

CULTURAL AND ENVIRONMENTAL
PARAMETERS FOR MECHANICALLY
HARVESTED CUCUMBERS

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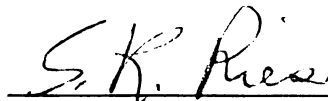
CULTURAL AND ENVIRONMENTAL
PARAMETERS FOR MECHANICALLY
HARVESTED CUCUMBERS

presented by

Frank D. Morrison

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ABSTRACT

CULTURAL AND ENVIRONMENTAL PARAMETERS FOR MECHANICALLY HARVESTED CUCUMBERS

by Frank D. Morrison

Cultural practices for the production of cucumbers for once-over harvest were studied for three consecutive years.

The highest consistent dollar per acre yield was obtained with the cultivar Spartan Dawn planted 9 inches between plants in the row and 9 inches between rows.

Nitrogen rates of approximately 60 pounds per acre were adequate for high production of once-over yields. Soil moisture requirements were critical for high plant populations, and supplemental applications of water were necessary during periods of insufficient rainfall.

A uniform sequence of harvests was accomplished if a successive seeding was made when the first true leaves of a previous seeding were visible. This seeding schedule resulted in plantings being harvested three days apart.

The most effective harvest index to obtain the highest dollar yield per acre was the development of fruit 2 to 2 1/2 inches in diameter with a limited yellowing of older fruit.

Temperature studies indicated that 50 F was approxi-

mately the critical minimum temperature for development of cucumber plants and fruit. The growth rate of seedlings was retarded equally by exposures to 40 F and 50 F for 4 hours regardless of plant age. However, when plants from seed of different sizes were subjected to 50 F for 4 hours, the plants from the larger seed exhibited more cold tolerance. Treatment of plants at 50 F for 36 hours delayed leaf development and time to anthesis compared to plants treated with 60 F for the same length of time. Exposure to 45 F for 12 hours altered the location of fruit set by causing desiccation of basal pistillate buds and flowers. Fruit elongation was reduced by one-half if the fruit was subjected to 45 F for 24 hours.

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by
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INTRODUCTION

Information regarding standard cucumber production has been concerned with crops grown to be hand harvested in 10 to 15 pickings and at populations from 8,000 to 20,000 plants per acre. The time required from planting to the first harvest varied from 45 to 60 days, and the harvest period extended from 4 to 6 weeks. With a destructive harvest the total yield was obtained in a period of 45 to 60 days, depending upon the variety and season. These changes in the manner of harvesting and length of the growing period required different crop production procedures.

The objectives of this research were to evaluate cultural practices suitable for the production of cucumbers for once-over harvesting, and environmental factors related to plant growth. Included were plant population and spacing studies in relation to yield, and the moisture and nitrogen requirements for plants grown at high populations. Suitable criteria for scheduling plantings so that an orderly harvest would be possible, and the stage of growth to make a once-over harvest to obtain the highest crop value were also studied. An evaluation was also made of the growth retarding effects of low temperatures on plants in various stages of growth.

REVIEW OF LITERATURE

Growth of cucumber plants:

An understanding of the growth and development of a cucumber plant (Cucumis sativus L.) is necessary when considering changes in the production methods required for mechanical harvesting.

Weaver and Bruner (84) determined that following germination the cotyledons were pulled out of the ground by the hypocotyl. A tap root several inches in length and much branched usually formed before the plumule unfolded. The root system was characterized by a strong tap root which penetrated to a depth of 6 feet at maturity although branching was not excessive below the two foot level (35, 84, 85). The branch roots spread widely to a radius of nearly 20 feet, and the main laterals had numerous secondary branches 2 to 8 feet long which in turn branched until there was a remarkable network of rootlets that completely occupied the soil near the surface. In addition to the primary root system adventitious or nodal roots attained a length of 4 to 5 feet, and they also branched so that the absorbing area was increased (28, 84).

The stems of cucumbers were characterized by Hayward

(30) as prostrate, trailing, and usually angled in cross section. From the primary stem several secondary branches developed. Whitaker and Davis (85) described the main plant axis as a sympodium, and at each node a lateral branch continued the main axis and, by its growth, displaced the terminal branch so that the lateral occupied a position on the opposite side of the axis from the leaf which initiated at the node.

Most cultivars of Cucumis sativus L. are monoecious, bearing staminate and pistillate flowers on the same individual (66). In studies of the flowering behavior of monoecious cucumbers, the first staminate inflorescence occurred in the first or second leaf axil, and continued to develop in many leaf axils throughout the life of the plant (31). Several primordia were laid down in the leaf axil so that the flowers were borne in clusters. In a morphological study of pistillate flower formation Judson (33) observed that the first primordia occurred several nodes from the cotyledonary node.

Emerson (25) noted a sequence of phases in monoecious plants which became increasingly pistillate. Later it was observed that as the distance from the base of the stem increased, the percentage of female flowers increased (20). The cucumber, during development, changed from strongly

staminate to a strongly pistillate condition and the laterals were more pistillate than the main axis. These observations and those of Nitsch (47) indicated that the typical monoecious plant goes through three phases; a staminate phase, a monoecious phase and a pistillate phase.

The possible effect of the staminate-pistillate ratio on yield was examined by Edmund (23). He concluded that excessive production of either flower type could result in losses to growers.

The gynoeceious character of sex expression has been described as one in which individuals bear exclusively pistillate flowers (66). Tkachenko (76) reported that "femaleness" and maleness" were controlled by a pair of genes, and that the former is dominant.

A technique for breeding gynoeceious cucumbers was described in 1960 (48). A homozygous gynoeceious line (MSU 713-5) was produced by crossing a gynoeceious segregate found in the Korean race Shogoin and the pickling variety SMR 18 (82). Later Peterson and DeZeeuw (49) described a hybrid (Spartan Dawn), which was a cross of MSU 713-5 with Spartan 27 as the pollen parent. The sex expression was predominately female with an average of two staminate flowers per plant under Michigan field conditions. Pistillate flowers were often borne at the first node and

opened before pollen was available from monoecious plants at the same time.

In addition to genetic factors, sex expression was also affected by environmental factors. The number of fruit per plant was one of the key factors in successful cucumber production for a single harvest. In a study of fruiting characteristics, it was noted that cultivars varied in their capacity to develop a number of fruit at one time (41, 51, 67, 74). Tiedjens (74) theorized that simultaneously fertilized flowers developed equally well, but that less advanced ones were arrested in their development.

Putnam (51) conducted inhibition studies which indicated that further fruit development was arrested on plants when the marketable fruit was not removed. After a period of 7 days no appreciable fruit development occurred when the original fruit was left on the plant. However, when the marketable fruit was harvested, inhibited fruit resumed growth and continued to develop into marketable size.

In additional work by Putnam (51) attempts were made to overcome fruit inhibition by applying several growth regulating chemicals to plants grown in the field and in the greenhouse at various stages of growth. The results were inconsistent and varied with environmental conditions with all of the compounds tested. He concluded that the

chemicals tested were not effective in increasing once-over yields of pickling cucumbers.

Development of a mechanical harvester

The transition from hand to mechanical harvesting of cucumbers has received increasing emphasis in recent years (2, 17, 18, 72). The need for harvest mechanization becomes more critical as additional hand harvested crops are mechanized and labor becomes less available.

In 1959 Stout and Ries (70) initiated a study of multi-pick cucumber harvesters. At that time several patents for harvesters had been issued and several machines had been developed. Extensive tests were conducted using the existing machines and an experimental harvester was constructed (11, 12). None of the machines tested performed in a consistently desirable manner. Stout et al. (69) enumerated the problems encountered with multi-pick harvesters as follows: accumulative damage to plants with resultant decrease in yields, inadequate mechanical components for removing fruit set near the base of the plant, inability to remove and retrieve all marketable fruit from certain cultivars, low yields because of wide row spacing required by machines, pulling of plants from the soil when vine growth is luxuriant or anchorage poor, and small acreage capacity for a machine because of the necessity of

repeatedly harvesting the same plants.

In view of these problems, efforts were concentrated on the development of a machine for a destructive harvest. It was suggested that a successful once-over harvester should perform at least five functions. These are: pick up and orient the cucumber plants for fruit detachment; detach the fruit; transport the fruit away from the detachment device; separate the fruit from foreign material; and discharge the vines (71).

Delong (22) tested several machines for removal of fruit from the vines. A component consisting of two flat rubber rollers was successful in removing a high percentage of the fruit.

In 1964 Stout et al. (69) described a harvester prototype using this constriction principle combined with mechanisms to convey plants to the rollers. The fruit were removed and conveyed to containers and the vines discharged. Commercial production of this machine, with modifications, began in 1964.

