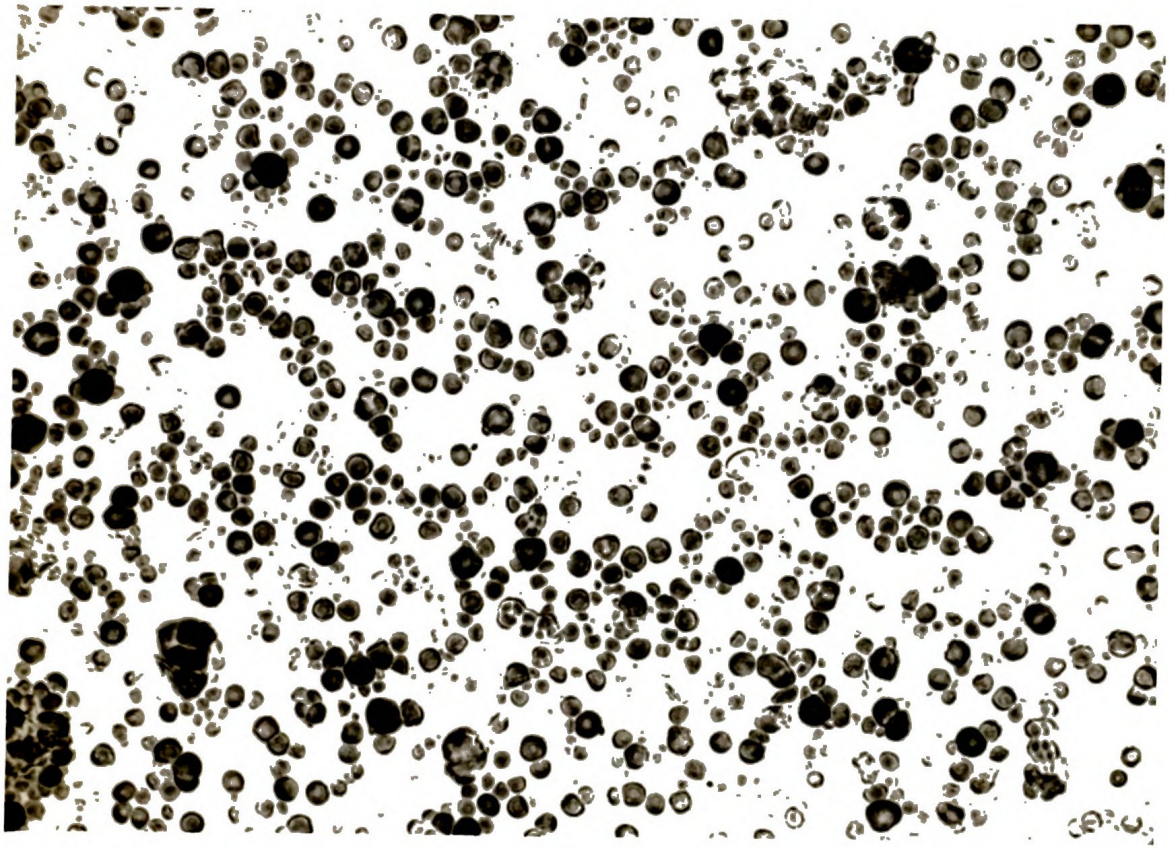
Terminal shoot growth, leaf size and fruit diameter measurements were taken at three day intervals until starch accumulation was observed and then at weekly intervals for the remainder of the season. Ten shoots, leaves and fruits were selected at random around the perimeter of each tree and tagged for identification to insure that the successive measurements were taken on the same samples. A metric rule and a direct reading metric micrometer (Model 49P-1-R1, Federal Products Corporation, Providence, R.I.) were used to take the growth measurements.

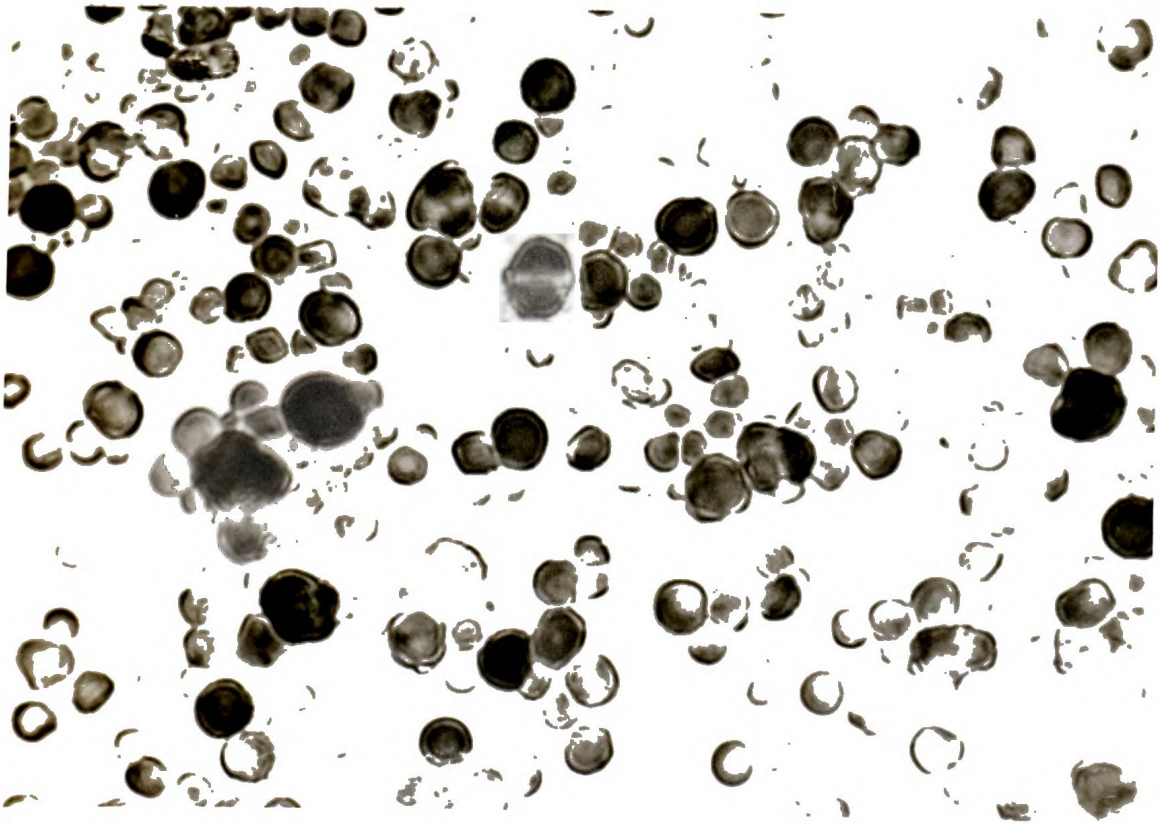
The presence of starch was determined subjectively in ten developing fruits at each sampling period with I_2-KI reagent (Phillips and Poapst, 1952) on a mid-daily basis starting two weeks after full bloom. Measurements ceased after starch began to accumulate. Both a laboratory and a field test for starch were employed. The laboratroy test consisted of macerating a small quantity of fruit cortical tissue on a glass slide in the presence of a small quantity of I_2-KI solution and observing the first appearance of starch granules at a magnification of 500x (Fig. 2). The field test consisted of cutting fruits longitudinally and

Figure 2 Photomicrographs of apple starch granules at the initial stage of accumulation.

Magnification: Top-- 1 inch = 40 μ

Bottom-- 1 inch = 20 μ





28a

observing the blue-stained starch granules after applying a few drops of I_2-KI solution.

Respiration rates of fruits at three harvest dates, 127, 135, and 143 days from full bloom, were obtained at 70 F as CO_2 evolution from approximately a 1500 g. sample of fruits (Claypool and Keefer, 1952) to determine the time of the climacteric.

Additional meteorological information was obtained during the growing season from the Official U.S. Weather Bureau station located at a similar elevation about 1/4 mile from the site of the experimental trees. These observations included daily maximum and minimum temperatures.

II. Modified Environmental Study, 1962.

The same McIntosh trees that were used in 1961 were used in 1962 but the conditions were modified to include the effects of high day and night temperatures, light intensity and photoperiod as follows:

1. One tree on EM VII was provided a night temperature of 75 F as in 1961.

2. One tree on EM II was provided 75 F minimum day and night temperature by keeping the tree covered with a white parachute both day and night and provided supplemental heat as before. This resulted in a reduction of light intensity during the day of approximately 4000 ft. candles less than the light intensity received by the uncovered trees.

3. One tree on EM II was covered continuously with a

green stained parachute and provided circulation and ventilation at the top and bottom of the tree to prevent heat accumulation during the day. The light intensity obtained varied from that of the uncovered trees by about 5000 ft. candles.

4. One tree on EM VII was left uncovered and provided supplemental light for three hours after sunset from four 150 watt incandescent lamps located near the upper periphery of the tree and provided the long day treatment.

5. Two trees on EM VII were enclosed in wood frames and provided with removable dark cloths which were placed in position at night and removed at 9:00 and 10:30 a.m. and thus provided two short day treatments.

6. Two other trees were left uncovered and served as controls.

Temperature records were obtained with thermocouples and a recording potentiometer as in 1961. The modified environmental conditions were commenced four days after full bloom (May 11) and continued until after starch accumulation was observed.

Growth measurements and starch accumulation tests were taken as in 1961. Samples of fruit were selected at random every three days from May 27 to June 19, 1962 from the various treatment trees for cell division observations. The fruits were fixed in formalinacetic acid-alcohol (FAA) solution immediately after harvest, imbedded in paraffin and sectioned with a rotary microtome. The tissue sections from

the same position (near the calyx) on all fruits were stained with safranin-heamatoxylin (Sass, 1961) and examined mico-scopically for dividing or newly divided cells.

III. Natural Environment Study, 1962.

To ascertain the variability in starch accumulation and maturation of McIntosh under a wide range of natural environmental conditions trees were selected in orchards at various locations in the western Michigan fruit belt. Two McIntosh trees were selected in each orchard with the characteristics listed in the following Table.

TABLE 1. Characteristics of natural environment locations in 1962.

Location	Latitude (°)	(')	Longitude (°)	(')	Altitude (ft. above sea level)	Distance from Lake Michigan (miles)	Soil Type
A	41	59	86	16	773	16	Miami silt loam
B	42	20	86	10	670	8	Miami silt loam
C	42	36	86	9	680	5	Miami silt loam
D	43	5	85	11	850	49	McBride sandy loam
E	43	13	85	15	870	47	McBride sandy loam
F	43	7	85	18	850	46	Montcalm sandy loam
G	43	41	86	24	760	5	Kent silt loam
H	43	41	86	24	760	5	Kent silt loam
I	43	43	86	10	980	17	Emmet sandy loam
J	42	43	84	28	860	82	Coloma loamy sand

Maximum and minimum orchard temperature records were obtained by the grower for at least a 30-day period following bloom using a standardized thermometer located in a field crate at a height of five feet. Data of full bloom, petal fall, and starch appearance date (date of positive I_2-KI test) were obtained with the help of the grower and visits to the various orchards.

A sequence of seven consecutive harvests were made at each location at three-day intervals in an attempt to bracket the onset of the respiratory climacteric and the optimum harvest date for storage in conventional and controlled atmosphere storage (CA). One bushel of fruit was taken from the periphery of opposite sectors of each tree at each harvest. The two bushels of fruit per harvest per orchard, thus obtained, were randomized and sub-divided into three samples as follows:

1. 1/2 bu. for quality evaluation and measurement of respiration at harvest.

2. 3/4 bu. for conventional storage in air at 32 F.

3. 3/4 bu. for CA-storage in 5% CO_2 and 3% O_2 at 38 F.

An additional 3/4 bushel sample of fruits were obtained from orchards A and E (high nitrogen orchards) for CA storage in 5% CO_2 and 3% O_2 at 32°F.

The fruits were transferred to the laboratory the day of harvest. The fruits destined for storage were placed under refrigeration at 32 F immediately while those for quality evaluation and respiration determinations were

IV. Post-Storage Quality Evaluation:

The McIntosh fruit samples from the 1962 season placed in conventional storage at 32 F were examined in February, while the fruit from CA storage were examined in April. The same parameters used to judge quality at harvest were employed as described earlier. In addition, all fruits were examined for incidence and severity of scald immediately after storage and after one week at 70° F. Fifty randomly selected fruits were examined for internal disorders (core and flesh browning and mealy breakdown) after one week at 70° F. General appearance and eating quality of ten fruits from each harvest of each orchard from the two storage types was judged by a panel of three individuals.

Supplementary data on temperature, starch accumulation and respiratory climacteric for three locations was obtained in 1963.

placed at 70° F. Approximately 25000 samples of fruits were employed for respiration determinations as described earlier. Evaluation of flesh firmness as measured by a Magness-Taylor pressure tester with 7/16" tip, soluble solids as measured by a Zeiss Opton hand refractometer, and evaluation of fruit size, ground color with Cornell color chart (Smock and Markwardt, 1955) and percentage red coloration were made one day following harvest on 25 randomly selected fruits.

A study of starch accumulation and maturation of McIntosh as influenced by rootstocks under the natural environment was also undertaken in 1962. McIntosh on EM I, II, IV, V, VII, XII and XIII (17 years of age) located on the Horticulture Farm at East Lansing were employed. Starch accumulation was measured as described earlier. Harvests and measurements were made as described in the two previous paragraphs.

A study of the variability in starch accumulation date of 11 different varieties of apples located in an adjoining 36-year-old orchard was examined in 1962 and 1963. In addition, the diurnal fluctuation of starch content during the period between incipient starch appearance and net accumulation was investigated in 1962.

Leaf samples were collected from all orchards and were analyzed for nitrogen and mineral composition in the Plant Analysis Laboratory, Horticulture Department.

RESULTS

I. Modified Environmental Study, 1961.

A. The environment

McIntosh trees grown on EM II and VII rootstocks received the average weekly night temperature regimes shown in Table 2. The average minimum night temperature for the five week period following bloom was 49.2 F which was 1.9 F below normal for the East Lansing area. The percentage of possible sunshine received during this same period was 73% which was 7% above normal. The average daily maximum temperature for this period was 73.9 F which was 0.7 F above normal. Soil moisture was adequate for growth during this period.

B. Vegetative growth

The influence of the various night temperature regimes on shoot elongation and leaf expansion is shown in Figures 3 and 4. Shoot elongation and leaf expansion were considerably greater on trees which received the 75 F night temperature than on trees which received 65 F or the ambient night temperature. Growth at 65 F night temperature was slightly greater than that at the ambient temperature. Shoot elongation and leaf expansion ceased for all treatments on June 14 which was 28 days after full bloom. The apparent failure of the McIntosh VII 65 F night temperature treatment tree to respond to treatment was related to injury to the tree resulting from repositioning the tree after a windstorm.

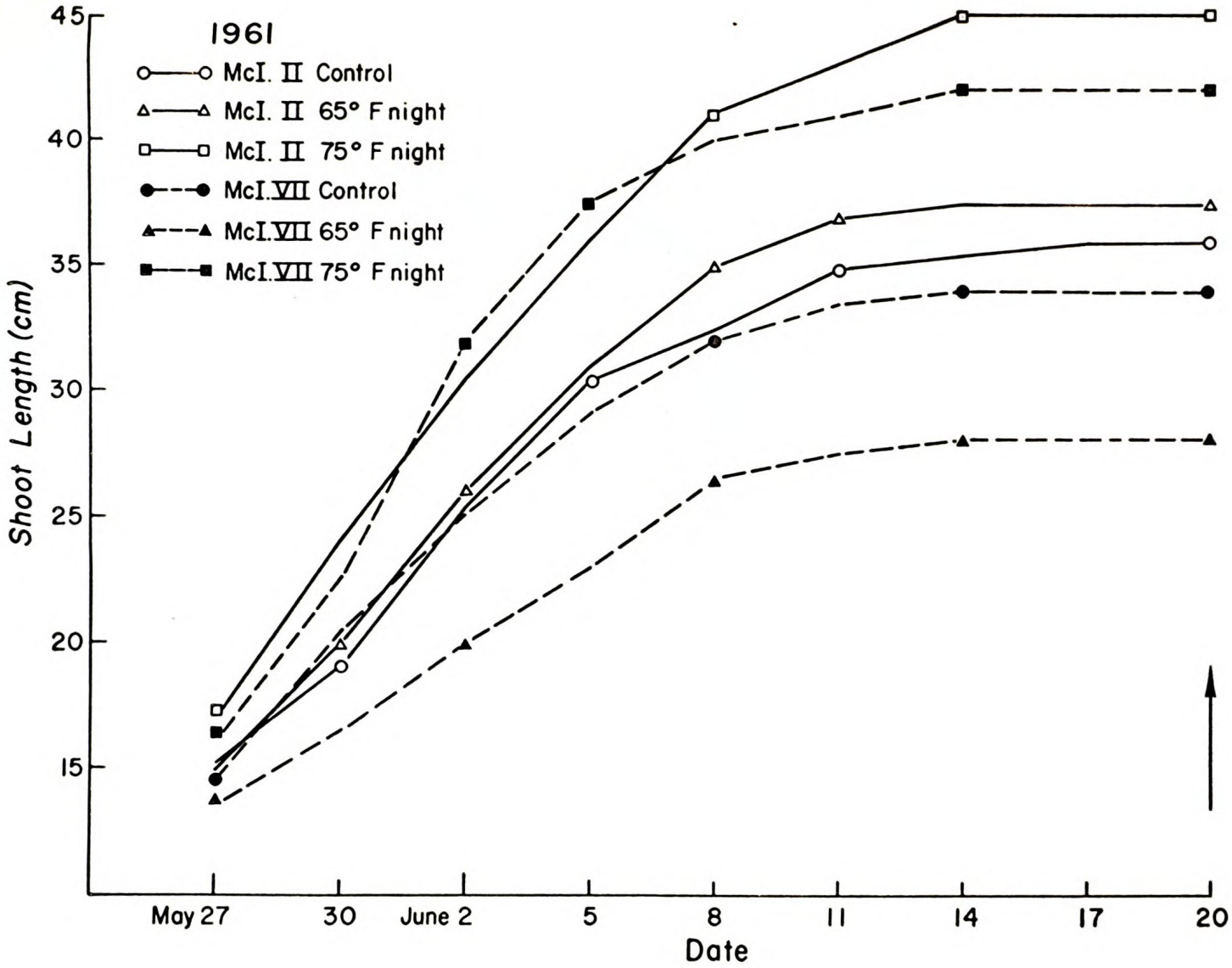
TABLE 2. Average weekly temperature (° F) regimes obtained for five weeks following petal fall in 1961 at the M.S.U. Horticulture Farm, East Lansing.

