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A comparison of nylon brushes, nylon brushes with rubber ribs, and rigid rods for harvesting snap beans

Campbell Pillow Ridley Jr.

To the Graduate Council:

I am submitting herewith a thesis written by Campbell Pillow Ridley Jr. entitled "A comparison of nylon brushes, nylon brushes with rubber ribs, and rigid rods for harvesting snap beans." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Biosystems Engineering.

Houston Luttrell, Major Professor

We have read this thesis and recommend its acceptance:

John J. McDow, Homer D. Swingle

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

September 14, 1967

To the Graduate Council:

I am submitting herewith a thesis written by Campbell Pillow Ridley, Jr. entitled, "A Comparison of Nylon Brushes, Nylon Brushes with Rubber Ribs, and Rigid Rods for Harvesting Snap Beans." 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.

Houston Luttrell

Major Professor

We have read this thesis and recommend its acceptance:

John J. McDow

Homer D. Swingle

Accepted for the Council:

Hilton A. Smith

Vice President for
Graduate Studies and Research

A COMPARISON OF NYLON BRUSHES, NYLON BRUSHES WITH RUBBER RIBS, AND RIGID RODS FOR HARVESTING SNAP BEANS

A Thesis

Presented to

the Graduate Council of

The University of Tennessee

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

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by

Campbell Pillow Ridley, Jr.

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THE PROBLEM

I. INTRODUCTION

The population of the continential United States in 1960 was 180 million men, women, and children. It has been estimated that by 1980 the population will be 244 million persons, and by the year 2000 the population will be nearly 330 million persons. Therefore, our food needs will increase 36 per cent by 1980 and 83 per cent by 2000 as compared to 1960 (5).

The amount of new land in today's densely populated world is limited. There has been a decline of our soil resources in the face of increasing food needs. There were 402 million acres of crop land in the continential United States in 1920 compared with 395 million acres in 1960 (5). The answer to the problem of increasing food needs and decreasing crop land lies principally in the application of science and technology to the present crop lands to make them more productive.

Prior to 1965 there was an ample supply of farm labor in the United States; but with increased pay rates and decreasing field labor, the importance of mechanization became more apparent. When labor is cheap and consumer prices low, multiple-pick hand harvesting seems logical. However, when labor is scarce and consumer prices are high, the idea of a single once-over harvesting machine becomes more realistic (3).

High production costs of fruits and vegetables have made these products appear high priced to the consumer. During their harvesting process, these two groups of products require a large amount of hand labor. Interest has been generated among the producers of mechanical equipment which will lower unit costs even though the equipment may be expensive (18).

There has been a mechanical harvester developed for practically every crop. However, the development of mechanical harvesting equipment for field crops was begun long before that of fruits and vegetables (18). Hiram Moore invented a combine harvester, which cut and threshed twenty to thirty acres of grain a day, for animal draught in 1836 (9). One of the first mechanical harvesters for beans was an experimental model of a snap bean picker that was developed in 1951 (13).

The United States Department of Agriculture Agricultural Statistics (21) lists the total United States acreage of snap beans in 1951 as 304,770 acres compared to 332,280 acres in 1965. The 1951 crop had a total value of $74,996,000 whereas the 1965 crop had a value of $91,679,000. These figures illustrate that snap beans have become an important economical crop during the last decade and a half.

II. STATEMENT OF THE PROBLEM

Mechanical harvesters are in great demand due to the amount of snap bean acreage. All snap bean harvesters on the market today break or bruise an undetermined amount of beans during harvest. These beans are a source of lost income to the grower. This wasted revenue becomes an important factor in growing and harvesting of snap beans. If a simple, small machine could be developed to harvest snap beans efficiently and with a minimum damage, many thousands of dollars would be saved annually. This technique would prove invaluable to the snap bean industry.

III. OBJECTIVE

The objective of this investigation was to compare nylon brushes, nylon brushes with rubber ribs, and rigid rods for harvesting snap beans efficiently and effectively.

CHAPTER II

REVIEW OF LITERATURE

According to How and Nyberg (13), attempts were made as early as the 1930's to develop a machine that would harvest snap beans satisfactorily, but these attempts met with little success. A central New York grower, in the late 1940's, observed his wife swinging a garden rake up through a row of beans. The process removed a number of bean pods. This grower was credited for originating the basic idea of the first commercial mechanical snap bean harvester. The machine consisted of a picking reel with steel fingers mounted perpendicular to and around a central shaft. The fingers stripped the beans from the plant as the reel rotated parallel to the bean row. One of the reels was mounted on each side of a conveyor belt so that as the reels were drawn along a row, the beans were picked from the plant and placed on the belt. A New York firm obtained patents using these principles and proceeded with commercial development. There were 113 harvesters used in New York during 1958 (13).