Plant spacing and population

The effect of plant density on the growth characteristics of various crops has received attention by several workers. These studies have been stimulated, at least in part, by the alteration of production practices as the crops

became more mechanized. Some of the observed responses were changes in the number of ears and leaves per plant on corn (24, 68); stems and pods per plant with peas (14, 79); bulb size of onions (14); root size of carrots (14); and size and soluble solids in muskmelons (29).

Plant densities have been expressed numerically as the Leaf Area Index which is the ratio of a unit of leaf area per unit of land area (84). The significance of this was discussed by Watson (83) in relating net measurements of photosynthetic efficiency (assimilation rates) to Leaf Area Index using dry weight of leaf samples from varying plant populations. The net assimilation rates of kale and sugar beets were compared and in both crops the NAR decreased as LAI increased. The decrease was at a much lower rate with sugar beets and was attributed to the different growing characteristics between the two crops. However, he suggested that the CO_2 concentration in the micro-environment should be considered.

In discussing the spatial arrangement of plants grown at a high density, Black and Watson (13) suggested that an even distribution of light over the entire leaf area of a crop would give an improved efficiency in the use of solar energy over that of a crop having the same leaf area but in which mutual shading of the leaves

occurred. This postulate was supported by research with peas by Bleasdale (14). He found that with optimum plant density the more nearly an "on the square" plant arrangement was used, the higher the yield.

The results from research trials in spacing of cucumbers were summarized by Banadyga (7) in 1949 as follows: "Varying results have been obtained with spacing tests. It is recognized that rows should be 5 to 7 feet apart, but much controversy exists on the spacing of the plants in row." Mississippi workers found that higher yields were obtained when plants were spaced 7.5 or 15 inches apart compared to 30 or 45 inches (1). Ries (56) reported increased early yields with close spacings in a 4 year study.

Concurrent with the development of a machine to harvest cucumbers in an once-over manner has been research to study the most suitable plant populations. Putnam (51) evaluated populations ranging from 22,000 to 87,000 plants per acre. Spacings varied from one to four feet between rows and were one half and one foot apart in the rows. Highest yields and greatest number of fruits per plant were from the one-foot spacings regardless of the distance between rows. Populations exceeding 43,560 plants per acre did not produce higher yields.

Results from research conducted in North Carolina indicated that the value of the crop increased with increasing plant populations. However, at the highest rates (224,000 plants per acre) the fruit, particularly the larger sizes, tended to be pointed on the blossom end (45).

In studies with a once-over harvesting machine at Michigan State University the highest value in both bushels and dollars per acre was obtained from plant populations of 31,500 when compared to lower populations (71).

Responses to nitrogen

The specific nitrogen requirement for satisfactory yields of pickling cucumbers has not been clearly established, probably because of the wide variety of conditions under which nutritional experiments have been conducted.

Nitrogen deficiency symptoms are first evident on the tops of plants concomitant with a reduction in rate of growth. Stems and leaves remain small, giving a stunted appearance. Fruits may be pale yellow in color and are often pointed at the blossom end.

Cucumber plants respond in various ways to nitrogen fertilizer. These responses include: vegetative growth (21, 54, 60); total yield (1, 8, 43, 54, 58, 64); early yield (56); flowering and fruiting characteristics (21, 55, 60); and fruit development (11, 43, 54, 74).

Radnikov (60) reported that nitrogen was the main element required by cucumber plants during the period of vegetative growth and early flowering but potassium was required in greatest amounts during fruiting.

Investigations conducted by Vogeles and Weber (80) indicated that the maximum need of cucumber plants for nitrogen occurred from the 31st to the 44th day of age. This agrees with the findings by Radnikov; however, Dearborn (21) proposed that growth of plants under high and low levels of nitrogen were approximately equal until flowering and fruiting began.

Reynolds (54) found that vegetative growth showed marked responses to increases in the level of nitrogen at all stages of growth. Growth increased in a linear manner with each increase in the nitrogen level with little or no tendency to level off even at the highest nitrogen levels. He interpreted this response to indicate a high nitrogen requirement throughout the life of the cucumber plant as far as vegetative growth is concerned. There was a slight decline and a delay in fruit production at the highest level of nitrogen compared to the medium level.

An influence on the sex expression at different nitrogen levels has been observed. Plants with a high

nitrogen supply produced more pistillate and fewer staminate flowers than with low nitrogen (21, 54).

Tiedgens (75) reported that nitrogen levels have an important bearing on the shape of cucumber fruit. Under conditions of normal pollination a high nitrogen level produced 100 percent normal fruits; whereas, low nitrogen produced only 63 percent, with 7 percent severely wasped (constricted in the middle). When pollination was delayed 24 hours after anthesis, all fruits were wasped or inferior in some way in the low nitrogen treatment. With high nitrogen all fruits were slightly wasped but were classed as good fruit.

Nitrogen nutrition has been related to susceptibility of seedlings to damping-off. Seedlings were more resistant to infection when adequate nitrogen was supplied. This resistance was associated with lignification of parenchyma cells in the region of infection and susceptibility with incomplete or no lignification (40).

Fertilizer rate and placement studies by Wittwer and Tyson (86) showed that band applications of up to 500 pounds per acre of 3-12-12 fertilizer were profitable on fairly productive soils. Side dressing with 200 pounds per acre of ammonium nitrate was not beneficial except on poorly drained soils of low fertility.

Miller (42) found that 60 and 90 pounds of nitrogen reduced yields below those produced from 30 pounds. Furthermore, the highest rate reduced plant stands. Ries and Carolus (58) obtained yields ranging from 361 to 440 bushels per acre with broadcast applications of 5-20-20 fertilizer. In 1961, Ries (57) recommended rates varying from 15 to 30 pounds per acre under Michigan conditions.

Miller (40) noted that 200 and 400 pounds of 5-20-20 per acre placed under the seed reduced both stand and yield. The largest yields were obtained when the fertilizer was placed 2 inches to the side and 2 inches below the seed. He stated that side placement provided nutrients in close enough proximity to the young seedlings to satisfactorily supply early nutrient requirements, yet far enough from their roots so that a minimum of injury resulted.

The benefits of high early yield from supplemental nitrogen have been reported by Ries (56). When comparing no nitrogen with 60 pounds per acre he obtained 215 and 267 bushels per acre respectively in an early harvest, and 295 bushels compared to 296 bushels respectively in a late harvest.

Water Relations

The response to irrigation by cucumber plants appears to be quite variable. Some reasons for this are undoubtedly

attributed to differences in rainfall and soil texture.

Whitaker and Davis (85) characterized the injury caused by a moisture deficiency in the plant as a wilting and drying process of the apical portion of the developing fruit and by death of a varying number of leaves per plant, as well as partial damage to individual leaves. The first evidence of damage was loss of color in leaves and fruit. It was generally most severe in the lobes of older leaves and the tip of the young developing fruit. Later the affected tissue lost its turgidity, became brown, and finally died. As injury progressed in severity, it affected an increasing amount of surrounding tissue. Finally, entire leaves or fruit were killed.

Some researchers have suggested that light, frequent irrigations which only wet the soil in the area of greatest root concentration are better than soaking ones at longer intervals (10, 37, 85). The shallow rooted cucumber quickly suffered from an excess or lack of moisture.

The frequency and amount of irrigation water necessary to produce a successful crop of muskemelons depended on depth and extent of root development, the amount of available water the soil could hold and the rate of water loss from the soil (85).

Schoenemann and Combs (61) stated that in the absence

of adequate rainfall, irrigation helped secure prompt, uniform emergence of cucumber plants. They suggested that the crop receive not less than one inch of rain or irrigation every 5 to 7 days, depending upon air temperature, wind, and humidity.

In working with cantaloupes at Davis, California, MacGillivray (38) found that yields were increased by irrigation 2 out of 3 years. There was no difference in either fruit size or earliness. With this same crop, Flocker et al. (27) noted that medium and high rates of commercial fertilizer combined with irrigation caused an increase in the proportion of large fruit and marketable yield.

Ware, et al. (82) found that at medium and high rates of commercial fertilizer, crop values per acre were \$393 and \$365 respectively without irrigation. The corresponding values were \$495 and \$570 when irrigation water was applied.

Scheduling Successive Plantings

The harvest schedule of a crop grown for processing should allow for the maximum use of all resources, including equipment, labor, and land. This necessitates a uniform and continuous harvest sequence. To achieve this, a crop must be planted in an orderly manner so that the quantity

harvested during any given period does not exceed the capacity of the harvesting resources or the processing plant.

The heat unit system has found widespread use as an index for timing of successive plantings and for predicting harvest dates (9, 15, 38, 53). This system employs the use of a base temperature, below which it is assumed no growth takes place. The mean of daily maximum and minimum temperature is determined and the base temperature is subtracted from this mean and the resultant value is referred to as a heat unit.

Barnard (9) stated that there were several factors in addition to temperature which might alter the rate of plant growth. These included soil fertility, soil type, soil drainage, topography, seed vigor and planting depth. Cultural practices such as root pruning during cultivation also affected the rate of growth.

