

May 1973

To the Graduate Council:

I am submitting herewith a thesis written by John Thomas King entitled "An Open-Helix Harvesting Mechanism for Use on Bell Peppers." I recommend that it be accepted for nine quarter hours of credit in partial fulfillment of the requirements for the degree of Master of Science, with a major in Agricultural Engineering.

B. L. Bledsoe  
Major Professor

We have read this thesis  
and recommend its acceptance:

John J. Mullan

David L. Coffey

Arthur H. Morgan

Accepted for the Council:

Hilton A. Smith  
Vice Chancellor for  
Graduate Studies and Research

313

AN OPEN-HELIX HARVESTING MECHANISM FOR USE ON BELL PEPPERS

---

A Thesis

Presented to  
the Graduate Council of  
The University of Tennessee

---

In Partial Fulfillment  
of the Requirements for the Degree  
Master of Science

---

by

John Thomas King

June 1973

## ACKNOWLEDGEMENTS

The author wishes to thank his Major Professor, Dr. Bobby L. Bledsoe. During the author's time as a graduate student and especially during this study, Dr. Bledsoe's assistance, advice, and patience have been invaluable. If it were not for Dr. Bledsoe, the author would probably have gone elsewhere for graduate school.

The author is grateful to Mr. A. H. Morgan, who first conceived the idea for this study, for his encouragement, suggestions, and interest during the modification and testing of this machine.

Grateful acknowledgement is due to Dr. John J. McDow, Head of the Department of Agricultural Engineering and Dr. David L. Coffey, Assistant Professor, Plant and Soil Science Department, for serving as committee members.

Thanks go to Mr. Earl Shelton and Mr. William Johnson for their help and encouragement during the modification of this machine. Also thanks are due to the other Agricultural Engineering Research Shop personnel and student employees of the Agricultural Engineering Department for their help in this study.

Special thanks go to the author's parents, Mr. and Mrs. John T. King for the opportunities and encouragement that they have given.

## ABSTRACT

The purpose of this investigation was to modify and evaluate an open-helix mechanism for harvest of bell peppers. The mechanism was modified and laboratory tests were conducted to determine the effect of different helix inclination angles and helix linear speeds on the harvesting efficiency.

The mean harvesting efficiency was 92.0 percent, and the mean percentage of single peppers harvested was 49.9 percent. Statistical analyses of the test results showed that there was a significant difference in the percentage of single peppers harvested and peppers harvested attached to stems for different helix inclination angles. Helix inclination angles tested were 20, 25, and 30 degrees. Helix linear speeds tested were 100, 105 and 110 percent of simulated ground speed. Helix linear speed had no significant effect on the response variables.

High speed motion picture films of the picking action were studied to determine the method of pod detachment. It was observed that fillets in the rear of the helix cage assembly striking stems at a distance below the point of attachment of the pepper caused the stem to fail, resulting in the harvest of peppers still attached to portions of plant stems. The coils of the helix cage assembly striking the pepper fruits and causing bending, twisting and axial (pulling) forces in the pedicel resulted in the detachment of single peppers. Also the stem of the pepper plant being struck near the point of attachment of a pepper and accelerated away from the pepper resulted in detachment of single peppers.

In these tests, the best results were obtained with a helix inclination angle of 30 degrees and with any of the helix linear speeds tested. A future prototype machine should have a longer helix cage assembly, and have the rear of the helix cage assembly as high above the ground as the tallest pepper plants.

## TABLE OF CONTENTS

| CHAPTER                                                     | PAGE |
|-------------------------------------------------------------|------|
| I. INTRODUCTION AND OBJECTIVES . . . . .                    | 1    |
| Introduction . . . . .                                      | 1    |
| Objectives . . . . .                                        | 2    |
| II. REVIEW OF LITERATURE . . . . .                          | 4    |
| Importance of the Pepper Crop . . . . .                     | 4    |
| Cultural Practices . . . . .                                | 5    |
| Vegetable Production Difficulties . . . . .                 | 6    |
| Mechanical Harvest of Peppers . . . . .                     | 7    |
| III. TEST EQUIPMENT AND PROCEDURE . . . . .                 | 11   |
| Test Equipment . . . . .                                    | 11   |
| Test Procedure . . . . .                                    | 23   |
| High Speed Motion Picture Study . . . . .                   | 31   |
| IV. RESULTS AND DISCUSSION . . . . .                        | 34   |
| Machine Performance . . . . .                               | 34   |
| Type of Detachment and Harvesting Action Analysis . . . . . | 46   |
| V. SUMMARY AND CONCLUSIONS . . . . .                        | 55   |
| BIBLIOGRAPHY . . . . .                                      | 58   |
| VITA . . . . .                                              | 61   |

## LIST OF TABLES

| TABLE |                                                                                                        | PAGE |
|-------|--------------------------------------------------------------------------------------------------------|------|
| I.    | Conditions for Tests . . . . .                                                                         | 27   |
| II.   | Harvesting Mechanism Efficiency and Damage to Bell<br>Peppers . . . . .                                | 35   |
| III.  | Analysis of Variance for Percentage of Single Fruits<br>Detached by Harvesting Mechanism . . . . .     | 39   |
| IV.   | Analysis of Variance for Percentage of Fruits on<br>Stems Detached by Harvesting Mechanism . . . . .   | 42   |
| V.    | Analysis of Variance for Percentage of Fruits<br>Unpicked or Damaged by Harvesting Mechanism . . . . . | 44   |

## LIST OF FIGURES

| FIGURE |                                                                                                         | PAGE |
|--------|---------------------------------------------------------------------------------------------------------|------|
| 1.     | The Machine Tested by Fullilove and Futral for Harvest<br>of Pimento and Bell Peppers in 1971 . . . . . | 9    |
| 2.     | View of Complete Harvesting Mechanism and Power Supply . . . . .                                        | 12   |
| 3.     | View of the Mechanism Frame Suspended From the Support<br>Structure . . . . .                           | 12   |
| 4.     | Assembled Helical Cage Unit . . . . .                                                                   | 14   |
| 5.     | Grooved Roller Used to Support Helix Cage Assembly and<br>Hold Coil Spacing Constant . . . . .          | 16   |
| 6.     | Grooved Roller in Place on Harvesting Mechanism . . . . .                                               | 18   |
| 7.     | Hydraulic Motor Used to Drive Helix Cage Assembly . . . . .                                             | 18   |
| 8.     | Side View of Hydraulic Power Supply . . . . .                                                           | 19   |
| 9.     | Top View of Hydraulic Power Supply Showing Components<br>of Flow Circuits . . . . .                     | 19   |
| 10.    | Front View of Suspension System with Harvester Mechanism<br>Attached . . . . .                          | 20   |
| 11.    | Side View of Suspension System with Harvester Mechanism<br>Attached . . . . .                           | 20   |
| 12.    | Carriage and Track Assembly Used to Simulate Forward<br>Motion of the Harvester . . . . .               | 22   |
| 13.    | Drive Unit for the Carriage Assembly . . . . .                                                          | 24   |
| 14.    | Front View of the Experimental Setup Before a Test Run . . . . .                                        | 29   |
| 15.    | Front View of the Experimental Setup After a Test Run . . . . .                                         | 29   |

## FIGURE

## PAGE

|     |                                                                |    |
|-----|----------------------------------------------------------------|----|
| 16. | Rear View of the Experimental Setup Showing the Pepper         |    |
|     | Plants after Harvesting Process . . . . .                      | 30 |
| 17. | Setup for High Speed Motion Picture Study . . . . .            | 33 |
| 18. | Mean Effect of Variables on Percentage of Single Fruits        |    |
|     | Detached . . . . .                                             | 38 |
| 19. | Mean Effect of Variables on Percentages of Fruits              |    |
|     | Harvested Attached to Portions of Stems . . . . .              | 41 |
| 20. | Mean Effect of Variables on Percentage of Fruits               |    |
|     | Unpicked or Damaged . . . . .                                  | 43 |
| 21. | Mean Effect of Helix Inclination Angle on Response             |    |
|     | Variables . . . . .                                            | 45 |
| 22. | Peppers in Class One, Detached when the Pedicel Failed . . . . | 47 |
| 23. | Peppers in Class Two, Detached when the Pod-Pedicel            |    |
|     | Junction Failed . . . . .                                      | 47 |
| 24. | Peppers in Class Three, Detached when Pedicel-Stem             |    |
|     | Junction Failed . . . . .                                      | 48 |
| 25. | Peppers in Class Four, Detached when Stem Failed . . . . .     | 48 |
| 26. | Peppers Damaged During Harvesting Operations, Class Five . . . | 49 |
| 27. | Photographs of Individual Frames from the High Speed           |    |
|     | Movie Film Showing Harvest of Two Single Peppers . . . . .     | 50 |
| 28. | Photographs of Individual Frames from the High Speed           |    |
|     | Movie Film Showing Peppers Harvested Still                     |    |
|     | Attached to Stem . . . . .                                     | 52 |

## CHAPTER I

### INTRODUCTION AND OBJECTIVES

#### I. INTRODUCTION

Since the day Adam selected and harvested an apple from the tree in the Garden of Eden, the world has been striving to develop a better apple, a better tree, and to improve the methods of harvest. Until recent decades, however, fruits and vegetables have remained in that select group of products individually selected and hand harvested.

It is obvious to anyone who is familiar with the production and marketing of farm products that fruits and vegetables must follow the trends established for the staple food and feed crops which succumbed to the technology of mechanization many years ago. Trends indicate that any fruit or vegetable crop that cannot be mechanically harvested will disappear from consumer shopping lists due to economic competition from those crops that can be mechanized (2). In 1969, only 58 percent of the vegetables produced in the United States were mechanically harvested. This figure is expected to increase to 75 percent by 1975 (16).

The production of sweet peppers is similar to production of tomatoes; both crops require a high labor input. When all parts of the country are considered, peppers are harvested practically all year round. In the past mechanical harvesting and handling of peppers has been limited primarily to the use of mechanical labor aids such as collecting belts and mobile platforms. Presently several dehydrator

companies are working with experimental machines for harvesting both sweet and chili peppers for processing. Experimental approaches to machine harvest have included methods ranging from severing the root system and taking the vine into the machine to removing the pods from the vine in the growing position. Shaking, stripping, and raking actions have been employed in the fruit separation process (4).

Since pepper is a high labor crop it has harvesting-cost-to-total-cost ratios similar to those of tomatoes. The high harvest labor requirement coupled with labor shortages permits a reasonable cost margin to justify development of a mechanical harvesting system (8).

A study of bell pepper detachment by an open-helix harvesting mechanism was organized at the University of Tennessee. The investigation was to expand an idea conceived by A. H. Morgan (9) that this vegetable can be harvested with the use of an open-helix machine element. This concept was tested to some extent by Shadden (12) on bell peppers and snap beans, and by Davenport (3) on snap beans.

The harvester as tested by Shadden did not have sufficient size and strength for successful harvest of bell peppers. The redesigned harvester tested by Davenport was believed to have the required size and strength for tests on bell peppers. However, to detach peppers the spacing between consecutive coils of the helix should remain constant. A way to maintain the constant spacing had to be devised.

## II. OBJECTIVES

The purpose of this study was to evaluate an open-helix harvesting mechanism, with the coil spacing held constant, for effectiveness in

detaching peppers from the plants in laboratory tests. Specific objectives were:

1. To modify a four-coil open-helix harvesting mechanism for use on peppers.
2. To devise a method for holding the coil spacing of the open-helix cage assembly constant during operation of the harvester.
3. To determine the effects of the harvester coil assembly linear speed and vertical inclination on picking efficiency.
4. To determine the pepper detachment action of the harvester through high speed motion picture analysis.

Laboratory test data were taken for the following response variables:

1. Percentage of peppers detached from stems.
2. Percentage of peppers harvested from plants but still attached to stems.
3. Percentage of peppers damaged or not picked (peppers lost due to machine limitations).

## CHAPTER II

### REVIEW OF LITERATURE

#### I. IMPORTANCE OF THE PEPPER CROP

The popularity of green peppers has increased markedly over the past 25 years. Peppers ranked sixteenth both in acreage and value among the 22 principal vegetables in The United States in 1965, and they are widely consumed.

Peppers are grown commercially in more than a dozen states in the South, parts of the East, Midwest, and West; and they are grown for local markets and home use in many other states. Georgia produces almost all pimento peppers used in the canning industry; paprika peppers are grown primarily in small areas in California and Arizona; and chili peppers are produced mainly in Southern California and New Mexico. Approximately 50,000 acres are devoted to sweet peppers, which are grown for the fresh and processing markets over a wide area, primarily in the Eastern half of the United States. Because of the wide area in which they are produced and variations in the growing conditions, sweet peppers are available most of the year, with a slight increase in production during the period May through August (8,15).

Production of peppers both for the fresh market and for processing increased substantially in the period from 1939 to 1965. The acreage more than doubled, rising from 22,800 acres to almost 48,000 acres, and farm value of the crop rose from \$4,881,000 to about \$37,000,000.

Sweet peppers are comparatively expensive to produce because of fertilizer, cultural and labor requirements. About 200 man-hours of labor per acre are required to grow and harvest sweet peppers. This figure has not changed materially for many years (15).

## II. CULTURAL PRACTICES

Generally peppers are planted in beds or on the flat, either by direct seeding or transplanting. If irrigation is used, it is usually furrow or sprinkler irrigation, and the number of water applications during the growing season varies (8).

The decision of when to harvest bell peppers is made by considering the size of the fruit and its stage of maturity. For the fresh market, the peppers are picked as soon as they reach approximately full size and become firm, but before they begin to turn red or yellow, as the respective colors may be when ripe. They are harvested by hand, placed in baskets, and hauled to a central area for grading (15). Peppers for processing are harvested after the pods ripen and change color. The harvest method is the same as for fresh market peppers.

Most of the peppers grown in Tennessee are usually harvested when they are full red ripe since they are for the processing industry. Harvests are usually one to two weeks apart over a period of ten to twelve weeks and are not recommended when only scattered red fruits show, since the ripe fruits will hold many weeks if sound. If many fruits are red, the harvesting will be more efficient. As for the actual harvesting process, picking into bushel baskets or hampers is recommended (1).

### III. VEGETABLE PRODUCTION DIFFICULTIES

One of the major problems in vegetable production is labor shortage. During the past hundred years, fruit and vegetable producers have depended upon new immigrants, migrant workers, and foreign contract workers to perform many of the peak seasonal farm labor tasks, but this is apparently coming to an end (14). Many Federal Government programs, such as the War on Poverty and other welfare programs, are aimed at improving the incomes of low-income workers. One way is to train seasonal workers for higher income, year-round jobs, thus removing them from the farm labor market.

Thor (14) predicts that in the decade ahead, vegetable producers can probably expect the following things. (1) Farm wage rates will increase substantially; (2) the supply of workers to perform seasonal labor will decrease; (3) housing and working conditions will improve; and (4) uncertainty about the availability of workers will increase.

Four alternatives are available to fruit and vegetable growers to relieve labor shortages:

1. Develop technology that will greatly reduce or eliminate the need for hand labor.
2. Increase wages and improve working conditions to a point where annual incomes and social status of the seasonal farm worker will be equal to the incomes and status of non-farm workers.
3. Diversify farming in the fruit and vegetable production areas to create year-round or nearly year-round employment for farm workers.

4. Divide the present commercial fruit and vegetable farms into thousands of small family-plot operations so that the farmer and his family can do most of the work.

The first alternative seems the best choice since the others would result in a substantial increase in the cost of food. Although this alternative will adversely affect some people, it would help many more since low income persons are burdened more by high food prices than are middle or high income persons.

#### IV. MECHANICAL HARVEST OF PEPPERS

Some mechanical labor aids have been used for pepper harvest in recent years. These include (1) collecting belts straddling six or eight rows, and (2) mobile grading and packing platforms. Attempts at complete mechanical harvest of sweet peppers have been made in the Southeast and West. Both selective and once over harvest systems have been tried. Some pepper harvest attempts have been made with modified and unmodified tomato harvesters.

At least four machines have been designed to harvest peppers. Riggs (11) obtained a patent for a chili pepper harvester in which the harvesting mechanism was composed of a pair of oppositely rotating, elongated brushes arranged to operate parallel to the pepper row when moved forward along it. A portion of sweet peppers for the processing (dehydration) industry in California is being harvested with machines utilizing brushes. Sims (13) reported that the processing industry has not released information about these machines.