Week	Treatment			Avg. Daily maximum	Avg. Daily minimum
	Control[a] (night)	65° F[a] (night)	75° F[a] (night)		
1	[illegible]	63	[illegible]	65	[illegible]
2	55	64	75	72	46
3	65	66	77	79	53
4	68	68	78	80	56
5	62	65	75	74	50

[a] average of hourly night temperatures between 9 p.m. and 6 a.m.

Figure 3

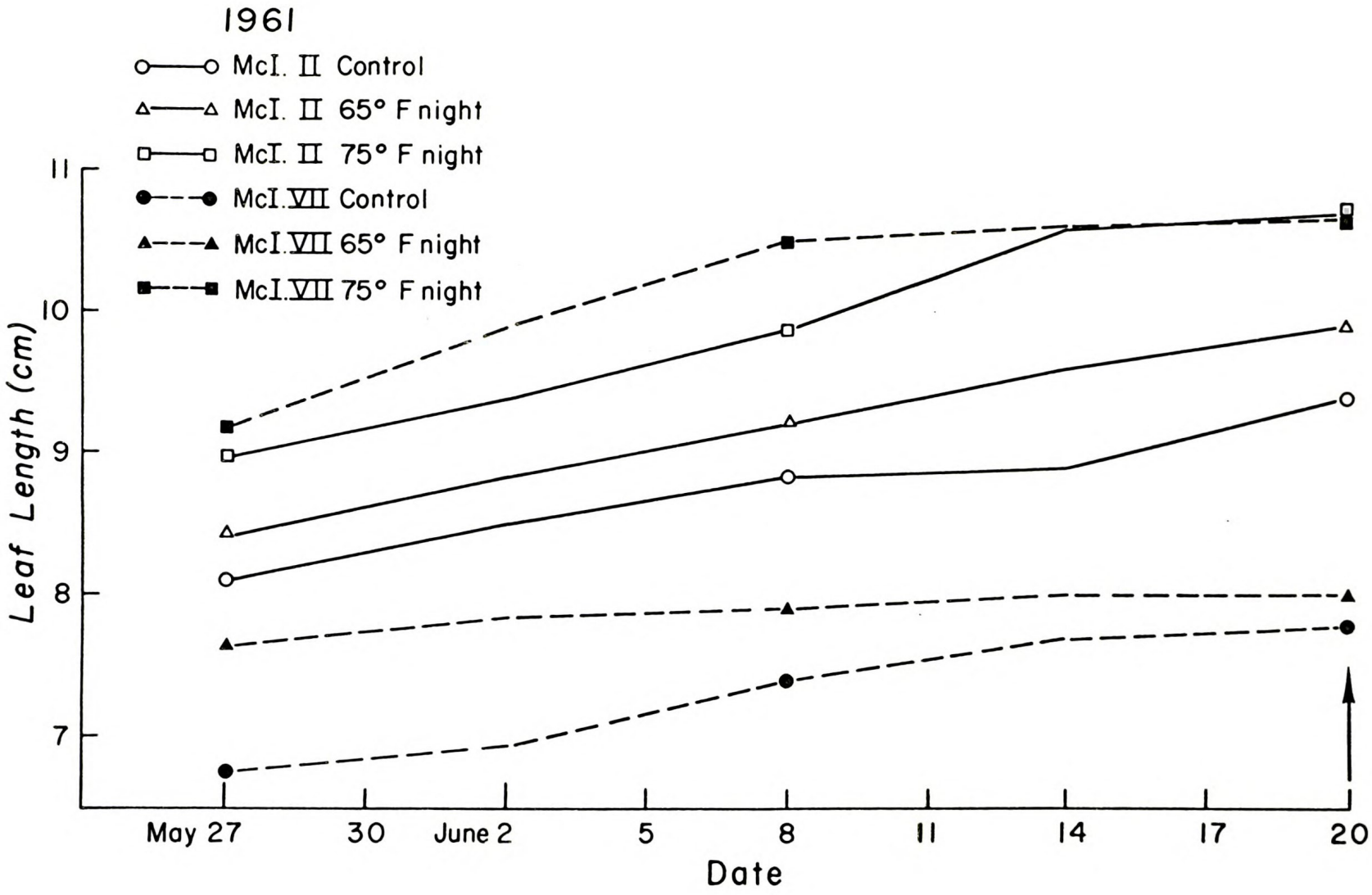
The influence of night temperatures on McIntosh shoot elongation at East Lansing in 1961. Arrow indicates discontinuation date of the treatments.


1961
McI. II Control
McI. II 65° F night
McI. II 75° F night
McI. VII Control
McI. VII 65° F night
McI. VII 75° F night
Shoot Length (cm)
45
40
35
30
25
20
15
May 27
30
June 2
5
8
11
14
17
20
Date

57a

Figure 4

Influence of night temperature on McIntosh leaf growth at East Lansing in 1961. Arrow indicates discontinuation date of the treatments.


1961
McI. II Control
McI. II 65° F night
McI. II 75° F night
McI. VII Control
McI. VII 65° F night
McI. VII 75° F night
Leaf Length (cm)
11
10
9
8
7
May 27
30
June 2
5
8
11
14
17
20
Date

C. Fruit growth

High night temperature resulted in a more rapid increase in fruit size compared to the ambient temperature as shown in Figure 5. The 75° F treatment yielded larger fruits than either the 65° F or the ambient temperature. The leaf to fruit ratio was considerably in excess of that considered limiting to fruit growth since the total fruit load was very light for all treatments.

D. Starch accumulation

The influence of the various environmental treatments on starch accumulation in 1961 is given in Table 3. Starch accumulation was evident in fruits from all treatments on essentially the same date. The elapsed interval from full bloom to starch accumulation was essentially the same regardless of fruit size differences imposed by the different night temperature environments.

E. Fruit maturity

Fruit maturity was estimated by determining the respiratory behavior of samples collected from all treatments at three harvests at 8-day intervals. An insufficient number of fruits were present within each treatment to provide more than three determinations. The course of the respiratory climacteric of fruits from the various treatments is shown in Figure 6. The 75° F night temperature treatment resulted in a slight advancement of maturity. This was more evident with EM VII than with EM II. However, the exact date of preclimacteric minimum could not be obtained from so few

Figure 5

Influence of night temperature on McIntosh fruit growth at East Lansing in 1961. Arrow indicates discontinuation date of the treatments.

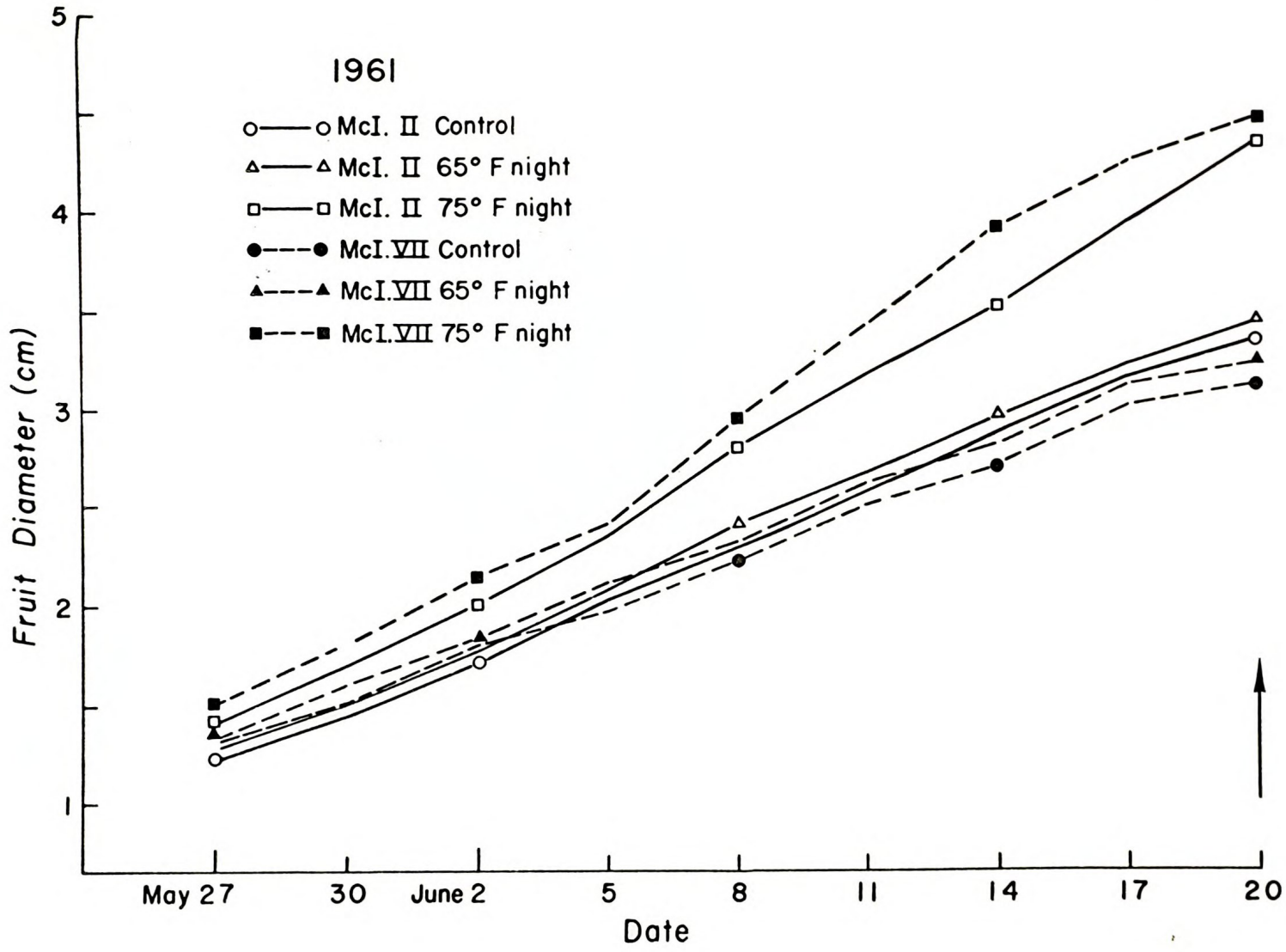

1961
McI. II Control
McI. II 65° F night
McI. II 75° F night
McI. VII Control
McI. VII 65° F night
McI. VII 75° F night
Fruit Diameter (cm)
5
4
3
2
1
May 27
30
June 2
5
8
11
14
17
20
Date

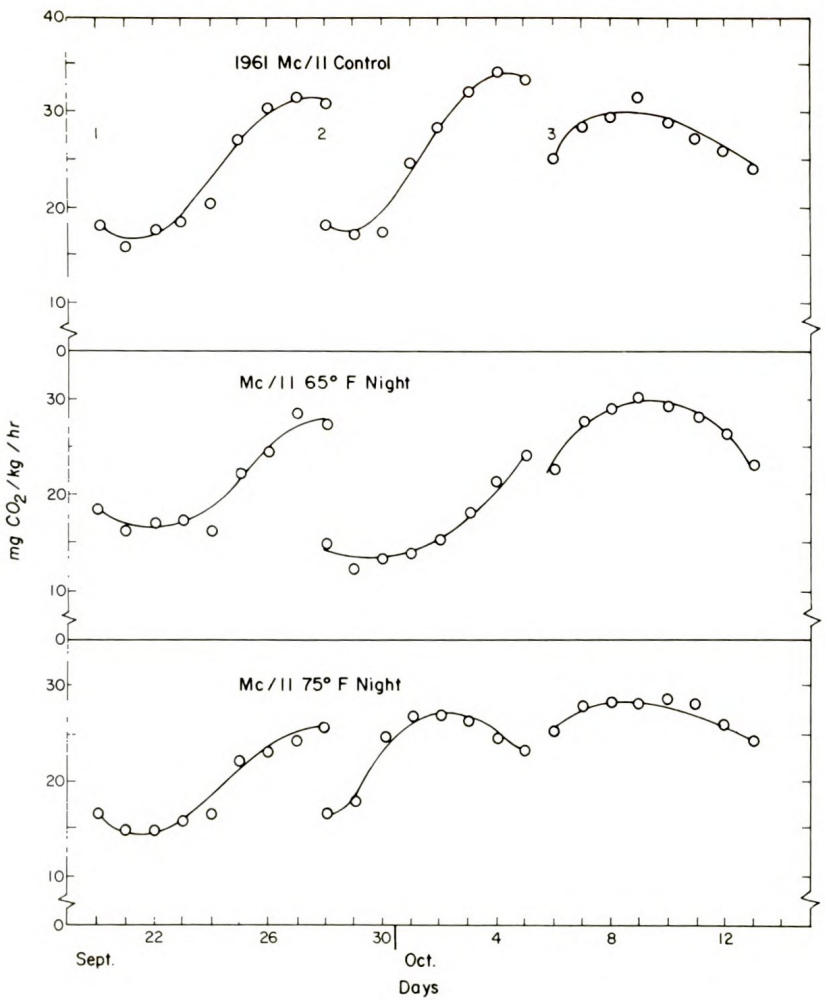
TABLE 3. Summation of maturity characteristics for McIntosh under modified environmental treatments, 1961.

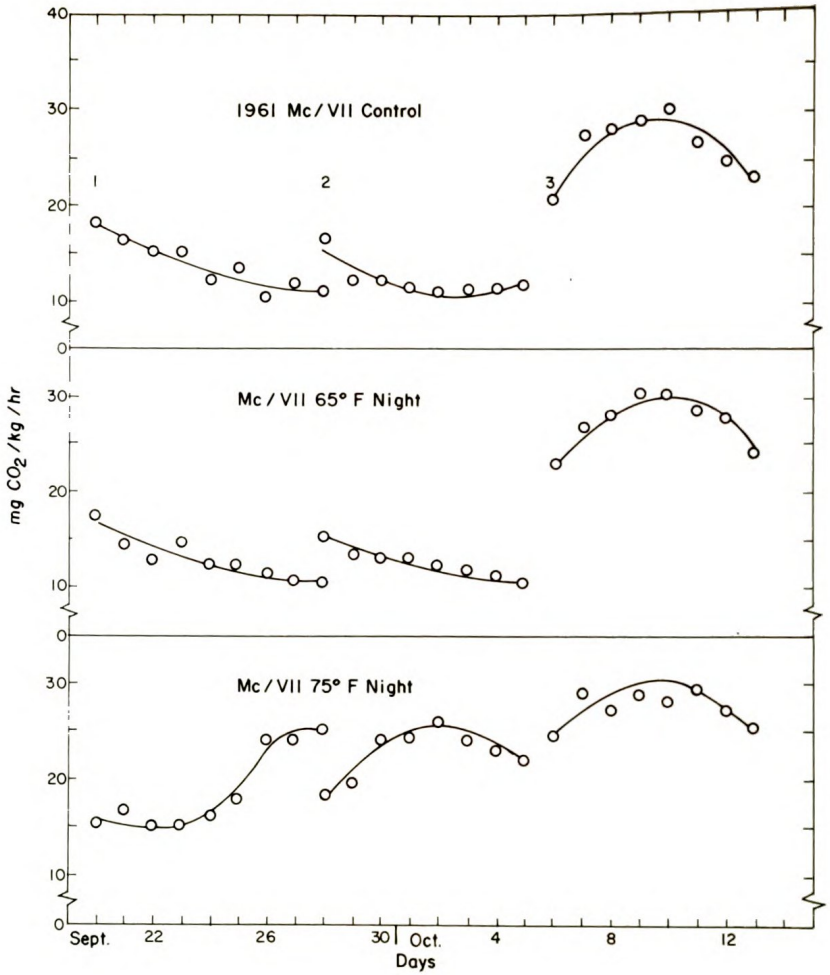
Treatment[a]	Full Bloom Date	Starch Accum. Date	Climacteric Date	Full Bloom to Starch Days	Starch to Climacteric Days	F.B. to Climacteric Days
Mc/VII 75 F, night	5/15	6/14	9/24	30	102	132
Mc/VII 65 F, night	5/15	6/15	10/2	31	109	140
Mc/VII Control	5/15	6/15	10/2	31	109	140
Mc/II 75 F, night	5/15	6/15	9/24	31	101	132
Mc/II 65 F, night	5/15	6/15	9/28	31	105	136
Mc/II Control	5/15	6/15	9/28	31	105	136

a/ Temperature treatments were started one week after full bloom and were discontinued one week after the starch accumulation date.

Figure 6

Respiratory climacteric of McIntosh fruits from modified temperature treatments at East Lansing in 1961.


1961 Mc/II Control
Mc/II 65° F Night
Mc/II 75° F Night
mg CO_2/kg/hr
1
2
3
Sept.
Oct.
Days


1961 Mc/VII Control
Mc/VII 65° F Night
Mc/VII 75° F Night
mg CO_2/kg/hr
1
2
3
Sept.
Oct.
Days

harvests. Fruits from all treatments with EM II and those from trees on EM VII which received the 75 F night temperature were more advanced in maturity than those from the EM VII control and the EM VII 65 F night temperature treatments.

No marked differences were observed in the physical characteristics of the fruit at harvest as a result of the high post-bloom night temperatures.

II. Modified Environment Study, 1962.

A. The environment

The modified environment study in 1962 employed the same trees as were used in the 1961 study. The 75 F night temperature treatment was retained, the 65 F night temperature treatment deleted and day length and light intensity treatments were added. The environmental conditions obtained in 1962 are given in Table 4. The average minimum night temperature for the five week period after petal fall was 4.1 F above normal for the East Lansing area. The percentage of possible sunshine received during this period was 75%, which was 9% above normal for the area. The average daily maximum temperature for this period was 80 F which was 6.8 F above normal. Soil moisture was adequate for growth during this period. The nutritional conditions of the trees were adequate and the nitrogen and potassium levels were in the normal range (Kenworthy, 1961) as shown in the Appendix.

B. Vegetative growth

As in 1961, high night temperature accelerated shoot

TABLE 4. Average weekly temperature (°F) regimes obtained for five weeks following petal fall in 1962 at the M.S.U. Horticulture farm, East Lansing.

Week	Treatment		Avg. Daily maximum	Avg. Daily minimum
	Control[a] (night)	75°F[a] (night)		
1	66	78	84	59
2	60	75	77	50
3	63	75	78	55
4	64	76	78	56
5	65	77	83	56

a/ Average of hourly night temperatures between 9 p.m. and 6 a.m.

elongation in 1962, see Figure 7. The low light intensity treatment resulted in longer and more slender shoot growth than was observed in the control. Low light intensity combined with a 75° F night temperature resulted in the greatest shoot growth of all the treatments. The short day treatment was similar to the control while the long day treatment resulted in the lowest shoot growth of all treatments. However, the tree which received the long day treatment was stunted in growth the previous year from wind damage and hence, did not yield a satisfactory test. Trees which received low light intensity and short day treatments underwent a secondary finish of terminal growth.

The influence of the various environmental treatments on leaf expansion is shown in Figure 8. Leaf expansion paralleled shoot elongation.

Shoot elongation and leaf expansion ceased on the same date for all except the low light intensity plus 75° F night temperature treatment.