Reath and Wittwer (53) studied the development of pea varieties and made observations on days to flowering and maturity, and degree days from seeding to flowering. Their observations suggested that both temperature and photoperiod had a marked influence on plant development.

Arnold (3) pointed out that heat units, at least in their present state of development, were not totally

reliable because the relationship between temperature and the rate of plant development is linear when it is undoubtedly curvilinear. He also suggested that factors in addition to temperature affected the rate of development, and that the temperature measured at a single location is used as a basis for the predictions in the varied microclimate of many fields.

The stage of physiological plant development was used in initial studies with pickling cucumbers (51). Putnam (51) found that with 7 successive plantings, made to establish a sequence of harvests throughout the growing season, a satisfactory criteria to determine the time of planting was the development of the first true leaf of plants in the preceding planting.

Determining Optimum Harvest Period

The fruiting characteristics, previously discussed, strongly influence the distribution of fruit size, number of fruit per plant, and consequently the total value of the crop. In view of this, an objective method is desirable to predict the stage of growth for optimum yields of pickling cucumbers.

In working with tomato cultivars of indeterminate maturity, Ries and Stout (59) used the growth stage at which the first fruit had started to deteriorate as a

criteria for conducting a single harvest. In later studies with tomatoes, Austin (4) and Austin and Ries (5) indicated that the cessation of stem enlargement and the development of 15 inflorescences were the most reliable indices considered to predict the harvest date for the earliest once-over maximum yield of ripe fruit.

Putnam (51) proposed that the stage of growth for maximum yield in once-over harvesting of cucumbers usually occurred about 2 days following the appearance of grade 3 fruit. When testing a prototype mechanical harvester, harvests were conducted when there appeared to be a maximum of grade 1 and grade 2 fruit (59). It was determined that the maximum dollar yield resulted when harvesting was delayed until most of the fruit reached grades 2 and 3 with just a few over grade 3. The loss in value when a fruit matured to grade 4 was negligible due to the increase in grades 2 and 3.

Effects of Low Temperatures on Plant Growth

The minimum and optimum temperatures for growth of cucumbers have been studied by many researchers (1, 6, 16, 36, 65, 73). According to Bailey (6) the most suitable temperatures for rapid growth were between 60 and 65 F at night and up to 100 F in bright sunshine with an ample supply of moisture.

Kotowski (35) determined that cucumber seed does not germinate at soil temperatures as low as 51.8 F, but remained in cold soil for a considerable time, then germinated when the temperature became favorable. The low limit of germination appeared to be somewhere between 52 and 64 F. Other workers stated that germination was best at 70 and nil at 50 F or lower (1, 16).

Results obtained by Schroeder (62) indicated that the critical temperature for water movement through a cucumber root was between 60 and 70 F. Raleigh (52) experienced similar results with muskemelons and suggested that 70 F or slightly higher was the most suitable soil temperature for the crop.

It was observed that cucumber plants wilted severely during the mornings on bright days following low night temperatures (62). Apparently when the soil temperatures reached 55 to 60 F the cucumber plant was unable to obtain sufficient moisture to replace that lost through transpiration due to the slow water movement through the plant.

Mitchell (46) found that a pronounced response to root temperature was evident in plant leaves. A temperature increase from 50 to 68 F doubled the dry weight of stems and roots after 21 days of growth with a three-fold increase in dry weight. Seaton and Kremer (65) planted cucumbers in

two different soil environments with identical air temperatures. After 30 days, plants in soil at 60 F were only 5 inches high whereas plants in soil at 85 F were 30 inches high. Generally flowers opened at 58 to 60 F and anther dehiscence and nectar secretion occurred above 62 F. Temperatures above 70 F were required for pollen tube development. In similar work, Nitsch et al. (47) reported that cucumbers produce pistillate flowers under conditions of low temperatures and short days and staminate flowers under opposite conditions.

Miller (41) reported that night temperatures of 60 F produced fruit with a greater length to diameter ratio than those grown at 70 F.

As the mechanization of cucumber harvesting became a reality there was considerable information available concerning the response of cucumbers to the environment in which they were conventionally grown. The development of a technique by Peterson (48) for breeding gynoecious cucumbers, and basic information accumulated by Putnam (51) regarding cultural practices for a single harvest of the crop were substantial contributions to the success of mechanical harvesting. Nevertheless, knowledge of the most suitable practices for production for once-over mechanical harvesting of pickling cucumbers was inadequate.

MATERIALS AND METHODS

General procedures

During the 1963-1965 growing seasons the experimental plots were located in East Lansing, Michigan on either Hillsdale sandy loam or Wauseon fine sandy loam soils. Soil analysis values for the soils were 54 and 88 pounds per acre of available P and 160 and 312 pounds available K per acre respectively. The pH of the former soil was 7.2 and 6.9 for the latter.

Fall seeded rye was plowed under prior to planting. Seedbed preparation and other growing practices were carried out in the usual manner except when a practice was included as a variable in the studies.

In 1963, 350 lb/A of 14-14-14 fertilizer was broadcast and disced into the soil; six hundred pounds per acre of 12-12-12 fertilizer was broadcast in both 1964 and 1965.

In 1963, all plots were planted by hand. A Planet Junior was used for 1964 seedings and plants were thinned to the desired spacing in the row. A tractor mounted 185 International Harvester seeder was used for the 1965 seedings. Adjustments were made on the seeder for the appropriate row spacings.

Overhead irrigation was used to apply supplemental water to assure uniform germination of all plantings, for irrigation studies, and to provide ample soil moisture when rainfall was inadequate.

All plots were hand weeded, and in 1965, the pre-emergence herbicide NPA was applied at the rate of 4 lb/A. However, where herbicides were used additional hand weeding was still necessary.

The plots were harvested by pulling the plants and stripping the fruit to simulate a destructive, once-over harvest. The fruit from each plot was graded, weighed and counted.

Yield data were converted to dollar value per acre to represent the relative value of the crop harvested. Yields expressed in bushels per acre were often misleading. For example in 3 different experiments the yields in bushels per acre were 377, 521 and 553. The corresponding dollar per acre values were 207, 252 and 142. Thus, the yield expressed as bushels per acre did not reflect the actual value of the crop to the grower.

The fruit grades and values used to establish dollar value per acre for all plots were as follows:

Grade	Diameter (inches)	Price/100 lb (dollars)
1	Below 1 1/16	5.60
2	1 1/16 - 1 1/2	2.00
3	1 1/2 - 2	1.00
4	2 - 2 1/2	.50
Culls	Imperfect or yellow fruit	--

Data were statistically evaluated by analysis of variance and separated into single degrees of freedom where applicable. Mean differences were compared by Duncan's multiple range test.

Plant population studies

The spacing plots in 1963 were arranged in a two-dimensional arithmetic design. Spacing between plants increased arithmetically from the center by 6 inch increments. Plants were oriented in such a manner that each square was a mirror image of another. Each square was considered a replication and represented one-fourth of a larger square, (Figure 1).

Planting dates were June 13 and July 1 with the respective harvest dates beginning July 29 and August 14. The cultivars used were Spartan Dawn and MSU FC-11, a determinate dwarf type plant. The latter matured about 3 days earlier than Spartan Dawn.

In 1964 and 1965 the plots were arranged in a split plot design with the main plots varieties and the sub

feet	3.0	2.5	2.0	1.5	1.0	.5
3.0	4145 <u>1/</u> 10.5 <u>2/</u>	4387 9.9	5959 7.3	7669 5.7	10729 4.1	17926 2.4
2.5	4387 9.9	5762 7.6	7049 6.2	9056 4.8	12700 3.4	21146 2.1
2.0	5959 7.3	7049 6.2	8609 5.1	11084 3.9	15502 2.8	25929 1.7
1.5	7669 5.7	9056 4.8	11084 3.9	14253 3.1	19982 2.2	33252 1.3
1.0	10729 4.1	12700 3.4	15502 2.8	19982 2.2	27923 1.6	46839 .9
.5	17926 2.4	21146 2.1	25929 1.7	33252 1.3	46839 .9	77786 .6

1/ plants per acre

2/ square feet per plant

Figure 1. Two-dimensional arithmetic design employed in 1963 plant spacing trials.

plots spacings. Each treatment was replicated 3 times. The cultivars grown in 1964 were Spartan Dawn, SMR 18 and SR 6. Those included in 1965 plots were Spartan Dawn and a MSU semi-dwarf breeding line identified as Cage 23.

Seeds were planted on June 1 and July 3 in 1964 and the fruit harvested July 22 and August 25 respectively. At each harvest the fruit from all spacings and cultivars was harvested. In 1965 the planting dates were June 1 and July 2. When plants in each spacing of each cultivar reached the appropriate stage of growth they were harvested.

The harvest criterion was based on the stage of development of the fruit. When the most mature fruit of each variety was 2 to 2 1/2 inches in diameter, the 1963 plots were harvested. The harvests in 1964 and 1965 were made when the most mature fruit of each variety began to turn yellow.