The conventional spacing between rows of snap beans for mechanical harvesting has been thirty-six to thirty-eight inches, but J. M. Huffington (14) reported that some growers in Oregon were planting snap beans in thirty inch rows for machine harvest.

Several machines, both in the United States and in foreign countries, have been developed which successfully harvest snap beans.

A. A. Duncan (6) described a few of these machines which harvest snap beans on rows of less than the standard thirty-six to thirty-eight inch width. The Pix-All mechanical harvester, manufactured in the United States, will harvest snap beans, lima beans, and southern peas planted on a row spacing of thirty to thirty-two inches as well as the conventional thirty-six to thirty-eight inch row.

Three machines that pick snap beans on less than thirty-six inch rows are produced in the Netherlands. They are the Mather and Platt, the Ploeger, and the Borga. The Mather and Platt is a one row machine that has picking fingers attached to a belt rather than a cylinder, and the fingers are drawn through the bean vines in a straight path rather than a short arc (*i.e.* when the stripping fingers are attached to a rotating picking real or cylinder). Rows that are 15½ inches apart may be harvested by this machine (6).

The Ploeger is a lightweight, tractor drawn machine that has a separate, stationary cleaning facility. Its harvesting unit is a small picking reel along side a conveyor belt. The belt has the same width as the diameter of the reel. A row spacing of 17½ inches is harvested with this type machine. A single blower type "precleaner" is used to remove trash from the beans, and another conveyor belt deposits the beans into a field container (6).

The tractor drawn Borga harvester has the picker and cleaner units driven entirely by tractor power-take-off. It consists of a small conventional picking reel with adjustments for row width and operates on a twenty-four inch row spacing (6).

Different designs were not the only dissimilarities that arose when the mechanical snap bean harvester became a reality instead of a dream. How and Nyberg (13) stated that there were varied opinions regarding the best method for using the harvester effectively. A few growers utilize the machine for a second picking that followed a hand harvest or reserved the machine for fields with such poor yields that the picking crews were unwilling to go into the field to hand pick the beans. These growers were farmers who had labor crews readily available; therefore, the use of the mechanical harvester was secondary.

Employing the harvester for a second or third picking was found to be generally unfavorable both from a cost and quality standpoint. Beans that were mechanically harvested after the first picking ranged widely in maturity and contained some beans that were damaged by the first picking. Also, yields in later pickings were much lower and costs per ton were much higher than yields and costs in the first picking (13).

Some growers have employed harvesters which place the beans into pallet boxes. Other growers have utilized harvesters which place the beans into sacks. Harvesters that were equipped to place the beans into pallet boxes were usually operated by two men, whereas three men were necessary when the harvester placed beans into sacks. Even though additional equipment was costly in adapting the harvesting operation to pallet box handling, the labor saved more than offset the added expense for equipment (13).

In 1958 the Rochelle Asparagus Company (10) reported it had achieved an over-all harvesting saving of 30 per cent compared to the cost of hand picking green and wax beans by using mechanical snap bean harvesters and jumbo wire-bound pallet boxes. Using three harvesting machines, a tractor mounted fork lift, and twelve workers, the company was able to pick a field of beans cleaner, more efficiently, faster, and more economically than has been done by 200 hand pickers.

Fifty-seven farms were analyzed in New York during 1962 by How and Nyberg (13) to determine the average cost per acre when the snap beans were harvested either by hand or by machine on different size allotments. The results showed the average cost was $22 per acre when the grower harvested more than 250 acres by machine, $30 per acre when the grower harvested less than 175 acres by machine, and $78 per acre when the grower harvested any acreage by hand.

Hood and Drew (12) used a Chisholm-Ryder Hi-Boy harvester in the fall of 1965 to pick snap beans and compared the cost per bushel with that of hand harvesting. The harvester picked two thirty-six inch rows simultaneously, using flexible steel fingers mounted on rotating picking reels to strip both beans and foliage from the plants. A fan was used to separate leaves and trash from the beans. The beans were then moved by a conveyor belt to bulk bins at the rear of the harvester. Filled bins were taken by a tractor with a fork-lift to the dumping and sizing operation. The beans were dumped into a rotating "sizer" and then hand graded before being packed into baskets. The entire procedure cost

$3.80 per bushel when the mechanical harvester was employed, but harvesting by hand cost $4.40 per bushel.