C. Fruit growth

High night temperature accelerated fruit growth as was observed in 1961 and is shown in Figure 9. Low light intensity suppressed fruit growth but this was overcome when combined with a high night temperature. Day length did not seem to have any marked effect on fruit growth. Although considerable differences in fruit size among treatments were evident 30 days after full bloom, there was little difference in fruit size at harvest time. This suggests

Figure 7

Influence of night temperatures, light intensity and day length on McIntosh shoot elongation at East Lansing in 1962. Arrow indicates discontinuation date of the treatments.

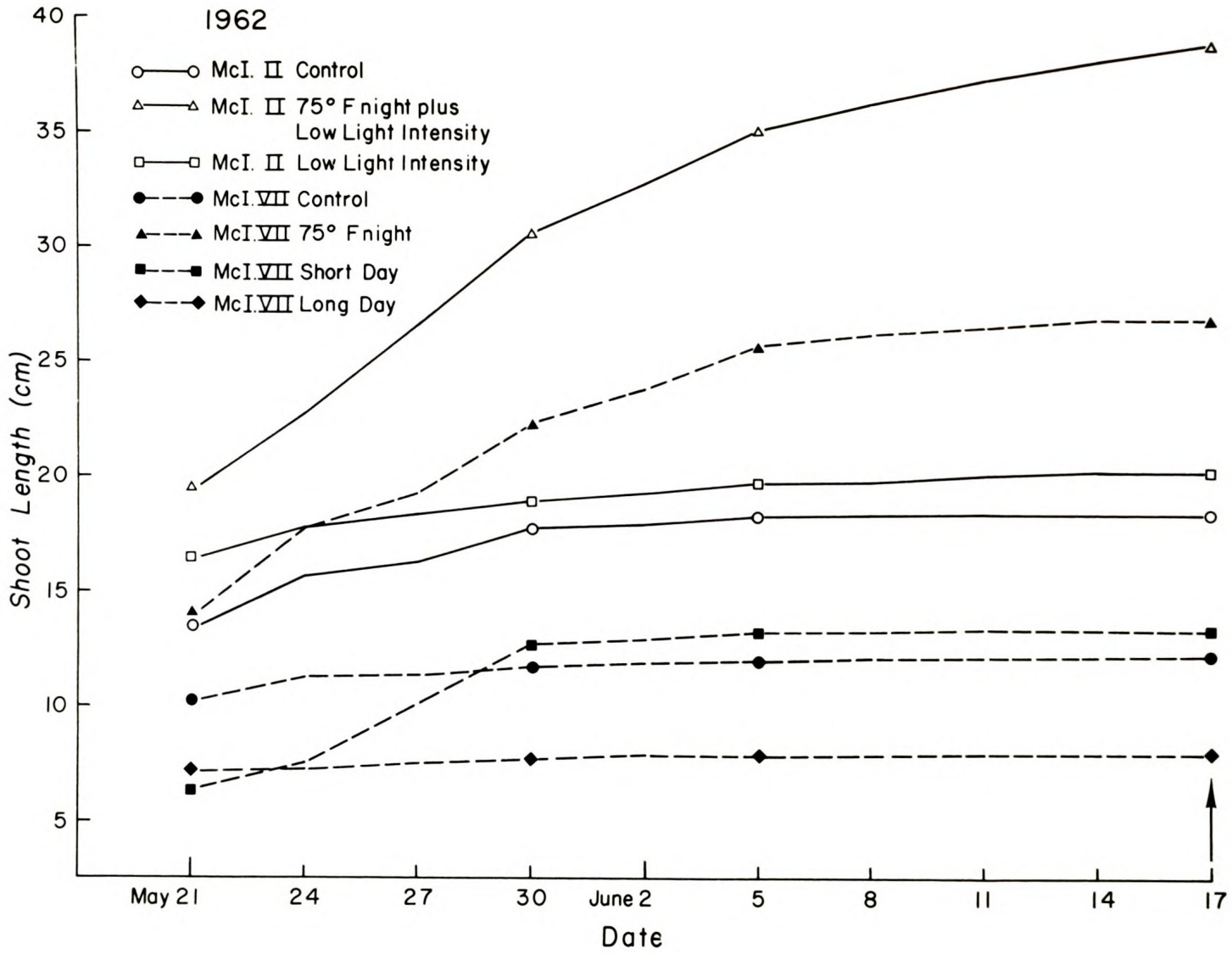

1962
McI. II Control
McI. II 75° F night plus Low Light Intensity
McI. II Low Light Intensity
McI. VII Control
McI. VII 75° F night
McI. VII Short Day
McI. VII Long Day
Shoot Length (cm)
40
35
30
25
20
15
10
5
May 21
24
27
30
June 2
5
8
11
14
17
Date

Figure 8

Influence of night temperature, light intensity and day length on McIntosh leaf growth at East Lansing in 1962. Arrow indicates discontinuation date of the treatments.

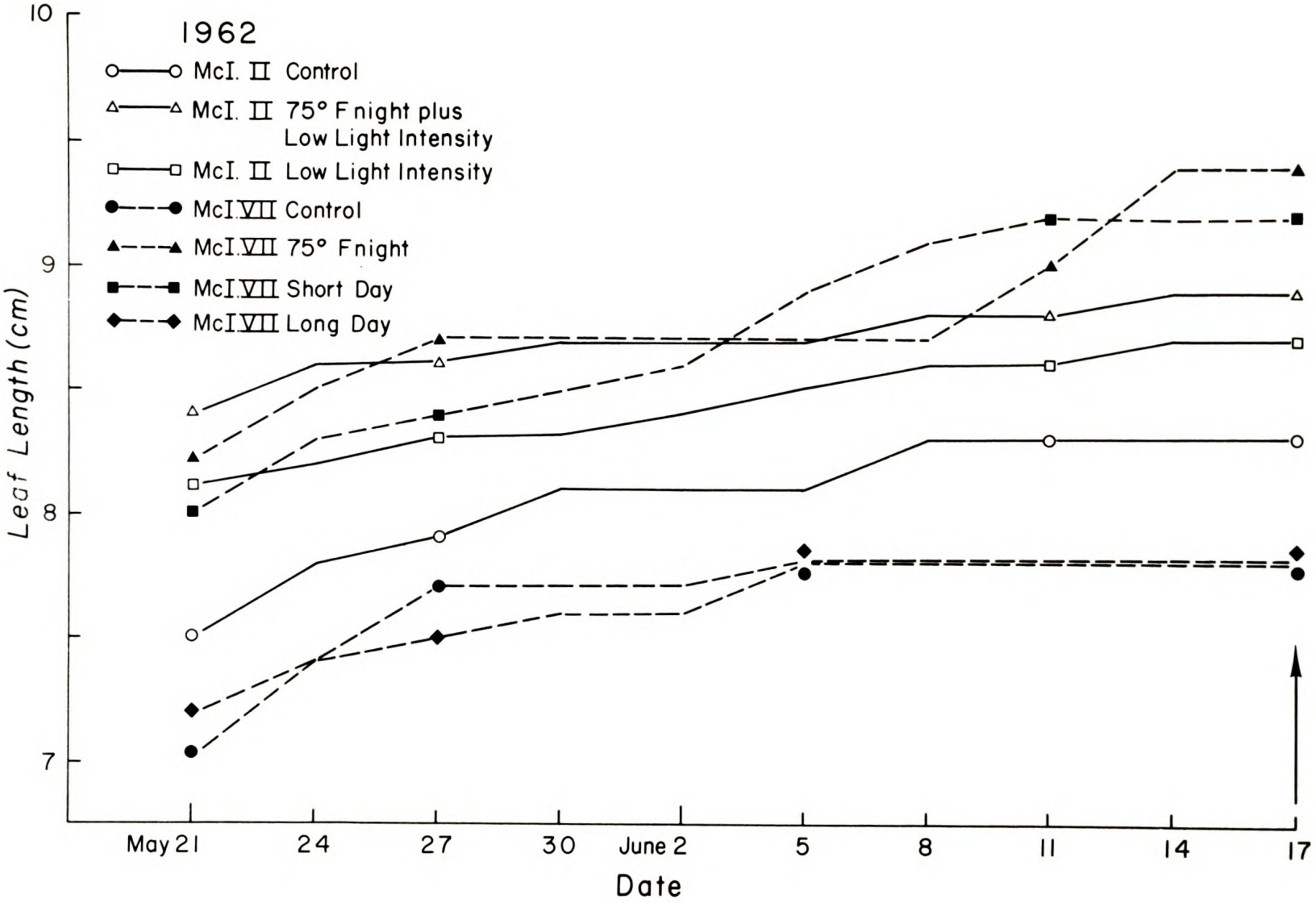
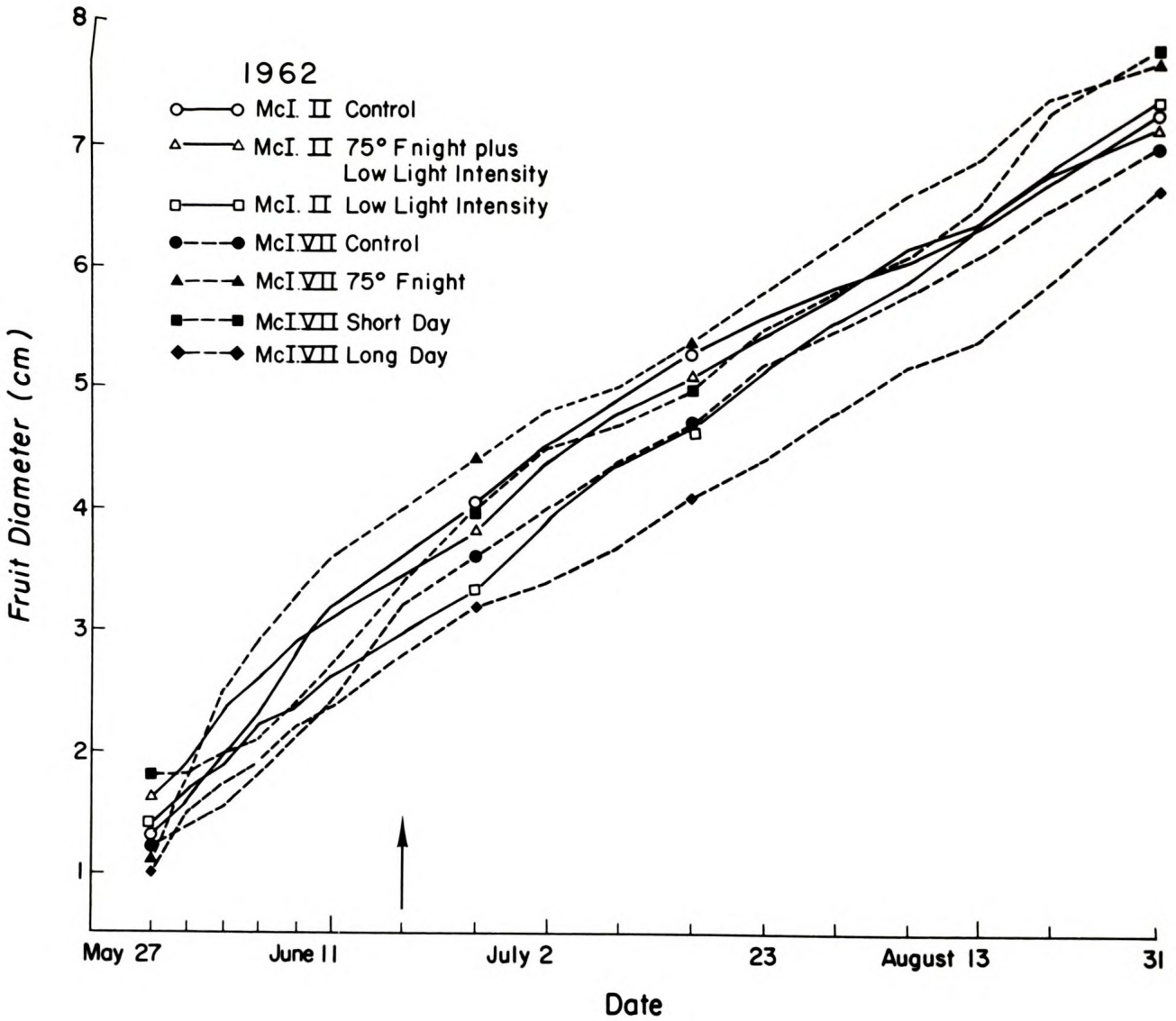

1962
McI. II Control
McI. II 75° F night plus Low Light Intensity
McI. II Low Light Intensity
McI. VII Control
McI. VII 75° F night
McI. VII Short Day
McI. VII Long Day
Leaf Length (cm)
10
9
8
7
May 21
24
27
30
June 2
5
8
11
14
17
Date

Figure 9

Influence of night temperature, light intensity and day length on McIntosh fruit growth at East Lansing in 1962. Arrow indicates discontinuation date of the treatments.


1962
McI. II Control
McI. II 75° F night plus Low Light Intensity
McI. II Low Light Intensity
McI. VII Control
McI. VII 75° F night
McI. VII Short Day
McI. VII Long Day
Fruit Diameter (cm)
8
7
6
5
4
3
2
1
May 27
June 11
July 2
23
August 13
31
Date

that ultimate fruit size is essentially independent of early season night temperatures. The influence of high night temperatures on fruit growth during the remainder of the growing season was not investigated.

D. Starch accumulation and cell division

The influence of the various environmental treatments on starch accumulation in 1962 is given in Table 5. High night temperatures shortened the interval from full bloom to starch accumulation by two days. The greatest effect on starch accumulation occurred in the low light intensity treatment where a delay of nine days was observed. High night temperature combined with low light intensity partially overcame the delaying effect of low light intensity on starch accumulation.

A relationship was found between cessation of cell division, cessation of shoot elongation, June drop and starch accumulation in the McIntosh fruits (Table 6). All these events occurred at about the same time, which was about 30 days after full bloom. Although the different environments altered the dates of cessation of cell division and starch accumulation, the association between the two was not changed.

E. Fruit maturity

The course of the respiratory climacteric of fruits from the various environmental treatments is shown in Figure 10. Essentially no differences are discernible among the respiratory curves of fruits from trees which received

TABLE 5. Influence of modified environments on the maturation of McIntosh at East Lansing in 1962.

Environment [a]		Full Bloom Date	Starch Accum. Date	Climacteric Date	F. B. to Climact. (Days)	S. A. to Climact. (Days)	Full Bloom to Climacteric (Days)
Control (ambient)	Mc/VII	5/11	6/10	9/10	30	102	132
75 F Night	Mc/VII	5/10	6/7	9/14	28	99	127
Short day	Mc/VII	5/11	6/12	9/20	32	100	132
Control (ambient)	Mc/II	5/11	6/10	9/8	30	90	120
75°F Night + Low Light Intensity	Mc/II	5/10	6/13	9/8	34	87	121
Low Light Intens.	Mc/II	5/10	6/18	9/8	39	82	121

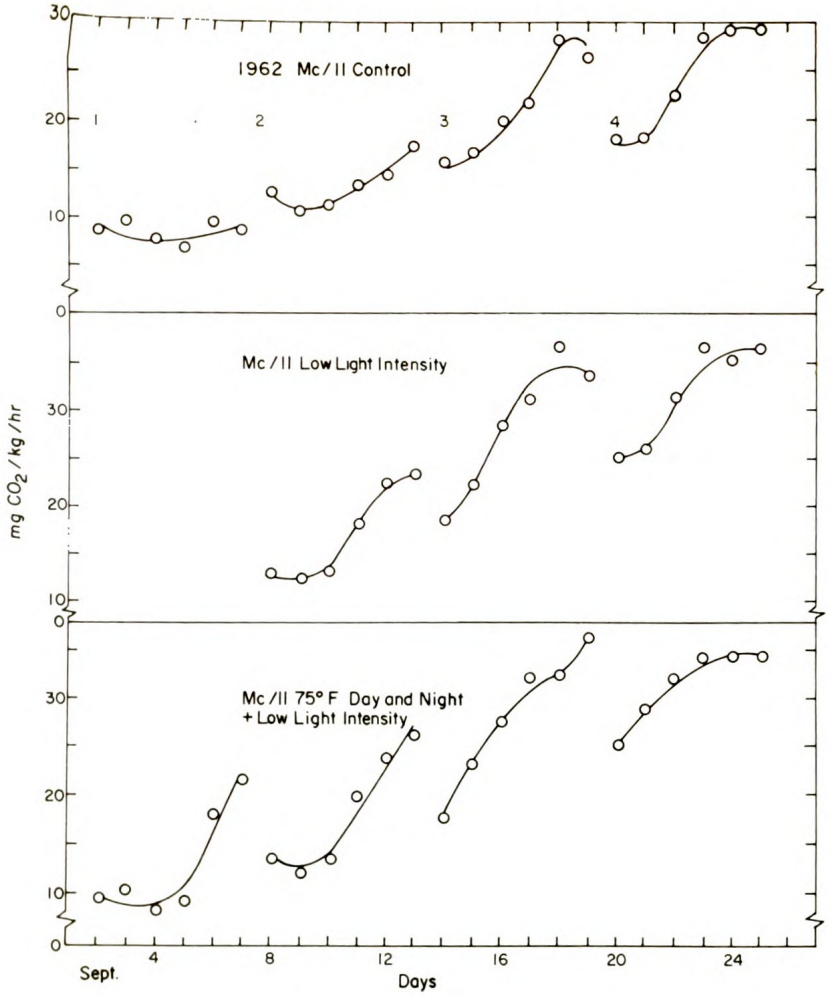
[a] Temperature treatments were started four days after full bloom and were discontinued one week after the starch accumulation date.

