MECHANICAL CUCUMBER HARVESTING

Thesis for the Degree of M. S.

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Ronald Keith Leonard

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By

Ronald Keith Leonard

AN ABSTRACT

Submitted to the College of Agriculture of Michigan
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Approved Wesley F. Buchele

Michigan ranks first in the United States in the production of pickling cucumbers. Because of the expense and uncertainty of the transient labor used to harvest this crop, a suitable harvesting machine is desired by the Michigan farmer.

The purpose of this thesis is to set forth (1) basic data gathered concerning the physical properties of the cucumber vines and fruit, (2) the design and development of a pneumatic vine trainer and (3) the invention, design and development of a new mechanical cucumber harvester.

The review of literature revealed in a general manner some of the physical characteristics of the cucumber which must be considered in the development of a mechanical harvester. It traced the brief history of harvesting mechanization to the beginning of this investigation.

The study of the problem of providing a commercially acceptable cucumber harvester logically divides into three phases as follows: (1) Physical Properties of Selected Varieties of Pickling Cucumbers, (2) Vine Training for Mechanical Harvesting and (3) Mechanical Cucumber Harvester.

Data were taken on three days during the harvest season to determine the effect of time of day, location of the fruit on the vine and the size of cucumber on the picking force. It was found that the picking force varied significantly only with the size of cucumber.

The picking forces for several varieties were measured. It was found that Wisconsin SMR-12 required the least picking force of the varieties tested.

The strength of the leaves was measured and found to be stronger than required for the vacuum pickup unit used on the mechanical harvester.

The specific weight, the specific gravity and the weight-size relationship of the fruit were determined.

Measurement data were taken to record the geometric size and configuration of the vines, leaves and fruit.

To facilitate the development of mechanical cucumber harvesters which operate from one side of the row, a pneumatic vine trainer was developed which trained the vines to grow perpendicular to the row center. Data were recorded to measure its effectiveness for training the vines and to evaluate its effect upon the fruit set in the root zone.

A mechanical cucumber harvester was invented, designed and constructed which utilized two new principles, i.e. a vacuum pickup and elevating unit and a cleated belt picking bed. This machine was developed so that it functioned satisfactorily under typical field conditions. It was found that a negative static pressure of 10 inches of water acting over an effective hole area in the belt of 42 square inches was required to pick up and elevate the vines. The picking bed functioned in a satisfactory manner but no picking efficiency data were obtained.

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INTRODUCTION

Michigan ranks first in the production of pickling cucumbers, growing nearly one-fourth of the cucumbers raised for pickles in the United States. Ries (1958) states that 40,000 acres yielded an average of 111 bu per acre during the years 1955 to 1957 and was worth about five million dollars a year to the Michigan farmers. Migrant labor for growing and harvesting this crop is now imported from the Southern United States and Mexico. The cost of harvest labor alone is equal to one-half the total value of the crop. Because of the expense and uncertainty of the transient labor used to harvest this crop and the physical exertion necessary to harvest cucumbers by hand, a suitable harvesting machine is desired by the Michigan farmer.

Members of the National Pickle Packers Association have encouraged every possible means to hasten the development of a mechanical cucumber harvester. Consequently, a cooperative research project was established at Michigan State University to further the development of such a harvester. This project is under the direction of Dr. W. F. Buchele and Mr. B. A. Stout of the Agricultural Engineering Department and Dr. S. K. Ries of the Horticulture Department.

During the summer of 1957, four machines (the only completely mechanical cucumber harvesters known to the National Pickle Packers Association) were furnished to Michigan State University by the Association to be used in any manner that would further the development of a commercially acceptable harvester. Since the author was not present for the 1957 field tests of these machines, he drew heavily upon the knowledge gained to form the basis for this study.

Stout (1958a) reported that the overall picking efficiency of these machines was less than 50 per cent. The harvesters varied (1) in their ability to pick up the cucumber vines, (2) in the amount of damage to the vines, fruit and leaves, and (3) in their ability to separate the cucumber fruit from the vines. Because of low picking efficiency and damage to vines and fruit, research into new mechanical devices for performing the functional requirements of a mechanical cucumber harvester was considered necessary to expedite the development of a commercially acceptable machine.

The purpose of this thesis is (1) to set forth basic data gathered concerning the physical properties of the cucumber vine and fruit, (2) the design and development of a pneumatic vine trainer and (3) the invention, design and development of a new mechanical cucumber harvester.

REVIEW OF LITERATURE

The literature review revealed few references dealing explicitly with mechanical cucumber harvesting. A reference source, compiled by Banadyga (1949), applied in a general manner to the entire field of pickling cucumber production. In discussing hand harvesting of cucumbers, Banadyga pointed out five factors which are also pertinent to mechanical harvesting. They were as follows: (1) Hand harvesting cucumbers for pickling is regarded as the largest expense in growing the crop; this expense is governed by the number of pickings. (2) Michigan research workers have shown that the total number of fruit set increases with more frequent pickings, but the total weight of fruit was greatest when there were longer intervals between pickings. (3) Studies of picking frequency ranging from one to seven days showed that financial returns to the farmer were greatest for the four day interval. (4) Many pickle packers pay a premium for small pickles. (5) Cucumber vines are easily injured during hand picking.

In a report on pickling cucumber varieties for Michigan, Peterson and Ries (1958) stated:

> On the basis of four years' results, it appears that the most widely acceptable variety is Wisconsin SMR-12 . . . . . Its principal defects are: (1) lack of firmness as measured by pressure test . . . .

In this same report the L/W (Length/Width) ratio for SMR-12 was 2.8 for cucumbers grown in Ingham County in 1955 and was 2.6 in 1956 and 1957. The ratio generally preferred by Michigan packers is approximately 2.6:1 with an acceptable range of 2.5:1 to 2.8:1. The pressure test referred to in this report was conducted with the standard fruit pressure tester with a five-sixteenth-inch tip. A pressure reading of 14 psi or higher is desirable.

In a report on mechanical cucumber harvesting, Allard (1956) discussed several physical characteristics of the cucumber vine and fruit which might affect mechanical harvesting. He noted that the cucumber was much heavier than an equal volume of vines and leaves and that the cucumbers hang down beneath the vine when the vine is held taut by lifting the end off the ground. He also observed that the size of the plants increased and the vines became brittle as the harvesting season progressed.

For hand harvesting cucumbers, Beattie (1930, 1942) stated that the cucumbers should be planted in rows 6 to 7 feet apart. He observed that each plant branches profusely and forms from 15 to 25 lateral branches. Dependent upon the growing conditions, Beattie felt that pickling cucumbers should be harvested at intervals of 1 to 3 days.

Ries (1958) reported that the fruit should not be allowed to mature on the vine because mature cucumbers hinder the development of new fruit. In a report concerning the economics of irrigating pickling cucumbers, Hoglund

(1958) cited a significant increase in production with a proper combination of fertilizers, irrigation and management. This indicated that future levels of production may be higher; hence, the current harvesting conditions could soon undergo considerable change.

Hall and MacGillivray (1956) reported that a 44-foot wide field conveyor (designed to transport the hand harvested cucumbers to the center of the machine) tripled the hand harvesting rate.

George (1955) indicated that a human carrier for harvesting vegetable crops reduced the harvest time for cucumbers 15 per cent.

Chisholm (1955) described the development of a mechanical cucumber harvester invented by Gilbert[1]. This machine will replace 40 harvest hands and harvest 1 to 1½ acres per hour.

In a report entitled "Mechanical Cucumber Harvester Operation of 1955", Borsenik (1955) furnished data concerning the Grew cucumber harvester[2]. Borsenik found that when compared with the total number of cucumbers in the field, 54.8 per cent were picked in a saleable condition and that the machine operated at the rate of five-eights acre per hour.

At the inoeption of this investigation four machines

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[1]US PATENT NO. 2,829,484.

[2]US PATENT NO. 2,841,947.

designed to harvest cucumbers were undergoing preliminary field testing at Michigan State University under a cooperative agreement with the National Pickle Packers Association. Stout (1958a) described these machines. They included the Gilbert and Grew machines mentioned above, another machine invented by Grew, and the Craig machine. He reported that for the limited amount of data collected, the overall efficiency of these machines was less than 50 per cent.

Stout reported on two problems which limit successful mechanical harvesting with existing machines. These are (1) vine damage and (2) the inability to harvest the cucumbers growing within 6 to 8 inches of the row center. In a later paper Stout (1958b) reported that after several modifications of these machines, the above problems still existed.

The review of literature has suggested in a general manner several of the physical characteristics of the cucumber which must be considered in the development of a mechanical cucumber harvester. It traced the brief history of harvesting mechanization to the beginning of this investigation.

INVESTIGATION

This research endeavor logically divides into three distinct phases and is presented accordingly.

Physical Properties of Selected Varieties of Pickling Cucumbers

The importance of using basic physical data concerning agricultural crops in the solution of mechanization problems is slowly gaining recognition. The topics presented herein were considered to be of fundamental interest to the design and development of mechanical cucumber harvesting equipment.

Objectives

The objectives were to provide physical and design data concerning the cucumber vine and fruit. These data will include the following items: (1) picking forces, (2) strength of the cucumber leaves, (3) specific weight, specific gravity and weight-size relationship of the cucumber fruit and (4) geometric size and configuration of the vine, leaves and fruit.

Procedure

Wisconsin SMR-12 was selected as the variety to be used for all of the physical property studies. As indicated in the Review of Literature, it is "the most widely acceptable variety" in Michigan.