Fullilove and Futral (5,6,7) have designed experimental machines for the harvest of peppers, especially pimento peppers. The machine tested by them in 1971, shown in Figure 1, had a pair of counter-rotating picking cylinders to remove the fruit. Each cylinder was four feet long and consisted of four helical bars equally spaced about the rim. The helix angle of each bar was 30 degrees, and each cylinder assembly was inclined 30 degrees from the horizontal (ground). The diameter of each cylinder was eight inches. A space of one and one-half inches was left between the cylinders to allow the plants to pass through. The direction of rotation was upward at the point of contact with the plants. The cylinder bars produced a combination bending, shaking and snapping action which removed the fruit and threw it up and over to each side. This machine also included conveyors, cleaners, sizers, and a holding bin. In field tests, overall efficiencies of up to 91.9 percent were obtained with pimento peppers. The bell pepper tests resulted in 44 percent overall efficiency, but these tests were conducted under very poor field conditions. Bell peppers tend to have lower set fruits than pimento peppers. This plant characteristic contributed to the low harvesting efficiency; bell peppers could not be harvested as readily as pimento peppers.

It was reported by Fullilove and Futral (7) that vertical combing of the plants using a rake-type mechanism was acceptable, provided the action was very slow. Speeding up the action pulled the plants from the ground. Raking across the plant at right angles to the row showed the most promise.

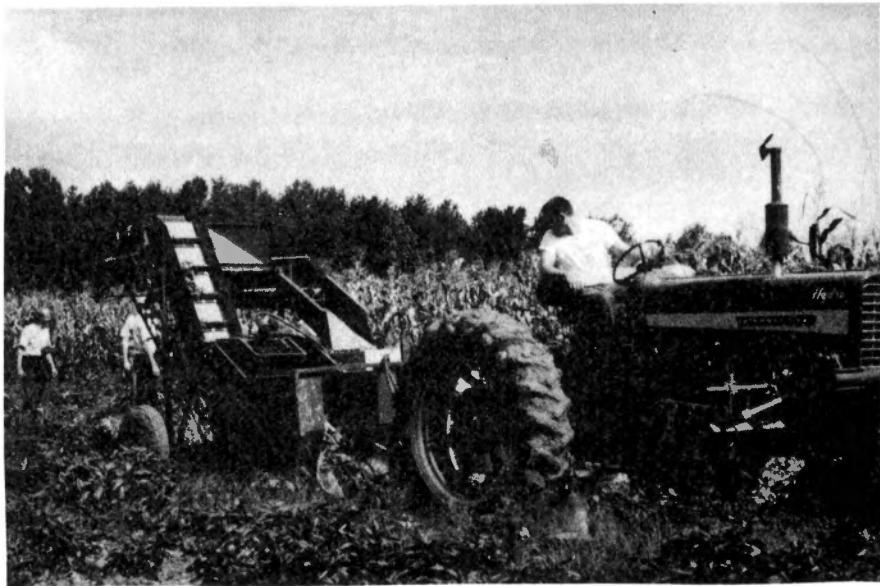


Figure 1. The machine tested by Fullilove and Futral for harvest of pimento and bell peppers in 1971.

As stated in Chapter I, a machine element to harvest pod vegetables was originated by Morgan (9) and evaluated by Morgan and Shadden (10). Tests showed that the first model of this harvester did not have the strength required for the successful harvest of bell peppers. The concept was then tested by Davenport (3) on snap beans using a revised laboratory model of the harvester which was structurally stronger than the machine previously tested. This report concerns modification of the machine to harvest bell peppers and the experimental results obtained.

## CHAPTER III

### TEST EQUIPMENT AND PROCEDURE

#### I. TEST EQUIPMENT

The harvesting mechanism built for this study consisted of a frame, a helix assembly, guide rollers (to keep spacing of the helix coils constant), a suspension system, and a power supply. The harvesting mechanism was designed to be a part of a once-over, one-row harvester. For testing it was supported by a stationary suspension system. Figure 2 shows the complete harvesting mechanism and power supply. The power supply consisted of a hydraulic motor driven by a tractor powered hydraulic pump. The harvesting mechanism and test setup were basically the same as those used by Davenport (3), with some required modification for peppers.

The frame of the mechanism, constructed primarily of 1-1/2 x 2 x 1/8 inch steel tubing, is shown suspended from the stationary support structure in Figure 3. The frame was 40-1/2 inches high, 36-1/8 inches long and 37-7/8 inches wide. The front of the frame was 2-1/2 inches shorter than the rear. This difference in height at the bottom front of the frame positioned the helix assembly coil tips near the ground line, making them the lowest members of the mechanism. The purpose of this design feature was to cause the helix points to enter the row and take plants into the cage assembly with the low-set peppers intact. The frame tapered inward at the bottom and formed an opening for the plants to pass through. The opening was 19 inches wide at the

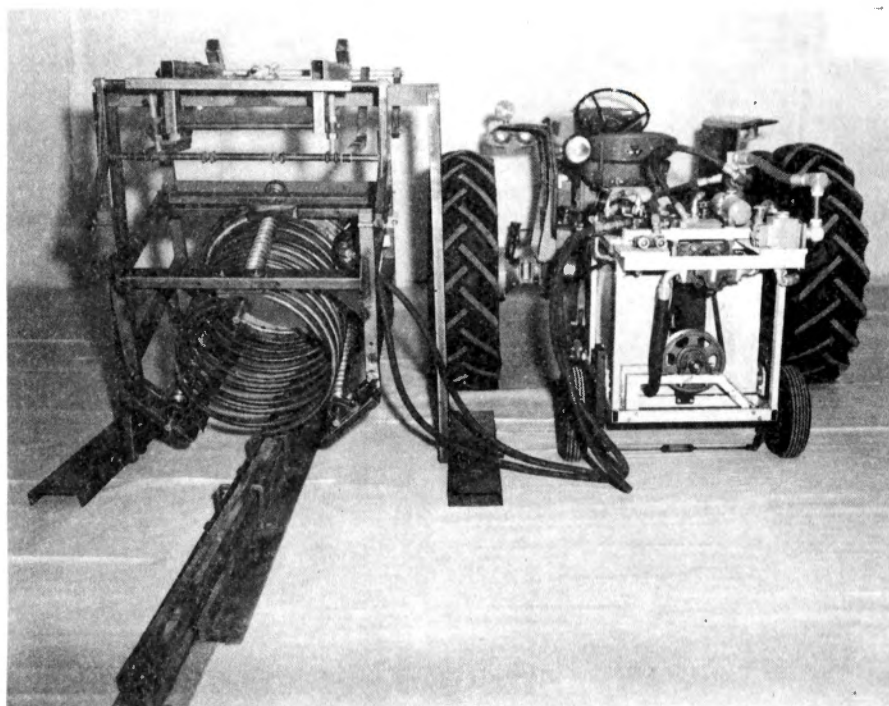


Figure 2. View of complete harvesting mechanism and power supply.

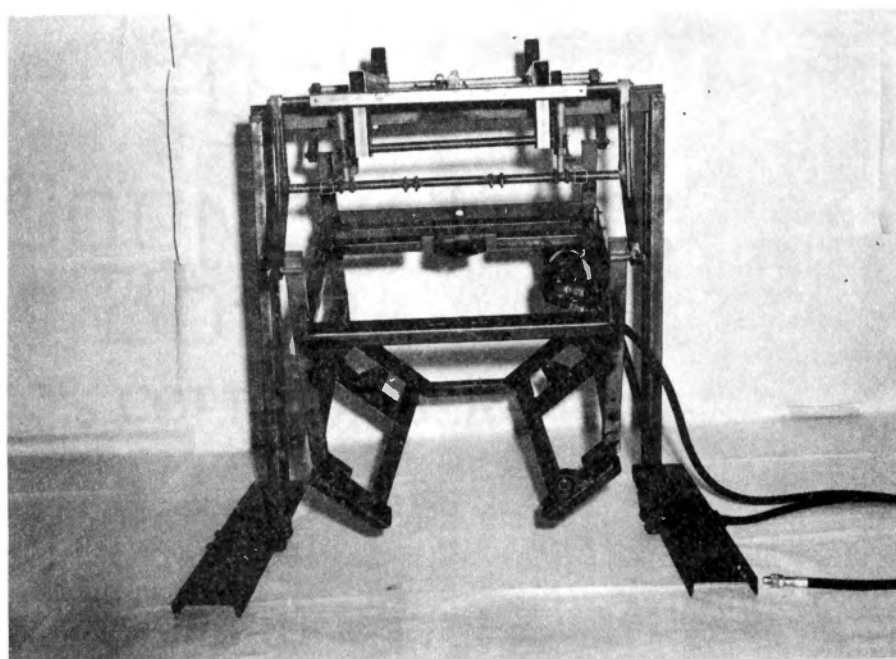


Figure 3. View of the mechanism frame suspended from the support structure.

front, 35 inches long and 14 inches wide at the rear. Except for one crosspiece at the rear, the bottom opening was unrestricted. It was believed that the rear of the harvesting mechanism would have sufficient ground clearance such that the crosspiece would not interfere with plant movement out of the machine. The sides of the frame were connected at the top front by a length of 2 x 3 x 3/16 inch steel tubing, with gussets of 3/8 inch plate added for stiffness. This construction was designed to keep the bottom of the frame from deflecting during operation. Economic consideration suggested using the helix assembly constructed by Davenport (3) with minor modification. It was believed that this assembly (Figure 4) would sufficiently test the concept of harvesting bell peppers with the open-helix machine element. The mean diameter of the helix coils was 24 inches. The helix assembly consisted of four helical coils bolted to the hub and spaced 90 degrees apart. Each coil was made of seamless steel tubing of 1 inch O.D. and 0.1196 inch wall thickness and had an overall length of 30 inches and a lead of 12 inches. When assembled, the coils formed a helical cage assembly which had a pitch of 3 inches, a lead of 12 inches and a space between two adjacent coils of 2 inches measured parallel to the axis of rotation. The leading end of each coil was plugged with a tapered, rounded tip to guide the coil around the plant stalks. To prevent plants from clogging at the junction of the coils and hub, metal fillets of 5/8 inch thick steel were bolted at the junction points. The hub was constructed from a 6 inch length of 26 inches O.D. by 9/16 inch wall thickness steel pipe. A steel ring with a 1/2 x 1-1/2 inch cross section was cut and welded around the center of the hub to

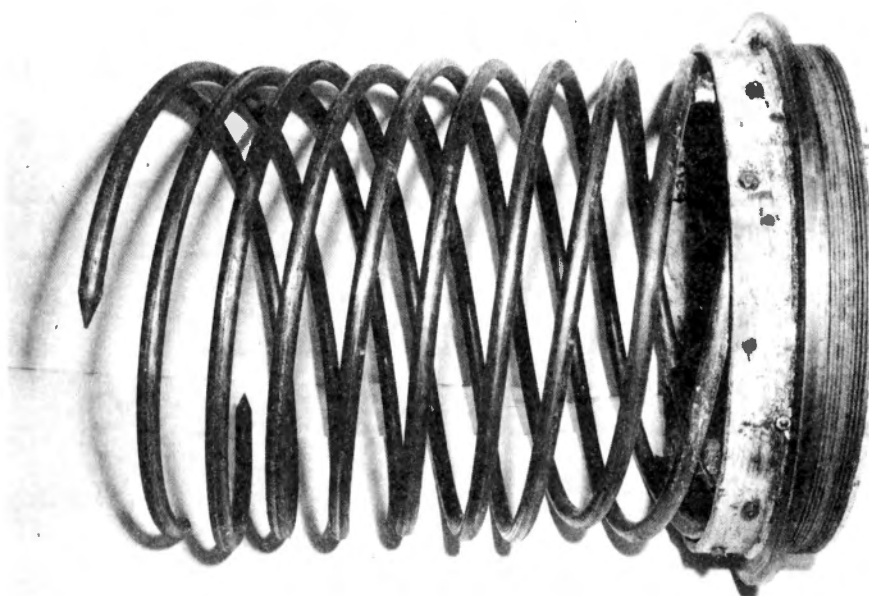


Figure 4. Assembled helical cage unit.

provide a means of support. Vee-shaped grooves for a 1-7/8 inch wide poly-V belt were machined in the back side of the hub to drive it.

The helix was positioned parallel to and directly over the centerline of the opening in the bottom of the frame. The helix was supported at the rear by plain grooved rollers which fit around the ring on the hub. The rollers were attached to the frame. The front of the assembly was supported by helically grooved rollers which served a dual role of supporting the assembly and holding the coils at a constant spacing. There were three of these rollers, shown in Figure 5, spaced approximately 120 degrees apart on the outside of the helix assembly. They were constructed from 3 inch diameter steel stock. The rounded grooves were 1-1/8 inches wide and 19/32 inch deep and were spiraled around the roller with a lead or pitch of approximately 1-1/2 inches. The grooved portion of the rollers was 24 inches long. One end of the roller was machined to a 1-3/16 inch diameter for a pillow block bearing, and the other end was bored and fitted with bearings which were mounted on 5/8 inch cold rolled steel shafts.

The rollers were mounted on the frame using the pillow block bearings in the front and mounting brackets constructed from angle iron in the rear. The 5/8 inch shaft portion of each roller was inserted into a hole in an angle iron bracket. The brackets were bolted through slots in the rear of the frame. The pillow block bearings were bolted through slots in the front of the frame. The slots provided for adjustment of the rollers relative to the helix so that the desired pressure could be exerted on the helix coils. This method of mounting was used on the bottom two rollers. The top roller was mounted

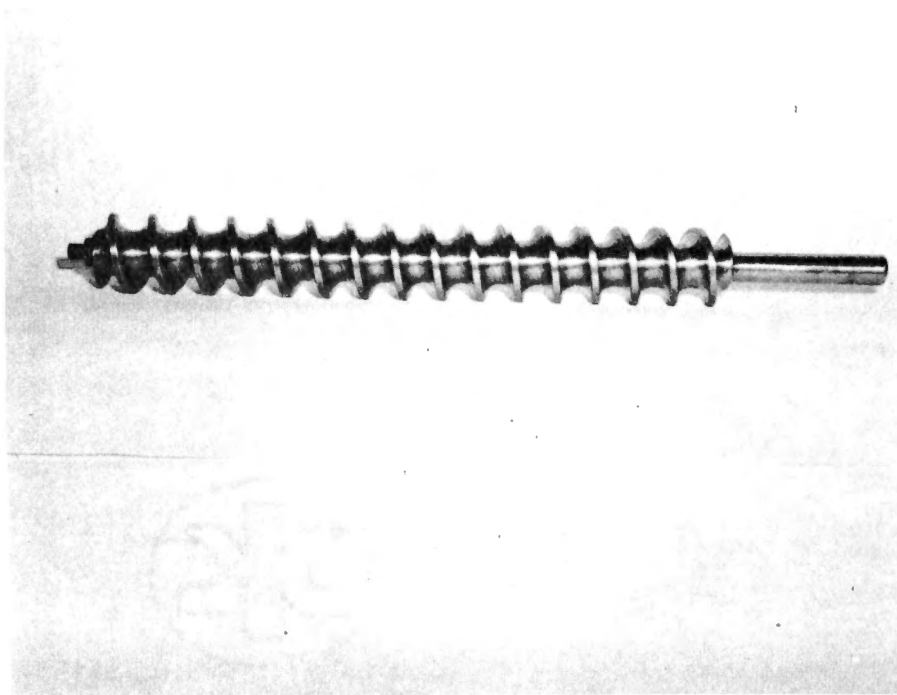


Figure 5. Grooved roller used to support helix cage assembly and hold coil spacing constant.

similarly except that adjustment was made using shims between the bearing and the frame.

When correctly mounted and lubricated, the diameter and pitch of the rollers were such that the helix would turn them, and no additional driving components were necessary. Figure 6 shows a roller in place on the harvesting mechanism.

