DEVELOPMENT AND EVALUATION OF A FRUIT DETACHMENT PRINCIPLE FOR ONCE-OVER MECHANICAL CUCUMBER HARVESTING

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DEVELOPMENT AND EVALUATION OF A FRUIT DETACHMENT PRINCIPLE FOR ONCE-OVER MECHANICAL CUCUMBER HARVESTING

By

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ABSTRACT

Submitted to the Colleges of Agriculture and Engineering of
Michigan State University of Agriculture and
Applied Science in partial fulfillment of
the requirements for the degree of

MASTER OF SCIENCE
IN
AGRICULTURAL ENGINEERING

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Max Myron DeLong

The harvesting costs of pickling cucumbers amount to about one half of the gross value of the crop. The increasing cost and the uncertain supply of harvest labor have encouraged the development of mechanical cucumber harvesters.

Multiple-harvest machines have been developed, but the efficiencies have not been consistently satisfactory. Some of the inherent problems of the multiple harvest machines would be eliminated by a once-over or destructive type harvester.

The results of an economic feasibility study of once-over cucumber harvesting revealed that the yields required for once-over harvesting were not unreasonable or unobtainable.

Preliminary studies were conducted to determine what actions and mechanisms would be suitable for removing the fruit from the vines in a once-over harvesting operation. Two flat rubber belts arranged to provide a constriction removed the fruit in a manner satisfactory for a once-over cucumber harvester.

For the principle investigation, a device was constructed which employed two flat rubber belts appropriately arranged. For all the tests the device removed 86 percent or more of the monetary value of the fruit originally on the plants. For 74 percent of the tests, the device removed 93 percent or more of the monetary value of the fruit originally on the plants. An average of 79 percent of the monetary damage occurred in Grade 1 fruit. An average of 15 percent of the undamaged fruit retained a stem.

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INTRODUCTION

In 1960, the pickle processing industry paid the nations' growers approximately 18 million dollars for cucumbers (13).* Michigan growers received about 25 percent or 5 million dollars of this amount (7).

Almost all of the cucumbers for pickles (subsequently referred to as fruit) are harvested by hand. Workers walk through the field and glean the marketable fruit. Because of the undesirable nature of hand harvesting, very few domestic workers can be hired. Thus, it is a common practice to bring in transient labor from the southern United States and Mexico.

Hand harvest is expensive in relation to the total value of the crop. It accounts for approximately 50 percent of the gross value of the harvest. Further, because of existing government regulations and pending legislation, the cost of labor has increased; and the supply of workers has become uncertain. Since the cost and supply of labor is a problem, partial or complete harvest mechanization must be sought if the continued growing of cucumbers is to be profitable.

There are at least three alternatives to the hand harvesting of pickling cucumbers. First, picking aids can be used. One of these machines was described as early as 1955 (5). A picking aid usually consists of a transporting device to carry the pickers across the

*The numbers in parentheses refer to references.

field in a sitting or prone position and some type of conveying system to carry the harvested fruit away from the picker. By transporting the workers, the objectional task of walking and stooping is eliminated from the harvesting of cucumbers. Partial mechanization of this type has not been fully evaluated at this time, but picking aids do offer a way in which present varieties can be harvested with a minimum of physical discomfort.

A second alternative to hand harvesting is to harvest present commercial varieties of pickling cucumbers with a machine that completely replaces the manual picker. A machine to do this must harvest a field several times during a season. Harvesters of this type are often referred to as multiple-harvest machines.

Multiple-harvest machines have received considerable attention during the past ten to twelve years (3, 4, 6, 10), but the inherent problems of machine multiple harvesting have caused Michigan State University researchers to abandon this method (9). At least one machine manufacturer, however, is still developing a machine based on this principle. The problems of multiple-harvest machines as summarized by Stout and Ries are (11):

a. Accumulative damage to plants with resultant decrease in yield

b. Inadequate mechanical components for removing fruit set near the base of the plant

c. Inability to remove and retrieve all the marketable fruit from certain commercial varieties

d. Decreased yields because of wide row spacing required by machine

e. Pulling of plants from the soil when vine growth is luxuriant or anchorage poor

f. Small acreage capacity per harvester because of the necessity of repeatedly harvesting the same plants

A third approach to mechanical harvesting of cucumbers is a once-over or destructive harvest in which all the fruit are removed from the plant at one time and the vine is destroyed. The success of this principle depends largely upon the capabilities of new varieties of cucumbers to produce single harvest yields that will be economically attractive.

A preliminary economic analysis has been conducted for this method (11). Although problems of developing new plant varieties, machines, and cultural practices exist, they do not seem to be insurmountable.

A successful once-over mechanical cucumber harvester must perform at least five functions:

1) Orientation or positioning of plants for fruit detachment
2) Fruit detachment
3) Fruit transportation away from the detachment device
4) Separation of fruit and foreign material
5) Vine disposal

Of these five functions, fruit detachment appears to be the most difficult. The development of mechanisms to complete the remaining operations has been started by the work done on multiple-harvest machines. This study was undertaken because of the need for a fruit detachment mechanism.

The objectives of this study were: 1) to develop and evaluate several fruit detachment principles, 2) to design and evaluate a device employing the most promising principle.

REVIEW OF LITERATURE

Intensive mechanical cucumber harvesting studies have been conducted at Michigan State University since 1957. Stout and Ries (10) described the harvesters that were tested during the 1957 and 1958 seasons. All of the machines were of the multiple-harvest type. The reported average efficiencies were: 1) 33.5 percent for the Grew Belt machine in 1957, 2) 43.7 percent for the Grew Roller machine in 1958, 3) 38 percent for the Chisholm-Ryder machine in early 1958, 79 percent later in 1958 and 90 percent in 1959 (8). However, no conclusive evidence has been available on the performance of the Chisholm-Ryder machine during the 1960 and 1961 seasons.

Michigan State University personnel have designed and built three models of a multiple-harvest machine. Leonard (6) designed and constructed a harvester in 1958, and the same machine with a few alterations was evaluated by Bingley in 1959 (3). Bingley stated that the return per acre was reduced by 76 percent because of the combined effects of vine training and mechanical harvesting.

Another Michigan State University experimental cucumber harvester was designed and constructed in 1960 using the most successful components developed by Bingley *et al.* (4). At the end of the 1960 season further developmental work on the multiple-harvest principle was not considered justified (9). At this time, Stout suggested that methods of harvesting cucumbers in a once-over process be developed.

When the present study was initiated, no specific information was available on once-over harvesting of cucumbers. Some information from previous studies was applicable to the problem of once-over harvesting.

Leonard (6) noted that prior to the first picking, the vines of the Wisconsin SMR-12 variety averaged about 24 inches in length, and the first few fruits were set near the base of the stem. The profuse leaf growth tended to form a canopy over the main stem and laterals from 6 to 8 inches above the ground.

Allard (1) indicated that cucumbers hung down when the vine was lifted off the ground, and that the size of the plants increased and the vines became brittle as the vines aged.

Bingley (3) reported that both fabric flights and roller flights on the picking unit removed foliage. The roller flights seemed to remove more foliage than the fabric flights.

Stuckman (12) stated that during the 1958 season, the grade distribution that gave a maximum net return per acre was when the fruit with diameters of $1\frac{1}{2}$ inches or less comprised 51 to 60 percent of the total weight. The period of time when a given grade distribution exists in a field of cucumbers may be as short as one day. Hence, a once-over harvester must harvest efficiently at the most desirable grade distribution and must have enough capacity to harvest the necessary amount of plants.

Stout and Ries (11) have analyzed the expected costs of producing and harvesting cucumbers in a once-over operation. The analysis considered the following items concerning the use of a machine: initial cost, interest rate, salvage value, useful life, power required, specific fuel consumption, fuel cost, repairs, maintenance, lubrication, taxes, insurance, shelter, capacity, and labor cost. Cost of production data was also considered.

Figure 1 is a modified chart from the economic analysis by Stout and Ries (11). Assuming the conditions listed on the graph and an average selling price of $1.25 per bushel of cucumbers, the break even points for various numbers of acres harvested per year are given. For instance, if a grower were to harvest 25 acres a year with a once-over mechanical harvester costing $3,000, he would need a yield of about 70 bushels per acre to pay for production, harvesting, and land costs. The significance of this chart as stated by Stout and Ries is that the break even yields and yields needed for a profitable net return to the grower do not present an unreasonable and unobtainable goal.

As indicated in this review of literature, a new approach to mechanical cucumber harvesting is needed. The once-over harvesting operation appears to be economically feasible. This approach is an abrupt change from present hand harvesting concepts and will require new machines to be designed and constructed. Bainer et al. made the following comments on the philosophy of experimental machine development (2):

When a radically new machine is being designed. . ., the

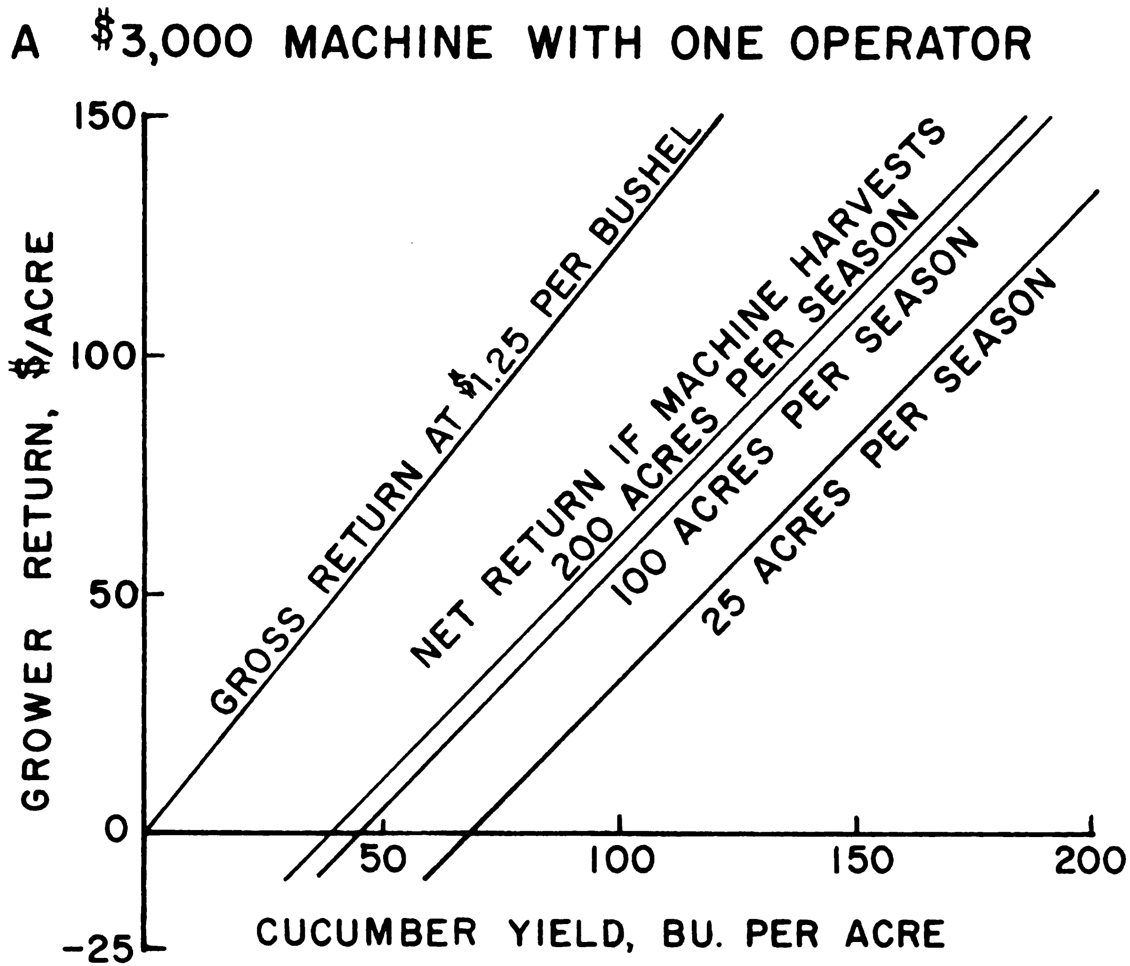

Figure 1. Yields required to break even using a once-over mechanical harvester. Adapted from Stout and Ries (11).

problem is more difficult and requires greater imagination and ingenuity in addition to good basic engineering ability.