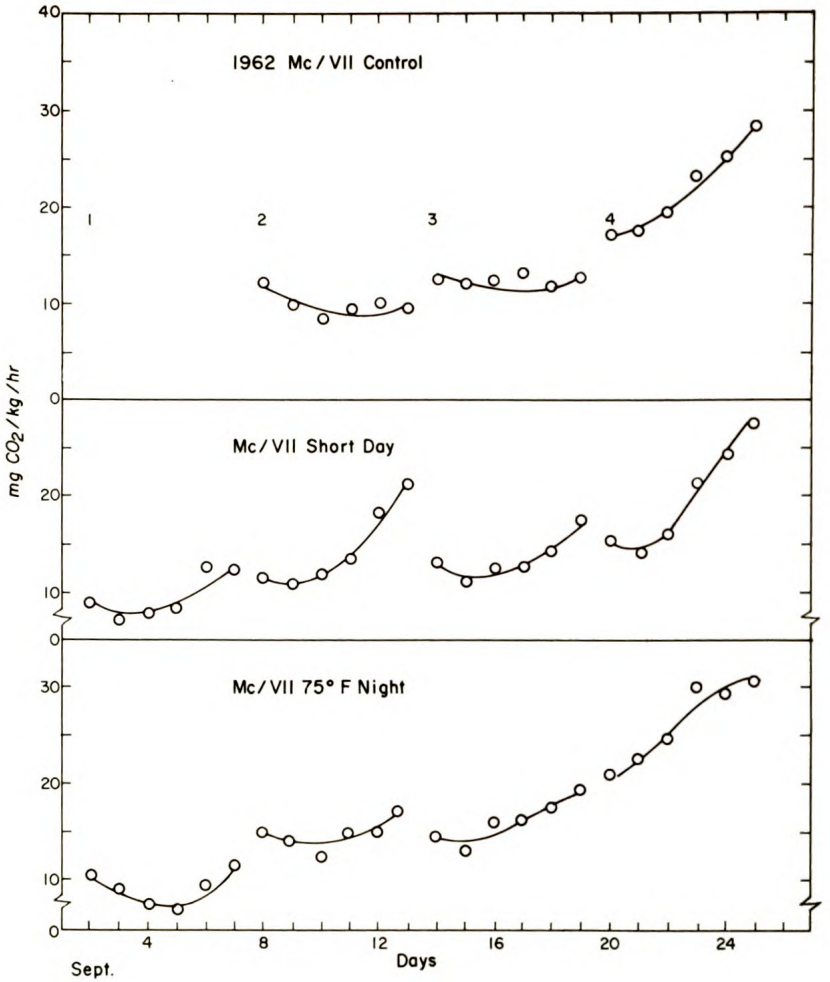
TABLE 6. The relationship between the date of the cessation of cell division in fruits, cessation of shoot elongation, June drop and starch accumulation in fruits of McIntosh from trees subjected to modified environments at East Lansing in 1962.

Observation		Environment						
		Mc/VII				Mc/II		
		75°F Night Temp.	Short Day	Long Day	Control (Ambient)	75°F Night Temp. Low Light Inten.	Low Light Intensity	Control (Ambient)
Cessation of cell division	June	5	10	6	9	8	12	9
Cessation of shoot elongation	June	8	8	9	8	14	14	5
June drop	June	8	8	8	11	11	17	11
Starch Accumulation	June	8	12	8	10	13	18	10

Figure 10

Respiratory climacteric of McIntosh fruits from modified environmental treatments at East Lansing in 1962.


1962 Mc/II Control
Mc/II Low Light Intensity
Mc/II 75° F Day and Night
+ Low Light Intensity
1
2
3
4
mg CO_2/kg/hr
Sept.
Days


1962 Mc/VII Control
Mc/VII Short Day
Mc/VII 75° F Night
1
2
3
4
mg CO_2/kg/hr
Sept.
Days

post-bloom environment of low light intensity, low light intensity plus 75 F night temperature, short day length or the ambient environment. The 75° F night temperature treatment appeared to have hastened maturity slightly. Fruits from trees grown on EM II rootstocks reached the preclimacteric minimum about a week earlier than those from trees on EM VII rootstocks. This was also observed in 1961.

No differences were readily apparent in the physical characteristics of the fruit at any of the three harvests regardless of the post-bloom environment received.

III. Natural Environment Study, 1962.

A. The environment

The various locations selected to evaluate natural environmental variations during the post-bloom period exhibited a range in full bloom date from May 4 to May 16. Trees at seven of the ten locations reached full bloom within three days of one another as a result of widespread unseasonably high mid-May temperatures. The heat units (base 40 F) accumulated at the various locations during the post-bloom period are given in Tables 7 and 8. The cumulative values for the 30 day period ranged from a low of 726 to a high of 832. The maximum difference between the various locations was only 106 units, and eight of the ten locations fell within 66 units. The accumulation of heat units from the same localities for the same 30-day period in 1963 varied from a low of 494 to a high of 695. The values for the

TABLE 7. Relationship between post-bloom temperatures and the elapsed interval from full bloom to starch accumulation and the preclimacteric minimum for McIntosh fruits from ten locations in 1962.

Location	F.B. to Starch (Days)	F.B. to Clim. (Days)	0-10 Days [a] High X	0-10 Days [a] Low X	0-10 Days [a] Heat [b] Units	11-20 Days [a] High X	11-20 Days [a] Low X	11-20 Days [a] Heat [b] Units	21-30 Days [a] High X	21-30 Days [a] Low X	21-30 Days [a] Heat [b] Units	31-40 Days [a] High X	31-40 Days [a] Low X	31-40 Days [a] Heat [b] Units
A	31	131	69	46	172	86	61	333	73	52	221	79	56	274
B	36	127	81	58	295	72	57	246	75	55	249	-	-	-
C	32	124	82	61	311	72	52	224	81	57	291	82	54	278
D	33	132	82	61	327	71	51	210	77	54	257	79	55	270
E	28	122	86	54	302	75	47	213	82	52	270	81	55	282
F	31	132	82	61	327	71	51	210	77	54	257	79	55	270
G	29	121	79	54	266	73	51	219	76	52	239	78	55	265
H	29	127	79	54	266	73	51	219	76	52	239	78	55	265
I	39	122	78	62	301	73	50	214	78	54	265	80	57	283
J	31	127	85	58	317	80	53	263	78	53	252	81	56	281

a/ Days after full bloom.

b/ A base temperature of 40°F was used to calculate heat units.

TABLE 8. Relationship between post-bloom temperatures and the elapsed interval from full bloom to starch accumulation and the preclimacteric minimum for McIntosh fruits from ten locations in 1962.

Location	F.B. to Starch (Days)	F.B. to Climac. (Days)	20 Days [a] High $\bar{X}$	20 Days [a] Low $\bar{X}$	20 Days [a] Accum. [b] Ht. Un.	30 Days [a] High $\bar{X}$	30 Days [a] Low $\bar{X}$	30 Days [a] Accum. [b] Ht. Un.	40 Days [a] High $\bar{X}$	40 Days [a] Low $\bar{X}$	40 Days [a] Accum. [b] Ht. Un.
A	31	131	78	54	505	76	53	726	78	54	1000
B	36	127	76	58	541	76	57	790	-	-	-
C	32	124	77	56	535	78	56	826	79	55	1104
D	33	132	76	56	537	77	55	794	77	55	1064
E	28	122	80	51	515	81	52	785	81	53	1067
F	31	132	76	56	537	76	55	794	78	55	1067
G	29	121	76	52	485	76	52	724	77	54	989
H	29	127	76	52	485	76	52	724	77	54	989
I	39	122	76	56	515	77	55	780	78	56	1063
J	31	127	82	56	580	81	54	832	81	55	1096

a/ Days after full bloom.

b/ A Base temperature of 40°F was used to calculate heat units.

other locations were quite evenly distributed between the low and the high values. The information on heat unit accumulation for the 1963 season is included here to point our marked differences in magnitude and distrubtion of the post-bloom temperature between the 1962 and 1963 seasons. The range in full bloom for the same localities in 1963 was May 9 to May 26 and the intermediate values were evenly distributed throughout this range.

Summation of heat units (40 F base temperature) from full bloom to the date of optimum storage harvest was obtained for only three of the ten locations and were as follows:

Location	Heat Units
D	3373
F	3445
J	3623

The nutritional conditions of the trees from all locations are shown in Tables 2 and 5 (see Appendix). Nitrogen and potassium levels were in the normal range (Kenworthy, 1961) except for locations E, G and J, which showed a slightly below normal level of potassium.

B. Starch accumulation

The elapsed intervals between full bloom and starch accumulation and a summary of post-bloom temperature conditions for ten locations under natural environments are given in Tables 7 and 8. The shortest interval was 28 days and the longest interval was 39 days. Eight out of the ten

locations were within a range of five days. There was no significant correlation between the interval from full bloom to starch accumulation and the post-bloom temperature conditions at the various locations. Post-bloom heat unit accumulation, average minimum temperature or average maximum temperature over a 40-day period, or 10-day increments thereof, bore no relationship to the elapsed interval from full bloom to starch accumulation.

Starch accumulation and post-bloom temperature data for McIntosh grown at East Lansing in 1961, 1962 and 1963 are given in Tables 9 and 10. These data do not show any apparent relationship between the post-bloom temperature conditions and the elapsed period from full bloom to starch accumulation.

In the 1961 season, the accumulation of starch in the developing apple fruit was observed to proceed very rapidly once the process was initiated. In 1962, a time study was undertaken to investigate the nature of starch accumulation during the initial period. Hourly and daily changes in starch content of McIntosh fruit are given in Table 11. Starch was first detected in fruits in mid-afternoon and was dissipated during the evening which followed. The following day starch was detected in mid-morning and was partially dissipated that evening. The diurnal fluctuation in starch content was evident again the following day. The third day after starch was detected, 80% of the fruits contained starch by 8:00 a.m. The rapid nature

TABLE 9. Relationship between post-bloom temperatures and the elapsed interval from full bloom to starch accumulation and the preclimacteric minimum for McIntosh fruits grown at three locations for the 1961, 1962 and 1963 seasons.

Location	Year	F.B. to Starch (Days)	F.B. to Climac. (Days)	10 Days [a] High $\bar{X}$	10 Days [a] Low $\bar{X}$	10 Days [a] Heat Units [b]	11-20 Days [a] High $\bar{X}$	11-20 Days [a] Low $\bar{X}$	11-20 Days [a] Heat Units [b]	21-30 Days [a] High $\bar{X}$	21-30 Days [a] Low $\bar{X}$	21-30 Days [a] Heat Units [b]
East Lansing	1961	31	135	65	42	153	67	46	167	66	58	313
	1962	31	127	85	58	317	80	53	263	78	53	252
	1963	33	130	67	46	165	65	41	131	82	54	284
Walker-ville	1961	29	122	69	43	160	77	56	268	-	-	-
	1962	39	122	78	62	301	73	50	214	78	54	265
	1963	37	125	64	40	116	79	58	284	76	52	241
Mears	1961	25	115	72	53	223	67	48	173	-	-	-
	1962	36	117	77	50	239	75	50	226	81	51	258
	1963	32	120	77	50	231	74	51	229	74	47	202

a/ Days after full bloom.

b/ A base temperature of 40°F was used to calculate heat units.

TABLE 10. Relationship between post-bloom temperatures and the elapsed interval from full bloom to starch accumulation and the preclimacteric minimum for McIntosh fruits grown at three locations for the 1961, 1962 and 1963 seasons.

Location	Year	F.B. Date	Clim. Date	F.B. to Starch (Days)	F.B. to Climac. (Days)	20 Days [a] High X	20 Days [a] Low X	20 Days [a] Accum. Ht. Un. [b]	30 Days [a] High X	30 Days [a] Low X	30 Days [a] Accum. Ht. Un. [b]
East Lansing	1961	5/15	9/27	31	135	66	44	320	66	49	633
	1962	5/11	9/15	33	127	82	56	580	81	55	832
	1963	5/9	9/16	33	130	66	44	296	71	47	580
Walker-ville	1961	5/26	9/25	29	122	73	50	428	-	-	-
	1962	5/15	9/14	39	122	76	56	515	79	55	780
	1963	5/17	9/19	37	125	72	49	400	73	50	641
Mears	1961	6/2	9/25	25	115	70	50	396	-	-	-
	1962	5/17	9/11	36	117	76	50	465	78	50	723
	1963	5/26	9/23	32	120	76	50	460	75	49	662

a/ Days after full bloom.

b/ A base temperature of 40°F was used to calculate heat units.

TABLE 11. Hourly and daily changes in starch content in McIntosh apples during initial stage of accumulation in 1962.

Date	Percentage of Fruits[a] Showing Starch							
	A.M.				P.M.			
	6:00	8:00	10:00	12:00	2:00	4:00	6:00	8:00
June 8	0	0	0	0	0	0	0	0
June 9	0	0	0	0	20	30	0	0
June 10	0	0	20	40	50	50	30	20
June 11	20	70	60	80	100	90	80	50
June 12	60	80	90	90	100	100	90	80
June 13	80	100	100	100	100	100	100	100
June 14	100	100	100	100	100	100	100	100

a/ Sample of 10 fruits.

of starch accumulation can be seen by following the course of accumulation at the 8:00 a.m. determination.

Starch accumulation was also studied for 11 other apple varieties at East Lansing in 1962 and the results are given in Table 12. Full bloom occurred within three days and starch accumulation occurred within 5 days for all varieties. There was no apparent relationship between the elapsed period from full bloom to starch accumulation and the number of days from full bloom to maturity for the various varieties. Ben Davis, a variety that normally requires about 155 days from full bloom to maturity, accumulated starch earlier than McIntosh which normally reaches maturity about 130 days after full bloom.

C. Fruit maturity

1. Physical characteristics

The physical characteristics of the McIntosh fruits from ten locations varied considerably when compared at approximately the same physiological age as seen in Table 13. The values presented represent the characteristics of the fruit at the harvest judged to be closest to the preclimacteric minimum. The amount of red coloration on fruits varied from 38% to 96%. Ground color rating varied from 3.7 to 4.6. Flesh firmness varied from 14.4 lbs. to 16.4 lbs. while soluble solids varied from 10.7% to 12.7%. Intermediate values for these physical characteristics were quite evenly distributed within the ranges given.

TABLE 12. The relationship between the date of full bloom, starch accumulation and harvest of several apple varieties at East Lansing in 1962.

Variety	Full Bloom Date	Starch Accum. Date	Commercial Harvest Date	Full Bloom to Starch (Days)	Starch to Commercial Harvest (Days)	Full Bloom to Commercial Harvest (Days)
Ben Davis	5/13	6/10	10/15	28	127	155
Famuse	5/11	6/9	10/2	29	115	144
Gideon	5/12	6/8	8/15	27	68	95
Grimes	5/12	6/8	9/25	27	109	136
Jonathan	5/13	6/11	9/20	29	101	130
McIntosh	5/11	6/11	9/14	31	95	126
R. Delicious	5/13	6/9	9/24	27	107	134
R. I. Greening	5/12	6/9	9/12	28	107	135
Steele Red	5/14	6/10	10/1	27	95	122
Wealthy	5/12	6/7	9/5	26	90	116
Wagener	5/11	6/9	9/27	29	110	139

TABLE 13. Physical characteristics of McIntosh fruits from ten locations at the onset of the respiratory climacteric.

Physical Characteristics	Location									
	A	B	C	D	E	F	G	H	I	J
Red coloration (%)	38	52	53	96	76	96	68	70	45	57
Ground color (rating)	3.8	4.6	4.6	3.7	4.6	4.1	4.1	4.8	4.2	3.8
Flesh firmness (lbs.)	15.4	14.8	14.4	15.8	15.2	15.3	16.3	15.3	14.6	16.4
Soluble solids (%)	11.7	12.2	12.5	12.6	11.0	12.7	12.4	11.7	10.7	12.5

Each value represents the mean of 25 fruits.

The change in red coloration, ground color, flesh firmness and soluble solids for approximately a three week harvesting period for ten locations is shown in Figure 11. No sharp change was evident for these characteristics over this period, although the onset of the respiratory climacteric for seven out of the ten locations occurred during the September 13 to 16 period. When the individual locations were plotted in a similar manner, no abrupt change was observed in these physical characteristics. The values for red coloration of fruits from all locations are given in Table 14.

2. Respiratory climacteric

The respiratory metabolism of McIntosh fruits from ten locations under natural environments over a three week period is shown in Figure 12. The climacteric rise in respiration rate is clearly shown for all locations except D and F. The reason for the absence of a marked climacteric for these locations is not known. The same locations did not show an abnormal elapsed period from full bloom to starch accumulation, nor did they receive markedly different post-bloom temperatures in comparison with the other locations. The respiratory behavior of fruits from location D for 1961 also showed a pronounced delay in the onset of the climacteric in comparison to fruits from other orchards in the same general area. With the exception of locations D, F and H, fruits from all locations commenced a climacteric rise within four calendar days of one another.

Figure 11

Change in red coloration, ground color, flesh firmness and soluble solids of McIntosh fruits over a sequence of seven harvests at ten locations in 1962. (Each value represents the mean for all locations at each harvest date.)

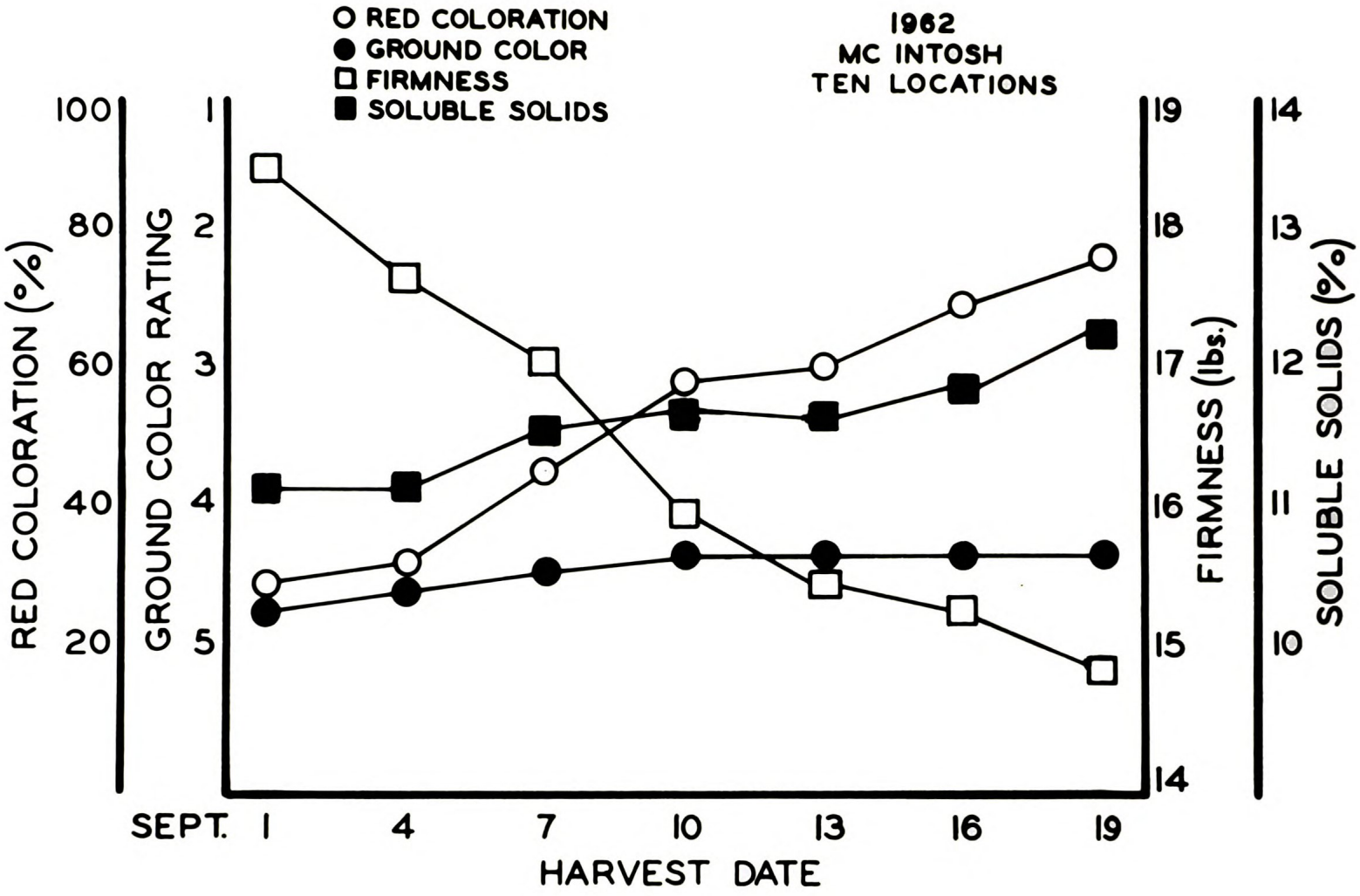

O RED COLORATION
● GROUND COLOR
□ FIRMNESS
■ SOLUBLE SOLIDS
1962
MC INTOSH
TEN LOCATIONS
RED COLORATION (%)
100
80
60
40
20
GROUND COLOR RATING
1
2
3
4
5
FIRMNESS (lbs.)
19
18
17
16
15
14
SOLUBLE SOLIDS (%)
14
13
12
11
10
SEPT. 1
4
7
10
13
16
19
HARVEST DATE