<u>Picking forces.</u> - The force necessary to separate the cucumber from the vine was measured in the field with the spring scale shown in Figure 1. A maximum stop indicator was attached to the indicating scale to record the maximum value of the shearing force. The spring scale was calibrated by using a set of standard weights.

The procedure for conducting the picking force tests was standardized as follows: The cucumber was held firmly against the ground; the spring-scale hook was placed around the stem adjacent to the cucumber. The scale was pulled slowly perpendicular to the axis of the cucumber and stem until the stem separated from the cucumber. The maximum value of the shearing force was recorded.

The picking force study was divided into two parts. First, a three-way classification statistical design was used to determine the effect of time of day, location of the fruit on the vine and the size of the cucumber on the picking force. Data were collected for three periods during the day, 8:30 to 9:00 a.m., 1:30 to 2:00 p.m. and 4:00 to 4:30 p.m. The positions on the vine were classified in two ways: Position 1 - 0 to 6 inches from the root, and Position 2 - beyond 6 inches. The sizes were divided according to H. W. Madison Company grades - number ones (size I), number twos (size II) and number threes (size III).

As each sample was taken, the weight of the cucumber was also recorded. These data were collected in a

Figure 1. Spring scale used to measure picking force.

Figure 2. Cucumber vine. Note the leaves and flowers or cucumbers at each node.

small plot of variety SMR-12, planted June 3 and located on the Michigan State University Horticulture Farm, for the first, third and fifth pickings. The data were obtained for the third and fifth pickings to check the effect of growing season on the picking forces.

The second part of the picking force study was to determine picking forces for several varieties of cucumbers grown on the Horticulture Farm. The procedure for securing the picking forces was the same as described above. For these data only picking forces and weight were recorded for each variety.

Strength of leaves. - The strength of the cucumber leaves was determined by placing the leaves over an orifice and then subjecting the leaf to a measured head of water (Figure 3). When the leaf failed the maximum head was recorded. Orifice plates containing 1/4, 1/2 and 3/4-inch diameter orifices were fastened in turn to the end of a pipe. Heavy grease was applied to the orifice plate before placing the leaf over the orifice. This was done to prevent water from leaking under the edges of the leaf and out of the orifices. After placing the leaf over the orifice and fastening the orifice plate to the pipe, the pipe was filled with water. A glass tube was fastened alongside the pipe and was used to determine the maximum height of the water column.

Specific weight, specific gravity and weight-size relationship. - For measuring the specific weight of the

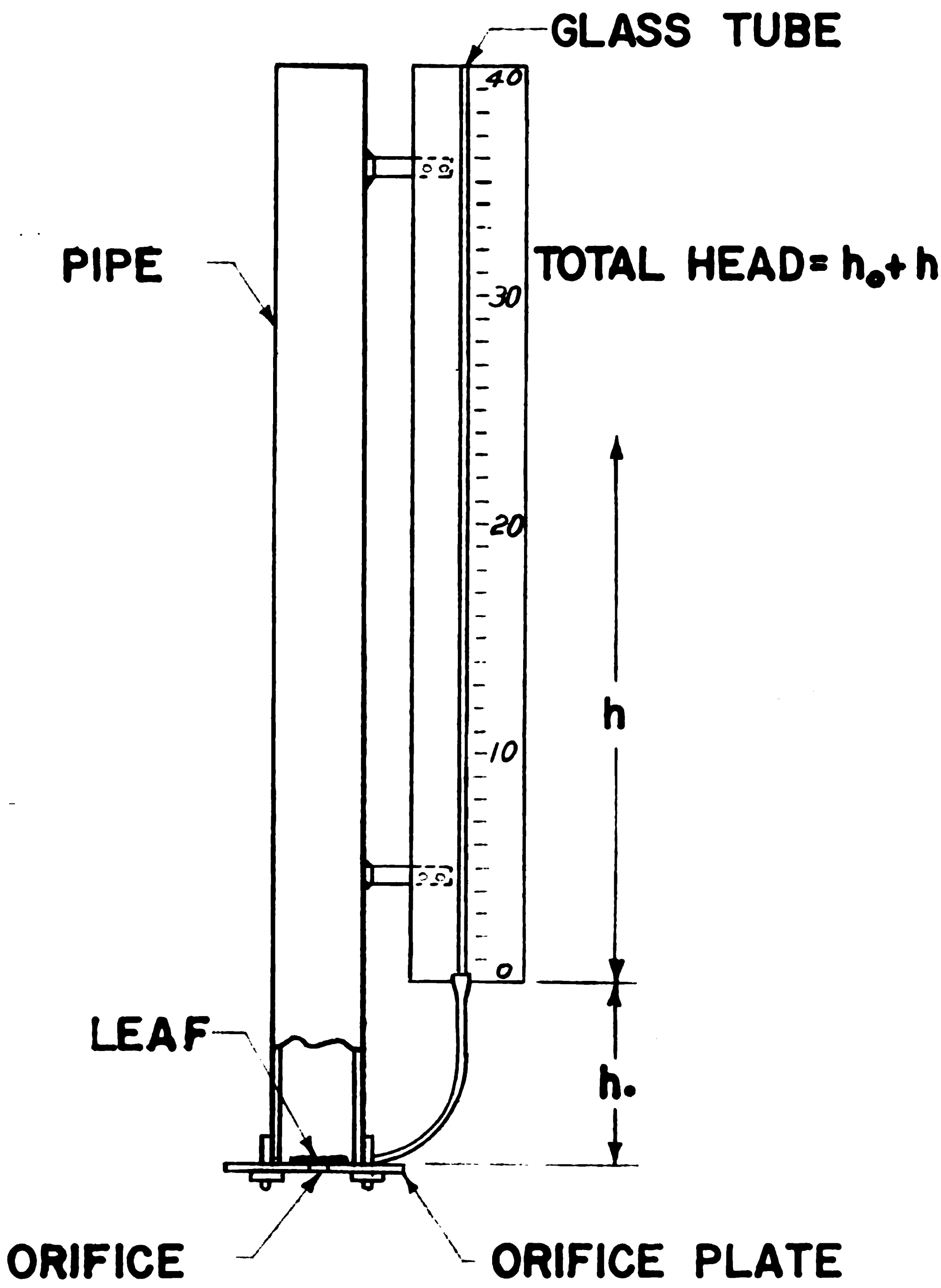


FIGURE 3. APPARATUS USED TO DETERMINE LEAF STRENGTH

cucumber the water displacement method was used to determine the volume of the cucumber. Before submerging the cucumber in the water, it was weighed on a gram balance scale. Graduate cylinders of 100, 500 and 2000 ml capacity were used depending upon the diameter of the cucumber. Since for water, 1 ml $\cong$ 1 cc, by dividing the weight in grams by the volume in cc, the specific weight of the cucumber was obtained directly. In metric units this is also equal to the specific gravity. As each of these measurements were taken, the length and diameter of the cucumbers were also recorded. This information and the weight of the cucumber were analyzed to establish the mathematical relationship which was discovered between the weight and length and the weight and diameter of the cucumber.

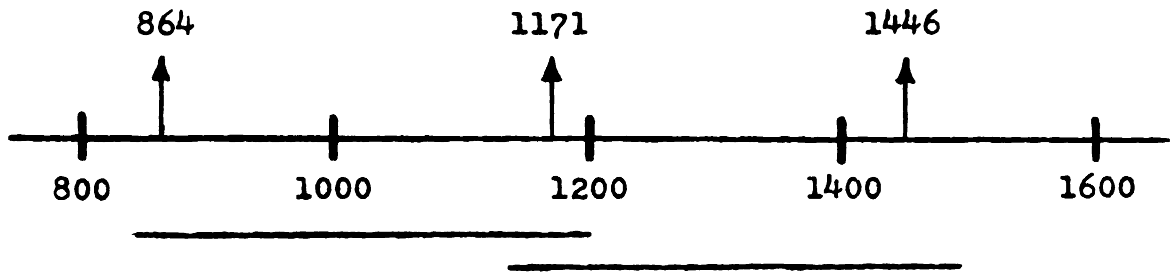
Geometric size and configuration of the vine, leaves and fruit. - To observe the growth characteristics of the vine, limited data were collected indicating the number, size and spacing of laterals at various stages of the vine growth. Also, the height of the leaves above the main stem, area of the leaves, diameter of the main stem and length of vine were recorded. The length, diameter and weight of the fruit were recorded for the specific weight determination.

Results and discussion

Picking forces. - An analysis of variance of the picking force data showed that the size of cucumber affected the picking force significantly at the 5 per cent level. The Studentized Range Test[1] of the picking force averages for the three sizes indicated that a significant difference existed only between the average of Size I and the average of Size III cucumbers. Table 1 portrays these results.

TABLE I

STUDENTIZED RANGE TEST[a] OF AVERAGE PICKING FORCE (gms) FOR SIZE I, II, AND III SMR-12 CUCUMBERS AT FIRST PICKING



[a]Lines joining any two numbers indicate no significant difference.

Position on the vine and time of day did not affect the picking force significantly, therefore, only force and weight were recorded during the third and fifth pickings.

Since force and weight had been recorded for each sample, it was possible to perform an analysis of covariance of the data. This analysis of the first picking data showed that, when all of the data were adjusted to the same weight of pickle to eliminate the effect of size, there was no significant difference in the picking force. This supports the previous analysis that picking force is dependent upon

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[1]David B. Duncan, "Multiple Range and Multiple F Tests," Biometrics, Vol. II, No. 1 (March, 1955), 1-42.

size.