The first experimental designs are primarily functional and generally deal with machine elements rather than a complete machine, the chief objective being to test and develop (or discard) certain ideas or principles of operation. Although durability and the refinement of mechanical details are not important in these early models (except to the extent necessary to permit adequate functional testing), the mechanical and economical practicability of the ideas should be given increasing consideration as the development progresses. The ultimate objective is, of course, to be able to perform the specified functions satisfactorily with as simple and efficient a unit as possible.

PRELIMINARY STUDIES

In July of 1961 preliminary studies were initiated to determine types of actions suitable for removing the fruit from the vines in a once-over cucumber harvesting operation. The studies were exploratory, and the mechanisms built to study the actions were not designed to be immediately adaptable to a field machine. The information gained from these studies was helpful in determining the avenues of approach to once-over cucumber harvesting.

A natural action to investigate was that developed by the picking beds of previous Michigan State University cucumber harvesters. The problem had been that when the efficiency of the picking bed was high, damage to the plants was also high. Because the plants would not have to survive the fruit detachment operation in this once-over harvest study, damage to the vine would not be a problem.

The previous picking beds agitated the plant on only one side. To make this type of agitation more severe, the device shown in Figure 2 was constructed. It employed two chain and flight mechanisms. The flights in contact with the vine moved away from the clamped root. This movement tended to remove fruit and foliage. To subject the plant to the action of the flights for a given amount of time, the clamp was also moved in a direction perpendicular to the motion of the flights.

For various tests the speed of the flights ranged from 200

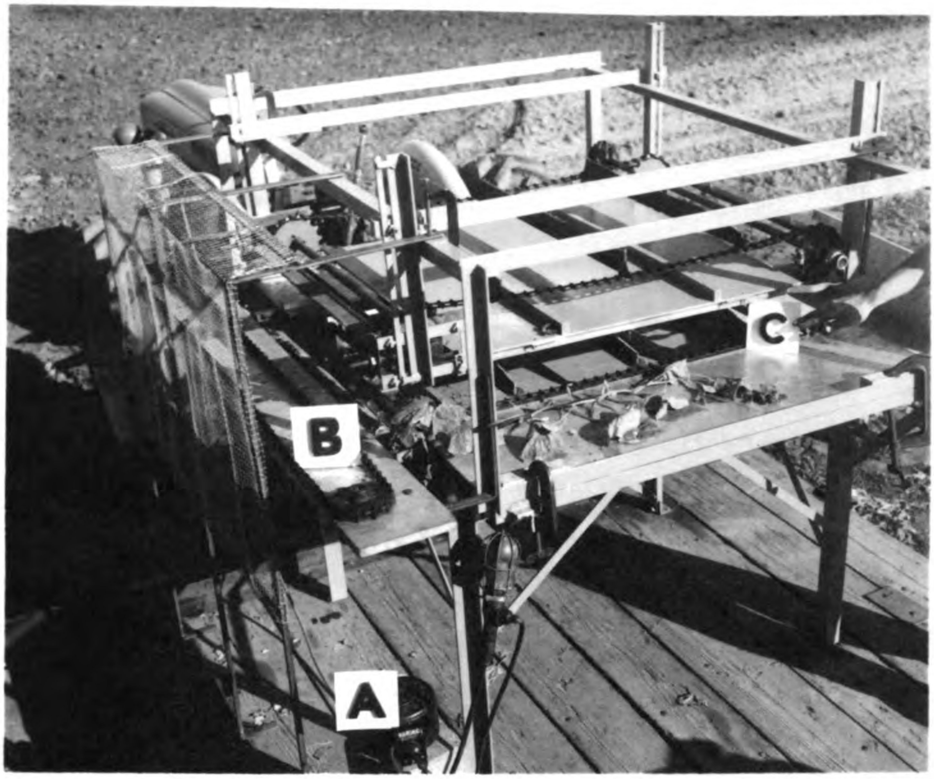

Figure 2. The double chain and flight fruit detachment device. A) variac for controlling speed of clamp; B) chain for moving clamp; C) a plant ready to enter flights.

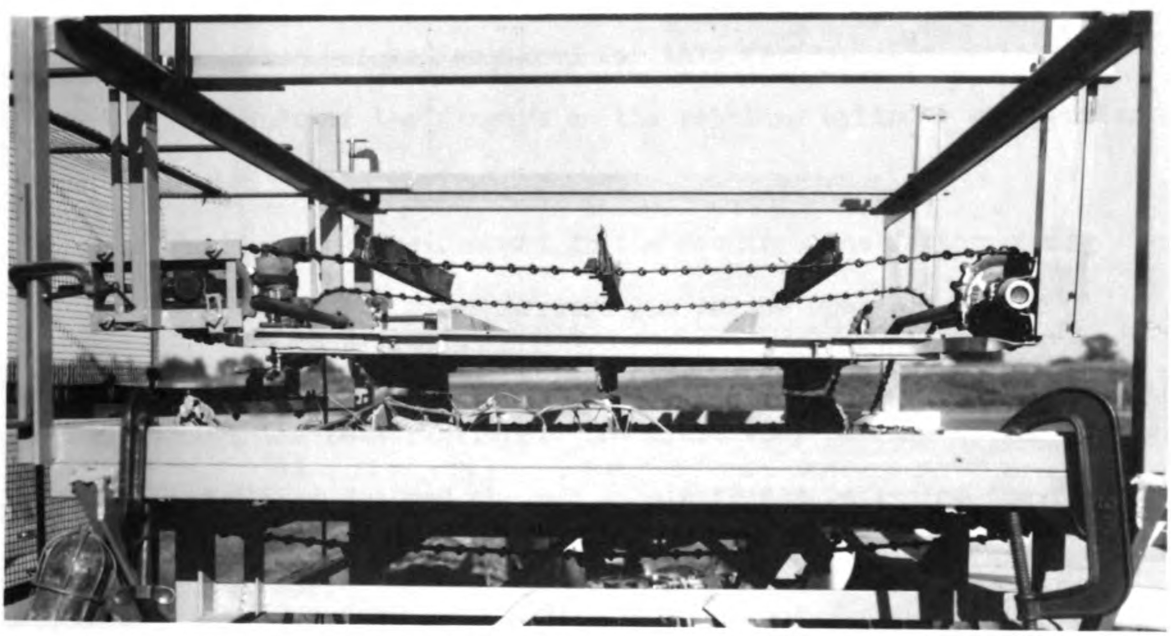

Figure 3. The flights on the double chain and flight device. The position of the flights shows the clearance between the upper and lower flights and the relative position of the flights.

to 500 fpm (feet per minute); the speed of the clamp ranged from 50 fpm to 250 fpm; and the clearance between the top and bottom flights ranged from zero to one inch.

The harvested fruit was collected in boxes located beneath and at the end of the lower chain and flight mechanism. This device removed 90 percent or more of the marketable fruit when the speed of the flights was 400 to 500 fpm and there was no clearance between the flights. Although the action produced by this device was quite effective in removing the fruit under certain conditions, to adapt the device to a field machine would require orienting and anchoring the plants. Since this would be difficult, the double chain and flight mechanism was not pursued further.

To duplicate the action described above, a rotating-cylinder, moving-concave mechanism (Figure 4) was built. Plant anchorage or plant orientation was not required for this device. The peripheral speed of the ends of the fingers on the rotating cylinder was greater than the speed of the moving concave.

When a plant was dropped in the machine, the faster moving fingers would draw the vines through the narrow openings of the slower moving concave. Fruit detachment resulted as the vines were drawn through the constrictions. The fruit were carried by the moving concave and either dropped through a hole in the bottom of the stationary concave or were carried out over the edge of the stationary concave. This mechanism appeared to have good capacity as it would take 3 to 4 plants at a time. However, there was considerable damage

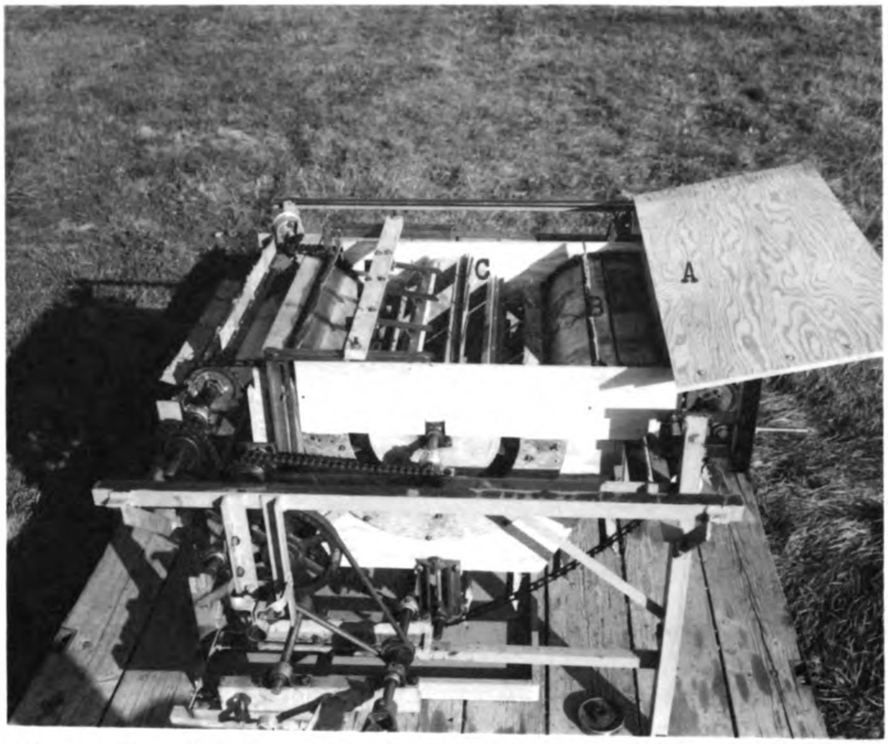

Figure 4. An overall view of the rotating-cylinder, moving-concave device. The plants enter at (A) and are drawn through the concave (B) by the cylinder (C).