Nitrogen levels

Two nitrogen levels were studied in 1963. One level was the initial application of 60 lb/A broadcast during seedbed preparation. An additional 50 lb/A broadcast immediately before planting comprised the second level.

The 1963 plantings were included in the two-dimensional arithmetic plot design used for spacing with

nitrogen as the sub-plot.

In 1964, Spartan Dawn and SMR 18 were spaced 12 inches apart in rows 12 inches apart. A randomized block design was employed with 3 replications for each nitrogen level.

Broadcast applications were made prior to planting with a grass seeder and side dressing applications with a Planet Junior. The nitrogen levels in pounds per acre were: 60, 180, and 360 pounds broadcast prior to planting; 60 pounds preplant broadcast plus 120 pounds side dressed; and 180 pounds preplant broadcast plus 180 pounds side dressed. The side dressing applications were made when the plants were in the 2 to 3 leaf stage of growth.

The center 25 feet of rows 30 feet long was harvested for each variety when the most mature fruit was 2 to 2 1/2 inches in diameter.

Irrigation requirements

In 1963 two irrigation levels were studied. The first level, identified as "minimum moisture," involved applying one-half inch of moisture following seeding. This application was the same for all plots and was applied to promote germination and establish the plants. The second level, "adequate moisture," was based on judgment and one-half to three-fourths of an inch of water was applied as needed to maintain optimum growth. Four and 5 irrigations

respectively were required for the June 13 and July 1 seedings.

The spacings in the two-dimensional arithmetic design described earlier were sub plots and irrigation levels the main plots.

Planting schedules

Successive seedings were made in 1964 and 1965 to determine a planting schedule that would result in a uniform sequence of fruit maturity.

In 1964 each planting consisted of 4 rows 25 feet long of both Spartan Dawn and SMR 18. When the plants were in the first true leaf stage they were thinned to one plant per foot. Successive plantings were made when the first true leaves of the preceding planting first appeared. There were three replications for each planting date.

The date was recorded when the most mature fruit of each variety in each planting was 2 to 2 1/2 inches in diameter and exhibited a slight yellow color.

For the 1965 studies Spartan Dawn was seeded in 4,100 foot rows spaced 1 foot apart with plants at 1 foot intervals in the row. Three different stages of plant development were used as the criteria for making successive seedings in 1965. The first seeding made was the index

planting. When approximately 80% of the plants had emerged in the index planting, the next seeding (A) was made. Planting B was seeded when the first true leaves were visible, and planting C when the first true leaves were unfolding on plants in the index planting. This series was repeated using planting B as the new index. Seedings were made from May 21 until August 9. The dates when the most mature fruit first showed a yellow coloration were recorded.

Stage of growth for harvest

Harvests were made in 1964 to determine the most appropriate growth stage to make a once-over harvest. During the first part of the harvest season, 3 stages of plant development were used as harvest criteria. These were based on the most mature fruit in each planting and were: harvest A - 1 1/2 to 2 inches in diameter; harvest B - 2 to 2 1/2 inches in diameter; and harvest C - turning yellow.

Midway in the season harvest A was discontinued because the fruit was too immature. Also, information was insufficient to determine if the highest values were realized at the time fruit was turning yellow. Therefore, harvest D was added in which the fruit was harvested when about 40 percent of the first set cucumbers

turned yellow.

In 1965 twelve 100 foot rows of Spartan Dawn were seeded in a randomized block with three replications of four rows each. The B, C, and D harvests used in 1964 were repeated.

Evaluation of low temperature effects

The growth retarding effects caused by low temperatures were studied during 1964 and 1965. There were 4 phases which included tests with germinating seedlings, greenhouse grown plants, field grown plants, and growth measurements of individual fruits.

Seedling studies

Seedlings were germinated in 10 cm petri dishes. Prior to using, the dishes were washed thoroughly, rinsed once with tap water and four times with distilled water. Two sheets of 90 mm Whatman No. 1 filter paper were placed in each petri dish to retain moisture, then 7 ml of distilled water were added. Ten Spartan Dawn cucumber seeds were distributed uniformly on the filter paper in each dish. The dishes were completely randomized in a growth chamber with 4 observations for each treatment.

The various time and temperature regimes employed

were administered by adjusting chamber controls for the appropriate temperature and time. The length of the primary roots of each seedling was measured to determine the extent of growth retardation.

Following observations made in the early tests alterations were made in the procedure due to wide variations that occurred within replications of a given treatment. Some of these variations were attributed to the fungicide-insecticide chemicals that had been applied to the seeds. In subsequent experiments all seeds were rinsed in 50 F running tap water for 20 minutes and later extended to 2 hours.

Air circulation within the growth chambers caused rapid evaporation of water within the petri dishes. To prevent desiccation of seedlings 8 ml of distilled water were added.

Temperature measurements in the petri dishes during low temperature treatment indicated that a temperature change of 25 F (from 75 F to 50 F) within a petri dish required 18 minutes when low temperature treatments began within the chamber. To account for this rate of heat exchange, the time at which plants remained at the desired low temperature was extended for an appropriate period.

Temperature studies were conducted with seeds of

different weights. Seed segregation was accomplished by passing seeds through a series of screens. The average weights of 4 groups of 10 seeds were 0.0314 grams and 0.0241 grams respectively from screen sizes of 1/14 inch by 1/2 inch, and 3/64 inch by 1/4 inch.

Seeds of these 2 sizes were germinated for 8 days, then treated at 50 F for 4 hours and the respiration rates determined. The rates were measured by placing the plant tissue into a 20 ml Warburg respirometer flask containing 3 ml of a treating solution (distilled water) and 0.2 ml 10% (W/V) KOH in a side arm for CO₂ absorption.

Respiration, as indexed by oxygen consumption, was determined manometrically according to the procedure of Umbreit et al. (78). The plant tissues were dried and weighed, and the data was expressed as micro-liters oxygen consumption/mg dry weight/unit time.

Greenhouse grown plants

Cucumber plants for the greenhouse tests were grown in a sand, peat and soil potting mixture with a ratio of 1-1-2. Three to 4 seeds were planted in each 10 cm clay pot. At the 1 to 2 true leaf stage the plants were thinned to 1 per pot. Fluorescent lights provided supplemental light for 16 hours each day. The plants were watered with tap water, supplemented with one-half Hoagland's nutrient

solution every 7 days. The experiments were arranged in a split plot design with the main plots time and the sub-plots temperature. There were 4 replications.

Low temperature treatments were made in growth chambers. After treatment, the plants were grown on greenhouse benches for the remainder of the experiment.

As plants were discarded following the first tests, a brown discoloration of roots adjacent to the wall of the clay pots was observed. This was attributed to abnormal exposure of the roots not insulated by soil to low temperatures during treatments. In subsequent tests plants were grown in 15 cm pots. Immediately before low temperature treatments were initiated, insulation was placed around each pot and removed again after treatment.

The number of days required for plants in each treatment to reach a pre-determined stage of growth was recorded.

Another experiment was designed to determine the comparative sensitivity of plant stems and roots to low temperatures. Plants were grown in vermiculite until the cotyledons expanded, at which time they were transferred to 250 ml beakers containing tap water. Aluminum foil was fitted over the top and sides. Four individual holes were punched in the foil and through each a plant was supported by cotton placed between the foil and the stem. The

beakers were placed in a rectangular pan which had insulation secured around the outside. A piece of molding clay on the bottom of each beaker was employed to maintain the position of the beakers. The medium in each beaker was aerated.

The plant treatments for stems and roots respectively were: 75 and 75 F; 75 and 55 F; 55 and 75 F; and 55 and 55 F. Growth chambers were used for the temperature treatments. One chamber was maintained at 75 F and the other at 55 F. In treatments 1 and 4 the temperature of the water within the pans and the beakers was constant with the chamber temperatures. Treatment 2 was obtained by filling two 20 liter plastic containers with tap water and placing in the 55 F chamber. Air pressure was employed to pump a small stream of water from the 20 liter containers to the pans within the 75 F chamber. The pan had an overflow outlet to allow a continuous flow of water. By reversing this system, treatment 3 was possible. The containers required refilling about every 6 hours.

The plants were subjected to this temperature regime for 1 week, then harvested. Records were taken of the dry weight of the stems and roots.

A randomized block design with 4 replications was utilized.

Field grown plants

In 1964 and 1965 two refrigeration units were utilized to subject field grown plants to low temperatures, thus attempting to simulate normally occurring low temperatures. Two 8 x 8 x 4 foot chambers for plants were constructed using one-fourth inch plywood, painted white on the outside, and insulated on the inside. Each chamber had a portion of the plywood notched out to fit around the evaporator.