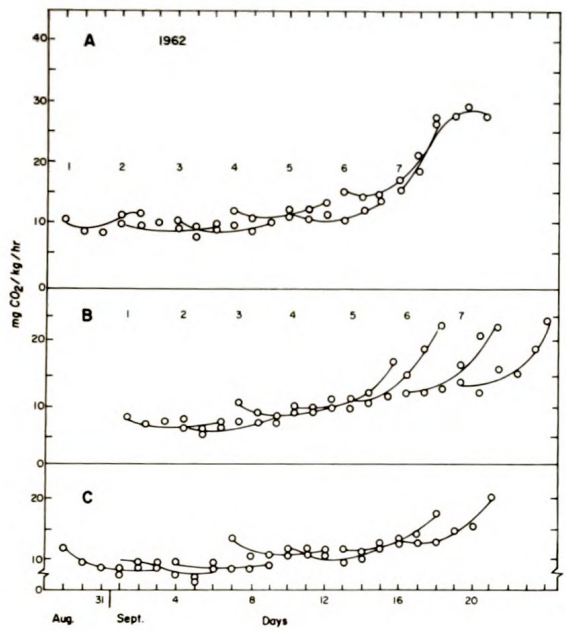
TABLE 14. Evaluation of red coloration (%) of McIntosh fruits from seven harvests at ten locations in 1962.[a]

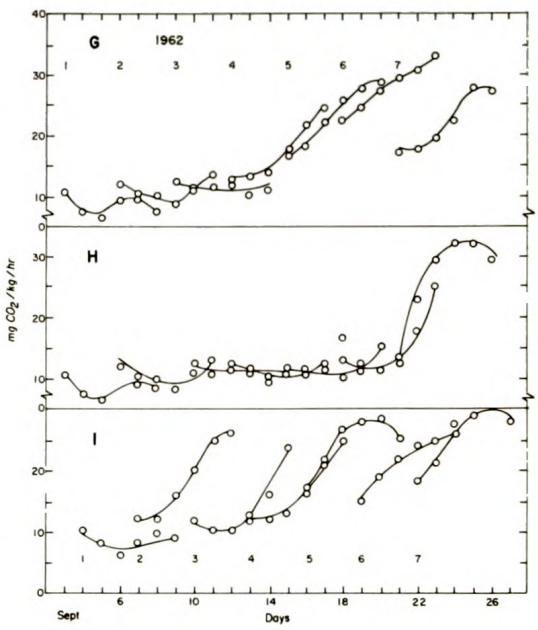
Harvest	Location										Average
	A	B	C	D	E	F	G	H	I	J	
1	20	17	16	53	32	47	-	-	22	32	30
2	17	18	13	55	35	57	-	-	27	22	33
3	22	32	35	73	58	92	-	-	50	37	46
4	32	42	35	83	76	80	68	60	45	53	58
5	33	33	45	82	85	83	70	63	58	57	61
6	38	52	57	89	88	86	86	70	68	63	70
7	45	50	53	96	93	96	91	73	75	67	77

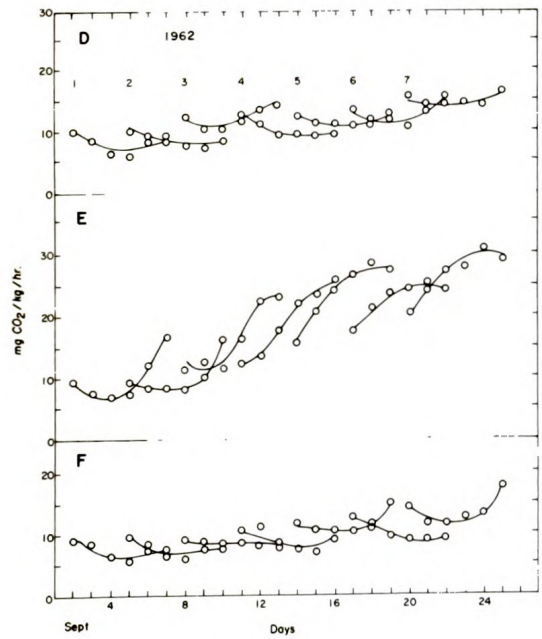
a/ Mean values of three independent determinations.

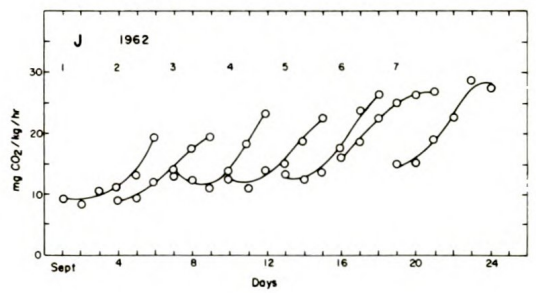
Figure 12

Respiratory behavior of McIntosh fruits from seven harvests at ten locations in Michigan in 1962. Fruits were harvested at 3 day intervals.


A
1962
B
C
mg CO2/kg/hr
Aug.
Sept.
Days


G
1962
H
I
mg CO2/kg/hr
Sept
Days


D
1962
E
F
mg CO2/kg/hr.
Sept
Days


J
1962
mg CO2/kg/hr
Sept
Days

607

3. Storage quality

Fruits from each of seven harvests of ten locations under natural environments were evaluated following air storage for five months or CA storage for eight months. The values obtained for ground color are given in Table 15. Ground color values at harvest are also included. Little difference was observed in ground color values at harvest over the course of a three week period within or between locations. The average change for all locations was only 0.4 units over the harvesting period. During air storage, fruits from later harvests for most locations registered a considerable change in ground color from that observed at harvest. The ground color of very immature fruits remained essentially the same during the storage period. The ground color change in storage generally increased with maturity of the fruit at harvest. This is readily apparent from the average values for all locations. The same general results were obtained for fruits following CA storage. The ground color change from that at harvest was greater after CA storage for eight months than after air storage for five months.

Flesh firmness values of fruits from the ten locations are given in Table 16. Marked differences were observed at harvest within, but not between, locations over the three week harvesting period. These differences were not readily apparent upon removal from air or CA storage. The average difference in firmness of fruits from all locations between

TABLE 15. Harvest and post-storage evaluation of ground color rating of McIntosh fruits from seven harvests at ten locations in 1962. The fruits were stored in air for five months or CA-storage for eight months.

Harvest	Location A	B	C	D	E	F	G	H	I	J	Average
Harvest											
1	4.8	4.8	5.0	4.5	4.8	4.6	-	-	4.8	4.3	4.7
2	4.5	4.8	4.6	4.1	4.7	4.4	-	-	4.8	4.2	4.5
3	4.6	4.6	4.6	4.0	4.8	3.8	-	-	4.7	3.9	4.4
4	4.3	4.3	4.7	3.9	4.6	4.0	4.1	5.0	4.2	4.0	4.3
5	4.1	4.5	4.4	4.0	4.6	3.8	4.0	4.9	4.8	3.8	4.3
6	3.8	4.6	4.5	4.2	4.6	3.8	4.0	4.8	4.5	3.8	4.3
7	4.4	4.7	4.6	3.7	4.8	4.1	4.0	5.0	4.2	3.3	4.3
Air Storage											
1	4.7	5.0	5.0	3.9	5.0	4.4	-	-	5.0	4.2	4.6
2	4.6	5.0	4.7	3.6	4.5	4.3	-	-	5.0	3.8	4.5
3	3.5	4.7	4.8	3.6	4.8	2.4	-	-	4.9	3.8	4.1
4	3.7	4.7	4.2	3.3	4.7	4.3	5.0	4.3	4.8	4.0	4.3
5	3.8	4.7	4.5	3.4	4.7	4.4	4.9	4.6	4.0	3.2	4.2
6	3.9	4.3	4.3	2.4	4.4	3.7	4.9	3.7	4.2	3.0	3.9
7	3.6	4.7	4.3	2.3	3.0	2.4	4.2	3.1	3.4	2.3	3.3
CA Storage											
1	3.4	3.2	3.6	2.6	4.4	3.3	-	-	3.8	3.2	3.4
2	4.0	4.2	3.2	3.0	3.0	3.1	-	-	3.6	3.1	3.4
3	3.8	4.2	3.4	2.8	4.1	1.9	-	-	3.8	3.0	3.4
4	3.6	2.8	3.3	2.2	4.1	3.0	2.2	3.3	3.2	2.9	3.1
5	3.0	3.1	3.1	2.9	3.8	2.8	2.2	3.1	2.7	2.8	3.0
6	2.6	3.1	3.4	1.5	3.8	2.0	1.6	2.9	3.0	2.9	2.7
7	2.6	2.9	3.1	1.4	4.0	1.7	1.0	2.1	1.8	2.8	2.3

A decrease in ground color score indicates an increase in the yellow ground color.

TABLE 16. Harvest and post-storage evaluation of flesh firmness (lbs.) of McIntosh fruits from seven harvests at ten locations in 1962. The fruits were stored in air for five months or CA storage for eight months.

Harvest	Location										Average
	A	B	C	D	E	F	G	H	I	J	
Harvest											
1	17.2	17.4	17.7	19.3	17.9	18.4	-	-	19.9	20.4	18.5
2	17.1	18.7	18.1	18.0	18.1	17.3	-	-	16.5	18.5	17.7
3	18.6	16.5	19.2	17.1	15.6	17.2	-	-	16.1	16.2	17.1
4	16.1	15.2	17.2	16.1	15.2	16.0	16.3	15.9	16.2	16.1	16.0
5	15.2	15.9	16.3	15.4	14.9	15.6	16.2	15.5	14.5	16.4	15.6
6	15.4	14.8	16.1	14.9	13.4	16.0	16.7	15.3	14.6	15.6	15.3
7	14.7	14.5	14.4	15.8	14.1	15.3	15.7	14.4	14.6	15.3	14.9
Air Storage											
1	11.7	11.2	12.6	12.8	15.8	12.2	-	-	11.7	12.1	12.5
2	11.7	10.9	12.5	13.7	11.8	12.0	-	-	12.0	11.7	12.0
3	11.8	11.0	12.1	11.7	10.5	11.9	-	-	11.3	12.3	11.6
4	10.7	11.1	11.5	12.3	10.9	12.0	12.2	12.9	10.9	11.9	11.6
5	10.9	11.0	10.8	12.2	11.3	11.3	12.2	12.2	11.0	11.3	11.4
6	11.1	11.0	11.2	11.9	11.4	11.5	11.6	12.1	10.7	12.2	11.5
7	10.8	11.2	11.7	12.1	11.0	11.5	11.3	12.3	10.7	12.3	11.5
CA Storage											
1	11.9	10.2	12.3	12.1	11.4	12.2	-	-	11.2	11.8	11.6
2	10.8	11.0	12.2	11.4	11.3	12.3	-	-	11.3	12.2	11.6
3	11.2	10.7	12.2	12.2	11.0	12.5	-	-	11.5	11.7	11.6
4	11.3	10.9	11.9	12.2	10.5	11.6	11.5	11.5	10.9	11.8	11.4
5	10.9	10.5	11.2	11.5	10.5	11.6	12.1	10.7	10.3	11.2	11.0
6	10.6	10.3	11.3	12.9	10.8	12.2	11.8	12.3	10.9	11.3	11.4
7	11.4	10.5	11.4	12.7	11.3	11.6	12.2	11.1	10.7	11.2	11.4

the first and the seventh harvest was 3.6 lbs. at harvest and only 1.0 lbs. and 0.2 lbs. after air and CA storage respectively. Flesh firmness values following storage were essentially the same within locations for all harvests.

Soluble solids values of fruits from the ten locations are given in Table 17. A gradual increase was observed over the three week harvest period. In general, the differences observed at harvest were retained during air storage or CA storage. The slight increase observed during storage for the fruits from the early harvest over that observed at harvest may be the result of hydrolysis of starch to sugar.

Ratings for appearance and eating quality following storage of the fruits from the ten locations under natural environments are summarized in Tables 18 and 19. Both appearance and eating quality were found to increase with the maturity at harvest. In general, the sixth and seventh harvests were judged as the most desirable in appearance and eating quality and generally coincided with the harvest judged to be closest to the preclimacteric minimum as shown in Table 20.

Scald was not evident on any of the fruits upon removal from air or CA storage, but developed quite extensively during one week at 70°F. The results of the scald evaluation are summarized in Table 21. No relationship was apparent between harvest maturity and scald development following air storage or CA storage. Scald was generally more severe following the eight months in CA as opposed to the five months in air storage.

TABLE 17. Harvest and post-storage evaluation of soluble solids (%) of McIntosh fruits from seven harvests at ten locations in 1962. The fruits were stored in air for five months or CA storage for eight months.

Harvest	Location										Average
	A	B	C	D	E	F	G	H	I	J	
Harvest											
1	11.0	11.4	11.4	11.4	10.6	11.5	-	-	11.0	11.7	11.2
2	10.7	11.3	11.1	11.7	10.5	11.9	-	-	10.9	11.9	11.2
3	11.1	11.9	11.6	11.8	11.1	12.3	-	-	10.6	12.5	11.6
4	12.0	11.5	12.2	12.1	11.0	12.0	12.4	11.3	10.[illegible]	12.3	11.8
5	11.4	11.9	11.8	11.6	11.0	12.1	12.4	11.2	10.8	12.5	11.7
6	11.7	12.2	11.6	11.8	11.0	12.4	12.8	11.7	11.0	12.6	11.9
7	12.5	12.4	12.5	12.6	11.8	12.7	12.8	11.5	11.5	13.0	12.3
Air Storage											
1	11.2	11.2	11.5	12.1	10.6	11.9	-	-	10.1	12.2	11.4
2	11.6	11.9	11.7	12.1	10.5	12.0	-	-	10.1	12.2	11.5
3	11.8	11.5	11.7	12.1	10.9	12.1	-	-	10.9	12.4	11.7
4	11.9	11.7	11.8	12.1	11.1	12.4	11.1	12.6	10.7	12.4	11.8
5	12.0	11.6	11.7	11.5	11.3	12.1	11.1	12.5	10.9	12.2	11.7
6	12.5	11.9	11.6	12.2	11.1	12.1	11.5	12.6	10.6	12.5	11.9
7	12.3	11.7	11.6	12.2	10.6	12.1	11.5	13.0	11.0	12.5	11.9
CA Storage											
1	11.9	11.4	11.6	12.1	10.2	11.1	-	-	10.1	12.0	11.3
2	11.1	11.4	11.9	12.2	10.6	12.0	-	-	10.1	12.0	11.4
3	11.6	11.4	11.8	12.0	10.7	12.2	-	-	11.1	12.0	11.6
4	12.0	11.8	11.9	12.5	10.6	12.1	11.5	11.2	10.6	12.2	11.6
5	11.6	11.9	11.7	11.7	10.8	12.1	12.5	11.4	10.2	12.0	11.6
6	11.9	11.8	11.8	12.0	11.3	12.0	12.9	11.8	10.4	12.3	11.8
7	12.6	11.8	12.0	13.0	11.1	12.4	13.0	11.0	11.5	12.5	12.1

TABLE 18. Appearance rating of post storage McIntosh fruits from seven harvests at ten locations in 1962. The fruits were stored in air for five months or CA storage for eight months.

Harvest	Location A	B	C	D	E	F	G	J	O	K	Rank
	Air storage										
1	5	3	4	4	4	4	-	-	6	3	5
2	5	3	4	4	4	4	-	-	6	3	5
3	4	3	4	3	4	3	-	-	4	3	4
4	2	2	1	3	-	3	1	4	5	2	3
5	2	1	3	3	2	2	4	3	2	2	2
6	3	2	3	2	3	3	3	1	3	1	2
7	1	2	2	1	1	1	2	2	1	2	1
	CA storage										
1	5 (5)[a/]	3	5	5	3	5	-	-	5 (3)[a/]	3	6 (4)[a/]
2	4 (6)	3	4	5	3	5	-	-	5 (3)	3	5 (6)
3	5 (6)	3	5	4	3	3	-	-	2 (2)	3	4 (5)
4	3 (4)	1	3	2	2	4	3	3	4 (3)	2	3 (4)
5	[illegible]	2	3	[illegible]	[illegible]	2	4	4	[illegible]	2	3 (3)
6	2 (3)	2	2	2	2	2	1	2	1 (2)	1	2 (2)
7	1 (1)	2	1	1	[illegible]	1	2	1	3 (1)	2	1 (1)

a/ 32°F CA-storage.

Smaller numbers indicate higher rating.

TABLE 19. Eating quality rating of post-storage McIntosh fruits from seven harvests at ten locations in 1962. The fruits were stored in air for five months or CA-storage for eight months.

Harvest	Location A	B	C	D	E	F	G	H	I	J	Rank
	Air storage										
1	5	3	4	5	4	5	-	-	4	5	5
2	5	3	4	5	4	5	-	-	5	5	5
3	4	3	4	5	4	5	-	-	5	5	5
4	3	2	3	4	-	3	1	2	4	4	4
5	3	1	3	4	1	4	3	4	2	3	3
6	2	2	1	2	3	2	2	3	2	1	2
7	1	2	2	3	2	1	1	1	1	2	1
	CA storage										
1	5 (4)[a]	5	4	5	4	4	-	-	4 (5)[a]	5	6 (4)[a]
2	4 (5)	4	4	5	4	5	-	-	5 (4)	4	5 (4)
3	2 (4)	3	4	4	4	3	-	-	2 (2)	3	4 (3)
4	5 (1)	2	3	2	3	2	2	4	5 (5)	5	4 (3)
5	[illegible]	4	3	2	[illegible]	1	2	[illegible]	[illegible]	3	3 (2)
6	1 (1)	1	2	1	2	3	1	1	1 (2)	2	1 (1)
7	3 (2)	1	1	3	1	2	1	3	2 (1)	1	2 (1)

[a] 32 F CA-storage.