To establish the relationship between picking force and size or weight, the data for all three pickings were analyzed separately. Regression equations of the form

$$F = a + bW \pm SE$$

where

F = Picking force in grams

a = F-intercept

b = Slope of the line

W = Weight in grams

SE = Standard error

were calculated for each set of data and are plotted in Figure 4. These equations for the first picking on July 31, 1958, third picking on August 7, 1958, and fifth picking on August 15, 1958, respectively, are as follows:

$$F = 902 + 3.55W \pm 410 \qquad (1)$$

$$F = 1002 + 2.72W \pm 387 \qquad (2)$$

$$F = 1107 + 2.05W \pm 472 \qquad (3)$$

Equations (1), (2) and (3) were tested for significance. The "t" tests for the slopes of the line at the 5 per cent level indicated no significant difference between any of the slopes; the "t" tests for the F-intercepts showed a significant difference between the F-intercepts of equations (1) and (3). It should be noted that (for the three dates) the slopes were decreasing while the F-intercepts

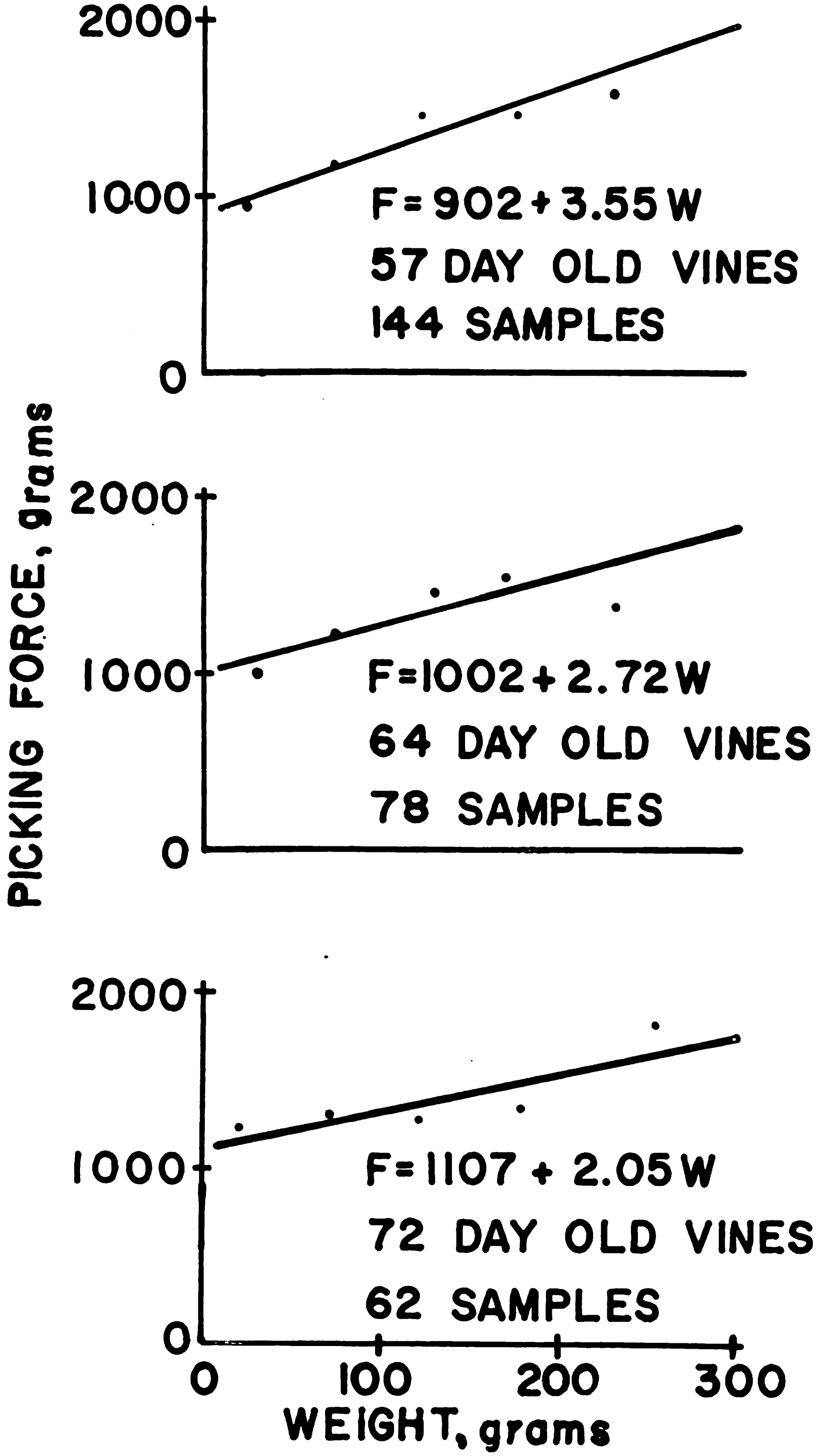

FIGURE 4. PICKING FORCE VS WEIGHT OF SMR-12 VARIETY

were increasing.

The average picking force and weight for the three dates are shown in Table 2.

TABLE 2

AVERAGE PICKING FORCE AND WEIGHT FOR THREE HARVEST DATES OF SMR-12 CUCUMBERS

Date	Force	Weight
1958	gms	gms
July 31	1162	72.8
August 7	1245	89.5
August 15	1369	128.0

The results of the picking forces obtained from ten different varieties of cucumbers grown on the Michigan State University Horticulture Farm are shown in Table 3 for two different dates. These data were adjusted to the same weight by using the mathematical relationships (1), (2) and (3) obtained for the SMR-12 variety. It was assumed that these relationships held for all varieties. The only justification for this assumption is simply that this is the only variety for which such a relationship has been obtained; however, the author feels that similar relationships can be found for all varieties.

Table 3 indicated that there was a difference in adjusted picking force between SMR-12 and the rest of the

TABLE 3

PICKING FORCES AND WEIGHTS FOR TEN VARIETIES OF PICKLING CUCUMBERS

Variety[a]	July 31, 1958			August 21, 1958		
	Average Force	Average Weight	Adjusted[b] Force	Average Force	Average Weight	Adjusted Force
	gms	gms	gms	gms	gms	gms
Wisconsin SMR-12	904	31	1160	1191	78	1260
Wisconsin SMR-18	1140	41	1315	1700	44	1870
Robinson Rx15	1308	55	1440	1786	74	1870
MSU No. 122 Chse 1955	1356	42	1530	1784	99	1790
Wisconsin SMR-15	1369	26	1610	1667	96	1690
Cr. Block #3, 1957	1461	52	1615	1541	71	1630
MSU Hybrid 213xMR25	1458	29	1670	1498	66	1600
MSU Hybrid 208xMR25	1660	75	1730	1666	113	1630
MSU Hybrid 122x143	1658	66	1760	1682	62	1805
Nappa 63	1612	36	1805	1666	59	1790

[a] Furnished by Dr. Ries and Dr. Peterson of the Horticulture Department.

[b] Values are for 100 gram cucumbers and were obtained assuming equations (1), (2) and (3) were valid for all varieties.

varieties. The other varieties are inconclusive because of the variation in adjusted picking force between the two dates.

<u>Strength of leaves</u>. - It was found that the cucumber leaves when acting as a diaphram over a three-fourths inch diameter orifice would support at least an 80-inch column of water. Because this strength was far in excess of the practical limit of pressures developed by mechanical fans, the leaf strength tests were terminated without determining the maximum strength. Earlier work performed by the author with vines grown in the greenhouse had indicated that the strength of the leaves would be considerably less. Since none of the leaves tested failed due to the static application of a water head of 80 inches, it was concluded that the use of a vacuum pickup device (described on page 32 of this thesis) would not be limited by the strength of the leaves.

<u>Specific weight, specific gravity and weight-size relationship</u>. - The average specific gravity of 109 cucumbers was 0.96 with a range of 0.89 to 1.00. The maximum error in measurement was $\pm$ 2.5 per cent. This error was primarily due to the volume measurement of the cucumber which was obtained by the water displacement method. The specific weight of the cucumbers was 60.0 pounds per cubic foot and the L/D (Length/Diameter) ratio was 2.8. This L/D ratio checks work reported in the Review of Literature for this same variety (Wisconsin SMR-12).

During the process of measuring the specific weight of the cucumbers it was discovered that there was a definite relationship between the weight and length and the weight and diameter of the cucumber. These relationships plot as straight lines on semi-logarithmic graph paper and are shown in Figures 5 and 6. The equations of these curves were obtained by the method of least squares and are as follows:

For length:

$$W = 2.44e^{0.82L} \tag{4}$$

For diameter:

$$W = 4.14e^{3.88D} \tag{5}$$

where:

W = Weight in grams

e = Base of natural logarithms

L = Length in inches

D = Diameter in inches

This discovery was of primary importance because picking force can now be related to length or diameter of the cucumber by using equations (1), (2) and (3) with equations (4) and (5). It is not known whether this same relationship holds for all varieties of pickling cucumbers, but since it has now been discovered it would be relatively easy to check.