Each year the plants were spaced one foot apart in rows 1 foot wide. The chambers were placed over the plants to provide the different temperature treatments for the prescribed time periods. The chambers were manually placed over the plants each day at 4:45 p.m. and removed the following day at 8:00 a.m. The temperature treatments were applied during this period. The chambers remained off of the plants during the remainder of the day except when treatments were longer than 12 hour periods. In these instances they remained over the plants until the temperature treatments were complete. Chambers were also placed over the check plants, without the refrigeration units operating, for the same length of time so that the dark period was equal for both check and treated plants.

Records were taken of plant developments rates and

plant yields.

Fruit growth measurements

Continuous fruit growth measurements were made using time lapse photography. The shutter release of a 16 mm camera was attached to a solenoid operated from a six-volt battery. The frequency of the shutter opening was controlled by an electrically operated time clock.

The camera, solenoid, and time clock were all mounted within a wooden case. A port-hole in the case prevented obstruction between the lense and the object. A tractor light was mounted on a swivel bracket on each end of the wooden case to light the subject.

Cucumber fruits were mounted in front of the camera lens on a mounting frame. A pocket watch, a maximum-minimum thermometer, and a centrimeter ruler were also mounted on the frame so that fruit growth, temperature, and time were recorded with each exposure.

It was necessary to select fruit to photograph which were located on nodes at least 8 inches distal to the base of the plant to allow for placement on the mounting frame.

Exposures were taken of both field and greenhouse grown plants. Greenhouse plants were photographed in a growth chamber to allow for a variety of temperature regimes.

RESULTS AND DISCUSSION

Plant population studies

The dollar value per acre of pickling cucumbers, which were subjected to a destructive harvest, increased with increasing plant populations in 1963 (Table 1). The greatest return in dollars per acre was realized from a population of 77,800 plants per acre. Extremely low values were obtained at the widest spacing, and the value per acre doubled as the number of square feet per plant was reduced by one-half.

In 1964 the yield from Spartan Dawn plants grown in rows 9 inches apart with 9 inches between plants in the row^{1/} (77,800 plants per acre) was no greater than the yields obtained from plants grown at closer spacings (Table 2). The total value was more for the June 1 seeding; however, the effect of spacing was the same for both planting dates. The value of SMR 18 was highest when June 1 seeded plants were spaced 6 x 6. However, in the July 3 planting, only the 6 x 3 spacing yielded more. The June 1 planting of SR 6 produced the highest values

^{1/} Hereafter the spacing between rows and between plants within rows will be denoted by 9 x 9, 12 x 6, etc.

Table 1: The relationship of area per plant with dollar per acre value (1963)

Sq ft/plant	Plants/acre	Dollar/acre value	
		Spartan Dawn	MSU FC-11
10.5	4,100	22 a <u>1/</u>	17 a <u>1/</u>
7.6	5,800	32 a	19 a
5.1	8,600	45 ab	36 a
3.1	14,300	85 bc	56 a
1.6	27,900	136 cd	126 b
0.9	46,800	172 d	169 b
0.6	77,800	248 e	302 c

1/ Means with uncommon letters are significantly different at 1% level.

Table 2: The association of yield with plant density for once-over harvest (1964)

Planting date	Plant spacing (inches)	Dollar per acre value		
		Spartan Dawn	SMR 18	SR 6
June 1	12 x 12	229 a <u>1/</u>	150 a <u>1/</u>	204 a <u>1/</u>
	9 x 9	453 b	218 b	365 b
	6 x 6	432 b	285 c	418 c
	3 x 6	485 b	208 b	234 a
July 3	12 x 12	206 a <u>1/</u>	153 a <u>1/</u>	- <u>2/</u>
	9 x 9	324 b	174 a	-
	6 x 6	327 b	164 a	-
	3 x 6	282 b	270 b	-

1/ Means with uncommon letters are significantly different at the 1% level.

2/ The July 3 planting of SR 6 was not harvested due to disease.

when plants were spaced 6 x 6. The plots in the July 3 planting were severely infected with disease and were not harvested.

In 1965 Spartan Dawn plants spaced 9 x 9 produced yields with the highest value per acre (Table 3). When plants were spaced 12 x 6 the yields were lower than 9 x 9 even though the population was not appreciably different. There were no differences among yields from the 4 highest populations of Cage 23.

Plants with a common planting date were harvested simultaneously in 1964. The following year plants from each spacing plot were harvested at what was considered the optimum maturity. This resulted in 2 different harvest periods with the 9 x 6 and 6 x 6 plantings harvested 2 days later than the other plots. This delay in harvest did not result in a higher value per acre (Table 3).

In all of the spacing tests there was an association between the greatest value and the highest yield of grade 3 fruit. This was most pronounced with plants spaced on the 9 inch square where approximately 42 percent of the total value were from grade 3 fruit (Table 4). The dollar values were identical for the 12 x 6 and 9 x 6 spacings, however, the yields were 446 and 317 bushels per acre respectively. There were more small fruit from the 9 x 6

Table 3: The influence of plant spacing on value (1965). 1/

Plant spacing (inches)	Plants/acre	Dollar per acre value	
		Spartan Dawn	Semi-dwarf Cage 23
12 x 12	44,000	131 a <u>2/</u>	117 a <u>2/</u>
12 x 6	87,000	208 b	225 b
9 x 9	77,800	302 c	221 b
9 x 6	116,000	208 b	242 b
6 x 6	174,000	162 a	263 b

1/ Average of June 1 and July 2 planting.

2/ Means with uncommon letters are significantly different at the 1% level.

Table 4: A comparison of the yield with value of different grades of Spartan Dawn (1965).

Plant spacing	Grade 1 Bu/A \$/A	Grade 2 Bu/A \$/A	Grade 3 Bu/A \$/A	Grade 4 Bu/A \$/A	Total Bu/A \$/A
12 x 12	9 26	17 17	120 60	112 28	258 131
12 x 6	12 34	40 40	142 71	252 63	446 208
9 x 9	16 46	63 63	254 127	264 66	597 302
9 x 6	17 48	68 68	136 68	96 24	317 208
6 x 6	15 44	52 52	110 55	44 11	221 162

spacing and more large fruit from the 12 x 6 spacing. This might suggest that the rate of fruit development was retarded at the higher plant populations. However, in 1965 when the cucumbers were harvested at optimum maturity, the maturity of the first set fruit was approximately the same for each plot.

As the plant population increased the number and weight of fruit per plant decreased (Table 5). Also the number of plants without fruit increased. Putnam (51) also observed that the number of fruit per plant was consistently greater when the plants were spaced 1 foot apart in the row compared to those spaced 6 inches apart.

In addition to fewer fruit per plant with population increases, the dry weight per plant decreased (Table 6). This indicated a decreasing capacity of plants to support developing fruit as populations increased above approximately 80,000 per acre. Undoubtedly, this decrease was due to insufficient carbon dioxide, light, water or nutrients. Hopen (32) indicated that both light and carbon dioxide limited plant growth and fruit set at high populations.

A comparison of the orientation of rows indicated that the number and total weight of fruit per plant were the same for east-west oriented rows as for those oriented

Table 5: The influence of plant density and direction of the rows on fruit development.

Sq ft/plant	Row Direction			
	North-South		East-West	
	Fruit no./plant	Fruit wt/plant (gm)	Fruit no./plant	Fruit wt/plant (gm)
2.4	3.4 ab <u>1/</u>	176 a <u>1/</u>	3.7 a <u>1/</u>	147 b <u>1/</u>
2.1	3.7 a	162 a	3.8 a	153 ab
1.7	3.1 bc	163 a	3.2 b	172 a
1.3	3.0 c	155 ab	3.4 ab	134 b
0.9	3.1 bc	131 b	2.9 b	139 b
0.6	2.5 d	115 c	2.4 bc	105 c
average <u>2/</u>	3.1	150	3.2	142

1/ Means with uncommon values are significantly different at the 5% level.

2/ Direction of rows is not significant at the 5% level.

Table 6: The relationship between area per plant and dry weight. 1/

Sq ft/plant	Dry wt/plant (gm)
10.5	32 a <u>2/</u>
5.0	31 ab
3.0	26 b
1.5	21 b
0.5	13 c

1/ Average of 3 different seedlings.

2/ Means with uncommon letters are significantly different at 1% level.

north and south (Table 5). Cucumber plants changed from upright to prostrate type growth when they reached the 4th to 5th true leaf stage. As they assumed prostrate growth the direction they became oriented was inconsistent and random except when winds prevailed from a particular direction. Thus, at high densities rows were distinguished only when plants were upright. During this period, however, plants were small and mutual shading minimized.

Spartan Dawn fruit from the 1965 spacing plots, measured to determine the length-diameter ratios, indicated that the ratio was not altered by high plant populations.