The rollers which supported the hub of the helix were mounted 120 degrees apart on the frame. They were 3-1/2 inches in diameter with a 9/16 x 1/2 inch groove to accommodate the hub ring. They were mounted by using a 1 inch pin inserted through holes in the frame and through the center of the rollers. The two sets of rollers supported the helix assembly and aligned it within the frame. The helix assembly was driven by a Hydreco hydraulic motor through a poly-V belt (Figure 7).

A hydraulic drive was chosen so that any speed within a desired range could be easily obtained. A separate unit shown in Figures 8 and 9 was constructed to produce the variable oil flow which drove the hydraulic motor of the harvester. The power unit had two flow circuits and sets of flow control valves, but for the tests of the pepper harvesting mechanism, only one flow circuit was used.

The primary objective of this investigation was to determine the feasibility of harvesting peppers with the open-helix mechanism. Since tests were to be conducted in the laboratory, a stationary suspension system was built to support the machine during tests. This system had provisions for angle and height adjustment. Figures 10 and 11 show front and side views, respectively, of the suspension system with the assembled harvesting mechanism attached. With this suspension system,

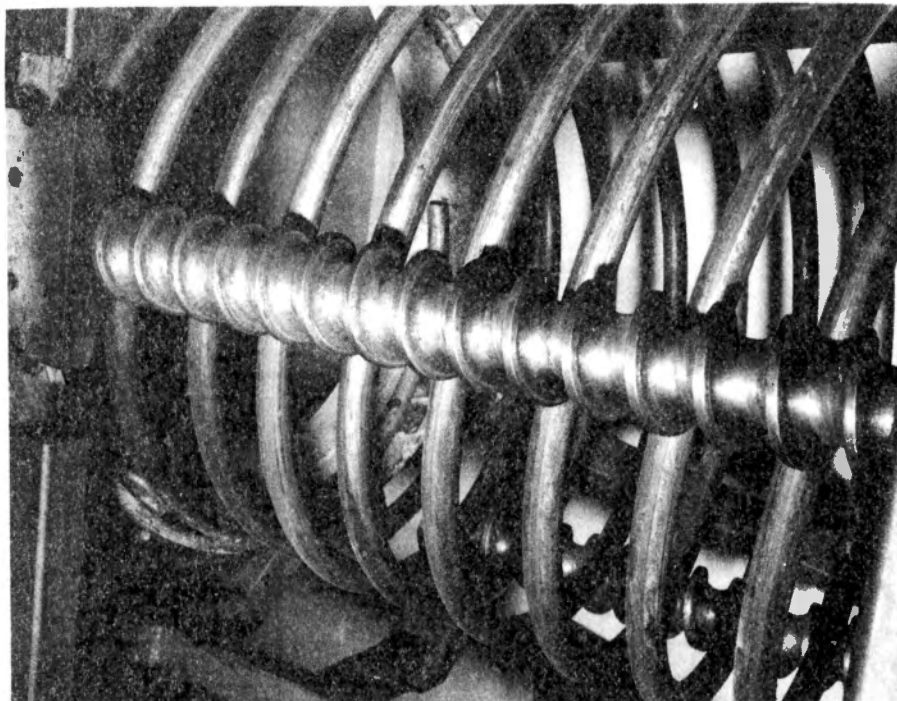


Figure 6. Grooved roller in place on harvesting mechanism.

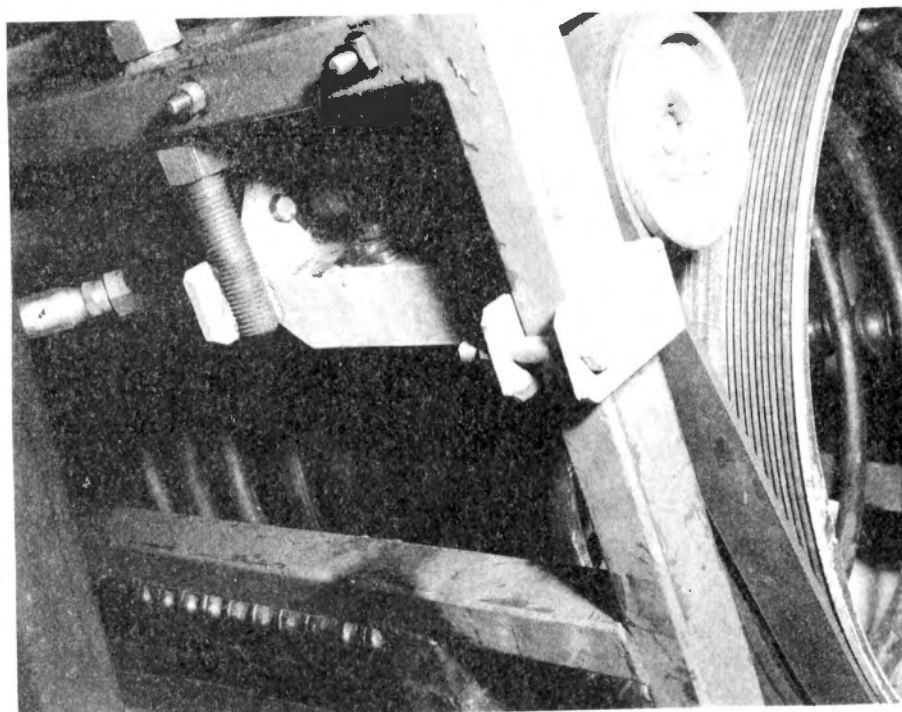


Figure 7. Hydraulic motor used to drive helix cage assembly.

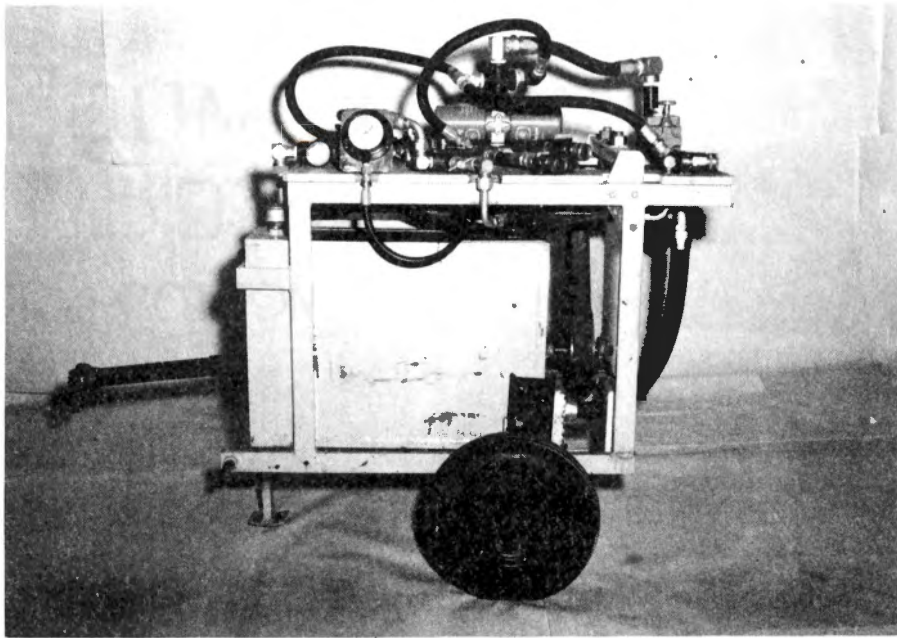


Figure 8. Side view of hydraulic power supply.

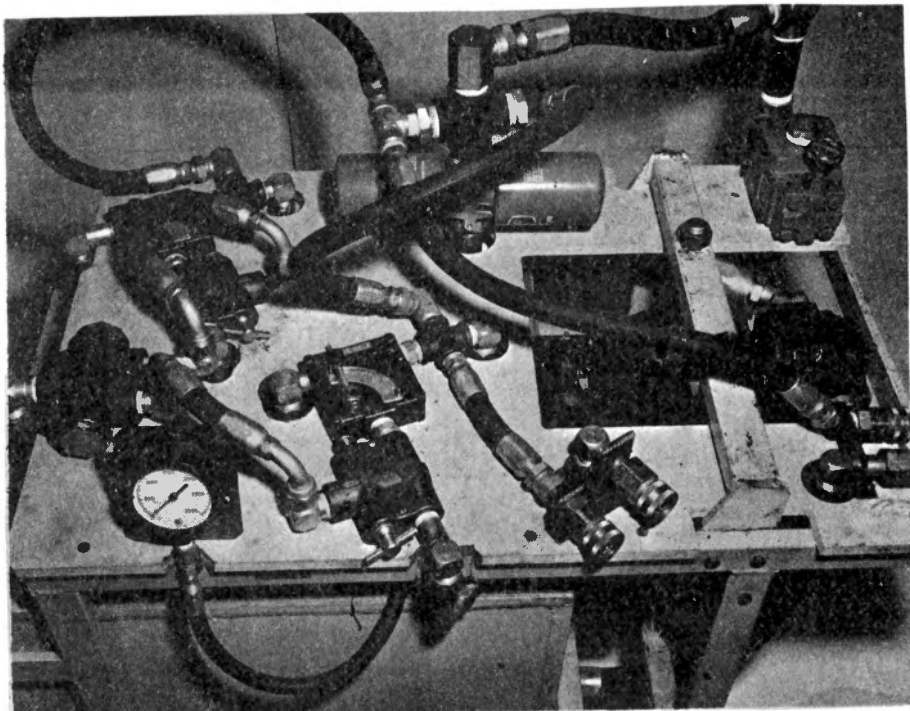


Figure 9. Top view of hydraulic power supply showing components of flow circuits.

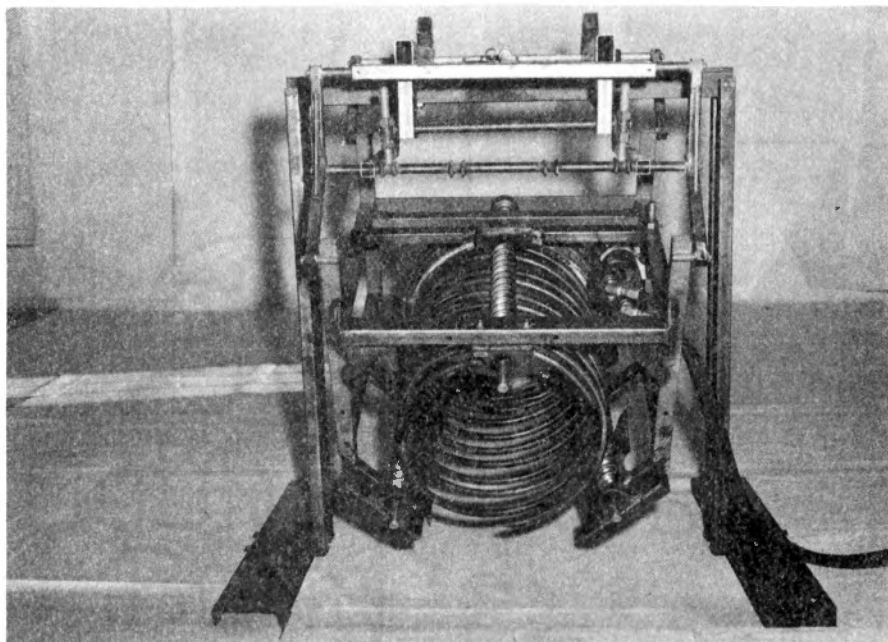


Figure 10. Front view of suspension system with harvester mechanism attached.

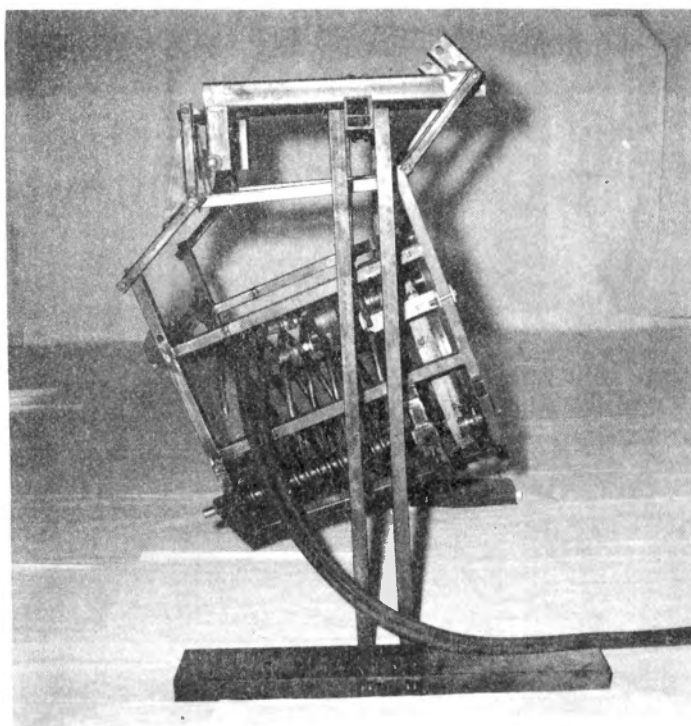


Figure 11. Side view of suspension system with harvester mechanism attached.

it was possible to obtain both the required coil assembly inclination angles of 20, 25, and 30 degrees measured from the horizontal and the height adjustments required for each angle.

Open construction was used throughout the harvester assembly to allow a clear view of the picking action. Since this was an investigation of pod removal from the plant, no attempt was made to develop a materials handling system for the detached pods.

It was necessary to devise some way of moving plants past the harvesting mechanism since it was stationary and the work was to be done in the laboratory. A plant holding carriage (Figure 12) was constructed for simulating forward motion of a harvester relative to a row of plants. This carriage had been used previously for bean harvesting studies and was modified to accept the larger pepper plants. The plants were mounted between two 1 x 6 inch wooden boards that comprised the carriage. The boards were lined with 1/8 inch thick fabric to reduce injury to plant stems and help hold them in place. Five plants were placed between the boards; the boards were then bolted together to clamp the plants in an upright position.

The carriage was positioned in a frame built on a large flat board to which two upright boards were fastened to form a U-shaped track. The track guided the carriage as it moved beneath the harvester.

During preliminary tests, it was discovered that the pod detaching action of the inclined helical cage assembly would lift the plants and carriage assembly from the track. Hold-down clamps were added to keep the carriage in contact with the track. The hold-down clamps were made of pieces of channel stock bent into the desired shape.

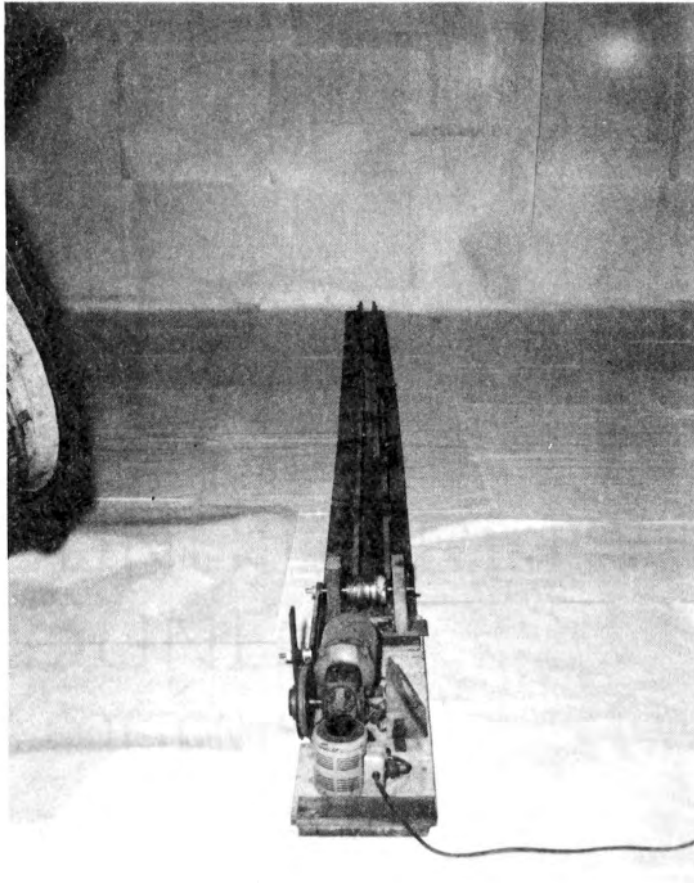


Figure 12. Carriage and track assembly used to simulate forward motion of the harvester.