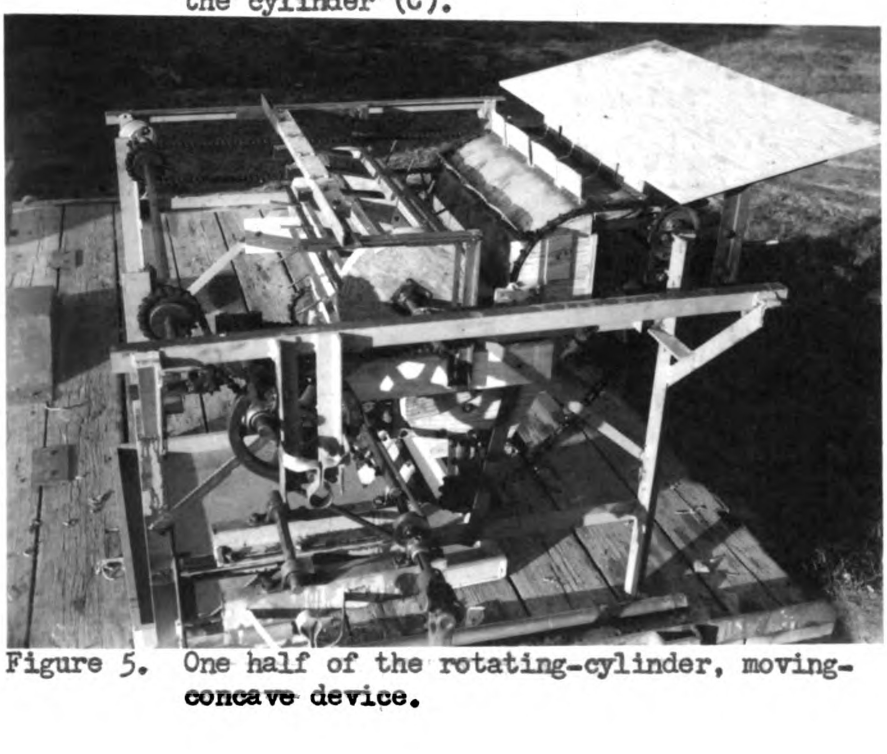

Figure 5. One half of the rotating-cylinder, moving-concave device.

to the fruit and vines tended to wrap about the fingers. The machine was cut in half (Figure 5) to see if less damage would occur, but this tended to decrease fruit detachment. The device did not warrant further investigation.

The fruit was also stripped from the vine by means of a pair of rollers. Various combinations of rollers were tested in a frame shown in Figure 6. As the vines were drawn through by the rotating rollers the fruit, being too large to pass through the opening, were stripped off. Good detachment resulted with both large and very small fruit when the roller surfaces were hard but aggressive enough to draw the vines through, and when at least one roller had a diameter of two inches or less. The contact between the rollers and the vine approached a line contact, and very little area was available for the rollers to pull on the plant. This often meant that the vine would stall before it completely passed through the rollers. The vines also had a tendency to wrap around the rollers.

Because of the excellent fruit detaching characteristics of some of the combinations of rollers, several additional devices were built which retained the characteristics of the rollers but increased the area of contact for pulling the plants through.

The device shown in Figure 7 was one such device. The rubber belts running over the small diameter pulleys detached the fruit in a very satisfactory manner and almost eliminated the problem of plant stalling.

To introduce the plant into the constricted area, it was

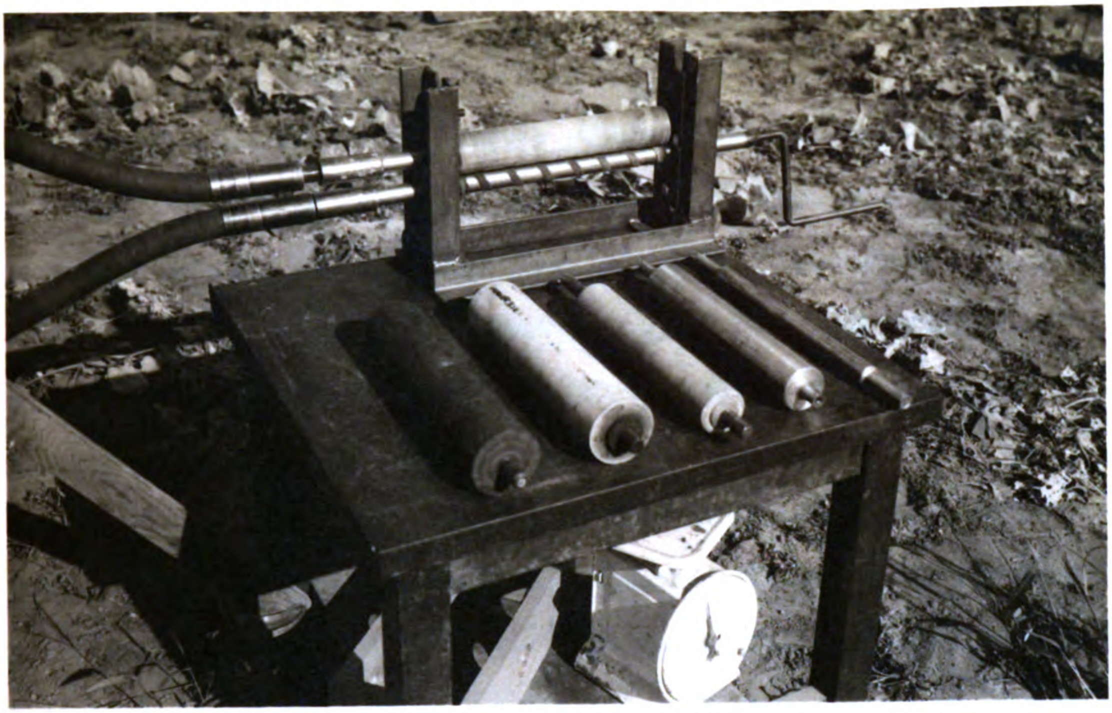

Figure 6. A frame for mounting various combinations of rollers.

Figure 7. A double belt fruit detachment device with a plant ready for entry into the constriction.

necessary to catch one or two leaves of the plant and then the vine would move through. A problem existed with this type of double belt arrangement because the detached fruit often inhibited entry of a vine that followed. In addition, a fruit entangled in a vine prior to detachment often became damaged; or when detachment did occur, the peduncle* remained on the fruit.

The supply of greenhouse plants was exhausted at the end of November, 1961, so the device mentioned above (Figure 7) was the last one tested during the 1961 season. This double belt arrangement was the most promising detachment principle tested during the preliminary studies; therefore, the plans for the 1962 season were based on a knowledge of the desirable and undesirable characteristics of the double belt device.

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*The term stem will subsequently be used in this study to mean the peduncle that remained attached to the fruit.

INVESTIGATION

The objective of this investigation was to design, construct, and evaluate a fruit detachment device suitable in principle for adaptation to a once-over mechanical cucumber harvester.

The design was based on the double belt device (Figure 7) that had been tested during the preliminary studies because that device had provided very good fruit detachment and required a minimum of plant orientation.

Principle of Operation

The design adopted for this investigation is shown pictorially in Figure 8. Side views of the actual device are shown in Figures 9 and 10.

A plant was placed on the introduction conveyor with the leaves up. After being carried to the end of the conveyor, an air blast from the fan and air duct floated the light parts of the plant up into the constriction. Because the belts were moving, the vine was pulled up between the belts. As the fruit on the vine came to the constriction, the fruit were detached from the stems and fell down into the catching box. The vine was carried up between the belt and ejected into the vine box.

After initial trials in June of 1962, two mechanisms were added to make the operation more efficient and reliable. A spring loaded roller (Figures 11 and 12) was placed inside the upper belt

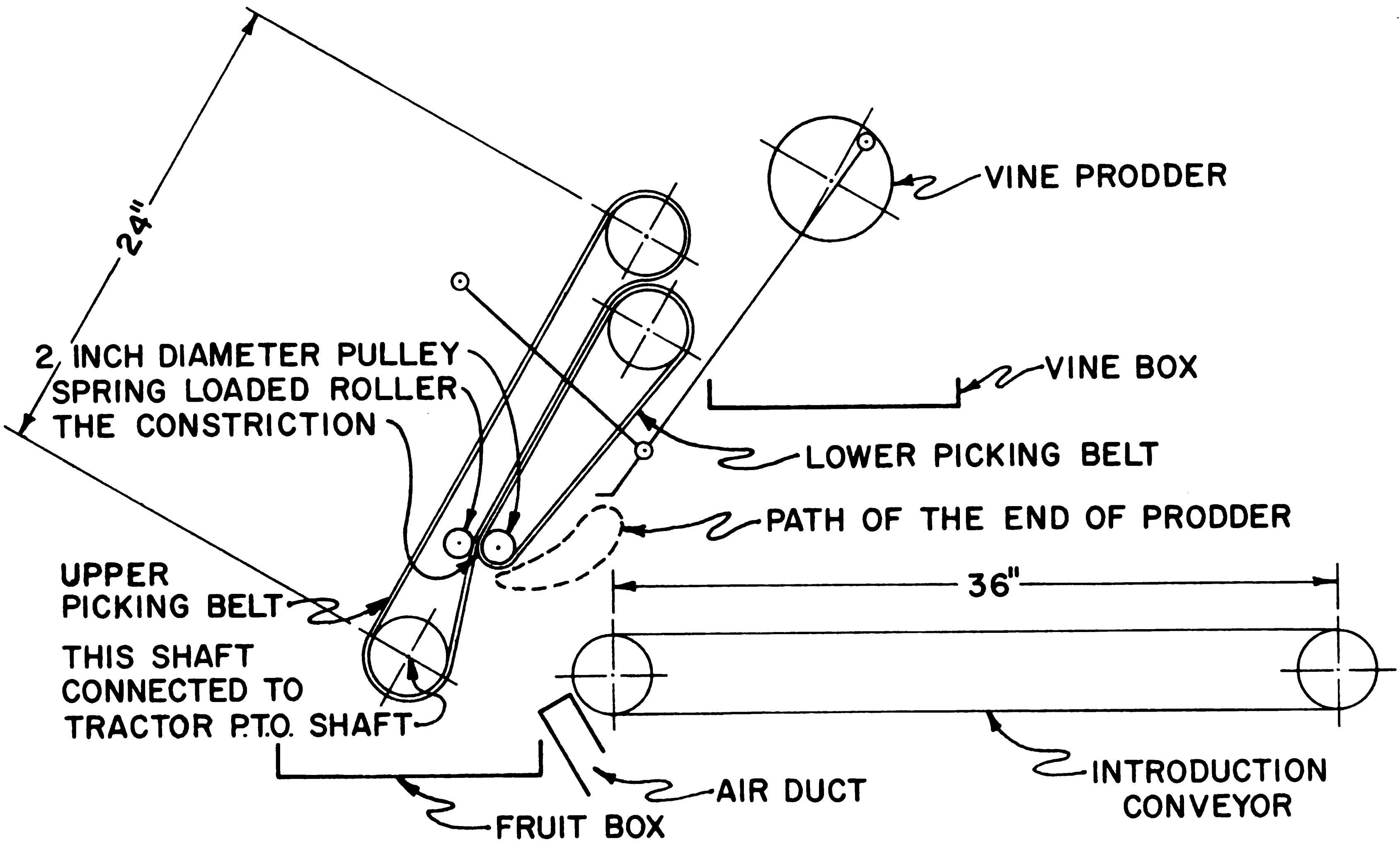

Figure 8. The essential components of the double belt fruit detachment device investigated during the 1962 season.