The grade prices used to compare the value in dollars per acre were representative of the prices paid during the 1963 season. The same prices were used for 1964 and 1965 to maintain uniformity. However, the 1966 contract prices reflect values for each grade which are 3 times those used in this study. When Spartan Dawn yields for 1965 were computed using 1966 prices the dollar per acre values were 434, 594, 889, 611 and 408 for the 12 x 12, 12 x 6, 9 x 9, 9 x 6, and 6 x 6 spacings respectively. However, these 1966 prices reflect the total cost of harvesting the crop, whereas in other years processors have absorbed much of the cost of procuring, housing, and transporting labor.

Nitrogen and irrigation

Supplemental applications of nitrogen in 1963 increased the yield of cucumbers only if additional moisture was supplied (Table 7). Part of the reduction in value when high nitrogen and non-irrigation were combined was due to a decrease in the number of marketable fruit. This adverse response might be a burning effect on the plant roots from the nitrogen salts, as reported by Miller (41).

Several of the Spartan Dawn plants in 2 different irrigation plots which had received the high nitrogen rates produced 6 to 12 fruit per plant with some in each grade. In reviewing the various conditions to which the plants were subjected, the high nitrogen level appeared to be a possible cause for this response.

A trial designed to test this hypothesis in 1964 established that there was no difference in the number of fruit per plant or yield value among the 5 nitrogen treatments (Table 8).

The medium and high rates of fertilizer caused a delay in flowering of 1 to 3 days compared to the lowest rate. A slight decrease in the number of plants per plot at the high nitrogen rates was also observed. Reynolds (53) and Miller (41) reported a similar response.

During 1963 both plantings responded to irrigation

Table 7: The effect of nitrogen and irrigation on the value of cucumbers. 1/

Irrigation Applications	Nitrogen Level		
	60 lb/A	100 lb/A	Average <u>1/</u>
	Dollars per acre		
4	370	418	394
1 (at planting)	322	190	256

1/ F value for interaction of nitrogen x moisture level significant at 1% level.

Table 8: The number of fruit per plant and yield values from different rates and methods of nitrogen application (1964). 1/

Nitrogen Application			
Lb/acre	Method	No. of fruit/plant	\$/acre value
60	broadcast	2.8	295
180	broadcast	3.1	245
360	broadcast	2.8	268
60 + 120	broadcast plus side dressing	2.7	266
180 + 180	broadcast plus side dressing	2.7	234

1/ F values for differences in number of fruit per plant and yield value not significant at 5% level.

and the number of marketable fruit per plant was doubled by applying supplemental moisture (Table 9).

Climatological data revealed that the amount of precipitation during the first part of the 1963 growing season was 2.75 inches and 4.93 inches when later planted cucumbers were growing (Table 10). During both plantings there were periods when supplemental moisture was necessary due to the distribution of the rainfall.

Scheduling successive plantings

The stage of plant development was used successfully as a criterion for scheduling cucumber plantings so that several plantings matured for harvest in a uniform manner. When successive seedings were based on the emergence of the first true leaf, the individual blocks were ready to harvest within 2 to 4 days of each other (Table 11).

If a second planting was made when approximately 80% of the previously seeded cucumbers had emerged, the harvest periods were 1 to 3 days apart (Table 12). Plantings matured about 7 days apart if the criterion used was the expansion of the first true leaf.

The planting criteria were not successful if plants were subjected to moisture stress or other conditions that retarded growth. Germinating conditions had to be ideal

Table 9: The effect of moisture on the number of marketable fruit per plant. 1/

Planting Date	Number of marketable fruit per plant	
	1 Irrigation at planting	4 Irrigations
June 13	0.9	1.8
July 1	1.2	2.1
Average <u>2/</u>	1.6	2.0

1/ Spartan Dawn at 77,800 plants per acre.

2/ F value for difference between irrigation levels significant at 5% level.

Table 10: Record of daily precipitation and mean daily temperatures at the Horticulture Farm, East Lansing, Michigan, for the 1963 growing season.

Date	Daily ppt (inches)	Mean daily temp (F) <u>1</u> /	Date	Daily ppt (inches)	Mean daily temp of (F)
June 13	.01	63	July 16	-	78
14	-	60	17	.19	80
15	-	62	18	-	85
16	-	67	19	.13	73
17	-	68	20	-	75
18	-	73	21	.12	74
19	-	69	22	-	77
20	.04	56	23	.02	74
21	-	59	24	-	77
22	-	66	25	-	84
23	-	65	26	-	85
24	-	71	27	-	77
25	-	77	28	.10	79
26	-	76	29	.08	77
27	-	80	30	-	69
28	-	75	31	.20	70
29	-	86	Aug 1	.52	68
30	-	82	2	.09	68
July 1	-	84	3	.14	75
2	-	83	4	-	71
3	-	66	5	-	70
4	-	66	6	-	74
5	-	73	7	-	75
6	-	70	8	-	71
7	-	69	9	1.01	73
8	-	63	10	-	66
9	-	58	11	-	69
10	-	63	12	-	68
11	-	70	13	.26	74
12	-	72	14	-	65
13	-	68	15	-	66
14	2.07	69	16	-	64
15	-	68			

1/ Temperature recordings were made with a thermograph housed 3 inches above the soil surface.

Table 11: Harvest data when planting is determined by development of the first true leaf (1964).

Planting date	Harvest date	Number of days from planting to harvest
May 16	July 14	59
May 25	July 16	52
June 3	July 20	47
June 11	July 23	45

Table 12: Scheduling cucumber plantings for a uniform harvest (Spartan Dawn).

Stage of growth of first planting	Planting date	Harvest date	Days from planting to harvest
First Planting	May 21	July 18	59
80% of plants emerged	May 26	July 20	56
First true leaf emerged	June 1	July 22	52
First true leaf expanded	June 7	July 25	48
Second Planting	June 1	July 22	52
80% of plants emerged	June 6	July 23	47
First true leaf emerged	June 9	July 25	46
First true leaf expanded	June 14	July 30	46

to promote plant uniformity in the early stages of cucumber growth.

Plantings based only on the number of days between seedings was not satisfactory for scheduling successive plantings. When temperatures were low plant growth was retarded. Thus plantings made several days apart matured for harvest at the same time.

Heat units were computed over a 3 year period using base temperatures from 48 to 60 F. There was no consistent pattern in the number of degree days necessary for a cucumber plant to reach maturity utilizing these base temperatures.

The number of degree days was determined for plants to reach a selected stage of development (Table 13). This also proved to be inconsistent even though different base temperatures were calculated for different stages of cucumber plant development.

Although heat units can be used as a successful guide for planting and predicting harvest dates of some crops, the sensitivity of cucumber plants to environmental factors is not sufficiently reflected by the heat unit system. With this crop, the emergence of the first true leaf proved to be the most satisfactory criterion since it generally occurred over a short period of time and the latitude for

Table 13: Plant development in relation to accumulated heat units.

Planting date	Stage of plant development											
	First true leaf unfolding				Bud emergence				Anthesis			
	50	53	56	59	50	53	56	59	50	53	56	59
May 21	115	83	59	41	305	231	165	109	452	354	264	184
June 1	92	68	44	24	318	269	200	136	426	356	266	181
June 11	116	95	74	53	302	262	202	143	506	433	340	248
June 22	88	70	52	34	259	214	169	124	490	406	322	238
July 6	85	67	49	31	303	246	190	136	455	374	294	216
July 21	135	108	81	54	365	302	240	180	550	454	349	267
July 30	83	68	53	38	377	314	241	189	448	360	266	200

error was minimized.

Stage of Growth for Harvest

The stage of growth at which a single harvest of cucumbers was made greatly affected the value of marketable fruit. If Spartan Dawn plants were harvested when the first-set fruit were grade 3, the dollar values per acre were lower than when fruits reached grade 4 (Table 14). There was a similar pattern in the development of the SMR 18 fruit. The total yield values for Spartan Dawn were related to the development of yellow fruit in grade 4 (Table 15). Concurrent with the progressive enlargement of the first-set fruit was a decrease in the number of small fruit harvested (Table 16). This resulted in a definite decrease of the crop. These results are likely due to the fruiting habits of cucumbers explained by Putnam (51). He found that after a period of 7 days no additional fruit development occurred when the original fruit were left on the plant. Thus, in the present studies the peak of highest value occurred when there was a wide distribution of fruit in all grades.

When Spartan Dawn plants were subjected to prolonged low temperatures or a moisture stress their fruit prematurely exhibited a yellow color. Although not as

Table 14: The relationship between fruit development and a single harvest (1964) 1/

Stage of most mature fruit	Dollars/acre	
	Spartan Dawn	SMR 18
No. 3 grade	191 a <u>2/</u>	156 a <u>2/</u>
No. 4 grade	253 b	184 a
Light yellowing of no. 4 grade	303 c	285 b

1/ Average of 3 different plantings.

2/ Means with uncommon letters are significantly different at the 5% level.