Geometric size and configuration of the vine, leaves and fruit. - It was difficult to obtain an exact indication

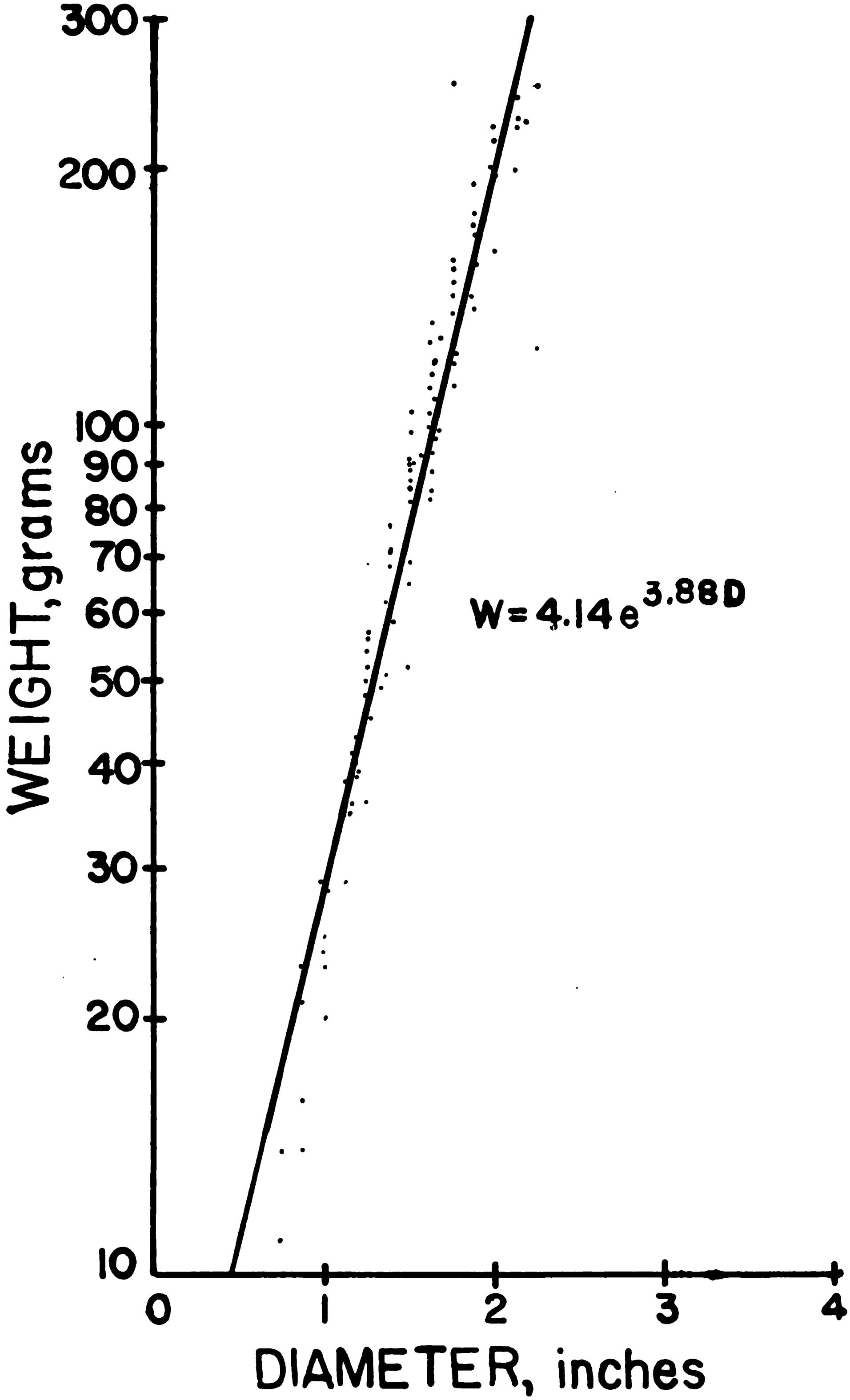

FIGURE 5. WEIGHT-DIAMETER RELATIONSHIP OF SMR-12 VARIETY

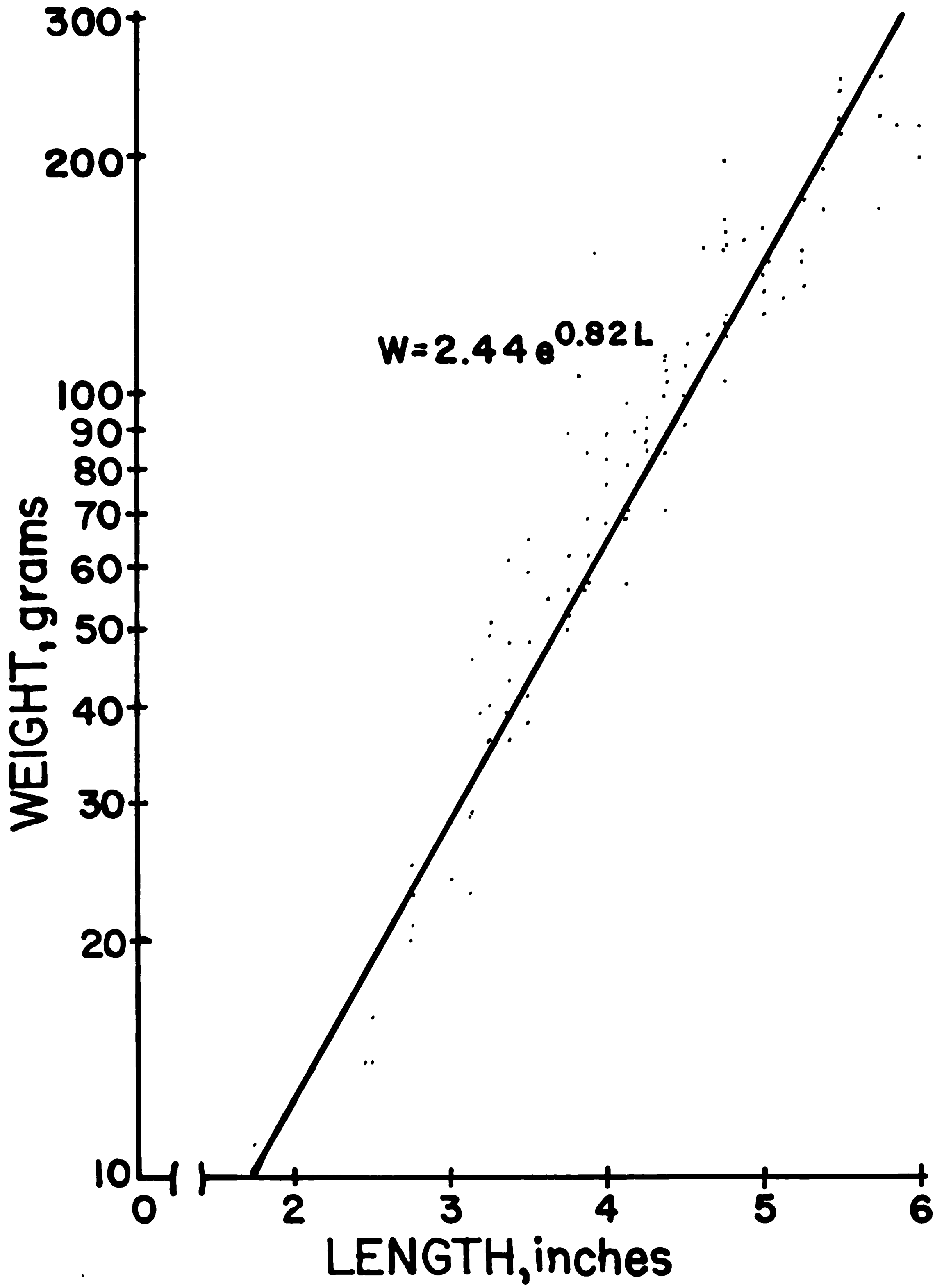

FIGURE 6. WEIGHT-LENGTH RELATIONSHIP OF SMR-12 VARIETY

of the size of the vine because of the differences that existed between the vines.

The vines start to topple over and "run" (grow along the ground) when approximately 8 to 10 inches high. Just before the first picking on vines planted on the F. C. Anderson farm located at Dansville, Michigan, the vines averaged about 24 inches long. At the time of the fifth picking the length of the main stem was from 60 to 72 inches. Experimental plots planted for machine harvest indicated that a 72-inch row spacing would be satisfactory because the vine rarely grows in a direction perpendicular to the centerline of the row.

Laterals (branches which start to grow perpendicular to the main stem) begin forming soon after the vine starts to "run". These laterals start growing at the root of the vine and the first 4 or 5 are spaced from 1 to 2 inches apart. At the time of the second picking nearly all of these laterals were within 12 inches of the root of the vine. After the first 4 or 5 laterals, the spacing between the leaves (which grow at each node where a lateral will later emerge) is from 3 to 4 inches. These leaves continue growing to the end of the vine. The number of laterals of sufficient age to bear fruit is usually 3 to 6. These laterals produce most of the cucumbers and at times nearly approach the size of the main stem. The flowers (male or female) emerge from the nodes as shown in Figure 2 on page 9. This figure also shows the manner in which the laterals and leaves are attached to the vine stem. The cucumbers are attached to the vine by stems which are approximately one-eighth inch in diameter and range from one-fourth to three-fourths of an inch long.

In the first one-half of the vine (including laterals) the average height of the leaves above the main stem was 7 inches. The stem of the leaves grows nearly perpendicular to the ground and to the main stem of the vine. The leaf in turn grows perpendicular to the leaf stem and is, therefore, nearly parallel to the ground. The area of the leaves varies considerably depending upon the size of the vine; however, the average area of the leaves measured was approximately 25 square inches. The total number of leaves for the average size vine at the time of the second picking was approximately 50 leaves.