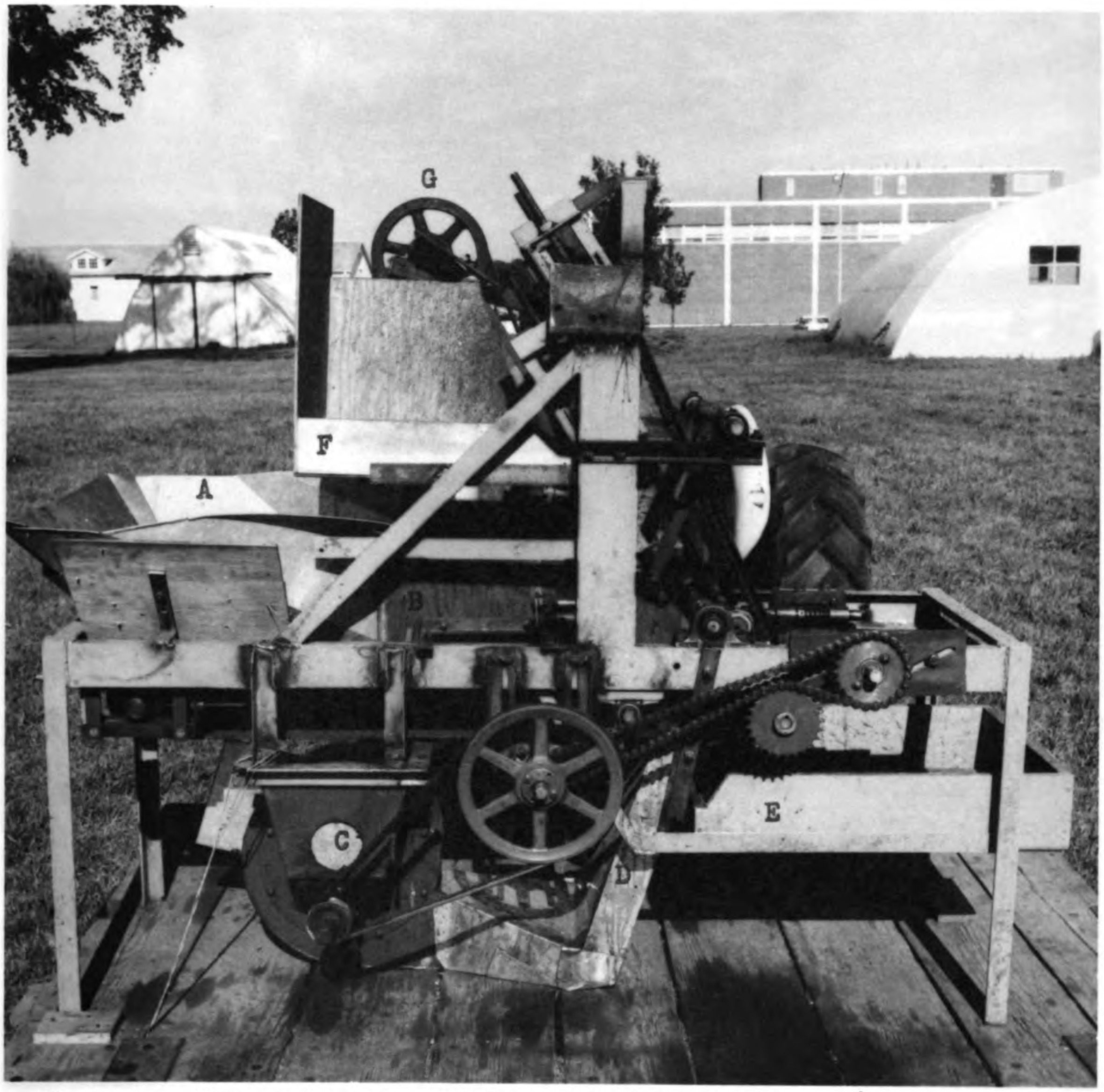

Figure 9. The right side of the double belt device. A) hopper; B) shield; C) fan; D) air duct; E) fruit box; F) vine box; G) vine prodder.

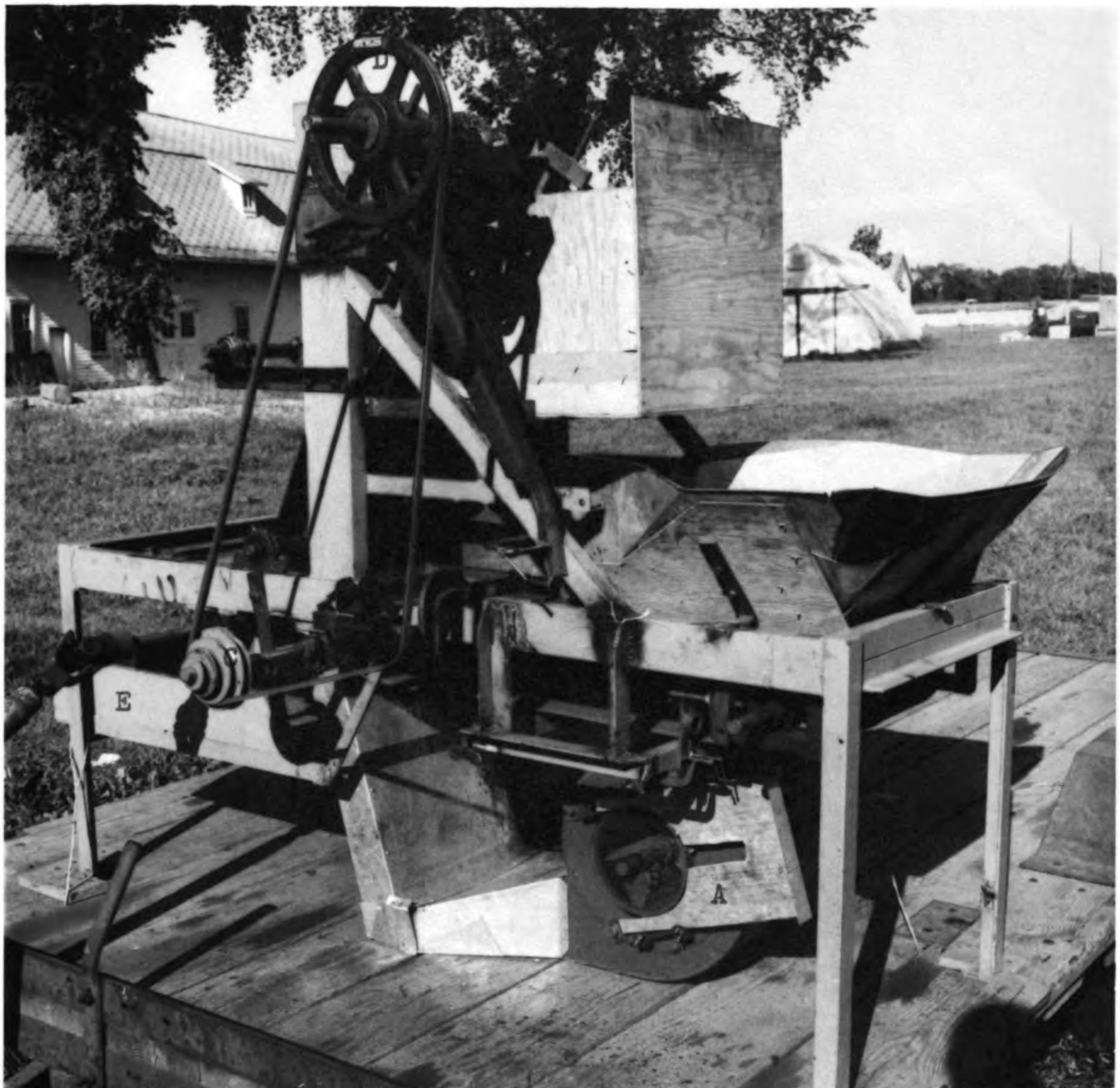

Figure 10. The left side of the double belt device. A) damper; B) inlet screen; C) multigroove V-belt sheave for driving the vine prodder; D) driving arrangement for the vine prodder; E) PTO shaft.

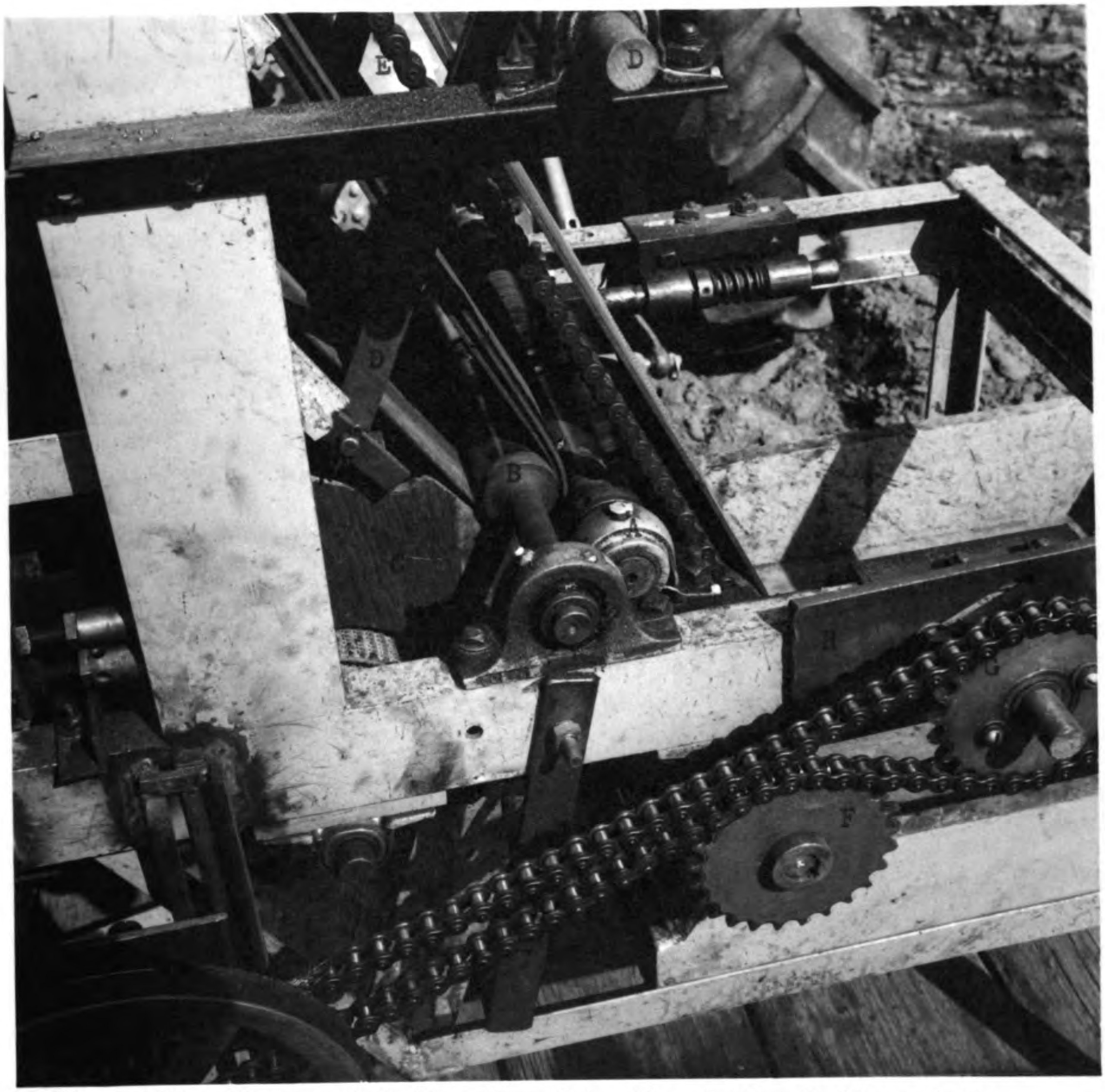

Figure 11. The constriction formed by the picking belts and the surrounding components. A) spring loaded roller and roller bearing; B) two inch diameter pulley; C) shield; D) vine prodder; E) chain for driving picking belts; F) shaft of picking belt pulley; G) fan drive chain; H) chain tightener.

at the point of constriction. This roller prohibited excessive movement of the upper belt away from the lower belt when the vines were drawn through the constriction. Excessive movement of the upper belt tended to damage the small fruit.