Table 15: Value of pickling cucumbers harvested at different stages of growth 1964 1/

Stage of most mature fruit	Dollars/acre	
	Spartan Dawn	SMR 18
No. 4 grade	279 a <u>2/</u>	182 a <u>2/</u>
Light yellowing of no. 4 grade	273 a	241 b
Moderate yellow- ing of no. 4 grade	129 b	240 b

1/ Average of 2 different plantings.

2/ Means with uncommon letters are significantly different at the 5% level.

Table 16: The value and grade of Spartan Dawn fruit harvested at different growth stages (1965).

Stage of growth of oldest fruit at harvest	Total value \$/A	Grade			
		1	2	3	4
Percent of total value					
No. 4 grade	222 a <u>1</u> /	34	14	37	14
Light yellowing of no. 4 grade	361 b	41	14	28	18
Moderate yellowing of no. 4 grade	131 c	2	1	48	45

1/ Means with uncommon letters are significantly different at the 5% level.

Table 17: The effect of pre-treatment of seed on root elongation. 1/

	Germination temperature	
	55 F	75 F
Elongation (cm)		
Pre-treatment of seed	0	69 a <u>2/</u>
Soaked in water for 2 hours	0	69 a
Rinsed in running water for 2 hours	0.75	95 b

1/ Root measurements were made 5 days following seed treatment.

2/ Means with uncommon letters are significantly different at the 5% level.

pronounced, this was also observed with SMR 18. Therefore, size as well as color were considered for determining the optimum time to harvest.

Based on these studies a once-over harvest had the highest value when it was conducted after there were fruit which measured at least 2 inches in diameter. However, the value declined as the number of grade 1 fruit decreased and the number of grade 4 fruit progressively showed a yellow coloration.

Evaluation of low temperature effects

Seedling studies

During preliminary studies with cucumber seedlings, growth rates of individual plants were inconsistent. Rinsing the seeds for 20 minutes prior to placing them in Petri dishes increased the uniformity of growth.

In subsequent studies, seeds were pre-treated and then germinated. Seedlings from seeds rinsed in continuously flowing tap water for a 2 hour period had a longer radicle than unrinsed seeds (Table 17). This increase was probably due to the removal of growth inhibitors contained in the testa. The flushing action of running water was more effective than merely allowing the seeds to remain in still water.

When seeds were subjected to 50 F for various time

regimes, only the 4 and 6 hour periods significantly retarded the growth rate (Table 18).

In further studies, seedlings were exposed to 40, 50, and 60 F at 2 different stages of germination. The growth rates decreased proportionally with the lower temperatures, regardless of the age of the seedling (Table 19). There was no difference between 40 and 50 F.

Kotowski (36) reported that cucumbers seeds do not germinate at temperatures as low as 51.8 F and that the low limit appeared to be somewhere between 52 and 64 F. Results from the present studies indicate that there is no growth at 50 F or lower. Furthermore, the results may be interpreted to indicate that the growth inhibiting influences accumulate with prolonged exposure to temperatures of 50 F or lower (Table 20).

The smaller seed which were germinated, and on the third day subjected to 50 F for 4 hours grew less than the larger seed treated in a similar manner (Table 21).

The apparent tolerance of the heavier seed to low temperatures may be attributed to a greater supply of food reserves and therefore increased ability to resume growth following the period of temperature stress.

Studies were conducted to determine the relationship between seed size and food reserve as measured by

Table 18: The growth retarding effects of 50 F temperature for various time periods. 1/

Duration of exposure (min)	Average length of 10 roots (cm)
Control (70 F)	3.3 a <u>2/</u>
7	3.2 a
15	2.7 a
30	2.8 a
120	2.8 a
240	1.7 b
480	1.1 b

1/ Seeds were treated on the 2nd day of germination and measured on the 3rd.

2/ Means with uncommon letters are significantly different at the 5% level.

Table 19: Comparisons of root growth of cucumber seedlings subjected to low temperatures at different stages of growth. 1/

Treatment temperatures (F)	Age of seedling when treated <u>2/</u>		
	3 days	6 days	Average
Root elongation (cm)			
40	112	116	114 a <u>3/</u>
50	110	113	112 a
60	149	158	154 b

1/ The duration of each temperature treatment was 4 hours. Seed were measured on the 8th day of germination.

2/ F values for differences in seedling age not significant at 5% level.

3/ Means with uncommon letters are significantly different at the 5% level.

Table 20: The influence of temperature on the growth of cucumber seedlings. 1/

Duration of exposure	Root length (cm)
70 F full time	4.5 a <u>2/</u>
50 F for 4 hr	3.1 b
50 F for 8 hr	1.5 c

1/ Seedlings were treated on the second day of germination and measured on the fourth.

2/ Means with uncommon letters are significantly different at the 5% level.

Table 21: A comparison of cucumber seed sizes on root growth of germinating seedlings. 1/

Individual seed size (mg wt)	Temperature regime <u>2/</u>	
	A	B
	Root growth (cm)	
Below .0250	113	93
.0251-.0290	131	124
.0291-.0330	145	130
over .0330	147	146

1/ F value for temperature regime x seed size significant at 1% level.

2/ Treatment A germinated at 70 F full time; treatment B subjected to 4 hours 50 F on the third day of germination. Measurements made on the seventh day of germination.

respiration rates. There was no significant difference between the rates as measured by oxygen consumption (Table 22).

Greenhouse grown plants

The growth of greenhouse plants subjected to 50 F temperature for 36 hours was retarded. Fourteen days after treatment the plants treated at 50 F for 36 hours averaged 1.7 and 1.9 fewer leaves per plant respectively than plants treated at 60 F or the controls maintained at approximately 75 F (Table 23). There were no apparent adverse affects on growth to plants receiving a 6 hour exposure to either 50 F or 60 F, or to 36 hours at 60 F. The number of days to anthesis averaged 3.9 less on plants treated with 60 F than those treated at 50 F.

Within 2 to 3 days following exposure of plants to 50 F for 36 hours a desiccated appearance of leaf margins was observed. It was postulated that these areas suffered from moisture stress due to the inhibited movement of water through the plant as explained by Kotowski (36).

When different plant parts were exposed to low temperatures, the dry weight of the roots from plants maintained at 55 F were reduced by 78% while the stem and leaves were decreased by 52% (Table 24). At the 55 F

Table 22: Oxygen uptake by seedlings of different seed size

Screen size (inches)	Temperature treatment	ul O ₂ /mg dry wt/2 hr
1/14 x 1/2	70 F full time	19.08
1/14 x 1/2	50 F for 4 hr	17.64
3/64 x 1/4	70 F full time	14.91
3/64 x 1/4	60 F for 4 hr	14.73

1/ F values for differences in oxygen uptake not significant at 5% level.

Table 23: The effect of low temperature on leaf number and days to anthesis. 1/

Temperature (F)	Av no. of leaves 14 days after treatment	Days to anthesis
50	2.3 a <u>2/</u>	32.7 a <u>2/</u>
60	4.0 b	28.8 b
75	4.2 b	28.2 b

1/ Plants were treated for 36 hours during the first true leaf stage.

2/ Means with uncommon letters are significant at the 5% level.

Table 24: Growth when stems and roots were subjected to different temperatures.

Temperature (F)		Dry wt of 5 plants (gm)	
stems	roots	Stems and leaves	Roots
75	75	1.32	0.72
75	55	1.01	0.43
55	75	0.72	0.27
55	55	0.64	0.16

stem and 75 F root levels, the dry weight of roots was reduced by 63% compared to 40% for roots at 55 F with stems and leaves at 75 F (Figure 2). This indicated that the temperature of the micro-environment as well as within the plant may have been several degrees higher than 55 F.

Field grown plants

The treatment of field grown plants with 45 F for 12 hours caused desiccation of the basal pistillate buds (Figure 3). The first fruits were set on the 5th to 7th nodes of plants treated at pistillate bud emergence (Table 25). Plants treated at anthesis responded in a similar manner and set fruit on nodes more distal to the base than the control plants. Within 2 to 3 days following treatment both pistillate buds and flowers abscised.

When control and treated plants were harvested simultaneously the fruit was in different stages of development (Table 26). If a harvest was made as fruit on the treated plants reached optimum maturity for a once-over harvest, the control plants had passed the optimum maturity and vice versa. The delay in growth ranged from 3 to 7 days depending upon temperatures.

Several plants were selected which had enlarging fruit



Figure 2. Cucumber plants after 7 days exposure to different stem and root temperatures (fahrenheit). Stem and root temperatures left to right respectively; 75:75, 75:55, 55:75 and 55:55



Figure 3. The effect of short periods of low temperature on fruit set, (left) control and (right) 45 F for 12 hours

Table 25: The retarding effect of 45 F temperatures on pistillate bud development.

Refrigeration treatment <u>1/</u>	Average no. of nodes to first fruit
control	3.8 a <u>2/</u>
12 hr at pistillate bud stage	6.2 b
12 hr at anthesis	5.9 b

1/ Refrigeration treatments were 45 F.