Smaller numbers indicate higher rating.

TABLE 20. Summation of maturity characteristics for McIntosh from ten locations in 1962.

Location	Full Bloom	Starch Accumulation	Climacteric	FB to Starch	Starch to Clim.	FB to Clim.	Best Storage Harvest		Starch to Best Storage Harvest		FB to Best Storage Harvest	
							Air	CA	Air	CA	Air	CA
	(date)	(date)	(date)	(days)	(days)	(days)	(date)		(days)		(days)	
A	5/4	6/4	9/12	31	100	131	9/11	9/10	99	98	130	129
B	5/11	6/16	9/15	36	91	127	9/12	9/15	88	91	124	127
C	5/14	6/15	9/15	32	92	124	9/10	9/12	87	89	119	121
D	5/13	6/15	9/22	33	99	132	9/13	9/14	90	91	123	124
E	5/14	6/11	9/13	28	94	122	9/16	9/14	97	95	125	123
F	5/13	6/13	9/22	31	101	132	9/13	9/13	92	92	123	123
G	5/16	6/14	9/14	29	92	121	9/18	9/17	96	95	125	124
H	5/16	6/14	9/20	29	98	127	9/18	9/17	96	95	125	124
I	5/15	6/23	9/14	39	83	122	9/17	9/15	86	84	125	123
J	5/11	6/11	9/15	31	96	127	9/13	9/15	94	96	125	127

TABLE 21. Post-storage evaluation of scald (%) on McIntosh fruits from seven harvests at ten locations in 1962. The fruits were stored in air for five months or CA-storage for eight months.

Harvest	Location A	B	C	D	E	F	G	H	I	J	Average
Air Storage											
1	47	50	83	55	11	62	-	-	22	38	46
2	19	60	65	44	2	79	-	-	-	45	39
3	30	77	84	63	24	88	-	-	16	60	55
4	34	88	78	67		98	27	10	18	38	51
5	48	37	77	57	14	91	7	18	6	36	39
6	7	76	74	66	69	82	9	4	10	20	42
7	21	77	82	55	39	90	15	9	6	10	40
CA Storage											
1	35 (40)[a/]	77	100	76	33	66	-	-	70 (17)[a/]	89	68
2	42 (18)	53	99	27	60	21	-	-	84 (13)	90	60
3	23 (9)	66	93	76	43	59	-	-	40 (23)	96	62
4	68 (12)	44	95	70	43	66	51	30	32 (30)	88	59
5	35 (45)	83	93	48	49	79	50	77	42 (11)	83	64
6	38 (16)	54	96	54	56	63	58	22	20 (4)	86	55
7	52 (20)	66	84	73	44	66	26	18	59 (2)	65	55

a/ 32°F CA-storage.

The results of the evaluation for core browning are given in Table 22. No relationship was apparent between harvest maturity and core browning. Considerable variation was observed between the different locations. Core browning was reduced markedly by storing fruits in CA storage.

Flesh browning occurred to a marked extent in late harvested fruits from only three of the ten locations and then only in fruits from air storage as seen in Table 23.

IV. EM Rootstock Study, 1962.

A. The environment

McIntosh grown on seven EM rootstock trees were selected to evaluate the influence of the East Malling rootstocks on McIntosh fruitsc maturity and quality. Full bloom date was the same for all rootstocks as shown in Table 24. All the rootstocks were located at the same location and received the same environments. The heat units (base 40 F) accumulated at this location during the 30 days and 40 days following full bloom were 832 and 1096 respectively.

The nutritional conditions of the trees of all rootstocks were adequate as shown in Tables 3 and 6 (see Appendix). Nitrogen and potassium levels were in the normal range (Kenworthy, 1961).

B. Starch accumulation

The elapsed intervals between full bloom and starch accumulation for the various EM rootstocks under the same environments are given in Table 24. The interval was 31 days for all rootstocks.

TABLE 22. Post-storage evaluation of core browning (%) of McIntosh fruits from seven harvests at ten locations in 1962. The fruits were stored in air for five months or CA storage for eight months.

Harvest	Location A	B	C	D	E	F	G	H	I	J	Average
Air Storage											
1	50	82	0	38	98	10	-	-	86	64	54
2	72	56	14	42	74	0	-	-	82	64	50
3	50	42	26	16	76	0	-	-	86	50	43
4	22	28	16	10	-	10	6	66	78	40	31
5	20	36	22	18	60	0	26	94	66	54	40
6	6	34	0	30	78	8	17	54	92	42	36
7	32	26	18	14	64	10	16	62	96	56	39
CA Storage											
1	10 (14)[a]	0	0	0	0	0	-	-	4 (8)[a]	9	3
2	0 (42)	0	0	2	4	0	-	-	4 (6)	2	2
3	2 (18)	0	0	6	2	2	-	-	6 (0)	14	4
4	8 (4)	0	0	2	0	0	10	4	20 (12)	10	5
5	10 (2)	0	2	12	0	0	8	0	2 (16)	6	4
6	2 (2)	0	0	2	2	0	6	4	2 (20)	4	2
7	2 (4)	0	4	10	4	0	12	14	18 (10)	24	9

a/ 32°F CA-storage.

TABLE 23. Post-storage evaluation of flesh browning (%) of McIntosh fruits from seven harvests at ten locations in 1962. The fruits were stored in air for five months or CA-storage for eight months.

Harvest	Location A	B	C	D	E	F	G	H	I	J	Average
	Air Storage										
1	0	4	0	0	0	0	-	-	0	0	0
2	0	0	0	0	0	0	-	-	0	0	0
3	0	0	0	0	0	0	-	-	0	4	0
4	0	0	0	0	-	0	0	0	2	12	1
5	0	4	0	0	2	0	0	2	0	4	1
6	0	2	4	0	8	0	0	0	0	6	2
7	12	0	2	4	16	0	0	2	6	20	6
	CA Storage										
1	0 (2)[a]	0	0	0	0	0	-	-	0 (0)[a]	0	0
2	0 (0)	0	0	0	0	0	-	-	0 (0)	2	0
3	0 (2)	0	0	0	0	0	-	-	0 (0)	0	0
4	4 (0)	0	0	0	0	0	0	0	0 (0)	2	1
5	0 (0)	0	2	0	0	0	0	0	0 (2)	0	0
6	0 (0)	0	0	0	2	0	0	0	0 (2)	2	0
7	5 (0)	4	0	0	0	0	0	0	0 (2)	2	1

a/ 32°F CA-storage.

TABLE 24. Summation of maturity characteristics for McIntosh grown on East Malling rootstocks in 1962.

Characteristic		Rootstock I	II	IV	V	VII	XII	XIII
Full bloom	(date)	5/11	5/11	5/11	5/11	5/11	5/11	5/11
Starch accumulation	(date)	6/11	6/11	6/11	6/11	6/11	6/11	6/11
Climacteric rise	(date)	9/15	9/15	9/12	9/15	9/15	9/0	9/12
Best harvest	(date)							
Air storage		9/12	9/14	9/13	9/13	9/13	9/13	9/15
CA storage		9/13	9/15	9/13	9/13	9/15	9/13	9/13
FB to starch	(days)	31	31	31	31	31	31	31
FB to climacteric	(days)	127	127	124	127	127	121	124
FB to best harvest	(days)							
Air storage		124	126	125	125	125	125	127
CA storage		125	127	125	125	127	125	125
Starch to climacteric	(days)	96	96	93	96	96	90	93
Starch to best harvest	(days)							
Air storage		93	95	94	94	94	94	96
CA storage		94	96	94	94	96	94	94

C. Fruit maturity

1. Physical characteristics

The physical characteristics of the McIntosh fruits from the seven EM rootstocks varied considerably when compared at the same physiological age as seen in Table 25. The values presented represent the characteristics of the fruit at the harvest judged to be closest to the onset of the respiratory climacteric. The amount of red coloration on fruits varied from 37% to 70%. Ground color rating varied from 4.4 to 5.0. Flesh firmness varied from 15.3 lbs. to 17.4 lbs. while soluble solids varied from 12.3% to 13.4%. Intermediate values for these physical characteristics were quite evenly distributed within the ranges given.

The change in red coloration, ground color, flesh firmness and soluble solids for approximately a three week harvesting period for EM rootstocks is shown in Figure 13. No sharp change was evident for these characteristics over this period. Although the onset of the respiratory climacteric for six out of seven rootstocks occurred during the September 12 to 15 period. When the individual EM rootstocks were plotted in a similar manner, no abrupt change was observed in these physical characteristics. The values for red coloration for all roostocks are shown in Table 26.

2. Respiratory climacteric

The respiratory metabolism of McIntosh fruits from seven EM rootstocks over a three week period is shown in Figure 14. The climacteric rise in respiration rate

TABLE 25. Physical characteristics of McIntosh fruits grown on seven East Malling rootstocks at the onset of the respiratory climacteric.

Physical Characteristics	Rootstock						
	I	II	IV	V	VII	XII	XIII
Red coloration (%)	57	65	70	60	65	37	52
Ground color (rating)	4.8	4.6	4.7	4.4	5.0	5.0	5.0
Flesh firmness (lbs.)	15.7	16.0	16.3	15.3	15.6	17.4	16.5
Soluble solids (%)	12.8	12.9	12.4	12.3	12.8	13.4	12.4

Each value represents the mean of 25 fruits.

Figure 13

Change in red coloration, ground color, flesh firmness and soluble solids of McIntosh fruits over a sequence of seven harvests from seven EM rootstocks in 1962. (Each value represents the mean for all rootstocks at each harvest date.)

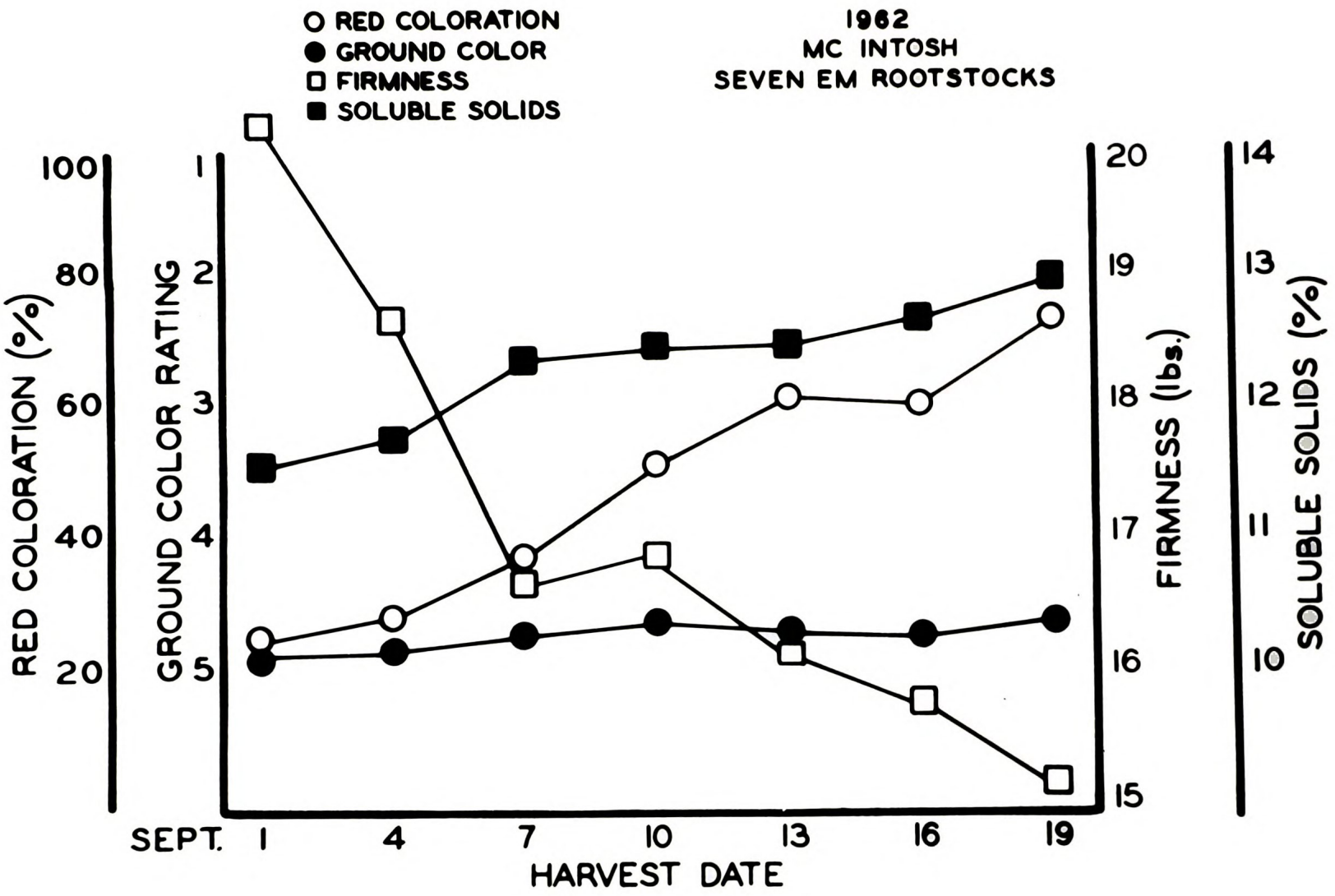

O RED COLORATION
● GROUND COLOR
□ FIRMNESS
■ SOLUBLE SOLIDS
1962
MC INTOSH
SEVEN EM ROOTSTOCKS
RED COLORATION (%)
100
80
60
40
20
GROUND COLOR RATING
1
2
3
4
5
FIRMNESS (lbs.)
20
19
18
17
16
15
SOLUBLE SOLIDS (%)
14
13
12
11
10
SEPT. 1
4
7
10
13
16
19
HARVEST DATE

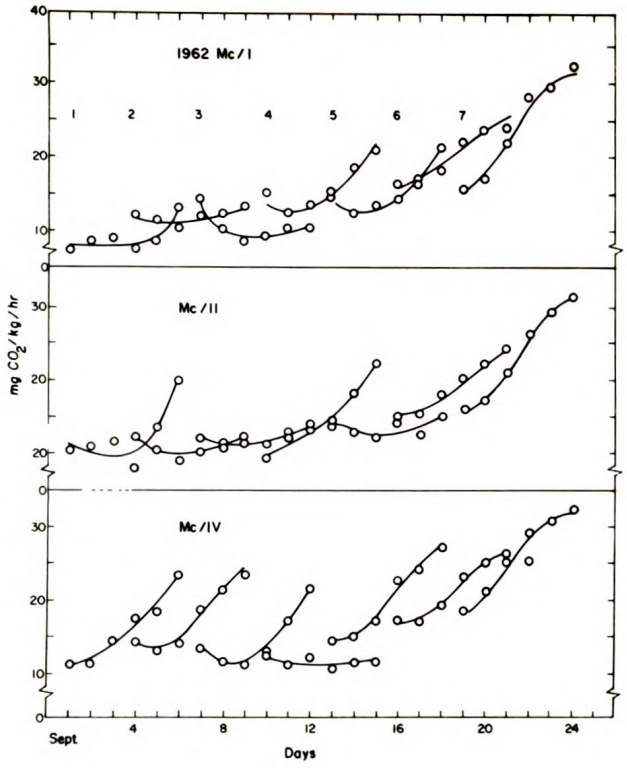
TABLE 26. Evaluation of red coloration (%) of McIntosh fruits from seven harvests from trees on seven EM rootstocks in 1962. The fruits were stored in air for five months or CA storage for eight months.[a/]

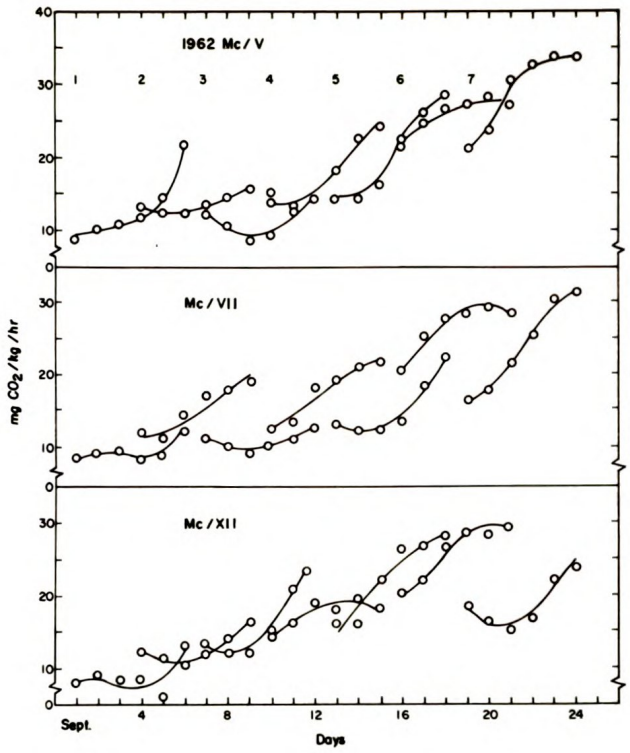
Harvest	Rootstock							Average
	EM I	EM II	EM IV	EM V	EM VII	EM VII	EM XIII	
1	30	23	33	[illegible]	[illegible]	23	[illegible]	25
2	48	32	25	27	[illegible]	20	27	29
3	48	42	33	40	35	25	40	38
4	[illegible]	60	53	60	55	37	37	52
5	62	63	70	65	63	57	52	62
6	57	65	75	60	65	62	47	61
7	[illegible]	73	68	77	77	72	68	74

a/ Mean values of three independent determinations.

Figure 14

Respiratory behavior of McIntosh apples grown on seven EM rootstocks in 1962. Fruits were taken from seven harvests at 3 day intervals.