A vine prodding mechanism (Figures 11 and 13) was added to assure entry of the vines into the constriction. Because the detachment area was solidly shielded (Figure 11) to keep fruit and vines from escaping, the air used to float the plants up into the constriction had to be exhausted out the area in which the plants were coming in. At times the vines were kept away from the constriction by the exhausting air, but the action of the vine prodder forced the vines back into the constriction.

Description of the Machine

To facilitate movement between the shop and field, the whole device was mounted on a two wheeled trailer. The power requirements of the device were not known so a tractor with a PTO (power-take-off) drive was used to ensure enough power to drive the device and maintain a constant speed during load. The speed of the device could be varied by changing the throttle setting on the tractor.

The introduction conveyor belt was rubber surfaced and 14 inches wide. The sheet metal hopper and the wooden shields (Figure 14) kept the vines on the belt. Adjustable bronze bearings on the rear of the conveyor permitted the proper tension to be applied to the belt.

The paddle type fan had a trash screen and a damper at the inlet (Figure 10). The outlet of the air duct was also screened to

Figure 12. The spring loaded mounting bracket for the spring loaded roller.

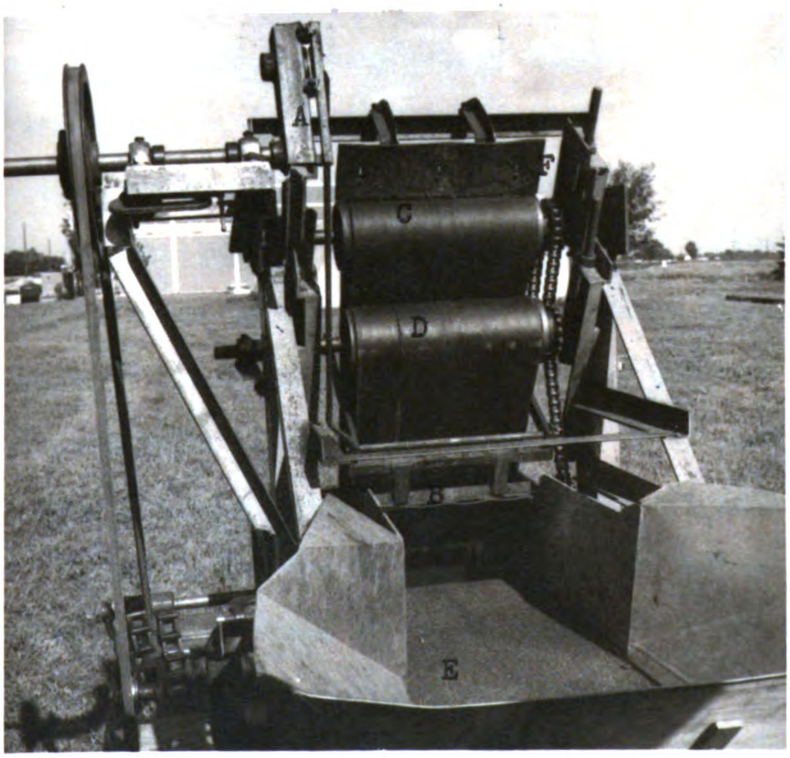

Figure 13. The picking belts, vine prodder and introduction conveyor. A) eccentric for driving prodder; B) prodder; C) upper picking belt; D) lower picking belt; E) introduction conveyor; F) vine wiper for upper picking belt.

prevent fruit and foreign material from falling into the fan housing.

The 12 inch wide rubber picking belts had a smooth but firm outer surface. A special section V-belt was vulcanized on the center of the pulley side of the belt to improve tracking qualities.* The ends of the belt were held together by metal lacing. The pulleys over which the picking belts ran were grooved to accomodate the V-belt. The bearings for the picking belt pulleys were all ball bearings, and the upper four bearings were adjustable to permit the proper tension to be applied to the belt.

The fruit box (Figure 9), located directly below the constriction, was removable. The vine box (Figure 9) was also removable and was located at the upper ends of the picking belts.

The spring-loaded, back-up roller (Figure 11) was a 1 3/16 inch shaft with a groove in the middle.

The vine prodder was driven from the shaft of the front introduction conveyor pulley. The vine prodder was designed to engage the plants on the downward stroke but not to inhibit the motion of incoming plants on the upward stroke. The tip of the vine prodder was made of sheet rubber. The sheet rubber was stiff enough to force the leaves and stems into the constriction, but pliable enough not to cause damage to the fruits that were at the constriction at the end of the downward stroke of the prodder.

One end of the shaft on the lowest picking belt pulley was connected directly to the tractor by a PTO shaft. The other end of

*The belts were purchased from A. J. Sparks Company, Grand Rapids, Michigan.

the shaft on the lower picking belt pulley drove the fan from one sprocket (Figure 11) and the introduction and the top two picking belt pulleys from another sprocket.

The speed of the PTO shaft ranged between 200 and 500 rpm. The speed ratio of the PTO shaft to the introduction conveyor shaft was 1.62:1. The ratio of the linear speed of the picking belts to the linear speed of the introduction conveyor belt was 1.46:1. The speed ratio of the PTO shaft to the fan shaft was 1:7. The speed of the vine prodding mechanism was kept between 40 and 60 strokes per minute for all operating speeds of the machine. The multiple V-belt sheave (Figure 10) permitted changes in speed ratios.

Data Collection

Plants were provided by the Horticulture Department of Michigan State University for testing the fruit detachment device. The plants grown specifically for machine harvesting use were the Spartan Dawn variety. The rows for these plants were 48 inches apart, and the plants were spaced on the average of 12 inches apart in the row.

When the supply of plants for machine harvesting was exhausted, additional plants were obtained from the guard rows of yield trial plots. The varieties available from the yield trial plots were Spartan Dawn and Wisconsin SMR-18. Row spacing and plant spacing in the row varied in the yield trial plots. Where possible a row of plants 25 feet long was used as a test sample. When a row this length was not available, then a sample of 25 plants was used.

The best time for once-over harvest seemed to be when Grade 3 fruit began to appear on the vines. The maturity of the vines was approximately 50 days using this criteria. Because of developmental work being carried on during the harvesting season, the best harvest times were sometimes missed.

At the beginning of a test, the spring loaded roller was adjusted so the greatest number of small fruit were removed without causing feeding problems. A twenty five foot row, or twenty five plants, were selected and the number of plants was recorded. The throttle setting of the tractor was adjusted to give the desired speed of the picking belts. A hand tachometer was used to determine the speed of the PTO shaft. The plants were placed individually on the introduction conveyor with leaves up. When the complete sample had been put through the machine, the damaged and undamaged fruit were taken from the fruit catching box and placed in separate sacks. The processed vines were weighed and the weight recorded. The vines were examined and any marketable fruit that appeared with the vines was placed in a separate sack. After a series of tests were completed, the damaged and undamaged fruit were taken into the laboratory. The undamaged fruit were counted, graded, weighed, and the stems remaining on the fruit were counted and measured. The information was recorded. The damaged fruit were graded and weighed; and as this information was recorded, the place where the damaged fruit appeared was also mentioned. Current grading information was used, and the sizes and values for the different grades are given in Table 1.

Table 1. Grade sizes and values used in this investigation

Grade	Diameter of Fruit (inches)	Value (Dollars/cwt)
1	$d < 1\ 1/16$	6.00
2	$1\ 1/16 \leq d < 1\ 1/2$	2.50
3	$1\ 1/2 \leq d < 2$	1.25
4	$2 \leq d$ *	0.50

*Fruit with diameters over two inches were not used if yellow spots were present.

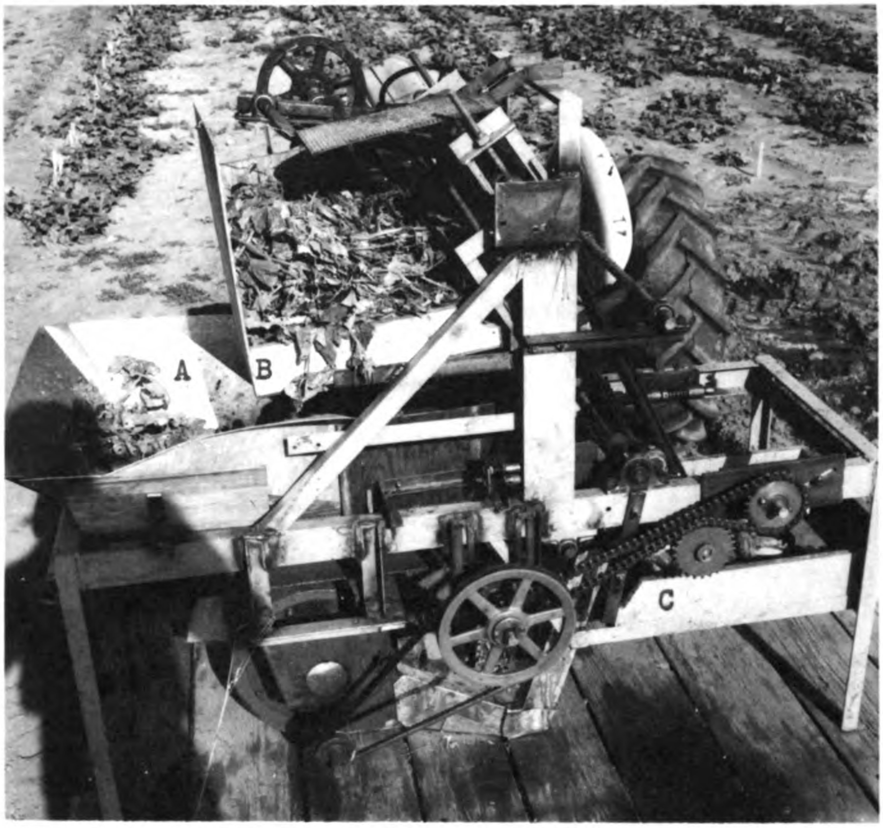

Figure 14. The right side of machine: A) vines in hopper; B) crushed vines in vine box; C) fruit box.

Figure 15. The fruit grading gauge and fruit samples: A) Grade 1; B) Grade 2; C) Grade 3.