A cable attached to the end of the plant-holding carriage extended to a winch drum. The drum was driven by an electric motor to wind up the cable and pull the carriage along the track. Figure 13 shows the carriage drive unit. Relative motion of the carriage with respect to the harvester was equivalent to that of the harvester moving down a row of stationary plants. An idler pulley clutch was used to disengage the drum winch to allow repositioning of the carriage for the start of another test. The linear velocity of the carriage was 75 feet per minute.

## II. TEST PROCEDURE

The effects of the helix assembly linear speed and the helix assembly inclination angle on pepper pod detachment were tested. Helix assembly linear speed (HLS) is defined as the horizontal component of linear speed along the longitudinal axis of the helix of a point in sliding contact with the coils and is expressed as a percentage of the simulated ground speed.

$$\text{HLS} = \frac{\text{lead of helix} \times \text{rev./min. of helix}}{\text{ground speed}} \times 100 \times \cos(\text{HIA})$$

The term HIA, the helix assembly inclination angle, is the angle between the longitudinal axis of the helix assembly and a horizontal plane.

Plants of pepper (*Capsicum Annum* L.) cv. Resistant Giant were used, and all tests were run in the laboratory. A 3 X 3 factorial combination of treatments was used. In all tests, the simulated forward velocity of the machine was held constant at 75 feet per minute. Five replications were run for each treatment combination. Five plants were included in each replication.

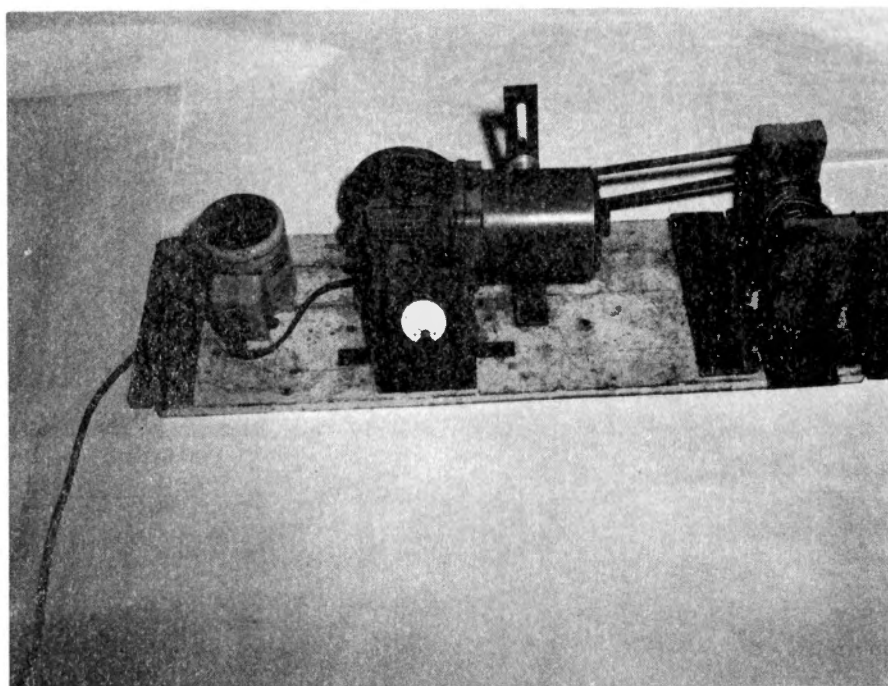


Figure 13. Drive unit for the carriage assembly.

The harvesting mechanism was not ready for testing until early October, and by that time the plants were maturing the last group of peppers that set during the growing season. Since the tests were conducted late in the season, the plants were large and the pods were located near the extremities of the plant stems. The test plants were grown on the University of Tennessee Plant and Soil Science Farm near Knoxville. They were pulled up, brought to the laboratory for the tests, and kept in the shade. All of the plants were used within 36 hours of the time they were brought in; and, in most cases, they were used within 12 hours. The root system was severed from the rest of the plant shortly before the tests were run so that the plants would fit into the plant holding assembly.

One light frost occurred before the tests were completed. This frost damaged the tips of the branches, but did not seem to harm the pepper pods or the main part of the plant.

The carriage track was positioned under the harvesting mechanism so that it was directly under and parallel to the centerline of the opening in the frame. The original intention was to position the helix so that the front of the helix would be just above the top of the plant holding carriage. When this position was used, and one of the points of the helix struck a plant stalk, the stalk would break or shatter leaving only a short stub in the carriage. Therefore it was necessary to raise the contact point so that the plant would have some room to deflect around the point. A height was chosen that positioned the lowest point of the helix approximately 2-1/2 inches above the top of the plant holding carriage.

It was felt that this machine, when positioned at an angle from the horizontal, would engage the plants near the ground; and, as the harvester advanced through the plants, the helix would give a gentle raking or combing action proceeding from the bottom to the top of the plants. It was hypothesized that this action would strip all the peppers larger than two inches in diameter from the plants. Because of the two inch spacing between the coils, it was thought that all fruits smaller than this, along with the plant stem structure, would slip between the coils and out the bottom of the mechanism.

The 3 X 3 factorial treatment arrangement resulted in nine treatment combinations. Levels of the independent variables were: helix linear speed (HLS) = 100, 105, and 110 percent of simulated ground speed; and helix inclination angle (HIA) = 20, 25, and 30 degrees. The desired HLS was obtained by adjusting the oil flow control valve in the hydraulic circuit supplying the helix drive motor. The rotational speed of the helix was measured by using a hand-held tachometer to check the speed of the hydraulic motor. The helix inclination angle was controlled by adjustments in the suspension system. The helix inclination angle was measured by using a machinist's protractor. The treatment combinations tested are given in Table I.

When the mechanism was constructed and set up for preliminary tests, it was positioned with the helix assembly inclined 20 degrees from the horizontal. A considerable amount of time and effort were required to change the inclination; so for convenience, the tests were conducted in the order given in Table I.

TABLE I  
CONDITIONS FOR TESTS

| Treatment                         | Simulated Velocity<br>of Machine<br>ft./min. | Helix Inclination<br>Angle from<br>Horizontal (degrees) | Helix Linear<br>Speed (% of<br>Ground Speed) |
|-----------------------------------|----------------------------------------------|---------------------------------------------------------|----------------------------------------------|
| HIA <sub>1</sub> HLS <sub>1</sub> | 75                                           | 20                                                      | 100                                          |
| HIA <sub>1</sub> HLS <sub>2</sub> | 75                                           | 20                                                      | 105                                          |
| HIA <sub>1</sub> HLS <sub>3</sub> | 75                                           | 20                                                      | 110                                          |
| HIA <sub>2</sub> HLS <sub>1</sub> | 75                                           | 25                                                      | 100                                          |
| HIA <sub>2</sub> HLS <sub>2</sub> | 75                                           | 25                                                      | 105                                          |
| HIA <sub>2</sub> HLS <sub>3</sub> | 75                                           | 25                                                      | 110                                          |
| HIA <sub>3</sub> HLS <sub>1</sub> | 75                                           | 30                                                      | 100                                          |
| HIA <sub>3</sub> HLS <sub>2</sub> | 75                                           | 30                                                      | 105                                          |
| HIA <sub>3</sub> HLS <sub>3</sub> | 75                                           | 30                                                      | 110                                          |

Each test run proceeded as follows:

1. The treatment combination was selected as described above.
2. The angle was set.
3. The plants were placed in the carriage.
4. The helix speed was set and checked.
5. The carriage drive was engaged to pull the plants through the harvesting mechanism.
6. After the plants had passed through the harvester, counts were made and recorded for the following types or classes of pepper detachment:
  - a. Pedicel failed
  - b. Pod-pedicel junction failed
  - c. Pedicel-stem junction failed
  - d. Stem failed with peppers still attached to stems
  - e. Peppers detached and visibly damaged
  - f. Peppers still attached to plants after harvesting process

Small pepper pods (less than approximately 1-1/2 to 2 inches minimum diameter) or overly mature pods (rotten or extremely soft) were not counted. The total number of peppers available was obtained by adding the number of peppers in each class of detachment. Peppers visibly damaged, such as those broken into several pieces, mashed severely, or those with a section torn loose from the fruit, were considered to be in the damaged class. Figure 14 shows the test setup just before a test run. Figures 15 and 16 show views of the setup

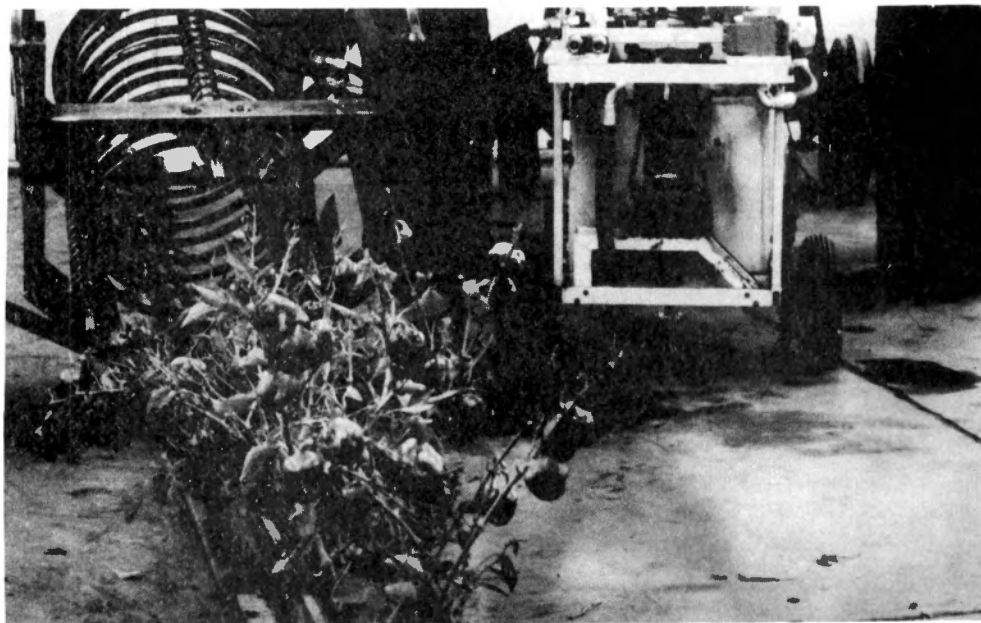


Figure 14. Front view of the experimental setup before a test run.

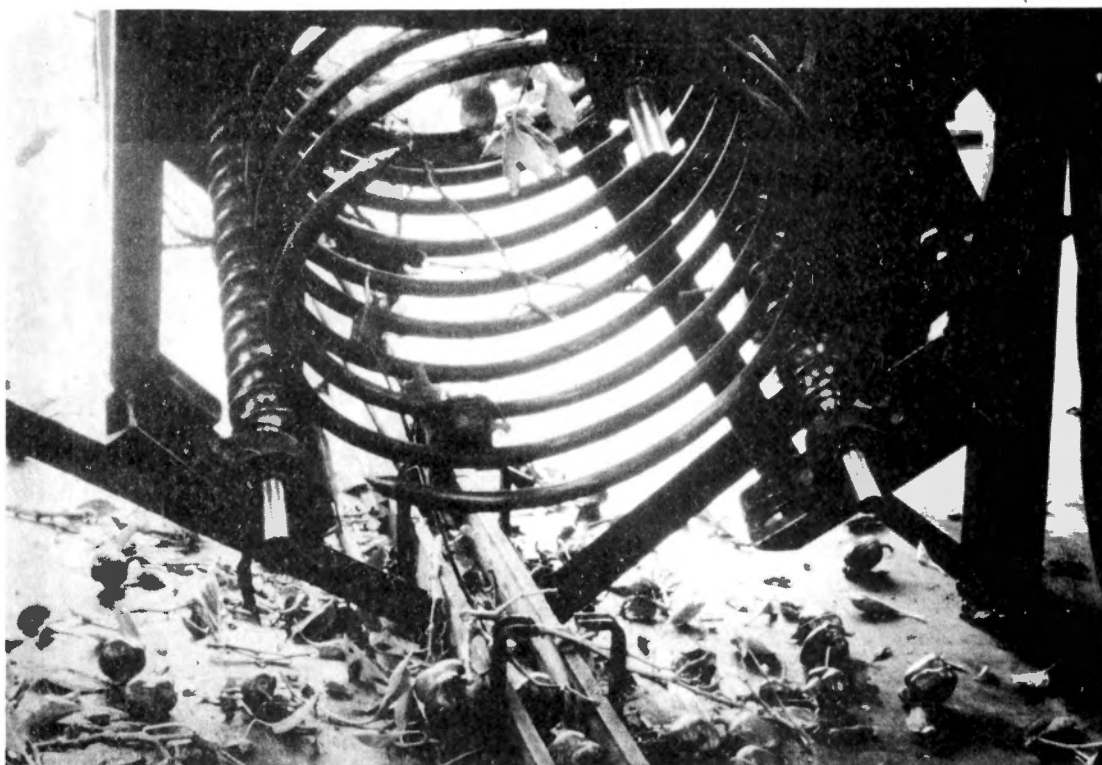


Figure 15. Front view of the experimental setup after a test run.



Figure 16. Rear view of the experimental setup showing the pepper plants after harvesting process.

after the test was conducted. Photographs of each class of pods can be seen in the results section.

### III. HIGH SPEED MOTION PICTURE STUDY

The detaching action of the harvesting mechanism was recorded on 16 mm film. A Red Lake Laboratories Hy-Cam high speed motion picture camera was used to expose the film. The camera speed was 450 frames per second. Two 650 watt quartz bromide lamps, a 1000 watt quartz iodine lamp, and a 180 watt incandescent lamp were used to provide illumination for the filming. A Honeywell Spotmeter was used to check light intensity and determine camera adjustments for each film action sequence. At the chosen camera speed, the camera electronic speed control gave one percent frame rate regulation. Thus film speed was used to calculate a time reference.

Three 100 foot rolls of film were used. Two films were taken of treatments  $HIA_3HLS_3$  and one film was taken of  $HIA_1HLS_1$ . Two films of treatment  $HIA_1HLS_1$  were planned; but due to camera trouble, one exposed film was lost. Figure 17 shows the setup for the high speed motion picture study; note that plant foliage has been removed to facilitate viewing of the harvesting action.

The films were analyzed using a LaFayette film analyzer. The analyzer was capable of projecting the film within a speed range of one frame per 1-1/2 seconds to normal projector speed (16 frames per second); also it could be stopped and reversed at any time. Use of this analyzer gave a slow motion interpretation of the harvesting action; the film could be studied frame by frame for film sequences

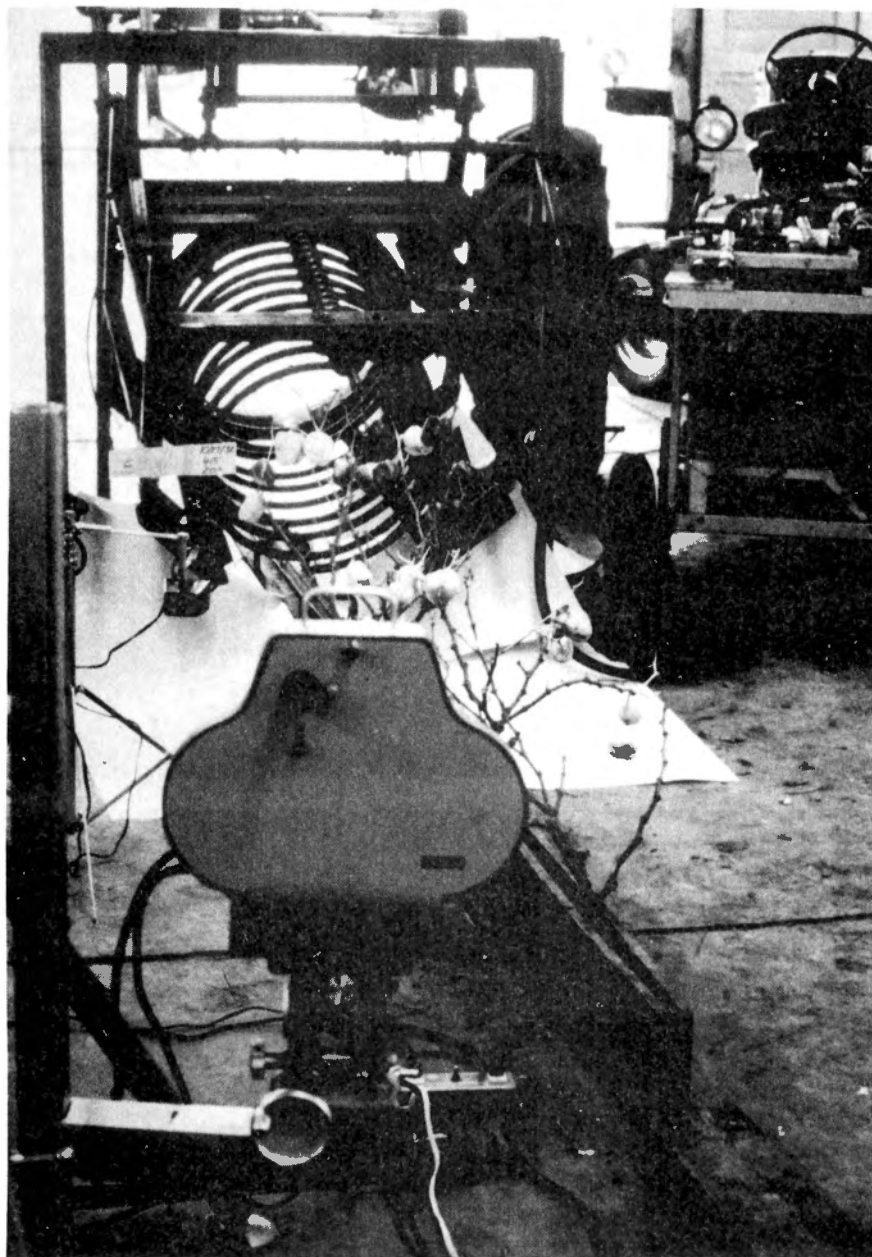


Figure 17. Setup for high speed motion picture study.

of particular interest. From this study, selected frames were chosen that illustrated successive phases of the harvesting action recorded by the particular film sequence. Enlarged photographs were made from the selected frames and can be seen in the results section.