It should be noted at this point that information about the length of vine, height and size of leaves, and number and spacing of laterals is subject to variations from plant to plant and from row to row. The numbers which have been presented for these items are averages for the vines in the plot from which the data were measured.

Vine Training for Mechanical Harvesting

Mechanical cucumber harvesters which pick from one side of the row require that the vines be trained to grow to one side of the row. Mr. Grew of Saginaw, Michigan, conceived the idea of training the vines (positioning all vines on one side of and perpendicular to the row center) with a modified Ferguson side delivery rake so that he could train vines for his mechanical cucumber harvesters. The modifications of this side delivery rake included removing one-half of the bars, changing the slope of the tines and rotating the rake reel backward.

This modified side delivery rake was furnished to Michigan State University along with the four mechanical cucumber harvesters at the initiation of this research project.

Field tests of this machine in 1957 revealed that it not only trained the vines but also caused extensive damage to the leaves and could only be used once or twice on the same vines during the early part of the growing season.

Objectives

The objective was to provide a machine for training the vines to grow to one side of the row which would not damage the vines and could be used as often as necessary during the growing season.

Procedure

Of the various ideas considered by the personnel working on this research project for training vines, a pneumatic device which would move the vines by air action alone appeared to offer the best possible solution. Because the mechanical cucumber harvester described on page 37 of this thesis utilized a John Deere Cotton Picker Fan, AL-1732N, this part of the machine was used in the construction of a vine trainer.

The vine trainer consisted of a large fan, a length of pipe and a discharge duct as shown in Figure 7. The fan was mounted on the Fast-Hitch drawbar of an International Model 230 tractor. The pipe extended alongside the tractor from the outlet of the fan to the front end of the tractor. The discharge duct was placed parallel to the ground about 4 inches above and slightly to one side of the row.

A disk attached to the cultivator frame was used to throw soil on the lower 2 to 3 inches of the vine to hold it in place after the action of the air had blown all the vines to one side of the row.

After field testing this machine to determine its effectiveness, an Allis-Chalmers Model G tractor and another fan (Clarage Fan Company, Ser. 5372U, Size 3/4) were secured and made into a vine trainer as shown in Figure 8. This machine was used throughout the season to train the vines for the harvesters and all data presented resulted from this machine.

Figure 7. Pneumatic vine trainer mounted on IHC Model 230 tractor.

Figure 8. Pneumatic vine trainer in action mounted on Allis-Chalmers Model G tractor.

The performance of the vine trainer was measured by selecting at random several sections in each row and then counting the total number of vines, the number of vines growing perpendicular to either side of the row and the number of vines growing parallel to the row. A vine was considered to be growing parallel to the row if it laid within a 30° angle from each side of the row center. These data were obtained for vines grown on bedded rows and on normal flat rows.

Data were secured to measure the effect of the vine trainer on the number of fruit set in the root zone (defined to be a strip 12 inches wide, 6 inches on either side of the row center).

Data were also collected to measure the natural growth of the untrained vine. All of the data were taken in a 5-acre field on the F. C. Anderson farm located at Dansville, Michigan, and are for Wisconsin SMR-12 variety. Approximately one-third of the vines were planted in bedded rows. The beds were constructed 7 inches high with 30° side slopes. The rows were all planted north and south on 84-inch centers.

Results and Discussion

The pneumatic vine trainer (Figure 8) provided a satisfactory method for training the vines. The optimum time for training is when the vines are 12 to 14 inches long and occurs shortly after the vines have started to "run." Several training operations were required because of unevenness in the emergence of the plants and because the plants are continually growing and forming new laterals.

The results of the effectiveness of the vine trainer at the fourth training operation are shown in Table 4.

TABLE 4

EFFECT OF PNEUMATIC VINE TRAINER ON 48 DAY OLD VINES 20 TO 24 INCHES LONG

Rows	Untrained Vines[a]		Vines Growing Parallel to Row	
	Before[b]	After	Before	After
	per cent		per cent	
Flat	1.9	1.6	17.5	7.6
Bedded	3.2	0.3	3.7	1.5

[a]Vines growing in direction opposite of training.

[b]Before fourth training operation.

Table 4 shows that after the fourth training operation less than 2 per cent of the vines were untrained. Part of these untrained vines were due to the row marker crops which were located in the center of the row. (The marker crops - oats, buckwheat or sudan grass - were planted to locate the center of the row for the machine operator). A vine would often tie to the marker crop and thus was impossible to move by wind action.

Table 4 also indicates that the fourth training operation reduced the number of vines growing parallel to the row in the flat rows by 10 per cent. This is a significant fact because it is desirable to have the vines and laterals straightened out perpendicular to the row center for the mechanical harvesters.

To establish the manner in which untrained vines grow, data were collected for flat, untrained rows and are reported in Table 5.

TABLE 5

NATURAL GROWTH OF UNTRAINED VINES PLANTED IN FLAT NORTH-SOUTH ROWS

Date	East	West	Parallel	Total Number of Vines
1958		per cent		
July 21	37	32	31	151
July 27	40	26	34	231
July 28	46	21	34	233
July 28	37	19	44	167
Averages	40	24	36	

The significant facts contained in Table 5 are explained as follows: (1) An average of 36 per cent of the untrained vines were growing parallel to the row. Unless these vines are straightened out, it is nearly impossible for the present mechanical harvesters to pick up the vines. When this figure is compared with the result shown in Table 4 of only 7.6 per cent of the vines growing parallel in the flat rows after the fourth training operation, it is apparent that the action of the vine trainer straightens vines which would otherwise grow parallel to the row. (2) An average of 16 per cent more vines were found to be growing to the east. The reason for this can be ascribed to the prevailing westerly winds. As local conditions may affect these results, they should not be construed to hold for all fields.

Since the vine trainer effectively straightened out the vine and laterals, a check was made on the number of fruit set in the root zone. These results are shown in Table 6.

TABLE 6

EFFECT OF PNEUMATIC VINE TRAINER ON NUMBER OF FRUIT SET IN THE ROOT ZONE[a]

Row	Number of Fruit	Number of Vines	Number of Fruit Per Vine
Flat, untrained[b]	330	199	1.6
Flat, trained[c]	227	294	0.8
Bedded, trained[c]	200	345	0.6

[a]Data are totals of four 50 foot sections selected at random from each row.

[b]Data taken from a strip 12 inches wide, 6 inches on either side of the row center.

[c]Data taken from a 6 inch strip on the trained side of the row.

The trainer reduced by one-half the number of fruit in the root zone on the flat rows and more than one-half on the bedded rows. There are two reasons for this result. First, because the vine is straightened out, there are fewer blossoms in the root zone. Second, the air blast removed some of the blossoms near the root.

Mechanical Cucumber Harvester

The machine described in this section was conceived in conferences between the author and his Adviser, Dr. Buchele, during the fall of 1957.

The preliminary design was completed during December, 1957, and January, 1958. This machine was constructed during the period from February through June, 1958. Field testing and developmental work were done during July and August, 1958.

Objectives

The objectives were to invent, design and develop a new mechanical cucumber harvester using a vacuum pickup device and a flight-elevator type picking bed.

Design and construction of the machine

The functional requirements of a mechanical cucumber harvester are as follows:

1. Pickup - make vines transportable.
2. Picking - remove cucumbers from the vines.
3. Separation - between vines and cucumbers.

4. Collection - vines on ground and cucumbers in container.

The design and construction of this machine were divided into five distinct phases and are presented accordingly. An overall view of the complete machine is shown in Figure 9.

Pickup unit. - Because one of the major problems with the existing mechanical cucumber harvesters was vine damage (breaking, crushing or pulling the vine from the ground) caused by the pickup units (rubber rollers or vine gathering points), a new approach to the problem of picking up the vine was sought. Since it was known that the fruit would hang down from the vine when the vine was held taut at the outer end and lifted off the ground, a search was made for a mechanical device which would accomplish this action.

The author had observed that there was a large leaf area for each vine. These leaves tended to form a canopy over the vines from 6 to 8 inches above the ground. This observation lead to the idea of a vacuum pickup which would grasp the leaves and then elevate the vine off the ground.

The vacuum pickup idea was selected because: (1) This apparatus would place the vines on the picking bed with the cucumbers hanging free. (2) With the existing machines the cucumbers become entangled in the vine and do not hang free and are sometimes crushed between the pickup rollers. (3) It would reduce machine contact with the vines and fruit

Figure 9. Overall view of the mechanical cucumber harvester. Note pickup unit at the left between front wheels, picking bed under the tractor and fan mounted on the drawbar.

because it would touch only the leaves and thereby cause less vine damage.

The requirements of the vacuum pickup device included the following items: (1) sufficient width to cover most of the vine, (2) correct amount of lifting force created by vacuum, (3) flexibility and (4) elevating capability.

To fulfill these requirements a three-ply rubberized fabric belt (perforated with one-half-inch diameter holes) was operated around a sheet metal vacuum chamber open on the underside (Figure 10). Crowned rollers were mounted at the top and bottom of the vacuum chamber and were adjustable for aligning and tightening the belt.

The belt speed and direction were geared so that the relative movement between the underside of the belt and the ground was zero. The vacuum chamber was sloped upward so that the vines, after being picked up, could be elevated from the ground to the picking bed by the moving belt. Because the bottom of the vacuum chamber was open, air could flow only through the holes in the underside of the belt. The force created by the vacuum on the inside surface of the belt caused the belt to pull against the edges of the vacuum chamber, thus sealing itself against possible leaks.