The fruit were graded with the device shown in Figure 15. The machine removed a considerable amount of very small fruit. Only the small fruit with no blossoms or dried blossoms were considered. The range of sizes of Grade 1 that were harvested are shown in Figure 16.

Damaged fruit (Figure 17) for these tests was defined as broken, gouged, or smashed fruit, and fruit with serious abrasions. Culls and oversize fruit were not considered in either damaged or undamaged classifications.

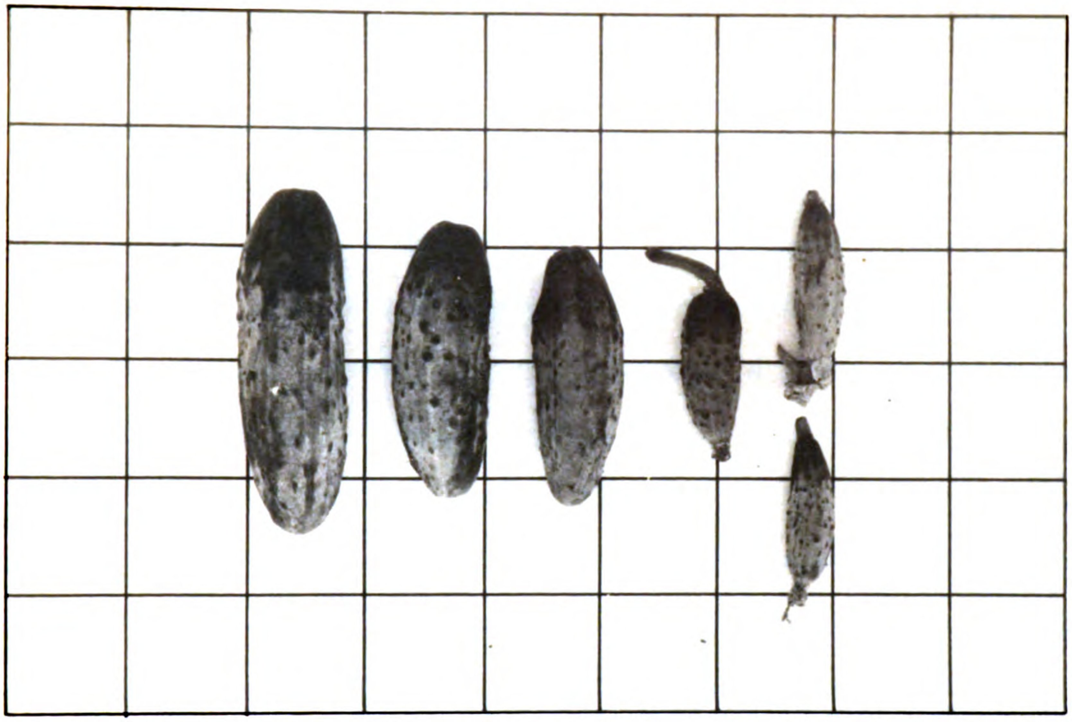

Figure 16. The range of sizes of Grade 1 fruit that were harvested. The actual size of the grid was one inch.

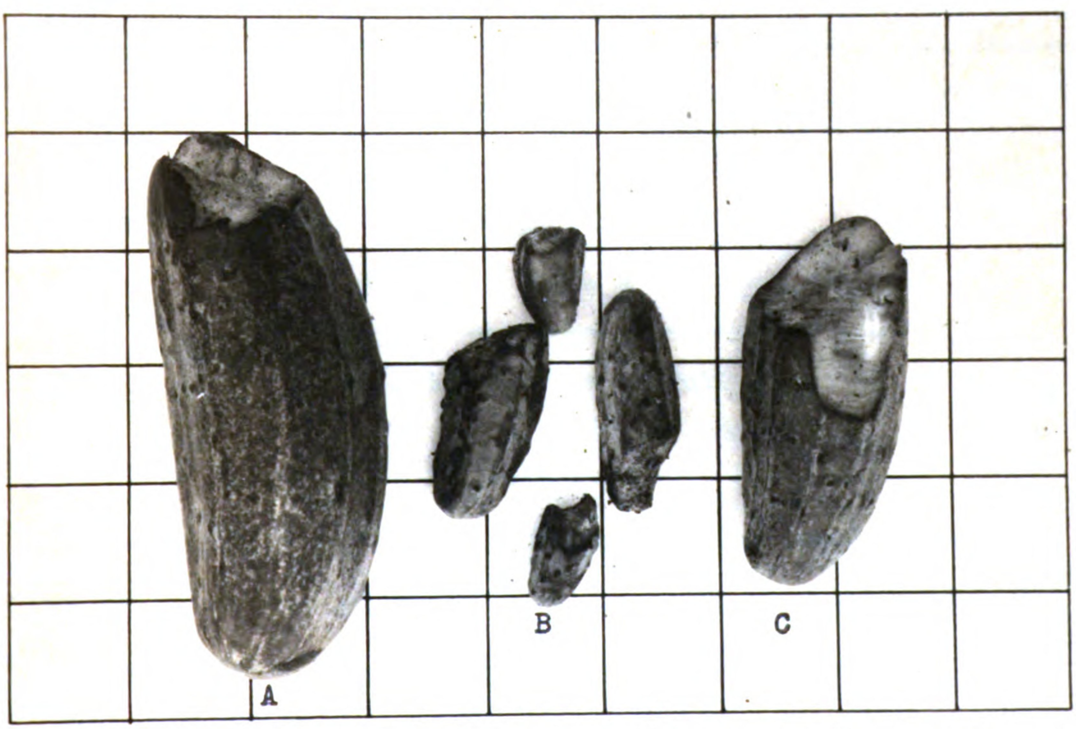

Figure 17. Damaged fruit A) Grade 3; B) Grade 1; C) Grade 2. The actual size of the grid was one inch.

Results and Discussion

The measure of performance of the fruit detachment device is defined for this study to be the ratio of the monetary value of the marketable fruit harvested to the monetary value of the marketable fruit available for harvest. When expressed as a percent, this ratio has been called effectiveness. Since weights of the marketable (undamaged) fruit and non-marketable (damaged) fruit were recorded for each test, it was convenient to compute the monetary value ratio on a weight basis. The price per unit of weight was not constant for the different grades (Table 1), so the weights were adjusted.

The mathematical definition of effectiveness is:

$$\text{Effectiveness} = \frac{\sum_{n=1}^{4} (\text{Weight of undamaged Grade N fruit}) \times (M_n)}{\sum_{n=1}^{4} (\text{Weight of undamaged and damaged fruit Grade N}) \times (M_n)}$$

where N = Grade of fruit

and $$M_n = \frac{\text{Price/cwt for Grade N fruit}}{\text{Price/cwt for Grade 1 fruit}}$$

The values of M_n are given in Table 2.

Figure 18 shows the effectiveness and the speed of the picking belts for each of the 23 tests. All of the tests had an effectiveness higher than 86 percent, and 17 of the 23 tests, or 74 percent had an effectiveness higher than 93 percent. The scattering

Table 2. Values of M_n for computing effectiveness

Grade	N	Price/cwt (Dollars)	M_n
1	1	6.00	1.000
2	2	2.50	0.417
3	3	1.25	0.208
4	4	0.50	0.083

of points precludes any suggestion of a trend between speed and effectiveness.

Figure 19 shows the distribution of the monetary damage for the various grades. In 11 of the 23 tests, all the damage for the test occurred in Grade 1 fruit. Hence, in these 11 tests the effectiveness was determined solely by the amount of damage in Grade 1 fruit. In the remaining 12 tests damaged Grade 1 fruit accounted for an average of 61 percent of the total monetary damage for a test.

The tendency for the effectiveness to decrease as the damage in Grade 1 fruit becomes a larger part of the total monetary damage (Figure 20) is explained by Figure 21. In Figure 21 the damage in Grade 1 fruit is relatively constant. Therefore, the constant proportion of damage in Grade 1 fruit tends to decrease the effectiveness as Grade 1 fruit make up a larger proportion of the sample. The tendency for the effectiveness to decrease as the damage in Grade 1 fruit becomes a larger part of the total monetary damage is verified by Table 3. In Table 3 the tests with a high percentage of Grade 1 fruit tended to have a low effectiveness.

Stuckman (12) has stated that in 1958, the farmers who sold cucumbers that averaged 51-60 percent Grade 1 and Grade 2 fruit by weight, received the highest net return per acre. This exact distribution may not provide the highest net return in a once-over cucumber harvesting operation, but this proportion of Grade 1 and 2 fruit should be a reasonable estimate.

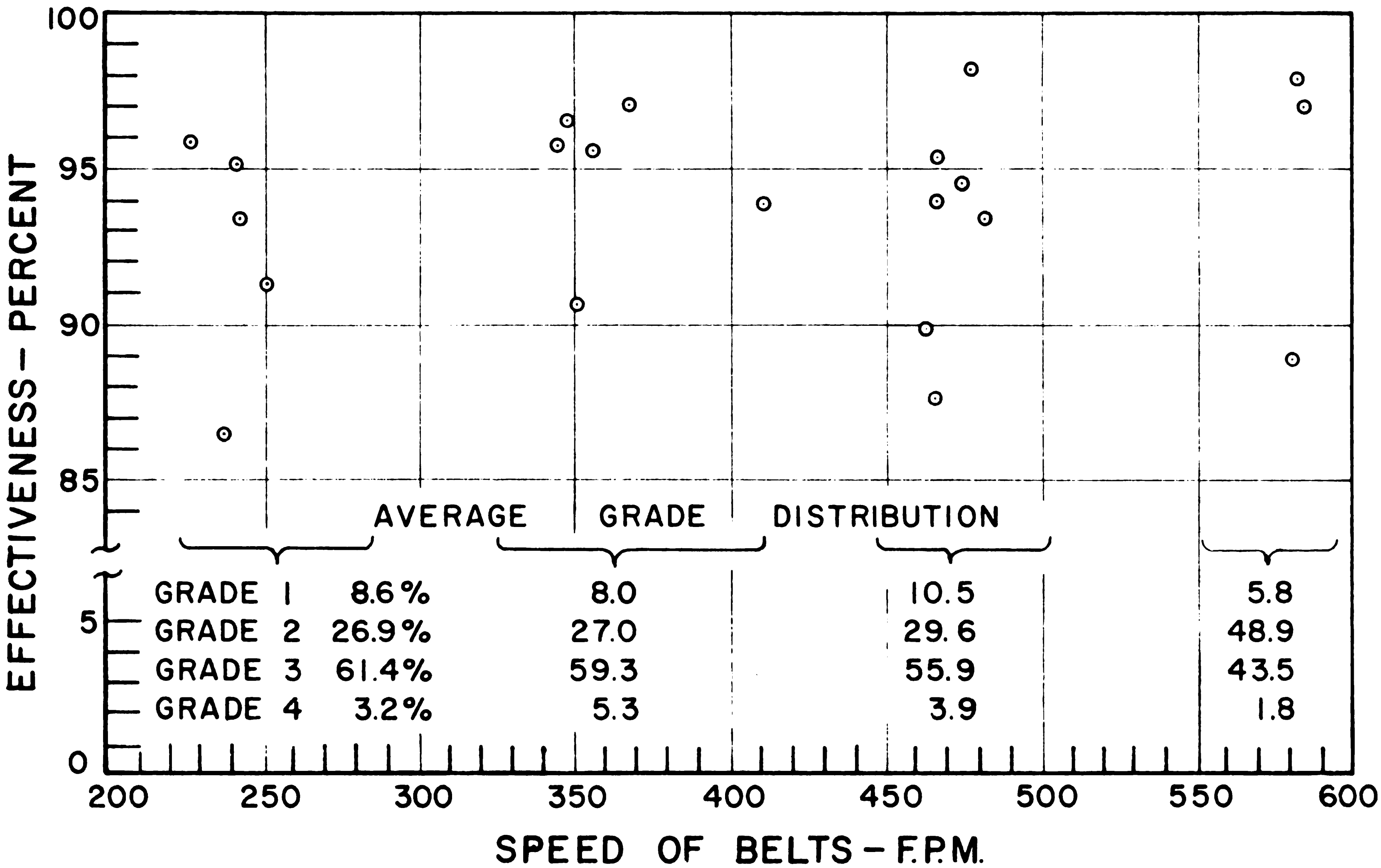

Figure 18. Effectiveness vs speed of picking belts. The average grade distribution for various speed ranges is given at the bottom of the Figure.