2/ Means with uncommon letters are significantly different at the 5% level.

Table 26: The delay of harvest maturity of Spartan Dawn plants exposed to 45 F refrigeration treatments. 1/

Refrigeration treatments	Grade of fruit			Total value <u>2/</u> \$/A
	1 and 2	3	4	
Control				
\$/A	31	16	38	85
% of total value	36	19	45	
12 hr 45 F				
\$/A	61	22	20	103
% of total value	59	21	20	

1/ Plants were treated at 5th leaf stage of growth.

2/ F value for differences between total value is significant at the 5% level.

approximately 3 cm in length. The remainder of the fruit on each plant was removed. The attached fruit was measured daily for 12 days and subjected to temperature treatments on the 6th day. The average elongation of all fruit during the 1st 6 days was 4.6 cm (Figure 4). During the 2nd 6 day period the average growth was 7.5, 3.4, and 2.7 cm respectively for the control, 24 hours at 45 F, and 36 hours at 45 F treatments.

Fruit Growth Measurements

A considerable effort was expended utilizing time-lapse photography to measure individual cucumber fruit. However, the major portion of the information obtained was not significantly different than the observations made in controlled environment studies. Hourly photographs did reveal that with a 75 F day and 65 F night, fruit elongated as much as 1 cm in a 12 hour period. This rapid rate of growth was observed only on a limited number of vigorous plants. There was no evidence of diurnal changes in growth rates. Tukey (77) similarly reported that cucumber fruit enlarged in diameter both during the daylight and night hours excepting for about a 5 hour period in the late afternoon and evening. During this period the cucumber fruit contracted because of a lack of moisture.

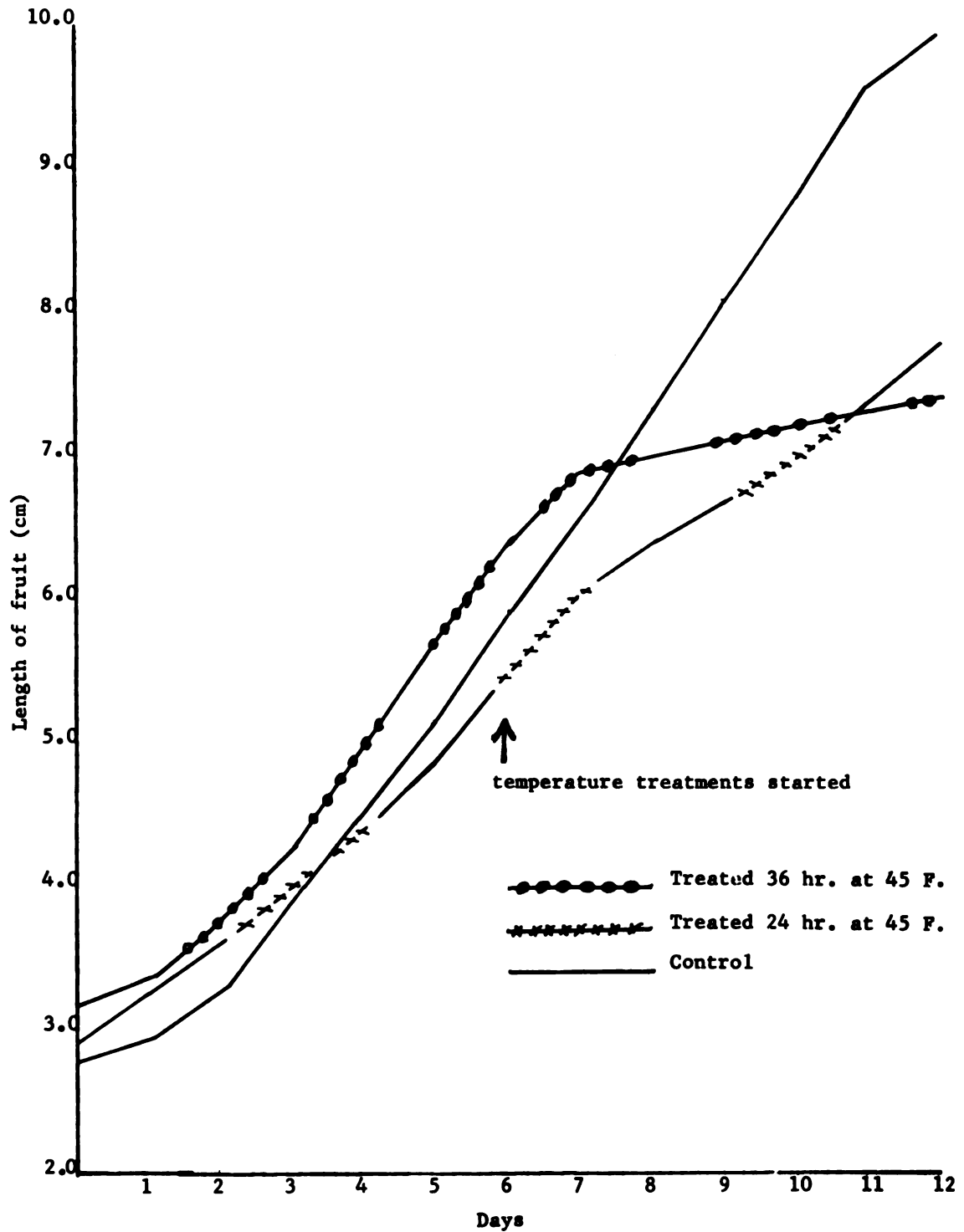


Figure 4. A comparison of fruit growth after exposure to different periods of 45 F (average of 4 fruit per treatment)

SUMMARY

Various plant populations and spacing arrangements of cucumbers were studied for three consecutive years to determine the optimum plant spacing for a once-over mechanical harvest. Spartan Dawn, a gynoeceious type cucumber was the principle cultivar used in all trials. All yield records were from a single destructive harvest. Dollar per acre values proved to be the most realistic means of expressing yield since this measurement accounted for both fruit size and volume.

Plant populations of approximately 77,800 plants per acre of Spartan Dawn consistently produced the highest dollar value per acre. The most suitable spacing arrangement was nine inches between rows with nine inches between plants in the row. When plants were spaced wider than nine inches by nine inches value per acre decreased. Plants spaced closer than this occasionally produced fewer fruit per plant which resulted in lower value per acre.

Different nitrogen levels were studied during a two-year period. In 1963, applications above 60 pounds per acre increased the yield only if supplemental moisture was applied. The following year the highest yields were from

broadcast applications of 60 pounds of nitrogen per acre. Yields were not increased by supplemental applications of nitrogen applied as a side dressing.

Moisture requirements were critical for cucumbers grown for mechanical harvesting. Experience indicated that inadequate soil moisture resulted in poor seed germination and variable plant growth and maturity.

Planting schedules determined by the stage of seedling development were effective when successive seedings were based on the emergence of the first true leaf. Using this criterion the individual blocks were ready to harvest approximately three days apart. This period was decreased if the second planting was based on 80 percent emergence and delayed if the second planting was based on expansion of the first true leaf. The emergence of the first true leaf proved to be the most satisfactory criterion because it generally occurred over a short period of time and there was less latitude for error.

Once-over harvests had the highest dollar per acre value when the first fruit set were 2 to 2 1/2 inches in diameter and exhibited a slight yellow color. At this stage of growth there was a wide distribution of fruit in each grade. Harvest values declined when they were delayed beyond the growth stage when approximately 20

percent of the first-set fruit began to exhibit signs of senescence. In general when growing conditions were favorable the grade and value of fruit declined rapidly within two days.

Cucumber plants in all stages of growth were adversely affected by 50 F or lower temperatures. Root elongation of germinating seedlings was retarded equally by exposure to 40 F and 50 F for four hours. As the length of exposure time increased, longer periods were required for plants to resume growth following favorable temperatures. Seedlings from large seed were less susceptible to adverse effects of low temperatures than seedlings from small seed.

Greenhouse grown plants were exposed to 50 F and 60 F temperatures for 36 hours. Fourteen days later the plants treated with 50 F averages two leaves less than plants treated with 60 F. An additional four days was required for plants to develop to anthesis when they were exposed to these same temperatures. There was no difference in growth rates of plants subjected to 60 F and 70 F temperature regimes for 36 hours.

The treatment of field grown plants with 45 F for 12 hours caused desiccation of basal pistillate buds. Plants treated at anthesis responded in a similar manner and subsequently set fruit on nodes more distal to the base than

the control plants.

Measurements of the growth of individual fruit revealed that a fruit may elongate as much as one centimeter in a 12 hour period during optimum growing conditions. However, 45 F for 24 hours reduced elongation by one-half.

These studies established cultural parameters that would assure the highest potential yield of Spartan Dawn cucumbers subjected to a single mechanical harvest. The successful implementation of these practices will be dependent on effective weed control and an adequate moisture supply throughout the growing season.

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