The amount of lifting force required to lift the vines could not be determined until the machine was operated in the field; however, preliminary calculations of air flow and static pressure indicated that the vacuum available at the one-half-inch diameter holes should be at least 5 inches

Figure 10. Side view of vacuum pickup unit. Note sheet metal vacuum chamber inside the belt, the transition elbows and the two rollers mounted on the front of the picking bed.

Figure 11. View of the picking bed.

of water to lift the vines.

<u>Picking bed</u>. - The picking efficiency of the existing mechanical cucumber harvesters was less than 50 per cent. This led to a search for new picking mechanisms.

After studying the existing machines and the preliminary designs of new picking principles conceived in conference, the cleated belt picking principle as shown in Figure 12 was selected as the mechanism to be investigated. This principle seemed desirable because it performed two functions - picking and elevating with one mechanism.

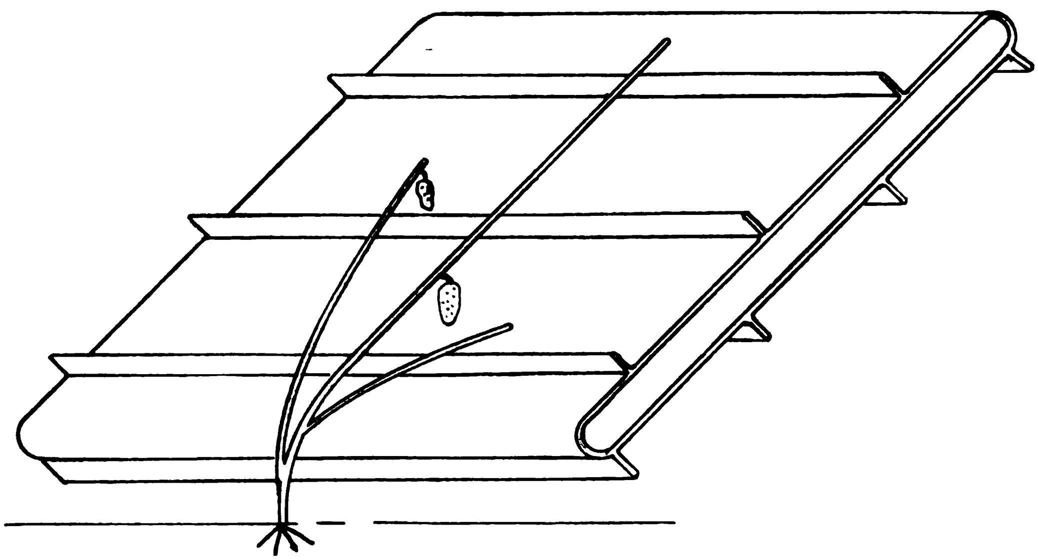

Figure 12. Cleated belt picking principle.

After cost estimates indicated that a composition belt was too expensive to be considered at that time, a search was conducted for a device which would: (1) simulate the action of the cleated belt and (2) allow variable height and spacing of the cleates so that the most efficient combination could be obtained. The unit constructed to fulfill these requirements is shown in Figure 11.

The cleats were fabricated by fastening a 20-gauge sheet metal angle to a 3-inch high strip of composition belting one-fourth-inch wide. The ends of these flight elevator cleats were fastened to a No. 60 roller chain. The chain operated around a sheet metal apron. Mounting shafts for the chain sprockets were located at either end of the apron. The cleats were spaced 12 inches apart and were 43 inches long. An interesting feature of the construction is the recessed grooves for the roller chain on each side of the picking bed.

This picking unit was designed to perform the picking, separating and collecting functions simultaneously.

<u>Fan and ducts</u>. - To create the vacuum at the holes in the pickup belt a John Deere Cotton Picker Fan, AL-1732N, was mounted on the Fast-Hitch drawbar of the tractor (Figure 13) and ducts were extended to the front of the tractor and joined to the sides of the vacuum chamber which was located inside the pickup belt (Figure 10).

The ducts were fabricated from 8-inch diameter galvanized stove pipe. Flexaust hose was used to join the ducts to the pickup unit. This provided the necessary flexibility for raising and lowering the pickup unit.

<u>Power application</u>. - The belt pulley drive shaft and the PTO (power take-off) drive shaft were used to supply

Figure 13. Rear view of harvester showing fan and ducts, main frame along right side and main drive shaft directly under main frame.

power from the tractor to drive the machine. Figure 14 shows details of the drive connections to the tractor.

A V-belt drive was used to power the fan. An 8.6-inch diameter double "B" section V-belt sheave was mounted in place of the regular flat belt pulley. Beneath this sheave a jack shaft was mounted on the Fast-Hitch drawbar so that the fan speed could be increased by driving a double "B" section 3.75-inch diameter sheave on the jack shaft. An 8-inch "C" section sheave located adjacent to the 3.75-inch diameter sheave on the jack shaft was then used to drive the 7-inch sheave on the fan.

The PTO was used to provide power to operate the remainder of the machine. A main drive shaft was installed along the right side of the machine and was driven by a No. 50 roller chain from the PTO (Figures 13 and 14). The picking bed was driven by taking power from the main drive shaft with No. 50 roller chain down to the pivot drive shaft on the bed. At the front end of the main drive shaft, a 2:1 reducing gear box was installed. From this gear box a No. 40 chain drive was used to power the pickup roller.

To control the main drive shaft, a combination slip-clutch and throw-out clutch was installed on the driven sprocket from the PTO (Figure 13).

<u>Main frame and mounting on tractor</u>. - As indicated previously, the fan was mounted on the Fast-Hitch drawbar of the tractor as shown in Figure 13. This was done so that the action of lowering the drawbar with the hydraulic lift

Figure 14. Drive connections to tractor. V-belts power fan and roller chain from PTO drives the machine.

Figure 15. Picking bed lift linkage. Note the picking bed roller chain drive at right.

would tighten the V-belts and thus act as a clutch to control the fan.

A main frame constructed from a 2-inch channel iron was installed along the right side of the machine as is shown in Figure 13. This frame was used to support the picking bed and the main drive shaft.

The pickup unit was mounted on beams extending on each side of the front end of the tractor (Figure 10). It was pivoted on the top roller and was lifted by installing a hanger (Figure 21) on the lower end of the pickup unit frame. The unit was raised and lowered by using the hydraulic lift arm on the left side of the tractor. A cable connected the hydraulic lift arm to the hanger on the lower end of the pickup unit frame.

The picking bed was lifted by a simple lever system (Figure 15) which was attached to the rear of the bed. The cable fastened to the top arm of the lift linkage (Figure 15) was connected to the hydraulic lift arm on the right side of the tractor.

Wherever possible, adjustments were provided in the mounting brackets to facilitate field testing to determine the proper relationship of the working parts of the machine.

Test procedure

The development of any machine is a long and tedious task. Before operating in the field, the entire machine was tested for mechanical fitness. Field testing the mechanical cucumber harvester was necessarily restricted to the availability of suitable vines. In order to lengthen the picking season, cucumbers were planted at four different dates by the Horticulture Department and made available to the Agricultural Engineering Department.

The test procedure for a machine which performs several functions is dictated by the order in which these functions occur in the machine. The test procedure was as follows: (1) The pickup unit was tested first as a separate unit and was developed until it operated satisfactorily. (2) The picking bed was then added to the machine and developmental work was conducted on the entire machine.

Vacuum pickup and elevating unit. - The static pressure in the system was measured with the U-tube manometer as shown in Figure 16. High static pressure losses were found in the elbows which joined the vacuum chamber to the flexaust tubing (Figure 10). After the elbows were improved, the pickup unit was operated in the field.

The proper combination of hole area, hole spacing and fan speed was then determined to provide adequate vacuum force for lifting the vines.

It was necessary to add two sponge rubber rollers (Figure 10) to the front edge of the picking bed to facilitate lifting the vines onto the bed. Before installing the rollers, the vines had often caught on the front edge of the bed due to insufficient clearance between the pickup unit and the picking bed.

Figure 16. U-tube manometer used for static pressure measurements.

Figure 17. Vine support rod located on picking bed.

Flight elevator picking bed. - This unit was first tested to determine its functional capabilities.

After determining that the picking principle was satisfactory, a vine support rod (Figure 17) was installed on the root zone side of the bed to prevent vines from being torn out of the ground.

Measurements were made of the force which the cleats were applying to the vines while on the picking bed. Figure 18 shows the manner in which these measurements were obtained. A trench was dug alongside the picking unit. A vine was pulled from the ground and placed on the picking unit with the root at ground level. The spring scale used in the picking force measurements was attached to the root of the vine and held so that the maximum tensile force at the root was measured.

Photographs were taken of the machine operation and of the condition of the vines after the machine had passed. Limited data were obtained to measure the vine damage and machine capacity. To do this, two test plots were laid out in adjacent rows. The machine was then timed for each run. The leaves and other material stripped from the vine were collected and weighed. An estimate of the total weight of the material which had passed over the machine was obtained. This was done by counting the total number of vines in the test strip and then multiplying this number by the average weight of several vines selected from that strip. Vine damage was then expressed as a percentage of weight lost.