1962 Mc / I
Mc / II
Mc / IV
mg CO_2/kg/hr
1 2 3 4 5 6 7
Sept.
Days


1962 Mc / V
Mc / VII
Mc / XII
mg CO_2/kg/hr
1 2 3 4 5 6 7
Sept.
Days

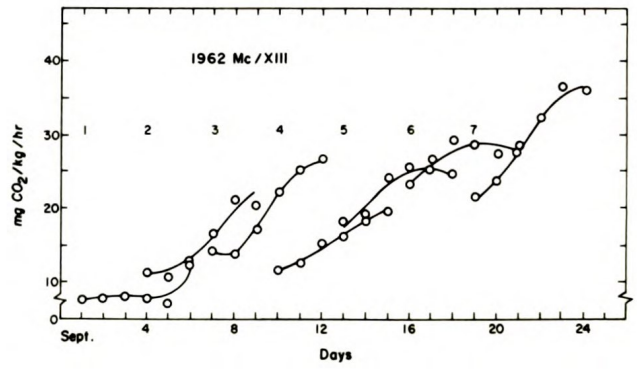
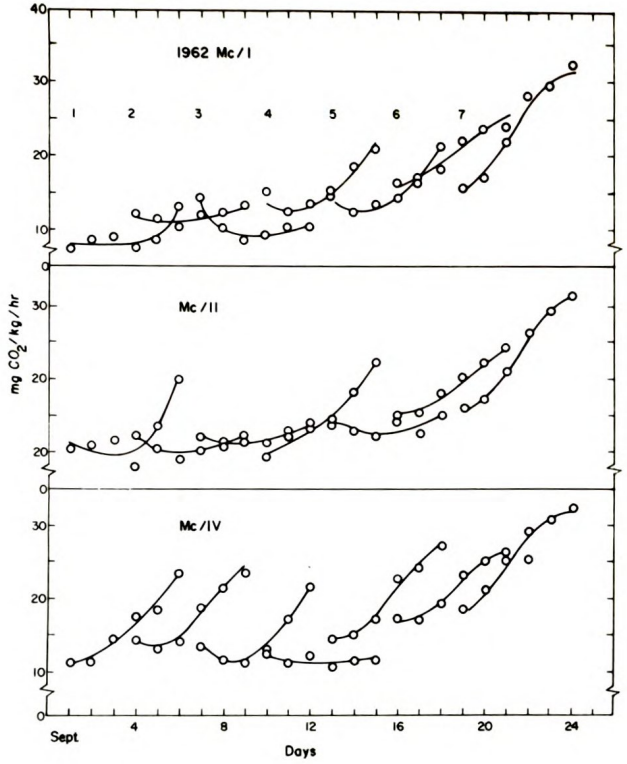
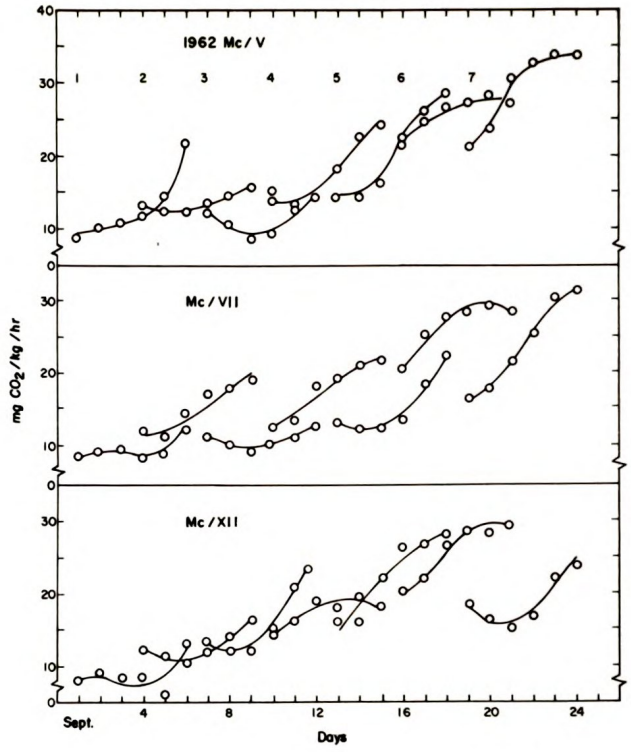
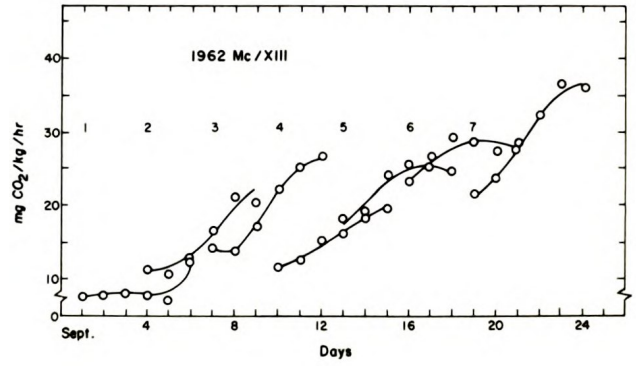

1962 Mc / XIII
mg CO_2/kg/hr
1 2 3 4 5 6 7
Sept.
Days

Figure 14

Respiratory behavior of McIntosh apples grown on seven EM rootstocks in 1962. Fruits were taken from seven harvests at 3 day intervals.


1962 Mc/I
1 2 3 4 5 6 7
Mc/II
Mc/IV
mg CO_2/kg/hr
Sept.
Days


1962 Mc/V
1 2 3 4 5 6 7
Mc/VII
Mc/XII
mg CO_2/kg/hr
Sept.
Days


1962 Mc/XIII
1 2 3 4 5 6 7
mg CO_2/kg/hr
Sept.
Days

commenced September 15 for EM I, II, V and VII. McIntosh from trees on EM rootstocks IV, XII and XIII showed a slightly earlier onset of the respiratory climacteric. The reason for this earlier climacteric in these three rootstocks is not known. These rootstocks did not have a different elapsed period from full bloom to starch accumulation in comparison to the other rootstocks. With the exception of rootstock EM XII, all rootstocks commenced a climacteric rise within three calendar days of one another.

3. Storage quality

Fruits from each of seven harvests from trees on seven EM rootstocks grown in one location under the same environments were evaluated following air storage for five months, or CA storage for eight months. The values obtained for ground color are given in Table 27. Ground color values at harvest are also included. Little difference was observed in ground color values at harvest over the course of a three week period within or between rootstocks. The average change for all rootstocks was only 0.2 units over the harvesting period. During air storage, fruits from later harvests from most rootstocks registered a considerable change in ground color from that observed at harvest. The ground color of very immature fruits remained essentially the same during the storage period. The ground color change in storage generally increased with maturity of the fruit at harvest. This is readily apparent from the average values for all rootstocks. The same general results were obtained

TABLE 27. Harvest and post-storage evaluation of ground color rating of McIntosh fruits from seven harvests from trees on seven EM rootstocks in 1962. The fruits were stored in air for five months or CA storage for eight months.

Harvest	Rootstock							Average
	EM I	EM II	EM IV	EM V	EM VII	EM XII	EM XIII	
Harvest								
1	4.8	4.7	4.8	4.8	4.7	5.0	4.9	4.8
2	4.9	4.7	4.9	4.7	4.8	5.0	4.9	4.8
3	4.9	4.6	4.1	4.8	4.6	5.0	5.0	4.7
4	4.6	4.3	4.2	4.6	4.8	5.0	5.0	4.6
5	4.5	4.7	4.7	4.3	4.9	5.0	5.0	4.7
6	4.8	4.6	4.4	4.4	5.0	5.0	5.0	4.7
7	4.8	4.4	3.9	4.6	4.9	4.7	5.0	4.6
Air storage								
1	5.0	4.4	4.5	4.6	4.9	5.0	5.0	4.8
2	4.9	4.7	4.1	4.4	4.9	4.9	5.0	4.7
3	4.7	4.2	3.8	4.3	4.8	5.0	5.0	4.5
4	4.7	4.0	4.0	4.0	4.8	5.0	5.0	4.5
5	4.0	3.6	3.1	3.9	4.5	4.8	4.8	4.2
6	4.4	4.0	3.8	3.6	4.7	4.8	4.6	4.1
7	3.8	3.6	3.4	3.2	3.6	4.3	4.2	3.3
CA storage								
1	4.7	4.3	4.3	4.5	4.2	4.2	4.9	4.4
2	4.8	4.3	4.3	4.4	4.5	4.3	4.9	4.5
3	4.4	3.7	4.2	4.3	4.3	4.4	4.9	4.3
4	5.0	3.5	3.6	3.8	4.6	3.9	4.3	4.1
5	4.4	3.9	4.6	4.0	4.0	3.9	4.6	4.0
6	4.2	3.5	3.4	3.3	3.8	3.9	4.2	3.7
7	4.3	3.4	3.5	4.0	3.5	3.3	3.9	3.6

A decrease in ground color score indicates an increase in the yellow ground color.

for fruits following CA storage. The ground color change from that at harvest was greater after CA storage for eight months than after air storage for five months.

Flesh firmness values of fruits from the seven EM rootstocks are given in Table 28. Marked differences were observed at harvest within, but not between, rootstocks over the three week harvesting period. These differences were not readily apparent upon removal from air or CA storage. The average difference in firmness of fruits from all rootstocks between the first and the seventh harvest was 5.0 lbs. at harvest and only 0.9 lbs. and 0.6 lbs. after air and CA storage respectively. Flesh firmness values following storage were essentially the same within rootstocks for all harvests.

Soluble solids values of fruits from the EM rootstocks are given in Table 29. A gradual increase was observed over the three week harvesting period. In general, the differences observed at harvest were retained during air storage or CA storage.

Ratings for appearance and eating quality following storage of the fruits from the seven EM rootstocks are summarized in Tables 30 and 31. Both appearance and eating quality were found to increase with the maturity at harvest. In general, the fifth and sixth harvests were judged the most desirable in appearance and eating quality and generally coincided with the harvest judged to be the closest to the preclimacteric minimum as was shown in Table 23.

TABLE 28. Harvest and post-storage evaluation of flesh firmness (lbs.) of McIntosh fruits from seven harvests from trees on seven EM rootstocks in 1962. The fruits were stored in air for five months or CA storage for eight months.

Harvest	Rootstock							
	EM I	EM II	EM IV	EM V	EM VII	EM XII	EM XIII	Average
Harvest								
1	20.9	19.4	19.9	20.3	17.5	21.8	20.8	20.2
2	18.3	18.5	18.6	18.5	17.7	18.2	18.5	18.7
3	17.1	15.5	15.9	16.5	16.5	18.2	17.0	16.7
4	16.4	16.2	17.3	16.7	16.8	17.4	17.4	16.9
5	15.7	15.8	16.3	16.0	17.1	16..	16.5	16.3
6	15.7	16.0	15.4	15.3	15.6	16.4	16.4	15.8
7	15.0	14.7	15.2	15.2	14.7	15.7	16.1	15.2
Air storage								
1	12.0	12.6	13.1	11.9	12.4	13.1	12.3	12.3
2	12.3	12.2	11.9	12.1	12.2	12.4	12.7	12.2
3	12.3	12.2	11.9	11.6	12.3	12.8	12.2	12.2
4	11.6	11.7	11.8	11.6	12.0	12.7	12.2	11.9
5	11.2	11.2	11.4	11.6	11.1	11.9	12.0	11.5
6	12.0	11.1	11.5	11.4	11.0	11.1	11.6	11.2
7	10.8	11.3	11.7	10.8	11.5	11.9	12.1	11.4
CA storage								
1	12.1	12.2	11.2	10.9	11.8	12.1	12.8	11.8
2	12.0	11.8	12.0	12.0	11.6	12.0	11.9	11.5
3	11.9	11.6	11.3	11.3	12.0	12.1	11.9	11.7
4	12.0	11.3	11.5	11.3	10.9	12.1	11.8	11.6
5	11.2	11.1	10.8	10.6	11.8	12.2	12.4	11.4
6	11.1	11.8	11.1	11.1	10.7	11.9	11.5	11.3
7	11.1	10.8	10.6	10.6	10.9	12.4	12.0	11.2

TABLE 28. Harvest and post-storage evaluation of flesh firmness (lbs.) of McIntosh fruits from seven harvests from trees on seven EM rootstocks in 1962. The fruits were stored in air for five months or CA storage for eight months.

Harvest	Rootstock							
	EM I	EM II	EM IV	EM V	EM VII	EM XII	EM XIII	Average
Harvest								
1	20.9	19.4	19.9	20.3	17.5	21.8	20.8	20.2
2	18.3	18.5	18.6	18.5	17.7	18.2	18.5	18.7
3	17.1	15.5	15.9	16.5	16.5	18.2	17.0	16.7
4	16.4	16.2	17.3	16.7	16.8	17.1	17.4	16.9
5	15.7	15.8	16.3	16.0	17.1	16.1	16.5	16.2
6	15.7	16.0	15.4	15.3	15.6	16.4	16.4	15.8
7	15.0	14.7	15.2	15.2	14.7	15.7	16.1	15.2
Air storage								
1	12.9	12.6	13.1	11.9	13.4	13.1	12.2	12.3
2	12.3	12.2	11.9	12.1	12.2	12.4	12.7	13.2
3	12.3	12.2	11.9	11.6	12.3	12.8	12.2	12.2
4	11.6	11.7	11.8	11.5	12.0	12.7	12.2	11.9
5	11.3	11.2	11.1	11.6	11.1	11.4	12.0	11.5
6	12.0	11.1	11.5	11.3	11.0	11.1	11.6	11.2
7	10.8	11.3	11.7	10.8	11.5	11.9	12.1	11.4
CA storage								
1	12.1	12.4	11.2	10.9	11.8	12.1	12.8	11.8
2	12.0	11.8	10.6	10.9	11.6	12.0	11.9	11.5
3	11.9	11.6	11.3	11.3	12.0	12.1	11.9	11.7
4	12.1	11.3	11.5	11.3	10.9	12.1	11.8	11.6
5	11.2	11.1	10.8	10.6	11.8	12.2	12.4	11.4
6	11.1	11.8	11.1	11.1	10.7	11.9	11.5	11.3
7	11.1	10.8	10.6	10.6	10.9	12.4	12.0	11.2

TABLE 29. Harvest and post-storage evaluation of soluble solids (%) of McIntosh fruits from seven harvests from trees on seven EM rootstocks in 1962. The fruits were stored in air for five months or CA storage for eight months.

Harvest	Rootstock							Average
	EM I	EM II	EM IV	EM V	EM VII	EM XII	EM XIII	
Harvest								
1	11.5	11.4	11.3	11.5	11.6	12.0	11.6	11.6
2	12.4	11.7	11.4	11.5	11.7	11.9	11.9	11.8
3	12.7	12.1	12.0	12.4	12.4	13.3	12.0	12.4
4	12.8	12.1	12.4	12.0	12.5	13.4	12.3	12.5
5	12.5	12.6	12.4	12.0	12.5	12.9	12.4	12.5
6	12.8	12.9	12.6	12.3	12.8	13.4	12.0	12.7
7	13.4	13.0	12.7	12.8	13.0	13.8	12.4	13.0
Air storage								
1	12.3	12.5	11.8	11.6	12.0	12.8	11.6	12.1
2	12.4	12.3	12.0	12.1	12.0	12.2	11.6	12.1
3	12.6	12.6	11.9	12.1	12.2	12.9	11.7	12.3
4	12.8	12.6	13.0	11.6	12.9	13.1	12.0	12.6
5	13.0	13.3	12.6	12.7	12.6	13.0	12.6	12.8
6	12.9	12.8	12.7	12.6	12.1	12.9	11.9	12.6
7	13.7	13.6	13.2	12.7	13.5	13.4	12.5	13.2
CA storage								
1	12.0	12.2	11.7	11.9	11.9	12.0	12.1	12.0
2	12.4	12.5	11.5	12.1	11.5	11.9	11.0	11.8
3	12.4	12.1	11.9	11.9	11.9	12.6	11.8	12.1
4	12.6	12.2	12.5	12.1	12.4	13.0	12.0	12.4
5	12.6	12.5	12.0	12.1	12.2	12.9	12.5	12.4
6	12.5	12.8	12.5	12.1	12.0	12.9	11.0	12.2
7	13.1	12.8	12.5	12.5	12.8	12.8	11.9	12.6

TABLE 30. Appearance rating of post-storage McIntosh fruits from seven harvests from trees on seven EM rootstocks in 1962. The fruits were stored in air for five months or CA-storage for eight months.

Harvest	Rootstock							Rank
	EM I	EM II	EM IV	EM V	EM VII	EM XII	EM XIII	
	Air storage							
1	4	5	3	5	3	3	6	6
2	1	5	3	3	3	3	6	5
3	3	3	3	4	3	3	2	4
4	4	4	2	5	2	2	5	4
5	1	2	1	1	1	1	3	1
6	2	2	2	2	2	2	4	3
7	1	1	2	3	2	2	1	2
	CA storage							
1	4	5	4	4	4	5	5	6
2	4	4	4	4	6	6	5	7
3	3	3	2	3	5	6	4	5
4	3	3	1	3	5	4	2	4
5	3	4	3	2	1	2	1	3
6	2	1	1	1	2	3	3	2
7	1	2	1	3	3	1	1	1

Smaller numbers indicate higher rating.

TABLE 31. Eating quality rating of post-storage McIntosh fruits from seven harvests from trees on seven EM rootstocks in 1962. The fruits were stored in air for five months or CA-storage for eight months.

Harvest	Rootstock							Rank
	EM I	EM II	EM IV	EM V	EM VII	EM XII	EM XIII	
	Air storage							
1	4	5	3	5	3	3	6	6
2	2	5	3	3	3	3	6	5
3	3	3	3	4	3	3	2	4
4	2	4	2	5	2	2	5	4
5	2	2	1	1	1	1	3	1
6	1	2	2	2	2	2	4	3
7	2	1	2	3	2	2	1	2
	CA storage							
1	6	5	4	4	4	5	5	6
2	6	4	4	4	6	6	5	7
3	4	3	2	3	5	6	4	5
4	2	3	1	3	5	4	2	4
5	3	4	3	2	1	2	1	3
6	5	1	1	1	2	3	3	2
7	1	2	1	3	3	1	1	1

Smaller numbers indicate higher rating.

Scald was not evident on any of the fruits upon removal from air of CA storage but developed quite extensively during one week at 70 F. The results of the scald evaluation are summarized in Table 32. Scald was generally more severe on fruits from the early harvests placed in air storage but not for fruits placed in CA storage. Scald was generally more severe following the eight months in CA storage as opposed to the five months in air storage.

The results of the evaluation for core browning are given in Table 33. No relationship was apparent between harvest maturity and core browning. Core browning was reduced markedly by storing the fruits in CA storage.

Flesh browning occurred to a marked extent in late harvested fruits from all rootstocks in air storage, as shown in Table 34. Flesh browning was reduced by storing the fruits in CA storage.

V. Predicting McIntosh Maturity

The elapsed interval from full bloom to the preclimacteric minimum was found to vary from 121 days to 132 days among the ten locations investigated in 1962 (Table 20). High heat unit accumulation, high night temperatures, and high day temperatures during the first ten days following bloom tended to shorten the interval from full bloom to maturity. High day temperature during the 21-30 day interval also tended to hasten maturity. High heat unit accumulation during the 11-20 day period significantly delayed maturity.

TABLE 32. Post storage evaluation of scald (%) on McIntosh fruits from seven harvests from trees on seven EM rootstocks in 1962. The fruits were stored in air for five months or CA-storage for eight months.