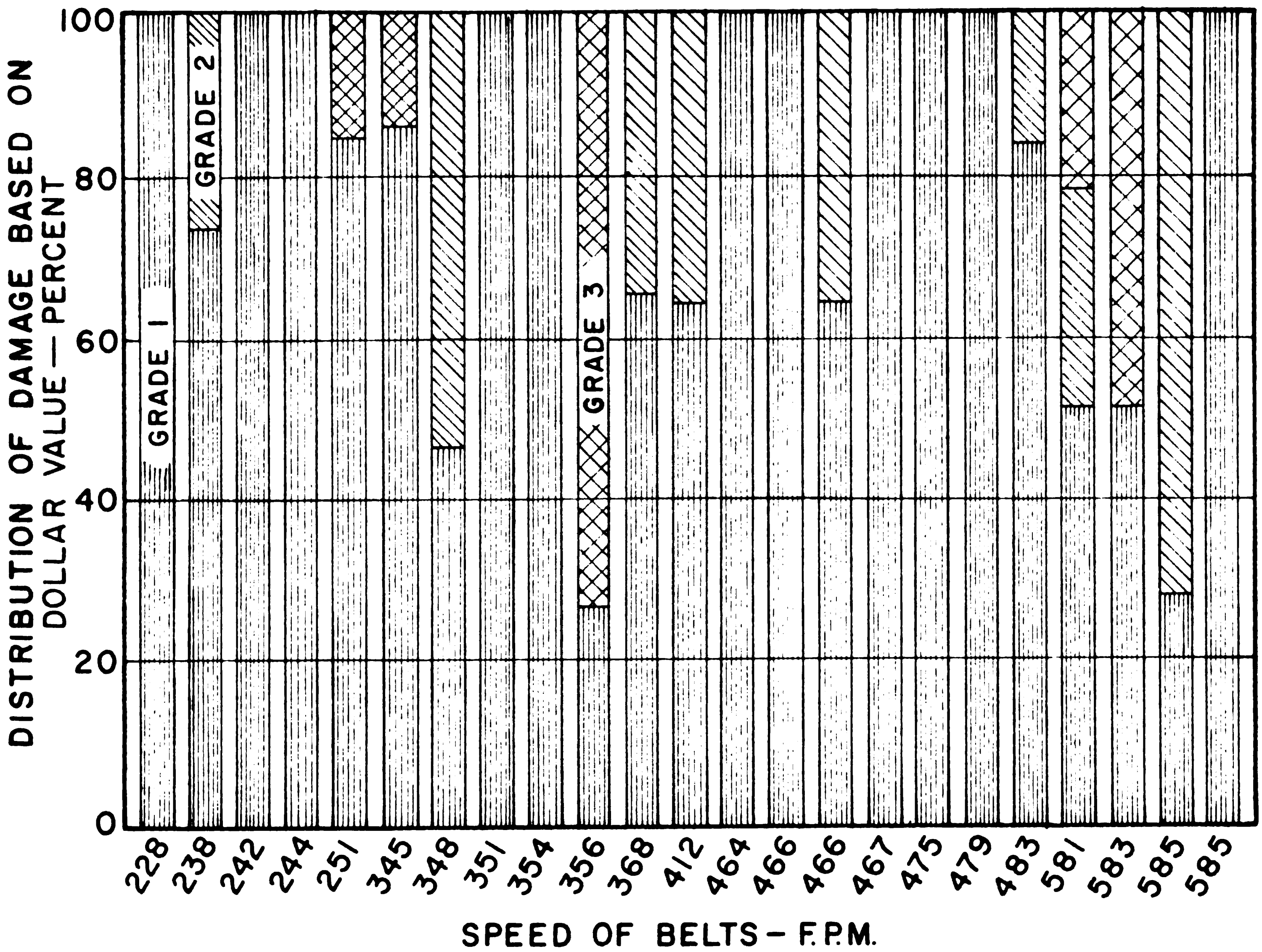

Figure 19. Distribution of monetary damage by grade vs speed of picking belts.

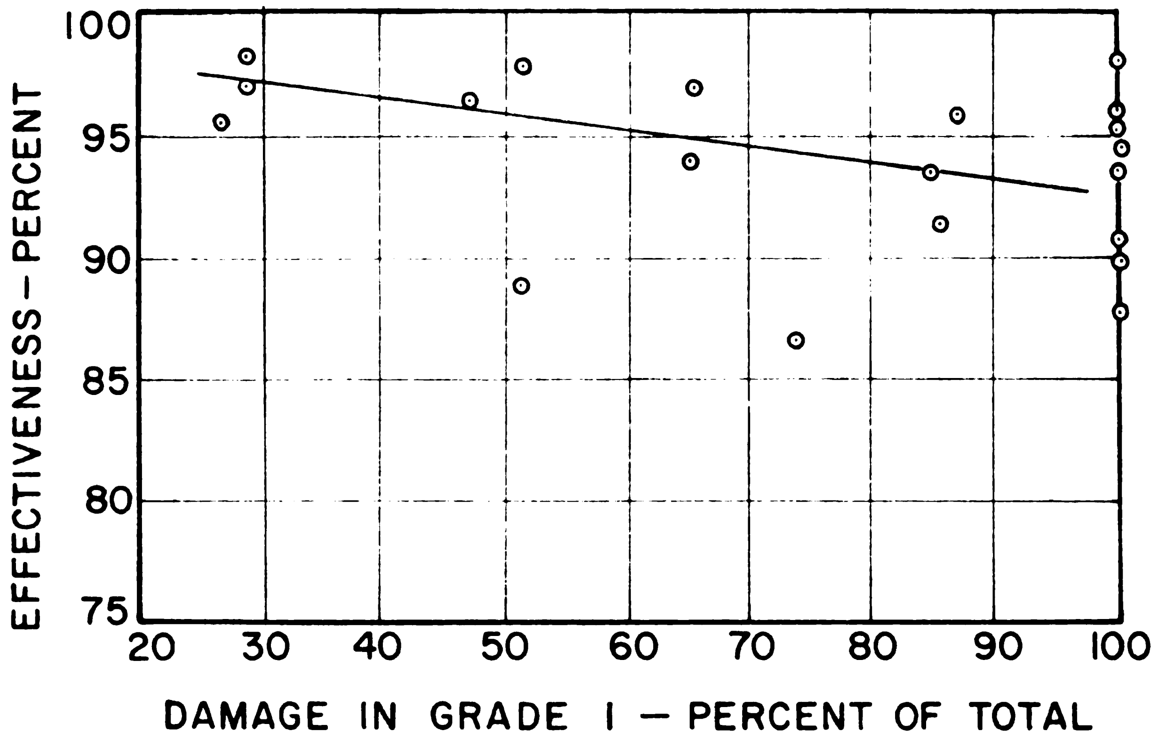

Figure 20. The tendency for the effectiveness to decrease as the percent of the total monetary damage increases in Grade 1 fruit.

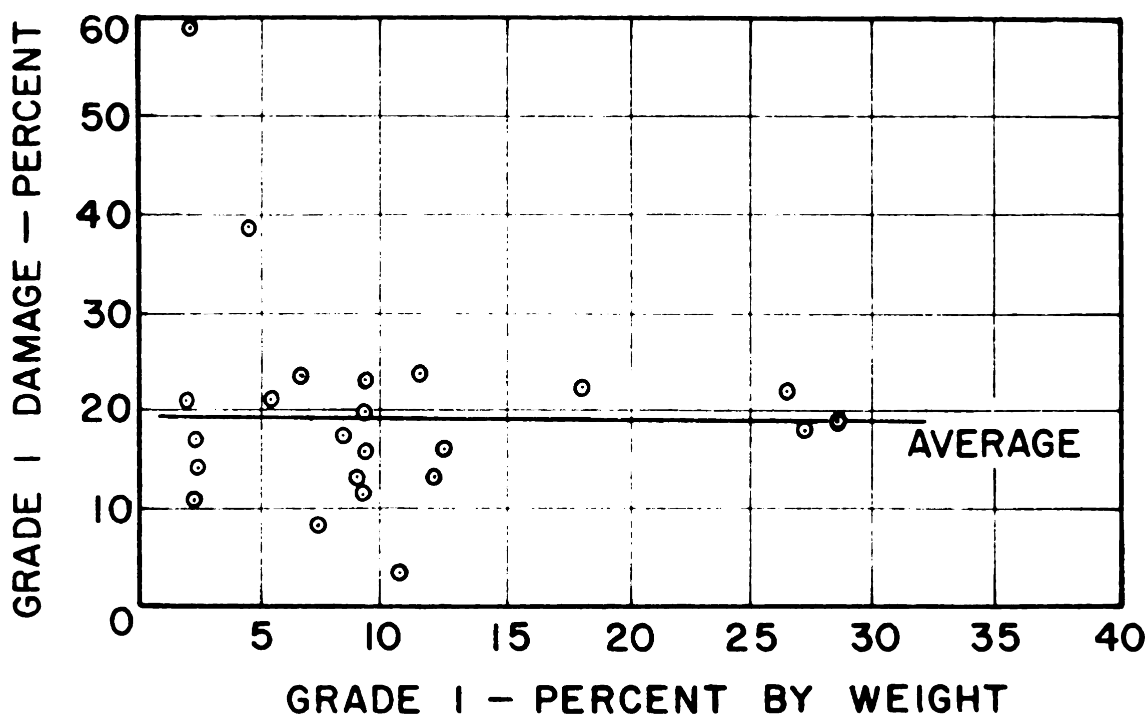

Figure 21. Damage tends to remain constant as the proportion of Grade 1 fruit increases in the sample.

Table 3. Effectiveness values arranged in descending order and the percent of Grade 1 fruit in the sample. A high proportion of Grade 1 fruit in the sample tended to result in a low effectiveness for the test.

Grade 1 Fruit in sample (Percent)	Effectiveness (Percent)
2.7	98.2
2.7	97.9
9.3	97.1
7.8	97.0
10.9	97.0
2.1	96.5
5.8	95.9
9.1	95.7
2.7	95.6
9.5	95.3
2.1	95.2
12.6	95.1
9.4	94.5
8.5	93.8
12.1	93.8
6.9	93.4
9.4	93.4
11.6	91.3
18.2	90.7
28.6	89.8
4.8	88.9
26.4	87.6
27.3	86.5

Figure 22 shows the effectiveness for the tests which had 51-60 percent Grade 1 and Grade 2 fruit by weight.