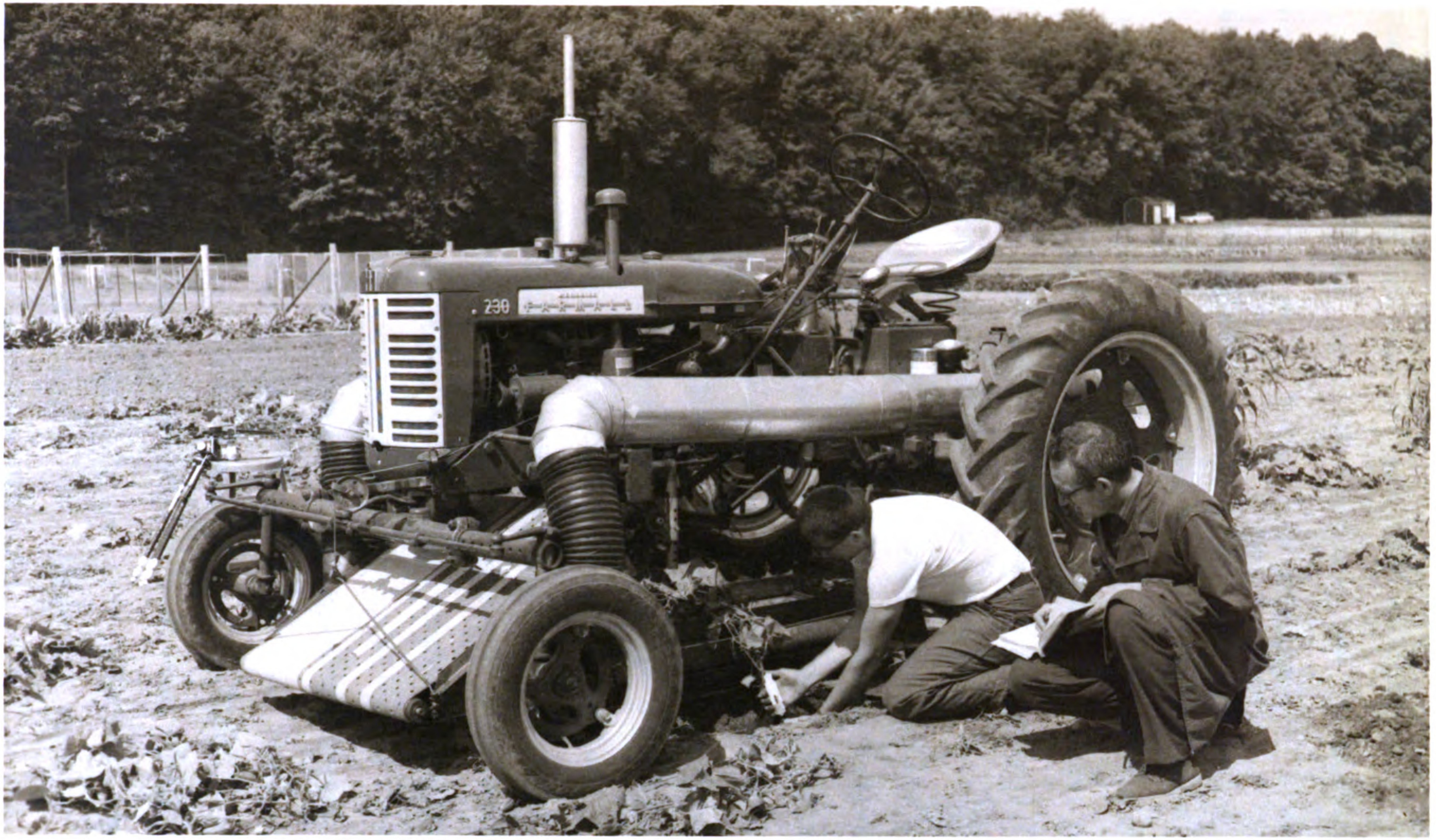

Figure 18. View showing the author and Dr. Buchele measuring vine tensile forces due to picking action of the cleats.

The capacity of the machine was then calculated by using the length of the plot, the time consumed for the machine to harvest this plot and a 6-foot row spacing.

Results and discussion

The entire machine described in this thesis was developed to operate satisfactorily. Because most of the harvest season was required for this developmental work, little time was available at the end of the season for testing the performance of the machine; however, data which were collected in the process of developing the machine will be set forth. The results presented include the following topics: (1) static pressure determinations, (2) final operating rpms and velocities of the machine elements, (3) tensile forces in the vine due to the picking action of the cleats on the picking bed, (4) vine damage and machine capacity and (5) description of the machine operation.

Static pressure determinations. - Figure 19 indicates that the minimum negative static pressure occurred in the vacuum chamber (at 2000 rpm, maximum engine speed) with the maximum effective hole area of 85 square inches in the belt. Figure 20 shows the relation of the negative static pressure to the tractor engine rpm. Field tests indicated that 10 inches of negative static pressure was required to elevate the vines as the machine moved down the row. This pressure was obtained by covering half the hole area with masking tape as shown in Figure 21. The effective width of the pickup belt was then approximately 24 inches.