## CHAPTER IV

### RESULTS AND DISCUSSION

#### I. MACHINE PERFORMANCE

Table II presents data on types of pepper detachment--the numbers and percentages of single fruits harvested, fruits harvested attached to portions of stems, and fruits damaged or not harvested. The percentage of undamaged harvested fruit ranged from a minimum of 77.1 to a maximum of 100.0. The mean percentage of undamaged harvested fruit was 92.0. An analysis of variance of the data determined the significance, if any, of the effects of the independent variables (helix assembly inclination angle and helix linear speed) on the dependent variables (single fruits harvested, fruits harvested attached to portions of stems, and fruits damaged or not harvested).

The mean effect of the independent variables on the percentages of single fruits harvested can be seen in Figure 18. Changing the helix inclination angle had a greater effect on the percentage of single peppers harvested than did the helix linear speed. The analysis of variance for single fruits harvested, Table III, shows that there was a significant treatment effect at the 0.01% level. Further analysis identified the significant main treatment effect to be the helix inclination angle. As the angle of the helix was increased, the percentage of single fruits harvested increased. The minimum percentage of single fruits harvested was 25.6, the maximum was 86.4, and the mean percentage was 49.9.

TABLE II

## HARVESTING MECHANISM EFFICIENCY AND DAMAGE TO BELL PEPPERS

| Treatment   | Replication | Number of Fruits Available | Number of Single Fruits Harvested | Number of Fruits Harvested Attached to Stems | Number of Fruits Damaged or not Harvested | Percent of Single Fruits Harvested | Percent of Fruits Harvested Attached to Stems | Percent of Fruits Harvested or not Harvested |
|-------------|-------------|----------------------------|-----------------------------------|----------------------------------------------|-------------------------------------------|------------------------------------|-----------------------------------------------|----------------------------------------------|
| HIA=20 deg. | 1           | 70                         | 30                                | 36                                           | 4                                         | 42.85                              | 51.42                                         | 5.71                                         |
|             | 2           | 60                         | 16                                | 37                                           | 7                                         | 26.67                              | 61.67                                         | 11.66                                        |
|             | 3           | 43                         | 11                                | 29                                           | 3                                         | 25.58                              | 67.44                                         | 6.98                                         |
|             | 4           | 39                         | 14                                | 22                                           | 3                                         | 35.90                              | 56.41                                         | 7.69                                         |
|             | 5           | 55                         | 24                                | 30                                           | 1                                         | 43.64                              | 54.55                                         | 1.82                                         |
| HIA=20 deg. | 1           | 49                         | 26                                | 21                                           | 2                                         | 53.06                              | 42.86                                         | 4.08                                         |
|             | 2           | 40                         | 11                                | 22                                           | 7                                         | 27.50                              | 55.00                                         | 17.50                                        |
|             | 3           | 68                         | 22                                | 41                                           | 5                                         | 32.35                              | 60.29                                         | 7.35                                         |
|             | 4           | 57                         | 22                                | 30                                           | 5                                         | 38.60                              | 52.63                                         | 8.77                                         |
|             | 5           | 43                         | 17                                | 26                                           | 0                                         | 39.53                              | 60.47                                         | 0.00                                         |
| HIA=20 deg. | 1           | 46                         | 16                                | 24                                           | 6                                         | 34.78                              | 52.17                                         | 13.04                                        |
|             | 2           | 57                         | 15                                | 37                                           | 5                                         | 26.32                              | 64.91                                         | 8.77                                         |
|             | 3           | 62                         | 25                                | 34                                           | 3                                         | 40.32                              | 54.84                                         | 4.84                                         |
|             | 4           | 69                         | 36                                | 27                                           | 6                                         | 52.17                              | 39.13                                         | 8.70                                         |
|             | 5           | 61                         | 23                                | 35                                           | 3                                         | 37.70                              | 57.38                                         | 4.92                                         |
| HIA=25 deg. | 1           | 45                         | 26                                | 18                                           | 1                                         | 57.78                              | 40.00                                         | 2.22                                         |
|             | 2           | 62                         | 25                                | 32                                           | 5                                         | 40.32                              | 51.61                                         | 8.06                                         |
|             | 3           | 43                         | 25                                | 17                                           | 1                                         | 58.14                              | 39.53                                         | 2.33                                         |
|             | 4           | 60                         | 36                                | 20                                           | 4                                         | 60.00                              | 33.33                                         | 6.67                                         |
|             | 5           | 35                         | 15                                | 12                                           | 8                                         | 42.86                              | 32.28                                         | 22.86                                        |
| HLS=100%    | 1           | 70                         | 30                                | 36                                           | 4                                         | 42.85                              | 51.42                                         | 5.71                                         |
|             | 2           | 60                         | 16                                | 37                                           | 7                                         | 26.67                              | 61.67                                         | 11.66                                        |
|             | 3           | 43                         | 11                                | 29                                           | 3                                         | 25.58                              | 67.44                                         | 6.98                                         |
|             | 4           | 39                         | 14                                | 22                                           | 3                                         | 35.90                              | 56.41                                         | 7.69                                         |
|             | 5           | 55                         | 24                                | 30                                           | 1                                         | 43.64                              | 54.55                                         | 1.82                                         |
| HLS=105%    | 1           | 49                         | 26                                | 21                                           | 2                                         | 53.06                              | 42.86                                         | 4.08                                         |
|             | 2           | 40                         | 11                                | 22                                           | 7                                         | 27.50                              | 55.00                                         | 17.50                                        |
|             | 3           | 68                         | 22                                | 41                                           | 5                                         | 32.35                              | 60.29                                         | 7.35                                         |
|             | 4           | 57                         | 22                                | 30                                           | 5                                         | 38.60                              | 52.63                                         | 8.77                                         |
|             | 5           | 43                         | 17                                | 26                                           | 0                                         | 39.53                              | 60.47                                         | 0.00                                         |
| HLS=110%    | 1           | 46                         | 16                                | 24                                           | 6                                         | 34.78                              | 52.17                                         | 13.04                                        |
|             | 2           | 57                         | 15                                | 37                                           | 5                                         | 26.32                              | 64.91                                         | 8.77                                         |
|             | 3           | 62                         | 25                                | 34                                           | 3                                         | 40.32                              | 54.84                                         | 4.84                                         |
|             | 4           | 69                         | 36                                | 27                                           | 6                                         | 52.17                              | 39.13                                         | 8.70                                         |
|             | 5           | 61                         | 23                                | 35                                           | 3                                         | 37.70                              | 57.38                                         | 4.92                                         |
| HLS=100%    | 1           | 45                         | 26                                | 18                                           | 1                                         | 57.78                              | 40.00                                         | 2.22                                         |
|             | 2           | 62                         | 25                                | 32                                           | 5                                         | 40.32                              | 51.61                                         | 8.06                                         |
|             | 3           | 43                         | 25                                | 17                                           | 1                                         | 58.14                              | 39.53                                         | 2.33                                         |
|             | 4           | 60                         | 36                                | 20                                           | 4                                         | 60.00                              | 33.33                                         | 6.67                                         |
|             | 5           | 35                         | 15                                | 12                                           | 8                                         | 42.86                              | 32.28                                         | 22.86                                        |

TABLE II (continued)

| Treatment   | Replication | Number of Fruits Available | Number of Single Fruits Harvested | Number of Fruits Harvested Attached to Stems | Number of Fruits Harvested Damaged or not Harvested | Percent of Single Fruits Harvested | Percent of Fruits Harvested Attached to Stems | Percent of Fruits Damaged or not Harvested |
|-------------|-------------|----------------------------|-----------------------------------|----------------------------------------------|-----------------------------------------------------|------------------------------------|-----------------------------------------------|--------------------------------------------|
| HIA=25 deg. | 1           | 28                         | 15                                | 7                                            | 6                                                   | 53.57                              | 25.00                                         | 21.43                                      |
|             | 2           | 39                         | 24                                | 7                                            | 8                                                   | 61.54                              | 17.95                                         | 20.51                                      |
|             | 3           | 42                         | 19                                | 15                                           | 8                                                   | 45.24                              | 35.71                                         | 19.05                                      |
|             | 4           | 49                         | 20                                | 27                                           | 2                                                   | 40.82                              | 55.10                                         | 4.08                                       |
|             | 5           | 54                         | 28                                | 23                                           | 3                                                   | 51.85                              | 42.59                                         | 5.56                                       |
| HIA=25 deg. | 1           | 34                         | 17                                | 14                                           | 3                                                   | 50.00                              | 41.18                                         | 8.82                                       |
|             | 2           | 27                         | 14                                | 10                                           | 3                                                   | 51.85                              | 37.04                                         | 11.11                                      |
|             | 3           | 30                         | 16                                | 13                                           | 1                                                   | 53.34                              | 43.33                                         | 3.33                                       |
|             | 4           | 30                         | 18                                | 12                                           | 0                                                   | 60.00                              | 40.00                                         | 0.00                                       |
|             | 5           | 46                         | 22                                | 23                                           | 1                                                   | 47.83                              | 50.00                                         | 2.17                                       |
| HIA=30 deg. | 1           | 53                         | 30                                | 17                                           | 6                                                   | 56.60                              | 32.08                                         | 11.32                                      |
|             | 2           | 50                         | 20                                | 27                                           | 3                                                   | 40.00                              | 54.00                                         | 6.00                                       |
|             | 3           | 69                         | 33                                | 30                                           | 6                                                   | 47.83                              | 43.48                                         | 8.70                                       |
|             | 4           | 53                         | 24                                | 27                                           | 2                                                   | 45.28                              | 50.94                                         | 3.77                                       |
|             | 5           | 44                         | 38                                | 4                                            | 2                                                   | 86.36                              | 9.09                                          | 4.55                                       |
| HIA=30 deg. | 1           | 40                         | 24                                | 11                                           | 5                                                   | 60.00                              | 27.50                                         | 12.50                                      |
|             | 2           | 47                         | 27                                | 17                                           | 3                                                   | 57.45                              | 36.17                                         | 6.38                                       |
|             | 3           | 52                         | 36                                | 13                                           | 3                                                   | 69.23                              | 25.00                                         | 5.77                                       |
|             | 4           | 57                         | 29                                | 22                                           | 6                                                   | 50.88                              | 38.60                                         | 10.52                                      |
|             | 5           | 31                         | 21                                | 7                                            | 3                                                   | 67.74                              | 22.58                                         | 9.68                                       |
| HLS=105%    | 1           | 28                         | 15                                | 7                                            | 6                                                   | 53.57                              | 25.00                                         | 21.43                                      |
|             | 2           | 39                         | 24                                | 7                                            | 8                                                   | 61.54                              | 17.95                                         | 20.51                                      |
|             | 3           | 42                         | 19                                | 15                                           | 8                                                   | 45.24                              | 35.71                                         | 19.05                                      |
|             | 4           | 49                         | 20                                | 27                                           | 2                                                   | 40.82                              | 55.10                                         | 4.08                                       |
|             | 5           | 54                         | 28                                | 23                                           | 3                                                   | 51.85                              | 42.59                                         | 5.56                                       |
| HLS=110%    | 1           | 34                         | 17                                | 14                                           | 3                                                   | 50.00                              | 41.18                                         | 8.82                                       |
|             | 2           | 27                         | 14                                | 10                                           | 3                                                   | 51.85                              | 37.04                                         | 11.11                                      |
|             | 3           | 30                         | 16                                | 13                                           | 1                                                   | 53.34                              | 43.33                                         | 3.33                                       |
|             | 4           | 30                         | 18                                | 12                                           | 0                                                   | 60.00                              | 40.00                                         | 0.00                                       |
|             | 5           | 46                         | 22                                | 23                                           | 1                                                   | 47.83                              | 50.00                                         | 2.17                                       |
| HLS=100%    | 1           | 53                         | 30                                | 17                                           | 6                                                   | 56.60                              | 32.08                                         | 11.32                                      |
|             | 2           | 50                         | 20                                | 27                                           | 3                                                   | 40.00                              | 54.00                                         | 6.00                                       |
|             | 3           | 69                         | 33                                | 30                                           | 6                                                   | 47.83                              | 43.48                                         | 8.70                                       |
|             | 4           | 53                         | 24                                | 27                                           | 2                                                   | 45.28                              | 50.94                                         | 3.77                                       |
|             | 5           | 44                         | 38                                | 4                                            | 2                                                   | 86.36                              | 9.09                                          | 4.55                                       |
| HLS=105%    | 1           | 40                         | 24                                | 11                                           | 5                                                   | 60.00                              | 27.50                                         | 12.50                                      |
|             | 2           | 47                         | 27                                | 17                                           | 3                                                   | 57.45                              | 36.17                                         | 6.38                                       |
|             | 3           | 52                         | 36                                | 13                                           | 3                                                   | 69.23                              | 25.00                                         | 5.77                                       |
|             | 4           | 57                         | 29                                | 22                                           | 6                                                   | 50.88                              | 38.60                                         | 10.52                                      |
|             | 5           | 31                         | 21                                | 7                                            | 3                                                   | 67.74                              | 22.58                                         | 9.68                                       |

TABLE II (continued)

| Treatment   | Replication | Number of Fruits Available | Number of Single Fruits Harvested | Number of Fruits Harvested Attached to Stems | Number of Fruits Damaged or not Harvested | Percent of Single Fruits Harvested | Percent of Fruits Harvested Attached to Stems | Percent of Fruits Damaged or not Harvested |
|-------------|-------------|----------------------------|-----------------------------------|----------------------------------------------|-------------------------------------------|------------------------------------|-----------------------------------------------|--------------------------------------------|
|             | 1           | 44                         | 27                                | 14                                           | 3                                         | 61.36                              | 31.82                                         | 6.82                                       |
| HIA=30 deg. | 2           | 52                         | 31                                | 18                                           | 3                                         | 59.62                              | 34.62                                         | 5.76                                       |
|             | 3           | 41                         | 29                                | 9                                            | 3                                         | 70.73                              | 21.95                                         | 7.32                                       |
| HLS=110%    | 4           | 52                         | 37                                | 13                                           | 2                                         | 71.15                              | 25.00                                         | 3.85                                       |
|             | 5           | 48                         | 33                                | 12                                           | 3                                         | 68.75                              | 25.00                                         | 6.25                                       |