Harvest	Rootstock							Average
	EM I	EM II	EM IV	EM V	EM VII	EM XII	EM XIII	
	Air storage							
1	38	20	42	29	60	55	64	44
2	38	22	9	38	35	23	51	31
3	35	22	4	33	54	55	45	36
4	34	5	6	16	17	19	7	14
5	3	28	11	8	43	21	13	18
6	3	3	0	6	4	0	0	1
7	0	0	2	5	0	0	0	1
	CA storage							
1	88	92	80	62	79	43	90	76
2	80	54	65	44	85	42	94	66
3	82	74	82	29	82	65	91	69
4	74	51	83	42	87	31	64	62
5	92	58	65	18	80	18	60	57
6	40	41	68	42	56	46	21	46
7	58	8	54	33	82	31	72	48

TABLE 33. Post-storage evaluation of core browning (%) of McIntosh fruits from seven harvests from trees on seven EM rootstocks in 1962. The fruits were stored in air for five months or CA storage for eight months.

Harvest	Rootstock							
	EM I	EMII	EM IV	EM V	EM VII	EM XII	EM XIII	Average
	Air storage							
1	54	30	42	40	50	36	64	45
2	0	8	51	58	52	70	77	45
3	22	43	31	58	50	52	79	48
4	38	62	10	62	53	43	74	49
5	46	25	36	76	36	55	72	49
6	52	38	30	51	56	35	71	48
7	42	50	62	89	72	58	60	62
	CA storage							
1	8	4	24	6	10	20	4	11
2	0	0	12	11	2	20	6	7
3	2	6	2	4	0	12	4	4
4	6	10	0	6	0	6	2	4
5	0	8	16	6	6	4	0	6
6	0	0	0	2	6	0	10	3
7	14	0	2	50	18	16	32	19

TABLE 34. Post-storage evaluation of flesh browning (%) of McIntosh fruits from seven harvests from trees on seven EM rootstocks in 1962. The fruits were stored in air for five months or CA storage for eight months.

Harvest	Rootstock							Average
	EM I	EM II	EM IV	EM V	EM VII	EM XII	EM XIII	
Air storage								
1	0	0	2	2	2	3	0	1
2	8	8	30	0	0	8	2	8
3	4	8	10	4	10	10	10	8
4	0	0	6	12	4	11	18	7
5	0	3	4	16	20	21	30	13
6	12	10	13	13	8	15	23	13
7	10	25	19	11	12	12	12	14
CA storage								
1	0	8	14	4	2	0	0	4
2	0	0	2	22	2	4	0	4
3	2	0	4	0	0	14	6	4
4	0	2	2	0	0	10	2	2
5	0	8	2	4	2	26	22	9
6	0	0	2	7	0	6	0	2
7	0	0	6	42	0	12	4	9

High night temperatures during this period may have been responsible since they tended to delay maturity, while high day temperatures did not. Scatter diagrams of the data provided trends but few significant correlations could be obtained.

The elapsed interval from full bloom to the preclimacteric minimum was found to vary from 115 days to 135 days among three of the ten locations employed in 1962 over the period from 1961 to 1963 as shown in Tables 9 and 10. Scatter diagrams of the data for three years for three locations revealed that high heat unit accumulation for ten and 30 days, high night temperatures for ten and 30 days and high average day temperatures for 20 and 30 days tended to shorten the elapsed period from full bloom to maturity. High night temperatures during the 21-30 day interval significantly delayed maturity. This was observed as a trend in heat unit accumulation during this period probably as a result of the high night temperatures.

The relationship of heat unit accumulation following bloom to the elapsed interval from petal fall to maturity of McIntosh in Maine found by Eggert (1960) was applied to the data from this study. Employing Eggert's 10, 20, 30 and 40-day regression equations revealed that the same relationship did not generally apply to the locations studied in Michigan in 1961, 1962 or 1963. The calculated elapsed intervals for ten locations in 1962 were generally about two weeks earlier than the observed and in no case was a

calculated interval shorter than the observed interval. Eggert's relationship was found to apply quite closely in 1961, 1962 and 1963 for the Mears area which had the latest full bloom. The average full bloom date and the average interval from full bloom to maturity for this location closely approximated the values observed by Eggert in Maine.

A close relationship was observed between the date of full bloom and elapsed interval from full bloom to maturity. A later date of full bloom shortened the elapsed period from full bloom to maturity. Blanpied (1960) observed a similar relationship in New York. Application of Blanpied's relationship (140 - 0.56 X full bloom date in May = elapsed days from full bloom to maturity) to the data from this study revealed a close parallel relationship, but the calculated values were generally one week later than those observed. Employing different constants in the equation could take this difference into account.

Employing calendar date to estimate fruit maturity for a given location between years was not a good approximation. Those locations studied for three years varied from September 15 to 27, September 14 to 25 and September 11 to 25 as shown in Table 10.

DISCUSSION

A 75 F night temperature regime for one month following bloom enhanced fruit, shoot and leaf growth over that observed for trees which received a 65 F night temperature or the ambient night temperature for the same period. Little difference between treatments was observed in fruit size at maturity, which suggests that high post-bloom temperatures do not markedly affect ultimate fruit size. The additional photosynthetic area obtained on trees which received the 75 F night temperature regime was apparently in excess to that required for optimal fruit growth later in the season. The enhancement of fruit growth rate by high post-bloom temperatures observed in this study is in general agreement with results obtained by Tukey (1956).

The elapsed interval from full bloom to the onset of starch accumulation was shortened by one day by high night temperatures in 1961 and by two days in 1962. The onset of starch accumulation was independent of fruit size within or between treatments. Low light intensity, which delayed starch accumulation, was the only environmental factor studied which markedly altered the interval from full bloom to starch accumulation. This delay may be related to a decrease in photosynthetic activity and hence to lower total energy supply to meet the demands of growth and development. The delay of nine days obtained with the low intensity

treatment was partially overcome when supplemented by high night temperatures which slightly advanced starch accumulation under the ambient light intensity.

The onset of starch accumulation closely coincided with the cessation of cell division, shoot elongation and the June drop of fruits for all environmental treatments. The cessation of cell division occurred about one month after full bloom, which is in agreement with the observation of other investigators (Tukey and Young, 1942; Smith, 1950; Bain and Robertson, 1951). The close relationship of starch accumulation to these processes would be expected in view of the reserve nature of starch. Once growth demands have been met by the existing leaf surface, any extra photosynthate could be directed to storage materials. The onset of starch accumulation may thus be looked upon as a compensation point between respiration and photosynthesis of the entire tree. The significance of this transition is not understood. It was postulated that the interval from full bloom to starch might be altered by the environment and thus serve as an integrater for the environment. High night temperatures and low light intensity did alter the interval, but the elapsed intervals bore no relationship to the time required to reach physiological maturity.

High night temperatures shortened the interval from full bloom to the preclimacteric minimum by four to eight days in 1961 and 1962. This is in general agreement with the results of Eggert (1960) who found that the accumulation

of heat units shortly after bloom was inversely related to the elapsed interval from full bloom to maturity.

Greater variability was observed in the elapsed interval from full bloom to starch accumulation among the ten locations under natural environments in 1962 than was observed for three years at East Lansing. No relationship was observed between the post-bloom temperature conditions and the interval from full bloom to starch accumulation in 1962 or 1963. Orchards which bloomed early required as long or longer to reach starch accumulation than orchards which bloomed late and vice versa.

No relationship was apparent between the length of the elapsed interval from full bloom to starch accumulation and the length of time required for the fruit to reach maturity. These results agree in this respect with the modified environment study.

The elapsed interval from full bloom to starch accumulation bore no relationship to the time required for 11 different varieties of apples to reach maturity in either 1962 or 1963. Starch accumulation was observed for all varieties within three days of each other for 1962 and 1963.

The wide range observed in the interval from full bloom to starch accumulation for the ten locations under natural environments is not understood. Individual interpretation of when starch is evident in developing fruits could be a possible explanation. However, the rapid transition from a negative to a positive test with the I_2-KI

reagent observed at East Lansing in 1961, 1962 and 1963 as well as the ability of the test to distinguish hourly and diurnal changes in starch content during the initial stage tends to repudiate this explanation.

The significance of the variance in days required for the fruit to reach starch accumulation in different seasons and orchards in terms of fruit growth and development is not understood. Some other factor in the environment which was not investigated may be responsible.

No variability was observed between rootstocks with respect to the elapsed interval from full bloom to starch accumulation and only slight differences were noted in the elapsed days from full bloom to maturity.

The date of the preclimacteric minimum and the best harvest date for air and CA storage coincided quite closely for fruits from the ten locations under natural environments and for fruits from the trees on various rootstocks. It is a general practice to harvest McIntosh fruits for air storage at a later stage of maturity than for CA storage, primarily from the standpoint of storage scald. However, the maturity of fruits placed in CA storage was not related to scald severity. Immature fruits placed in air storage scalded more severely than the more mature fruits. This is in general agreement with previous studies (Smock and Neubert, 1950). Core browning was not related to fruit maturity though one would expect more core browning in fruits from the later harvests since it is a senescent disorder.

Flesh firmness differences between fruits from different harvests entering storage was not retained during storage in air or CA in proportion to their initial values. Hard green fruits from the first harvest were of nearly the same firmness value after storage as fruit s harvested about three weeks later. This was true for all orchards and rootstocks under test. Fruits from CA storage were generally less firm than comparable fruits from air storage, probably because of the longer duration of the CA storage period.

Ground color did not change markedly during air or CA storage from the values observed at harvest for the early harvested fruits but changed measurably for fruits from the later harvests. The greater change observed for CA fruits was possibly due to the longer storage period.

Comparison of ground color, red coloration, flesh firmness and soluble solids of fruits over a sequence of seven harvests at three-day intervals for all orchards and rootstocks tested failed to indicate sufficiently marked changes to be of use as a guide to the best harvest date. These results are in general agreement with past experience in the use of these maturity indices.

The elapsed interval from full bloom to maturity was generally shortened in proportion to heat unit accumulation during the first month following bloom. This is in general agreement with the results obtained by Eggert (1960). High night temperatures as well as high day temperatures were effective in obtaining this interval. However, high night

temperatures during the third and fourth weeks following bloom were found to delay maturity significantly. This apparent paradox may be explained in terms of fruit growth and development. High night temperature was found to accelerate fruit, shoot and leaf growth during the first month following bloom. Fruit growth may have taken place at the expense of some phase of fruit development related to maturity during this period. The relationship between cell division and cell enlargement was influenced by night temperatures during this period. High night temperatures shortened the period of cell division and at the same time resulted in greater fruit growth rate suggesting that the two processes may become out of phase with one another.

Comparison of methods for predicting McIntosh fruit maturity applicable in other production areas were not found to be directly suitable for the conditions in Michigan for 1961, 1962 and 1963. The heat unit method used successfully in Maine (Eggert, 1960) applied to only one location in Michigan. The bloom period and post-bloom environment of this location were similar to those for the location in Maine used to develop the relationship. A relationship of heat unit accumulation and eventual maturity of fruit from the other locations must await more information.

Selecting the proper time for harvest by calendar date was found to be unsatisfactory.

The marked inverse relationship found in this study between the date of full bloom and the elapsed interval

from full bloom to maturity is in general agreement with the results obtained by Blanpied (1960) in New York. It varied, however, in that the elapsed interval was shorter in Michigan than in New York. A close relationship between the date of full bloom and the date of eventual fruit maturity was also obtained by Brooks (1945). The environmental factors responsible for the inverse relationship which was found in this study are not clearly understood at the present time. The post-bloom temperatures partially explain the relationship, but other factors such as soil temperature, natural day length, solar radiation as well as others may be involved which affect the total tree physiology and in turn fruit maturity.

SUMMARY

Environmental studies on maturity of McIntosh fruits were undertaken under modified and natural environments. High night temperature, low light intensity and photoperiod were the modified controlled environments, while the natural environments were provided by selecting ten locations distributed in Michigan at different altitudes and distances from Lake Michigan. A study of the influence of seven East Malling rootstocks (I, II, IV, VII, XII, XIII) on maturity was also undertaken.

High night temperatures during the first month following bloom increased the rate of vegetative and fruit growth and hastened maturity. Low light intensity enhanced vegetative growth, suppressed fruit growth and delayed maturity. High night temperatures overcame the suppressing effect of low light intensity on fruit growth. Day lengths three hours shorter or longer than the ambient had no marked effect on fruit growth. Trees which received low light intensities or a short day underwent a secondary flush of terminal growth.

Net accumulation of starch was observed in fruits about one month after full bloom and occurred within two days of the time it was first detected. Temperatures following bloom did not markedly affect the interval from full bloom to starch accumulation; low light intensity

lengthened the interval by about one week. The onset of starch accumulation coincided with the cessation of cell division, cessation of shoot and leaf growth and the June drop of fruits in 1962, while in 1963, shoot and leaf growth continued after starch accumulation commenced. The onset of starch accumulation appears to be the turning point in the growing season when photosynthetic capacity exceeds growth requirements.

No relationships were discernible between the post-bloom environments and the interval from full bloom to starch accumulation. The length of this interval bore no relationship to the length of the interval from full bloom to physiological maturity. The premise that starch accumulation may serve as a phsyiological parameter of the influence of the early growing season environment on fruit maturity was thereby invalidated.

The interval from full bloom to maturity was shortened in proportion to heat unit accumulation during the first two weeks following bloom. High light as well as high day temperatures were effective in advancing maturity. However, high night temperatures during the third and fourth weeks following bloom had a delaying effect on maturity.

Predicting fruit maturity by heat unit summation methods developing in other apple production areas was not satisfactory for environmental conditions experienced in Michigan in 1961, 1962, or 1963.

The interval from full bloom to fruit maturity was

shortened proportionally to delays in the date of full bloom. This may be related to generally warmer post-bloom temperatures which prevail in areas of late bloom.

The rate of change in red coloration, ground color, flesh firmness or soluble solids over a three week harvesting period was of little value in determining the proper harvest date for storage. The values of these characteristics varied considerably for fruits of the same physiological maturity from different locations in a single season.

Fruits from the harvests closest to the preclimacteric respiratory minimum rated highest in quality following five months storage in air or eight months storage in controlled atmospheres. No relationship was observed between maturity at harvest and the incidence of scald on fruits from CA storage or on fruits from various locations after air storage. However, immature fruits from trees grown on a number of East Malling rootstocks at the same location generally scalded more severely after air storage than the more mature fruits. Flesh and core browning were not related to maturity of the fruit at harvest.

All rootstocks exhibited the same full bloom and starch accumulation dates. However, EM IV and XIII reached the preclimacteric respiratory minimum three days earlier and EM XII six days later than the other rootstocks. In general, the best harvest dates for the McIntosh fruits grown on the different EM rootstocks coincided well with the date of the preclimacteric respiratory minimum.

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APPENDIX

TABLE 1. Nitrogen[a1/] and potassium[a2/] composition of McIntosh apple leaves sampled in July from the modified environment treated trees in 1962.

	Mc/VII				Mc/II		
%	75 F night T	Short day	Long Day	Control	75 F night T low light	low light intensity	Control
N	1.82	2.00	1.46	1.72	1.92	1.84	2.00
K	1.60	1.66	1.20	1.12	1.50	1.86	1.00

a1/ Kjeldhal

a2/ flame photometer

TABLE 2. Nitrogen [a1]/ and potassium [a2]/ composition of McIntosh apple leaves sampled in July from ten locations in Michigan in 1962.

	Location									
%	A	B	C	D	E	F	G	H	I	J
N	1.77	1.77	2.00	[illegible]	.09	1.74	1.97	[illegible]	2.19	2.09
K	1.56	1.48	1.49	[illegible]	.87	1.24	0.78	[illegible]	1.08	0.87

[a1]/ Kjeldhal

[a2]/ flame photometer

TABLE 3. Nitrogen [a1]/ and potassium [a2]/ composition of McIntosh apple leaves sampled in July from trees on seven EM rootstocks in 1962.

%	EM Rootstocks						
	I	II	IV	V	VII	XII	XII
N	1.93	1.89	1.77	1.90	2.13	2.28	2.25
K	1.81	0.95	1.04	1.00	0.90	1.30	1.04

[a1]/ Kjeldhal

[a2]/ flame photometer

TABLE 4. Spectrographic analysis of apple leaves sampled in July from the modified environment treated trees in 1962.

Treatment	%			PPM							
	P	Ca	Mg	Na	Mn	Fe	Cu	B	Zn	Mo	Al
Mc/VII											
75°F ni T°	0.159	1.14	0.28	26	62	134	34.4	28.3	22	5.2	176
Short day	0.202	1.26	0.25	35	63	124	28.0	30.7	34	5.6	226
Long day	0.273	0.80	0.22	35	99	108	16.6	28.3	26	3.6	279
Control	0.308	0.94	0.26	28	80	134	15.6	28.3	9	4.2	382
Mc/II											
75°F night T° + low light	0.175	0.87	0.25	29	63	180	29.0	40.4	24	4.0	410
Low light intensity	0.218	0.80	0.23	35	63	160	23.2	31.9	26	3.6	396
Control	0.175	1.02	0.28	17	67	124	15.6	28.3	7	4.8	252

TABLE 5. Spectrographic analysis of apple leaves sampled in July from ten locations in Michigan in 1962.

Location	%			PPM							
	P	Ca	Mg	Na	Mn	Fe	Cu	B	Zn	Mo	Al
A	0.210	0.66	0.14	64	166	218	13.3	32.5	0	3.0	*876
B	0.142	0.90	0.20	71	220	173	9.7	30.1	0	3.9	*838
C	0.163	0.77	0.14	52	549	142	7.2	22.5	0	3.0	218
D	0.214	0.92	0.20	255	38	124	9.3	36.7	20	3.1	530
E	0.188	1.31	0.30	25	116	123	17.6	27.1	3	5.6	478
F	0.227	1.12	0.25	256	48	160	9.4	33.0	15	4.8	637
G	0.124	0.94	0.28	22	78	130	11.5	22.5	3	4.4	180
H	0.128	0.75	0.16	22	120	140	13.4	19.6	0	2.6	177
I	0.171	1.31	0.27	233	126	*539	22.8	30.6	33	5.2	*1058
J	0.188	1.31	0.30	25	117	123	17.6	27.1	3	5.6	478

Values marked (*) denote approximate values extrapolated from curve for that particular element on spectrographic instrument.

TABLE 6. Spectrographic analysis of apple leaves sampled in July from trees on seven EM rootstocks in 1962.

Rootstock	%			PPM							
	P	Ca	Mg	Na	Mn	Fe	Cu	B	Zn	Mo	Al
EM I	0.132	1.08	0.22	99	44	148	12.8	30.1	19	4.8	*1139
II	0.128	1.08	0.27	115	59	144	12.9	27.7	18	5.2	*1143
IV	0.139	0.92	0.20	54	59	133	10.2	23.1	17	4.7	* 997
V	0.206	1.04	0.22	496	59	143	12.0	34.3	23	5.1	*1111
VII	0.171	0.96	0.20	693	58	164	19.4	33.7	24	4.9	*1598
XII	0.163	1.20	0.29	261	59	190	13.8	44.0	17	5.7	*1088
XIII	0.168	1.00	0.27	381	58	176	14.6	40.0	21	5.0	*1206

Values marked (*) denote approximate values extrapolated from curve for that particular element on spectrographic instrument.

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