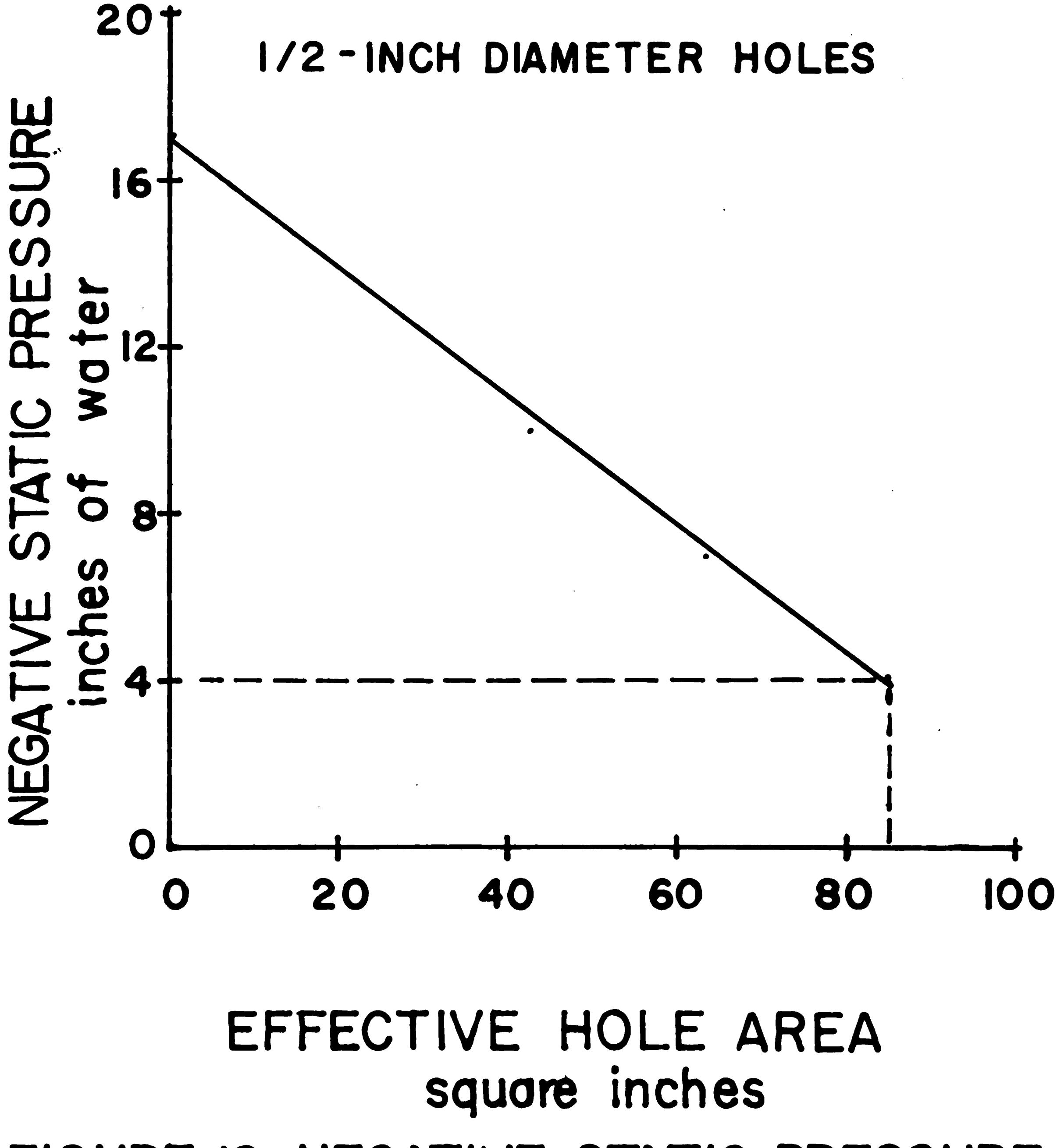

FIGURE 19. NEGATIVE STATIC PRESSURE VS BELT HOLE AREA

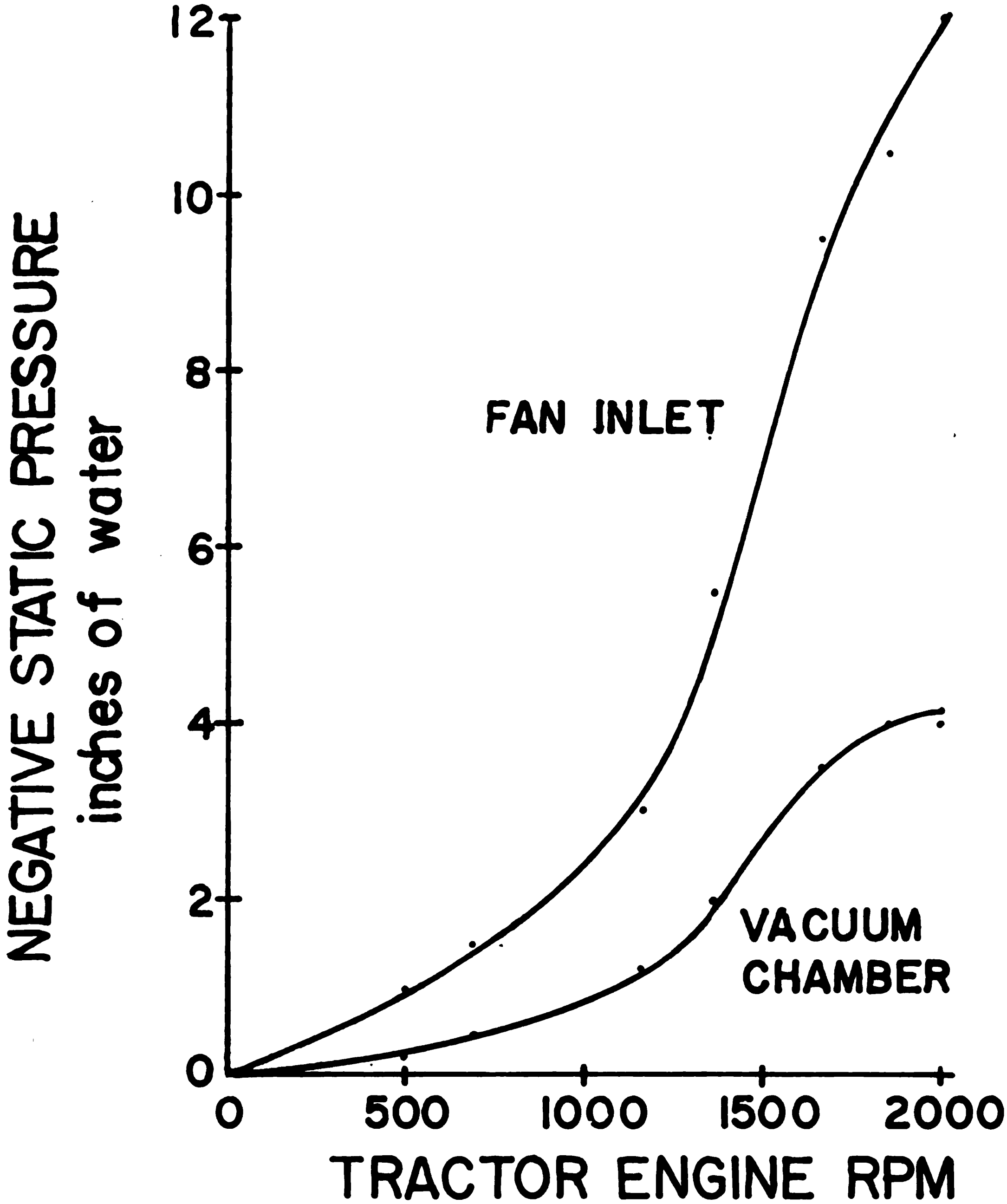

FIGURE 20. NEGATIVE STATIC PRESSURE VS ENGINE RPM

<u>Final operating speeds of machine elements</u>. - The rpm or velocity of the machine elements at the end of the development phase are as follows:

1. Tractor engine - 2000 rpm
2. Fan - 3400 rpm
3. Main drive shaft - 272 rpm
4. Picking bed - 344 rpm
5. Pickup belt - 86 rpm
6. Pickup roller, 5-1/4 inch diameter - 234 rpm
7. Pickup roller, 1-3/4 inch diameter - 602 rpm
8. Linear velocity of pickup belt - 71 fpm
9. Linear velocity of picking bed cleats - 338 fpm

<u>Tensile forces in vine due to picking action</u>. - Without the vine support rod (Figure 17), the picking action of the cleats on the picking bed pulled the vine out of the ground. This rod was positioned 10 inches above the ground and parallel to the top edge of the cleats. With the rod in this position, the tensile forces were then measured. Table 7 indicates the results of these force measurements. The maximum force of 2.5 lbs occurred at the greatest linear velocity of the cleats. With the rod located in this position, no vines were torn from the ground because of the action of the cleats tugging on the vines.

The results of the data collected to measure vine damage and machine capacity are set forth in Table 8. The results in Table 8 are not conclusive and are presented because they indicate the manner in which the performance of the machine can be measured and can serve as a basis for comparing future work done with the machine. The vines from which these data were obtained were a late planting on the Horticulture Farm. Although the vines had a nice, lush appearance, they were producing few fruit.

TABLE 7

TENSILE FORCES IN VINE DUE TO ACTION OF THE CLEATS ON THE PICKING BED

Vine Lengths	Vine Weight	Linear Velocity of Cleats on Picking Bed	Tensile Forces
inches	lbs	fpm	lbs
59	1.2	298	1.8
48	1.0	298	0.5
55	1.5	298	1.5
59	1.2	338	2.3
36	0.8	338	1.0
62	2.0	338	2.6
60	1.0	338	0.8
46	1.1	338	2.3

In later work conducted at Dansville, Michigan, on large, mature vines, estimated machine capacities of two to three times those set forth in Table 8 were obtained.

TABLE 8

VINE DAMAGE[a] AND MACHINE CAPACITY

Length of row	Time	Rate of Travel	Total Weight of material handled	Weight of[b] Material Removed	Vine Damage	Machine Capacity
ft	min	mi/hr	lbs	lbs	per cent	A/hr
70	2	0.40	42	0.48	1.1	0.29
81	2	0.46	30	0.52	1.7	0.33

[a]Expressed as per cent of weight removed.

[b]Does not include weight of cucumbers removed.

Description of machine performance. - The entire machine functioned satisfaotorily at the conclusion of the developmental work. Figures 21, 22, 23 and 24 show a sequence of operations of the machine.

Significant features of the performance of the machine are as follows: (1) The vacuum pickup unit lifted the vines without damage by grasping the leaves and elevated them onto the picking bed. Due to this lifting and elevating action, the cucumbers hung down below the vine. (2) The picking action of the cleats on the picking bed removed all commercial sizes of cucumbers from the vine. (3) Vine damage caused by the picking action of the cleats was less than 2 per cent (Table 7). (4) The vines moved across the bed perpendicular to the row center. (5) The vines fell from the bed so that they remained perpendicular to the row.

Figure 21. Front view of harvester approaching vines. Note pickup lift hanger and cable.

Figure 22. Vines passing through machine.

Figure 23. Top view of vines falling off rear of picking bed.

Figure 24. Condition of vines after harvester has passed. Notice vine is perpendicular to the row and is not damaged.

It must be remembered that these results are based upon the limited amount of testing which was conducted after the machine was developed until it performed satisfactorily in the field.

The following factors hampered field operations of the machine: (1) To obtain the proper ground speed for the machine and still operate the fan at the maximum rpm, it was necessary to tow the entire unit with another tractor. This problem could be minimized by using a tractor with a live PTO which also has a wide range of forward travel speeds. (2) The pivot side of the picking bed was mounted too close to the ground causing interference with rocks and uneven ground profile. (3) Continuous operation of the fan was limited to less than 45 minutes because the V-belt fan drive was not designed to transmit 10 hp.

The pickup and picking principles offer excellent possibilities for solving some of the harvesting problems referred to by Stout (1958a); however, further testing and evaluation of this machine is necessary before a new design of a machine using these principles is considered.

CONCLUSIONS

The data presented indicate the following:

1. The picking force depends on the size of the cucumber.

2. The picking force does not depend upon the time of day or the position on the vine.

3. The picking forces differ among varieties of cucumbers.

4. The use of a vacuum pickup and elevating device is not limited by the leaf strength.

5. The average specific weight of the cucumbers was found to be 60 pounds per cubic foot.

6. The average specific gravity was 0.96.

7. A relationship was discovered to exist between the weight and length and between the weight and diameter of the cucumbers. It may be expressed as

$$W = k_1 e^{aL}$$

or

$$W = k_2 e^{bD}$$

where

W = Weight in grams

L = Length in inches

D = Diameter in inches

k_1, k_2, a, and b = Parameters

8. The pneumatic vine trainer trained the vines without damage to grow perpendicular to the row center.

9. A new mechanical cucumber harvester was invented, designed and constructed.

10. The vacuum pickup and elevating unit on this machine will lift and elevate vines off the ground with the cucumbers hanging down from the vine.

11. The cleated belt picking principle will pick and elevate the cucumbers simultaneously.

12. The pickup unit caused no vine damage.

13. Vine damage due to the picking bed was less than 2 per cent for one harvesting operation.

SUGGESTIONS FOR FURTHER STUDY

1. The relationship between weight and picking force should be obtained for most commercial varieties of cucumbers.

2. Investigate the relationship of picking force to size of stem, fertility and other pertinent factors.

3. Study the use of the pneumatic vine trainer while cultivating the cucumbers.

4. Use the vine trainer to spread insecticides and to control diseases during the training operation.

5. Further analysis of the effect of the vine trainer on the number of fruit set in the root zone would be desirable.

6. Determine the field picking efficiency of the cleated belt picking principle.

7. Determine the most efficient height and spacing of the cleats.

8. Incorporate the air output from the fan with the vacuum pickup to aid in lifting the vines.

9. Consider the use of the air output from the fan for removing root line cucumbers.

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