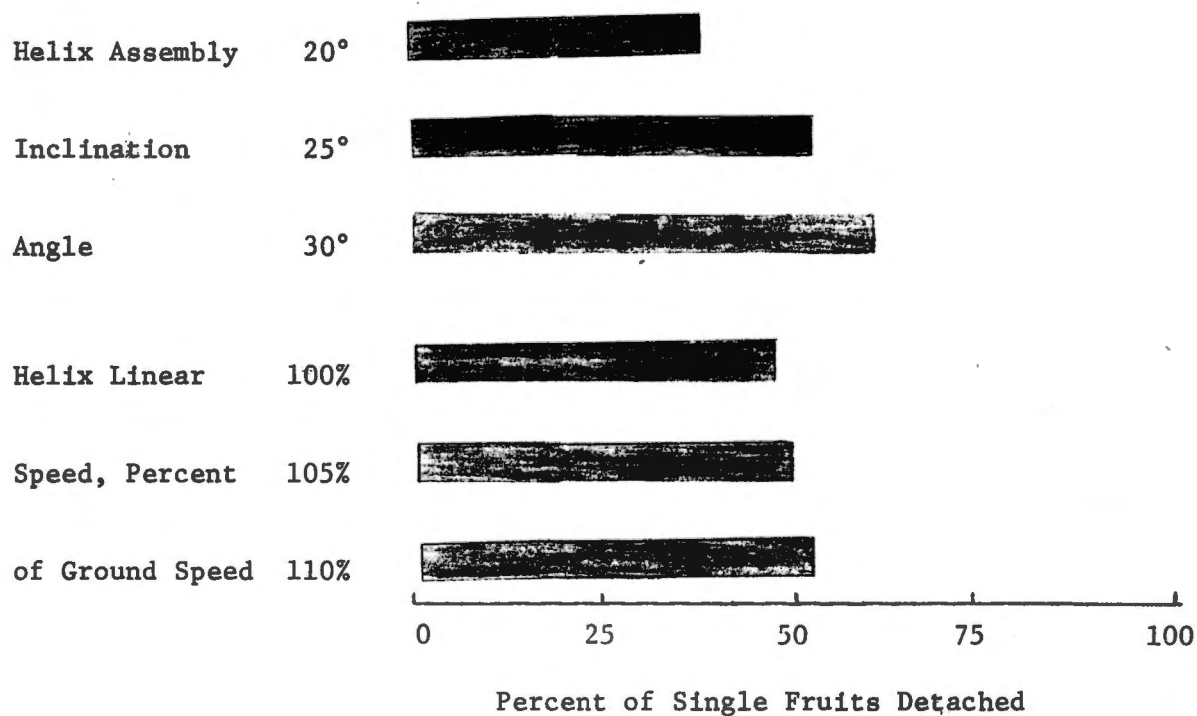


Figure 18. Mean effect of variables on percentage of single fruits detached.

TABLE III  
ANALYSIS OF VARIANCE FOR PERCENTAGE OF SINGLE FRUITS DETACHED  
BY HARVESTING MECHANISM

| Source of Variation | Degrees of Freedom | Sum of Squares | Mean Square | F-Ratio | Prob > F    |
|---------------------|--------------------|----------------|-------------|---------|-------------|
| Corrected Total     | 44                 | 8069.9620      | 183.4082    |         |             |
| Replications        | 4                  | 581.6124       | 145.4031    | 1.6404  | 0.1875 N.S. |
| Treatments          | 8                  | 4651.8492      | 581.4812    | 6.5600  | 0.0001**    |
| Helix Angle (HIA)   | 2                  | 4296.5054      | 2148.2527   | 24.2355 | 0.0001**    |
| Helix Speed (HLS)   | 2                  | 193.2405       | 96.6202     | 1.0900  | 0.3493 N.S. |
| HIA X HLS           | 4                  | 162.1033       | 40.5258     | 0.4572  | 0.7687 N.S. |
| Error               | 32                 | 2836.5005      | 88.6406     |         |             |

N.S. = Not significant at the 10 percent level of probability

\*\*Significant difference at the 0.01 percent level of probability.

The fruits harvested still attached to portions of stems ranged from a high of 67.4 percent to a low of 9.1 percent and the mean was 42.1 percent. Figure 19 shows the relation between the independent variables and percent of fruits harvested attached to portions of stems. Again the helix inclination angle had a greater effect on the dependent variable than did the helix linear speed. The analysis of variance for this dependent variable, Table IV, shows that there was a significant difference among the treatments at the 0.02 percent level, and this difference was the result of different helix inclination angles. As the helix angle was increased, the percentage of peppers harvested attached to portions of stems decreased.

The percentage of damaged or unharvested fruits ranged from a low of 0.0 percent to a high of 22.9 percent with a mean of 8.0 percent. Figure 20 shows that neither the helix inclination angle nor the helix linear speed had a pronounced effect on the percentage of peppers damaged or not harvested. The analysis of variance for this dependent variable, Table V, confirmed that there was no significant difference at the 10 percent level of significance.

Figure 21 shows the mean effect of changing the helix inclination angle on the three dependent variables. While the percentage of peppers damaged or not harvested remained constant, the percentage of single peppers harvested increased with a corresponding decrease in the percentage of peppers harvested attached to portions of stems as the helix inclination angle was increased.

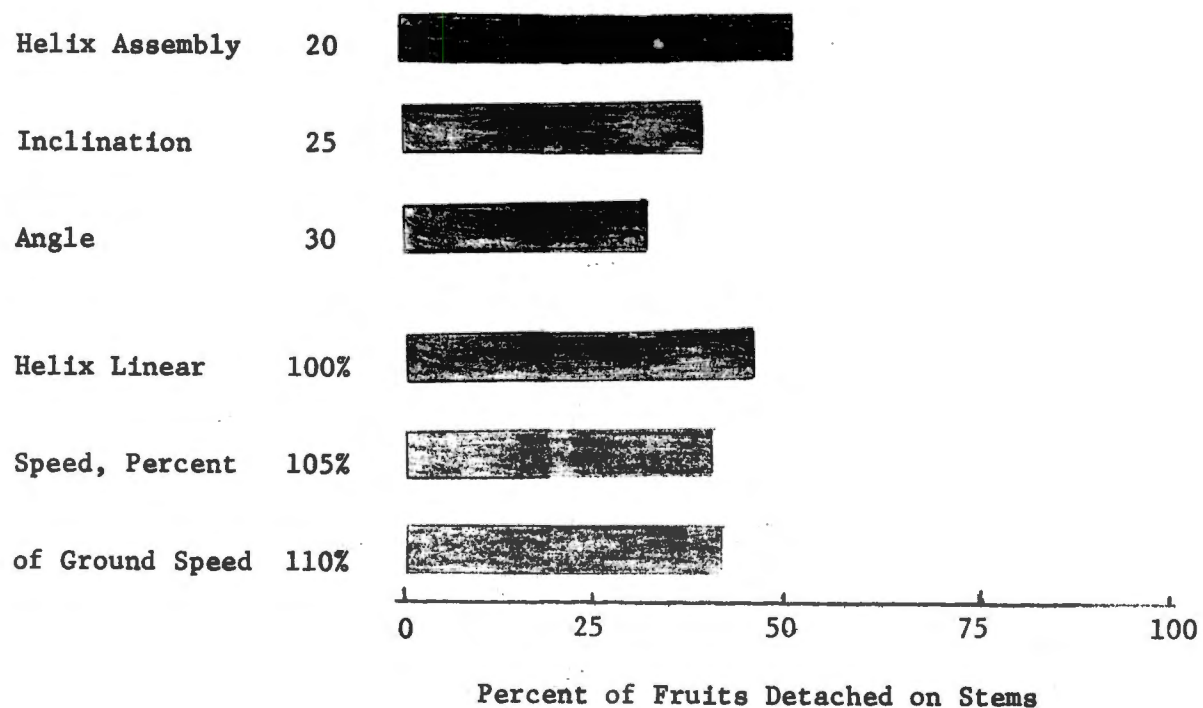


Figure 19. Mean effect of variables on percentage of fruits harvested attached to portions of stems.

TABLE IV

ANALYSIS OF VARIANCE FOR PERCENTAGE OF FRUITS ON STEMS  
DETACHED BY HARVESTING MECHANISM

| Source<br>of Variation | Degrees of<br>Freedom | Sum of<br>Squares | Mean<br>Square | F-Ratio | Prob > F    |
|------------------------|-----------------------|-------------------|----------------|---------|-------------|
| Corrected Total        | 44                    | 8397.5339         | 190.8530       |         |             |
| Replications           | 4                     | 367.7100          | 91.9275        | 0.9267  | 0.5377 N.S. |
| Treatments             | 8                     | 4855.4729         | 606.9341       | 6.1184  | 0.0002 **   |
| Helix Angle (HIA)      | 2                     | 4378.4219         | 2189.2109      | 22.0690 | 0.0001 **   |
| Helix Speed (HLS)      | 2                     | 231.9306          | 115.9653       | 1.1690  | 0.3239 N.S. |
| HIA X HLS              | 4                     | 245.1204          | 61.2801        | 0.6178  | 0.6560 N.S. |
| Error                  | 32                    | 3174.3511         | 99.1985        |         |             |

N.S. = not significant at the 10 percent level of probability.

\*\* = significant at the 0.01 percent level of probability.

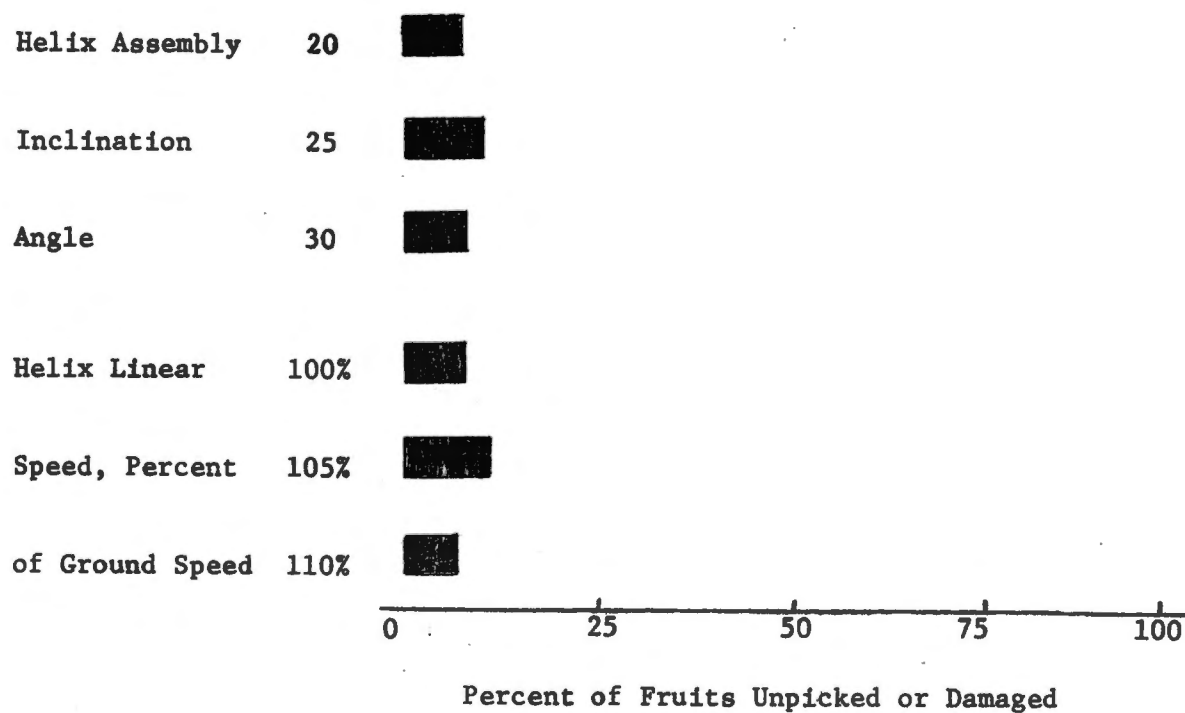


Figure 20. Mean effect of variables on percentage of fruits unpicked or damaged.

TABLE V  
ANALYSIS OF VARIANCE FOR PERCENTAGE OF FRUITS UNPICKED OR  
DAMAGED BY HARVESTING MECHANISM

| Source<br>of Variation | Degrees<br>of Freedom | Sum of<br>Squares | Mean<br>Square | F-Ratio | Prob > F    |
|------------------------|-----------------------|-------------------|----------------|---------|-------------|
| Corrected Total        | 44                    | 1282.6372         | 29.1508        |         |             |
| Replications           | 4                     | 146.9832          | 36.7458        | 1.3594  | 0.2692 N.S. |
| Treatments             | 8                     | 270.6590          | 33.8324        | 1.2516  | 0.3022 N.S. |
| Helix Angle (HIA)      | 2                     | 34.2849           | 17.1424        | 0.6342  | 0.5415 N.S. |
| Helix Speed (HLS)      | 2                     | 118.9231          | 59.4615        | 2.1998  | 0.1256 N.S. |
| HIA X HLS              | 4                     | 117.4511          | 29.3628        | 1.0863  | 0.3803 N.S. |
| Error                  | 32                    | 864.9950          | 27.0311        |         |             |

N.S. = not significant at the 10 percent level of probability.

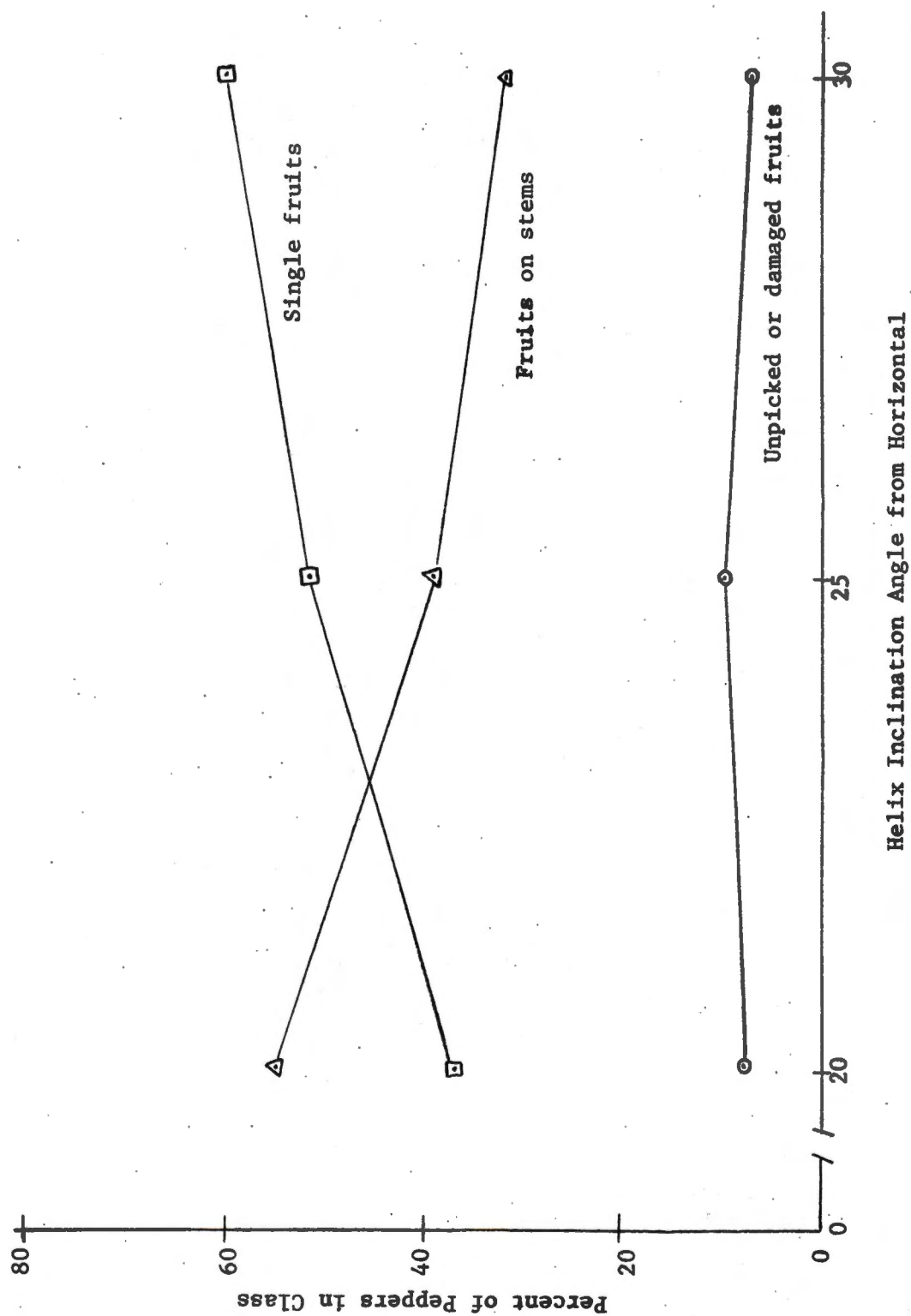


Figure 21. Mean effect of helix inclination angle on response variables.