Table 4 indicates the exact proportion of Grade 1 fruit and Grade 2 fruit that comprised the 51-60 percent proportion of Grade 1 and 2 fruit. Three of the four tests represented in Table 4 have a very favorable effectiveness.

Damaged fruit was found with the undamaged fruit and with the discarded vines* (Table 5). The damaged fruit found with the undamaged fruit would have to be removed under actual field conditions. The percentage figures in column five of Table 5 suggest what proportion of the total weight of fruit harvested might need to be removed by mechanical or human sorters.

The percentage of undamaged fruit with stems is shown in Figure 23. The lengths of the stems (peduncles) varied between 1/8 inch and 2 inches. In the speed range of 200 fpm to 400 fpm, an average of 13 percent of the fruit retained a stem. In the speed range of 400 fpm to 600 fpm an average of 17 percent of the fruit retained a stem. The increased speed of the belts caused the plants to be handled more severely, and the fruit had a tendency to be shaken or knocked off rather than being snapped off at the constriction.

The relatively narrow width of the picking belts only permitted plants to be fed into the device individually. Feeding the plants singly precluded any measurement of the capacity of the device.

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*All fruit appearing in the vine box with the discarded vines was damaged.

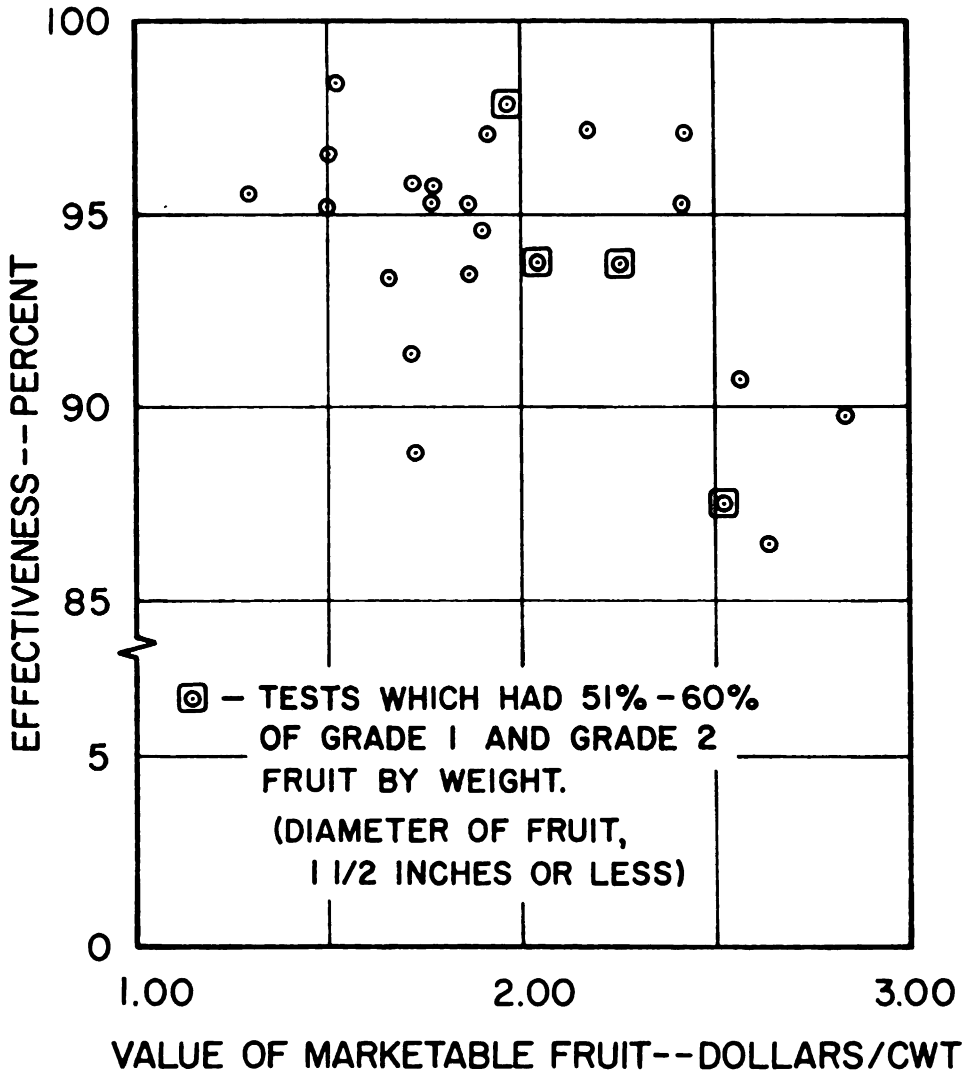

Figure 22. Effectiveness for tests which had 51-60 percent Grade 1 and Grade 2 fruit and the value of the harvested marketable fruit.

Table 4. The grade distribution for tests with 51-60 percent Grade 1 and Grade 2 fruit

Grade Distribution of Sample No.1 (Percent)	No.2 (Percent)	No.3 (Percent)	No.1 & 2 (Percent)	Effectiveness (Percent)	Value/cwt of Harvested Fruit (Dollars)
9.3	44.3	46.3	53.6	97.1	1.97
8.5	42.0	49.5	50.5	93.8	2.05
12.1	47.1	40.8	59.2	93.8	2.26
26.4	27.3	46.3	53.7	87.6	2.52

Table 5. Distribution of damage and the percent of the total weight of the test that appeared as damaged fruit in the fruit box

Test (gm)	W_1 Damaged fruit in fruit box (gm)	W_2 Damaged fruit in vine box (gm)	W_3 Total weight of Damaged and Undamaged fruit (gm)	$\frac{W_1}{W_3}$ (percent)
1	150	93	2578	5.8
2	44	48	7436	0.6
3	121	75	3911	3.1
4	129	62	9429	1.4
5	49	72	2949	1.7
6	148	20	4335	3.4
7	24	37	4000	0.6
8	97	22	2222	4.5
9	86	33	2030	4.0
10	60	12	3272	1.9
11	46	8	3647	1.3
12	34	39	3534	1.0
13	61	36	2610	2.5
14	117	12	3821	3.1
15	58	8	3581	1.6
16	79	14	3896	2.0
17	286	23	3915	7.3
18	18	12	2760	0.7
19	63	0	2457	2.5
20	52	82	6532	0.8
21	83	24	5430	1.5
22	3	28	6069	0.1
23	116	22	5906	2.0

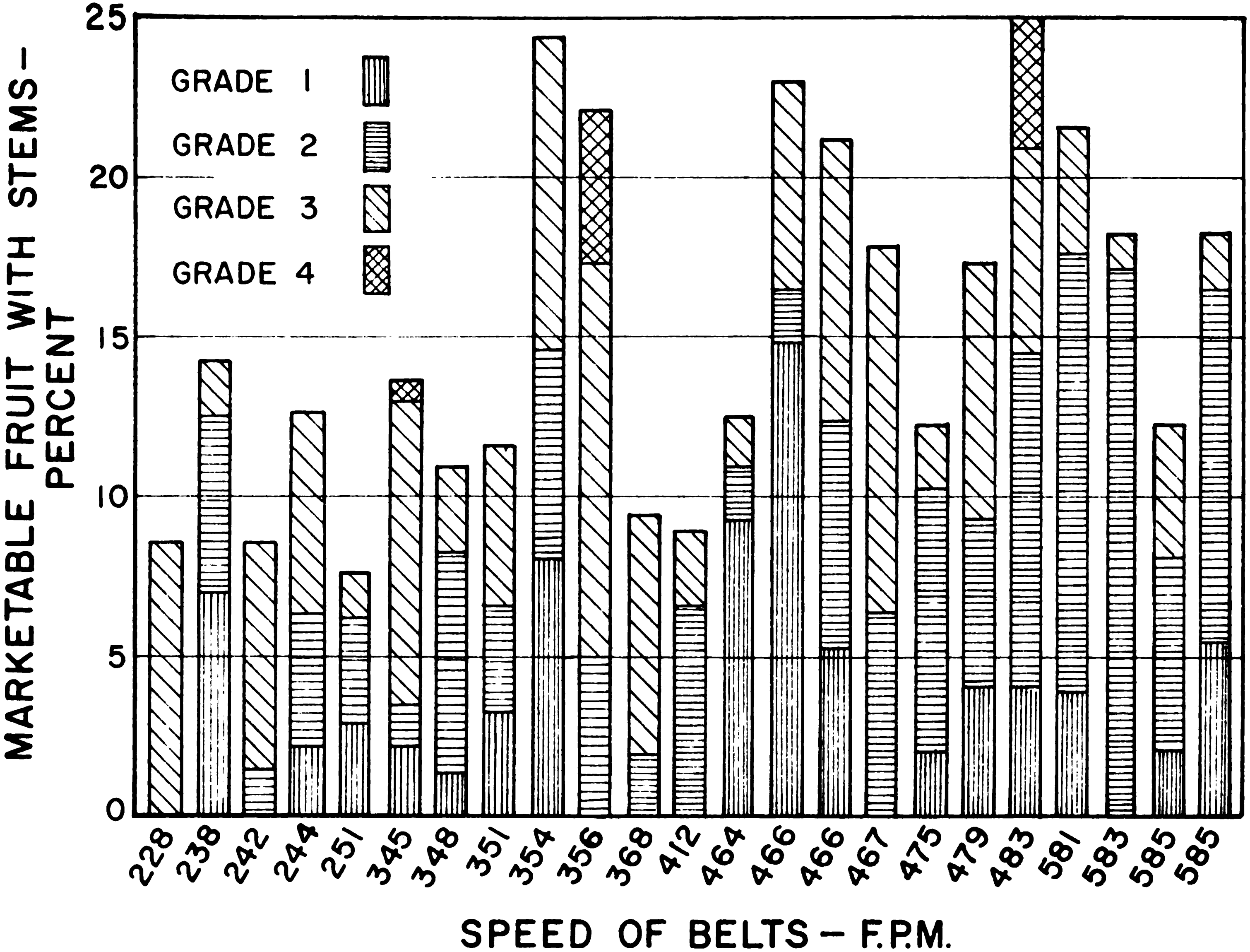

Figure 23. Percent of harvested marketable fruit that retained a stem.

CONCLUSIONS

1. The double belt fruit detachment device removes all sizes of marketable fruit.
2. All of the tests had an effectiveness higher than 86 percent. Seventy four percent of the tests had an effectiveness higher than 93 percent.
3. The tests with 51-60 percent of the fruit with diameters less than 1 1/2 inches had an average effectiveness of 93 percent.
4. An average of 79 percent of the monetary damage occurred in Grade 1 fruit.
5. An average of 15 percent of the undamaged fruit retained a stem.
6. The effectiveness did not appear to be a function of the speed of the picking belts.

SUGGESTIONS FOR FURTHER STUDY

1. Determine the effectiveness of a field size device using the principle of the fruit detachment device developed in this investigation.
2. Determine the grade distribution that provides the highest dollar return per acre.
3. Establish the minimum size of fruit that should be considered marketable fruit.
4. Establish precise damage criteria.

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