## II. TYPE OF DETACHMENT AND HARVESTING

### ACTION ANALYSIS

After each replication, pepper pods of at least two inches minimum diameter were grouped into one of six classifications. The undamaged fruits were classed according to the point of detachment: (1) in the pedicel, (2) between pod and pedicel, (3) between pedicel and stem, and (4) in the stem. The remaining pepper fruits were classified either as (5) damaged or (6) unharvested. In the subsequent data analysis, classes one, two, and three, illustrated in Figures 22, 23, and 24, were classified as single peppers. No further operations on these should be required before sending them to a processing company, or to the fresh market. Peppers in class four, illustrated in Figure 25, were considered as a separate group in the data analysis. These peppers would require a separate stemming operation to remove the portion of plant stem still attached. Peppers in class five, Figure 26, and class six were grouped together as lost fruit. So far as mechanized harvest is concerned, these peppers would be unavailable for sale to a processor or on the fresh market.

Analysis of high speed motion picture films identified sequences showing harvest of both single peppers and peppers still attached to portions of the plant stems. Also some of the results of contact between plant stems and the coils of the helix could be identified.

Figure 27 is a sequence of photographs from the high speed film showing the detachment of two single peppers. Observe both peppers A and B in this sequence of photographs. In Frame 0, pod A has just come

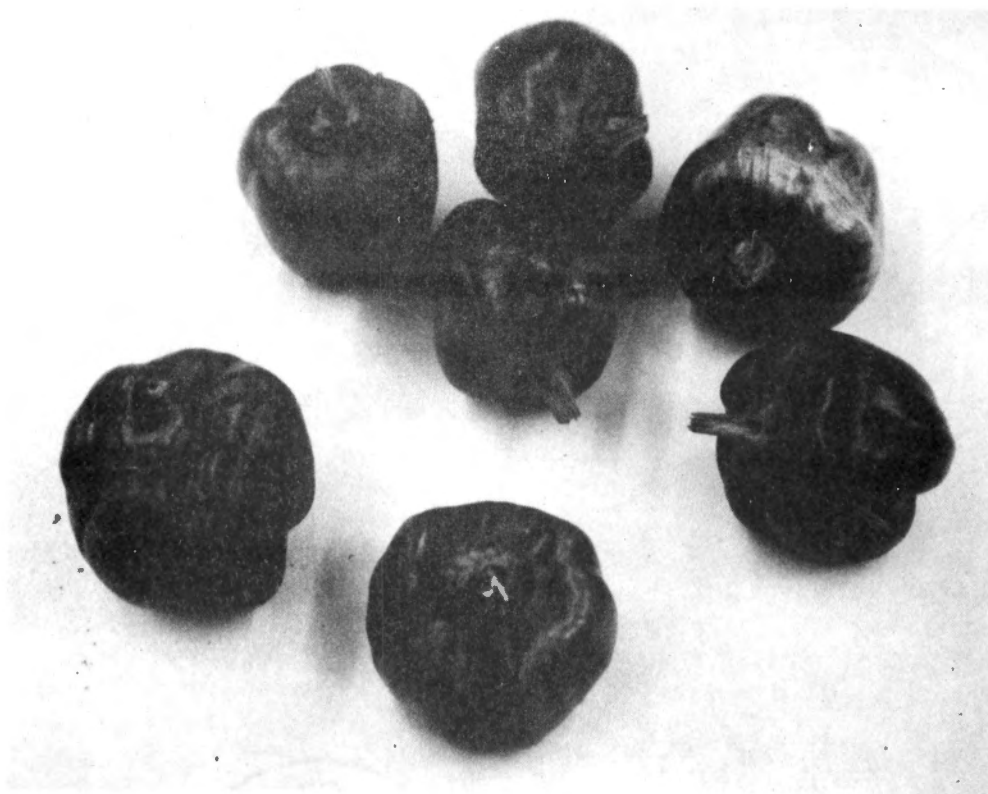


Figure 22. Peppers in class one, detached when the pedicel failed.

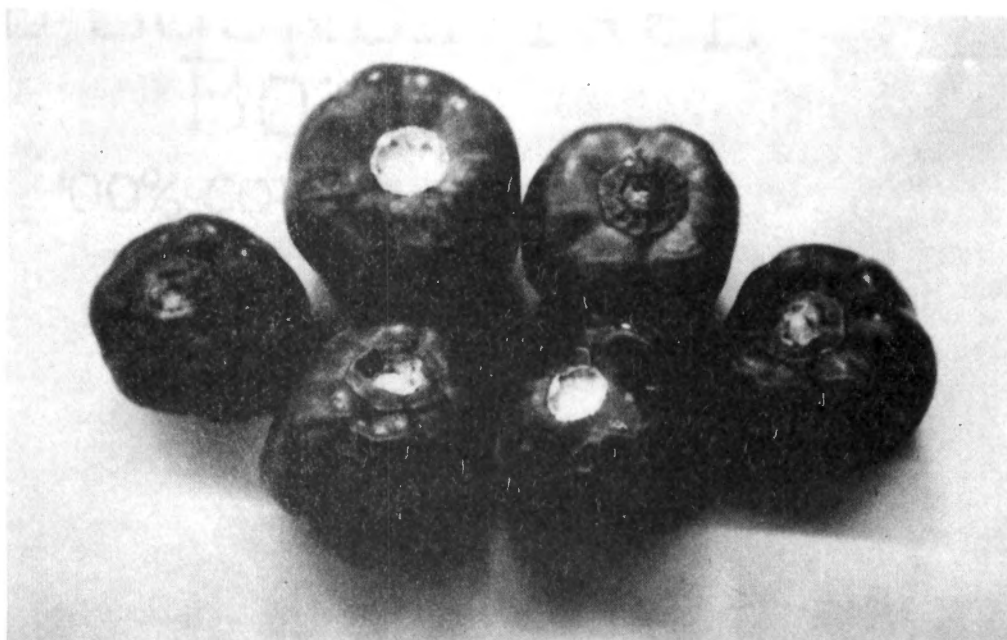


Figure 23. Peppers in class two, detached when the pod-pedicel junction failed.

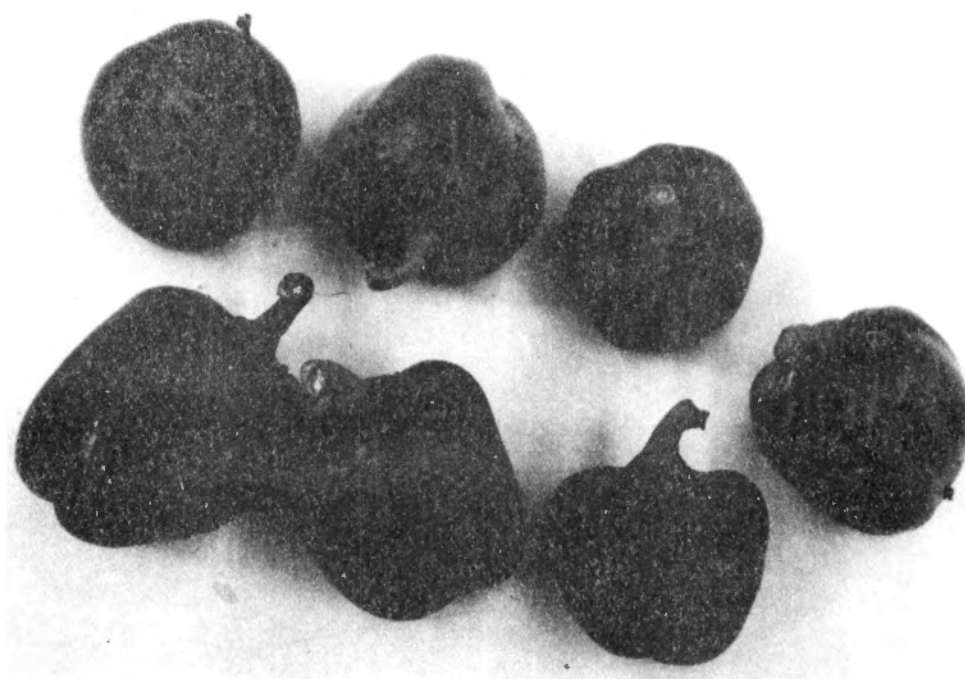


Figure 24. Peppers in class three, detached when pedicel-stem junction failed.

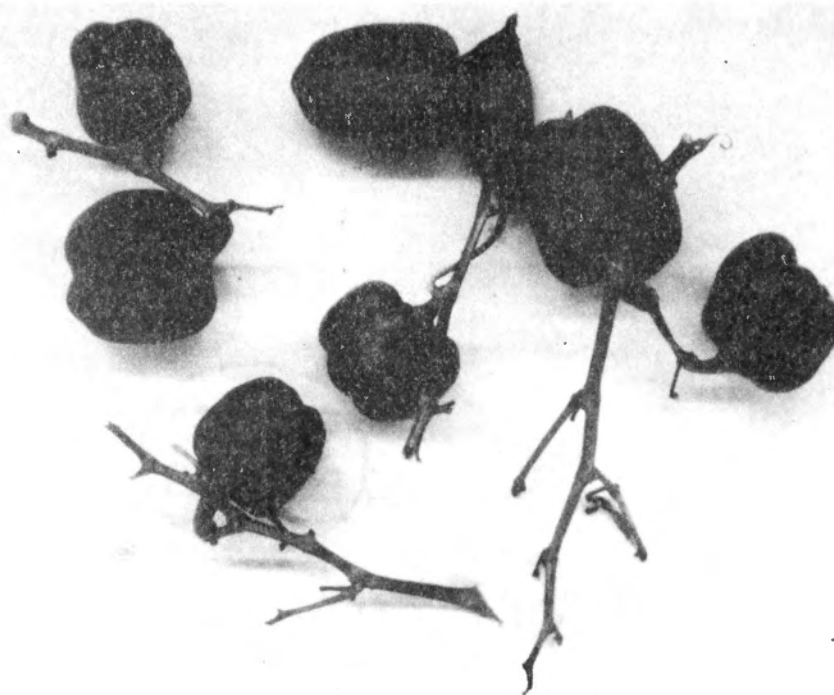


Figure 25. Peppers in class four, detached when stem failed.

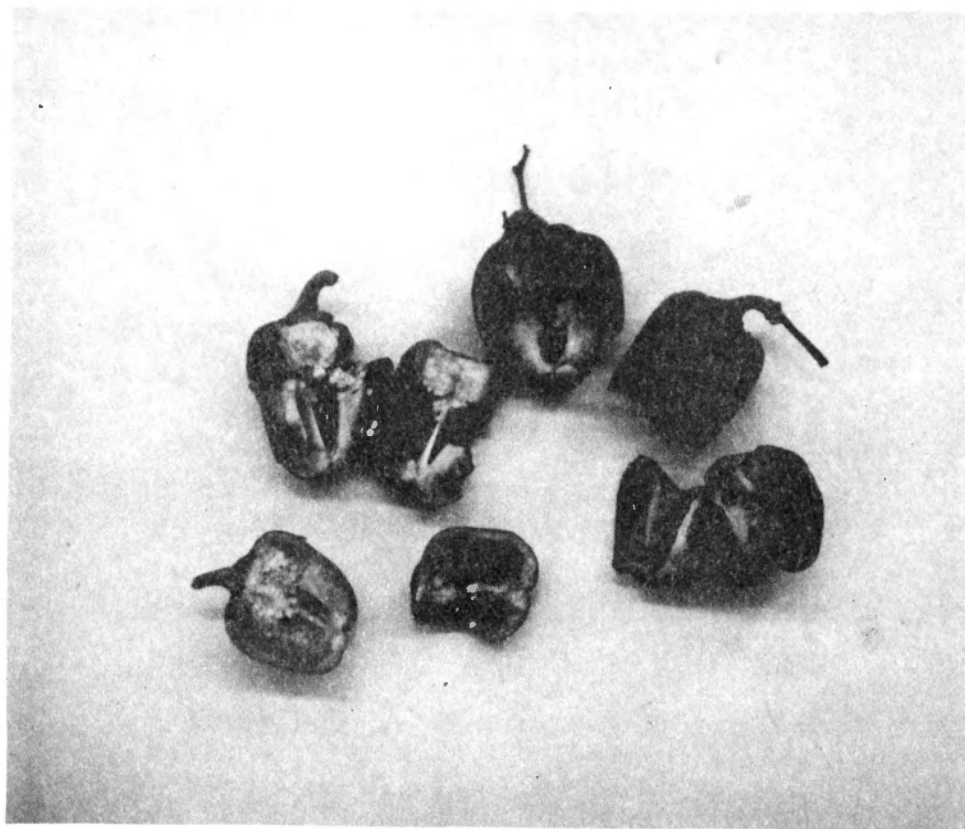
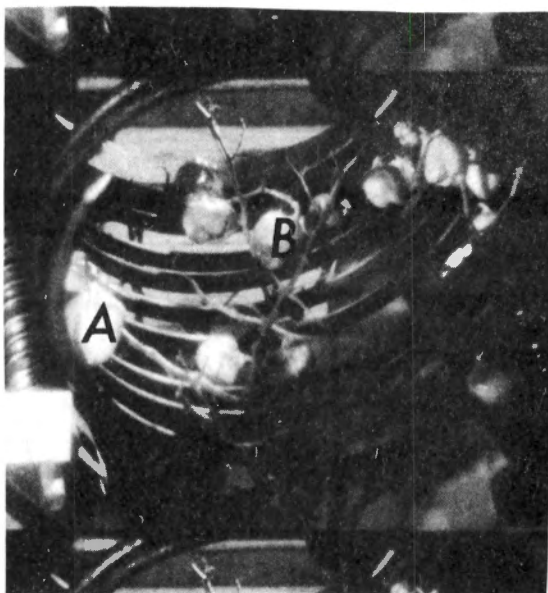
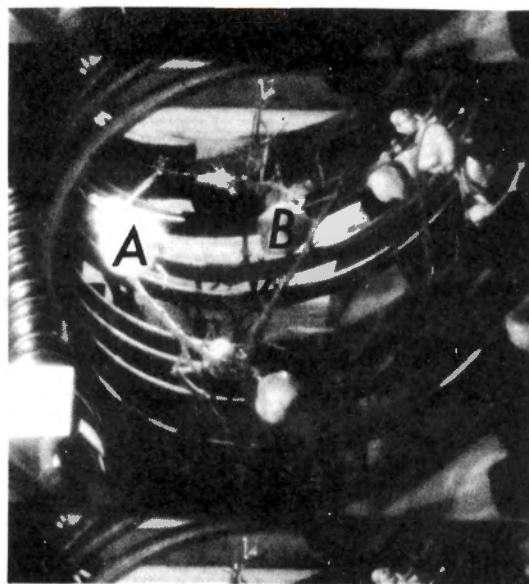


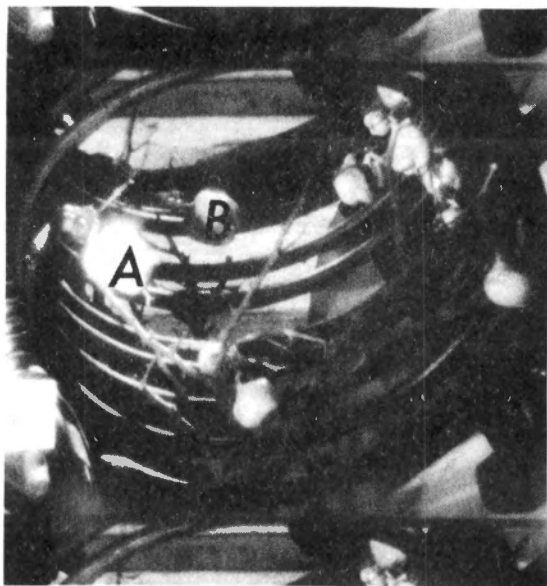
Figure 26. Peppers damaged during harvesting operations, class five.



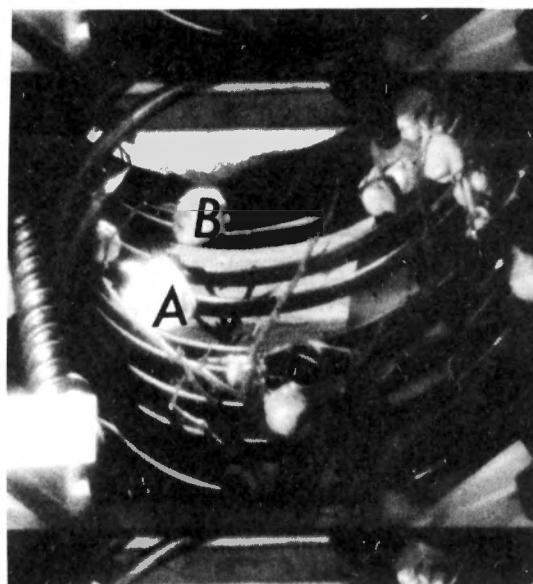
Frame = 0  
Time = 0



Frame = 40  
Time = 89 msec.



Frame = 62  
Time = 138 msec.

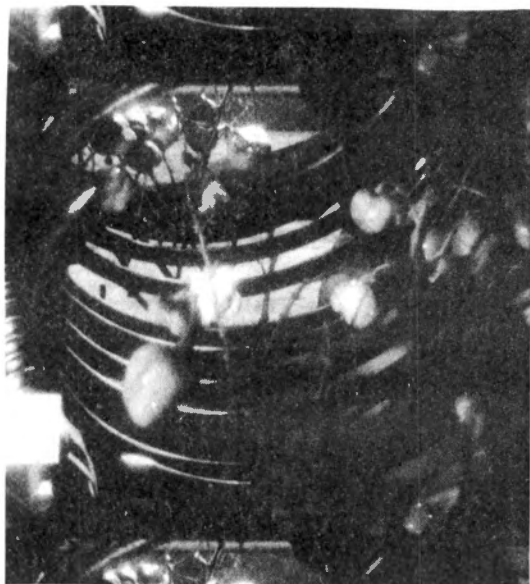


Frame = 75  
Time = 167 msec.

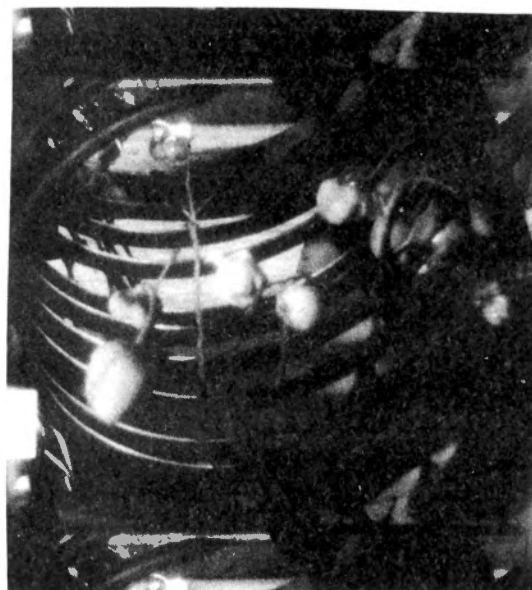
Figure 27. Photographs of individual frames from the high speed movie film showing harvest of two single peppers. (Camera speed = 450 frames per second.)

in contact with the clockwise rotating helix assembly. A rotating motion of the pod about its longitudinal axis results such that the pedicel is twisted. In Frame 40, pod A has rotated approximately 210 degrees. At this time, the stem to which pepper B is attached has just been struck by a fillet in the rear of the helix assembly. This action pulled the stem away from pod B and the resulting rotation of B put a bending moment on the pedicel. In Frame 62 pod A has rotated almost through a complete 360 degree movement about its longitudinal axis, and pod B has rotated through a horizontal angle of approximately 120 degrees with respect to the longitudinal axis of its pedicel. It is at approximately this time that both peppers are detached from their respective stems. The detachment of pod A was due to torsional stresses while the detachment of pod B was due to bending stresses. Frame 75 shows that both peppers A and B are clearly detached, and close study of the film revealed that the stem-pedicel junction failed in both cases. This sequence of photographs covers a time period of 167 milliseconds or approximately 1/6 second.

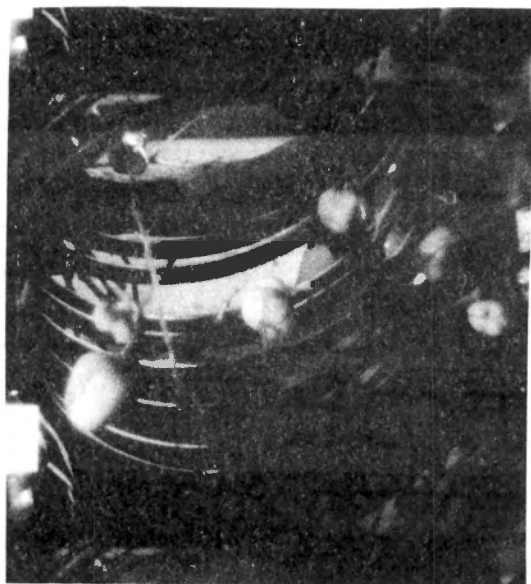
Figure 28 is a sequence of photographs from the high speed film showing the harvest of peppers attached to portions of stems. In Frame 0, a fillet in the rear of the helix assembly has just contacted the first of the plant stems. As the helix continues to rotate, the stems are deflected. In Frame 18, all the stems have been deflected to the left side of the frame. Because of the inertia of the plants, the top and bottom of the stems have attempted to remain in the same place, resulting in a bending and shearing action on the stems. In Frame 33, less than 1/10 of a second after contact was first made, the stems have



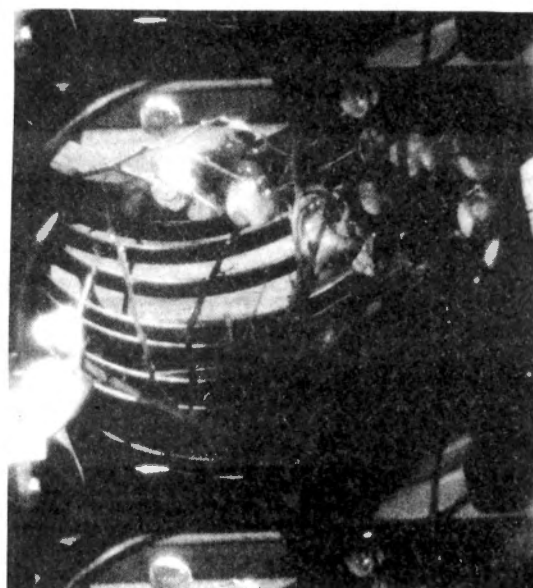
Frame = 18  
Time = 40 msec.



Frame = 0  
Time = 0



Frame = 33  
Time = 73 msec.



Frame = 210  
Time = 467 msec.

Figure 28. Photographs of individual frames from the high speed movie film showing peppers harvested still attached to stem. (Camera speed = 450 frames per second.)

begun to fail. After failure, the tops of the stems are carried around to the top of the helix. In Frame 210, the stem with peppers attached to the broken stem is clearly seen.

Note that at the rear of the harvester there are several peppers that are wedged in the space between the coils and the hub. Although it was not clearly shown in any of the films taken, it was hypothesized that this was one of the probable causes of damage to the pepper fruits.

During the tests and while viewing the high speed films, several other aspects of the harvesting action were noticed. Many of the single peppers were harvested by an upward bending action which put the pedicel in a bending type strain while simultaneously applying an axial (pulling) force. This action was the result of a pepper slipping partially into the space between two adjacent coils, then moving with these two coils as they rotated.

Another phenomenon that occurred several times during the tests was that of the leading tip of a coil striking a plant stalk as it moved across the row. When this happened, one of two events usually followed: either the plant stalk shattered at the point of impact, or the coil jumped out of mesh with the grooved rollers. When the plant stalk shattered, the upper plant structure was detached intact from the roots and left free inside the helix assembly. The coil jumping out of mesh resulted in a space between coils wider than the desired two inches. The wider space allowed both harvested and unharvested peppers to pass through. The sudden shock of the coil striking the stem would dislodge fruits in many instances before they entered the helix and the fruits would simply drop to the ground. If the above described event occurred

in a field-going machine, the probable result would be a decrease in harvest efficiency and a probable time loss due to removing whole plants from the machine or realigning the coils for proper mesh with the grooved roller.

Another condition occurred that might give trouble in a field machine. When a junction of stems on the plant was larger than two inches in diameter, it would not pass between the coils. The junction would either be crushed, resulting in the harvest of peppers attached to stems, or the plant would be pulled from the carriage, which in a field going machine might result in a work stoppage.

The independent variables chosen for consideration in this study were helix linear speed and helix assembly inclination angle. Changing the speed was found to have no significant effect on harvesting, while increasing the inclination angle resulted in more desirable harvest results. One problem is apparent with the increased inclination angle; the greater the angle, the more peppers tend to roll out the front of the machine. This of course would pose more problems for a prototype machine which would require a conveying system to remove the detached fruit from the helix cage assembly.

Perhaps the study should have included an additional independent variable, that of the distance between the rear of the coil and the ground. With a longer helix assembly a less steep angle could have been used and the rear of the harvester could have been higher above ground level. The ideal maximum height would be the top of the tallest plants encountered.

## CHAPTER V

### SUMMARY AND CONCLUSIONS

The objectives of this study were:

1. To modify a four-coil open-helix harvester design for use on bell peppers.
2. To devise a method for holding the coil spacing of the open-helix cage assembly constant during operation of the harvester.
3. To determine the effects of the harvester coil assembly linear speed and vertical inclination angle on picking efficiency.
4. To determine the pepper detachment action through high speed motion picture analyses.

The harvester was modified in the Agricultural Engineering Department research shop. The coil spacing was held constant by using grooved idler rollers to support the cage assembly. The harvester was tested with peppers cv. Resistant Giant grown on the Plant and Soil Science Farm near Knoxville.

The harvester was tested in the laboratory using three levels of helix linear speed and three levels of helix inclination. The simulated forward velocity was held constant at 75 feet per minute.

Analyses of variance for single peppers harvested, peppers harvested attached to stems, and peppers damaged or not harvested showed that there was no significant difference for the change in helix assembly linear speed.

Analysis of variance also showed that there was no significant difference in peppers damaged or not harvested for change in helix inclination angle.

There was a significant difference at the 0.01 percent level for both peppers harvested attached to stems and single peppers harvested with change in the helix inclination angle.

The difference was probably caused by the point at which the metal fillets at the rear of the helix assembly struck the plant. The lower the point of contact, the more stems would be broken and the more peppers would be harvested attached to portions of the stems.

Based on detachment and high speed film studies, three conclusions have been made. First, detachment was due primarily to bending stresses in components of the plant structure developed by a sudden acceleration of the pepper itself or a sudden acceleration of the stem away from the pepper. Second, the point at which the fillets at the rear of the helix assembly struck the plant was the primary factor determining the number of single fruits harvested compared to the number of fruits harvested still attached to portions of stems. The point of contact was controlled by the helix assembly inclination angle. Third, increasing the helix inclination angle, and thus the height of the rear of the helix assembly, provided the most desirable harvesting results.

The open-helix machine shows promise as a means for harvesting peppers, but the many problems brought out by these tests will need to be solved before a successful prototype machine can be built. If

further development of this idea is to follow this study, the following points are suggested for consideration.

1. A field prototype machine should be constructed since some problems can be encountered and solved only in the field.
2. The helix assembly should be longer and the rear of the assembly should be of a height just above the top of the majority of the plants for optimum harvest results.
3. The coils themselves should be as small as possible, the ideal coil would be constructed of the stiffest, strongest material available except for the leading end which should be flexible enough to deflect around plant stalks.
4. A materials handling system for the harvester will be needed.
5. Noise levels may be a problem.

## **BIBLIOGRAPHY**

## BIBLIOGRAPHY

1. Bird, J. J. Pepper Production in Tennessee, Publication 363, Agricultural Extension Service, University of Tennessee, Knoxville, August, 1965.
2. Cargill, B. F. "Introduction," Fruit and Vegetable Harvest Mechanization, Rural Manpower Center, Michigan State University, East Lansing: 3, 1969.
3. Davenport, J. D. "Development and Evaluation of Two Picker Reels for an Experimental Vegetable Harvester," Unpublished Master's Thesis, University of Tennessee, Knoxville, 1972.
4. Davis, Velmar. "Mechanization of Fruit and Pod Vegetables-- Introduction," Fruit and Vegetable Harvest Mechanization, Rural Manpower Center, Michigan State University, East Lansing: 211, 1969.
5. Fullilove, H. M. Personal Interview, Georgia Experiment Station, Experiment, April, 1972.
6. Fullilove, H. M. and J. G. Futral. "The Design of Pepper Harvesters," Unpublished report, Georgia Experiment Station, Experiment, 1971.
7. Fullilove, H. M. and J. G. Futral. "A Mechanical Harvester for Pimento Peppers," American Society of Agricultural Engineers Paper No. 72-148, 1972.
8. Lorenzen, Coby. "Development in Machinery for Processed Fresh Market Tomatoes and Sweet Peppers," Fruit and Vegetable Harvest Mechanization, Rural Manpower Center, Michigan State University, East Lansing: 220, 1969.
9. Morgan, A. H. Vegetable and Fruit Harvester. U.S. Patent No. 3,473,304. The Official Gazette of the U.S. Patent Office, 867 (3): 784-785, 1969.
10. Morgan, A. H. and Richard C. Shadden. "Preliminary Evaluation of an Experimental Helical Vegetable Harvester," Tennessee Farm and Home Science, Agricultural Experiment Station, University of Tennessee, Knoxville, 75: 5-7, July, August, September, 1970.
11. Riggs, Earnest. Harvesters for Peppers and Other Crops. U.S. Patent No. 3,613,339. The Official Gazette of the U.S. Patent Office, 891 (3): 949, 1971.

12. Shadden, Richard C. "Design and Evaluation of an Experimental Helical Vegetable Harvester," Unpublished Master's Thesis, University of Tennessee, Knoxville, 1969.
13. Sims, W. L. Extension Vegetable Specialist, Agricultural Extension Service, University of California, Davis, Correspondence with Dr. B. L. Bledsoe, March 1971.
14. Thor, Eric and John W. Mamer. "Rural Manpower-Overview," Fruit and Vegetable Harvest Mechanization, Rural Manpower Center, Michigan State University, East Lansing: 68, 1969.
15. Ware, George W. and J. P. McCollum. "Peppers," Producing Vegetables, The Interstate Printers and Publishers, Inc., Danville, Illinois: 299-308, June, 1959.
16. "What's Ahead," Implement and Tractor, 84 (24): 17, 1969.

## VITA

John Thomas King, Jr., was born February 10, 1948, in Bristol Virginia and raised in Sullivan County, Tennessee, the son of John T. and Marie B. King. He was educated at Cold Spring Elementary School and graduated from Holston Valley High School, Bristol, Tennessee, in June 1966. He entered King College in August 1966, transferred to the University of Tennessee, Knoxville, in June 1968, and received the Bachelor of Science with a major in Agricultural Engineering in December 1970. He entered the graduate school of the University of Tennessee in January 1971, and expects to receive the Master of Science degree with a major in Agricultural Engineering in June 1973.

He has been employed as a Research Assistant in Agricultural Engineering since February 1972. He is a member of the student branch of the American Society of Agricultural Engineers, Alpha Zeta honorary service fraternity of agriculture, and Gamma Sigma Delta honorary society of agriculture.