B. M. Kubik (15) wrote that in 1957 a New York grower, Elmer Boekhoute, said two men and a harvester developed by the Chisholm-Ryder Company replaced fifty of his hand pickers. Boekhoute used one man on the tractor and one man of the harvester.

A study was conducted in 1965 by the University of Tennessee Agricultural Experiment Station (20) to estimate the variable costs per hour in Tennessee for operating a mechanical snap bean harvester with three types of trailers. The harvester used was manufactured by the Chisholm-Ryder Company. The three types of trailers were: (1) a sacker, employing two and three men, (2) a pallet box, using two men, and (3) a hydraulic trailer, using one man. Labor, gas, repairs, and grease and oil comprised the variable costs. The total variable costs per hour for the harvester with trailer utilizing sacks were $4.55 and $5.70 for the two men and three men crews, respectively. The pallet box operation totaled $4.95 per hour while the hydraulic trailer type costs were only $4.20 per hour to operate.

The estimated annual fixed costs for the life of a Chisholm-Ryder snap bean harvester were calculated. The harvester employed both the sacker type and hydraulic dump bucket type trailers with the expected economic life of five and ten years. Included in the total fixed costs were annual depreciation, interest, insurance, and taxes. The total annual fixed costs for the life of the machine with the sacker type trailer were $3,345 and $2,106 for five years and ten years, respectively. Using the hydraulic dump bucket type trailer, the annual fixed costs were $3,675 and $2,317 for five years and ten years, respectively (20).

Mechanically harvested beans were analyzed for product quality associated with five levels of reel speed and three levels of tractor speed ranges for a Chisholm-Ryder snap bean harvester. This study was performed by the University of Tennessee Agricultural Experiment Station (20). The quality was dependent on the foreign matter in the beans, number of clusters (i.e. two or more pods held together by sections of stem), cluster weight, broken pods, yield per acre, and beans left in the field.

Another undesirable effect caused by harvesting snap beans is a color change of beans which have been bruised or broken. This color transformation, termed brown end coloration, is thought to be a natural process in the sequence of healing, according to Cooler and Lopez (4). The quality grade is lowered when brown end coloration is detected in snap beans. This problem is more severe with mechanically picked beans. A higher percentage of broken beans occur in mechanically harvested fields than in hand harvested fields. In a field that is machine harvested, 25 to 27 per cent of the beans are broken. Usually only 5 to 10 per cent of the beans harvested by hand are broken. Ordinarily, snap beans are very resistance to bruising by simple handling methods because the bean is light in weight (six to seven grans) and consists of a relatively tough pericarp (22).

The degree of bruising affects the severity of brown and coloration. Factors which influence more bean breakage during mechanical picking (*i.e.* immaturity, high water content, picker reel speed, tractor speed, etc.) all increase the problem of brown end coloration (4).

CHAPTER III

EXPERIMENTAL PROCEDURE

I. TEST EQUIPMENT AND MATERIAL

A comparison was made using nylon brushes, nylon brushes with rubber ribs, and rigid rods to harvest snap beans. Two Hesston brush roll cotton stripper reels with detachable nylon brushes and rubber ribs were used to remove beans and foliage from the plants. A stripping rod unit, utilizing three inclined, rigid rods, was used to remove the beans; but most of the foliage was allowed to pass between the rods.

Stripping reel. A tractor drawn sled frame was built and two cotton stripping rollers were fastened to the frame in such a manner that the rollers were adjustable in both the horizontal and vertical directions (Figures 1 and 2). The frame was constructed from 2 x 2 x 3/16 inch angle iron and was seventy-four inches long, forty-four inches wide, and thirty-six inches high. The sled runners were constructed from 3 x 3 x ¼ inch angle iron eighty-three inches long.

The reels were fifty-six inches long with a one inch diameter shaft. Around the shaft was a housing which contained four sets of nylon brushes alternating with four sets of rubber ribs. The maximum diameter of the reel was six inches. The rubber ribs were one-fourth inch thick while the nylon brushes were approximately one inch thick. Each brush and rib extended out two inches from the shaft housing,

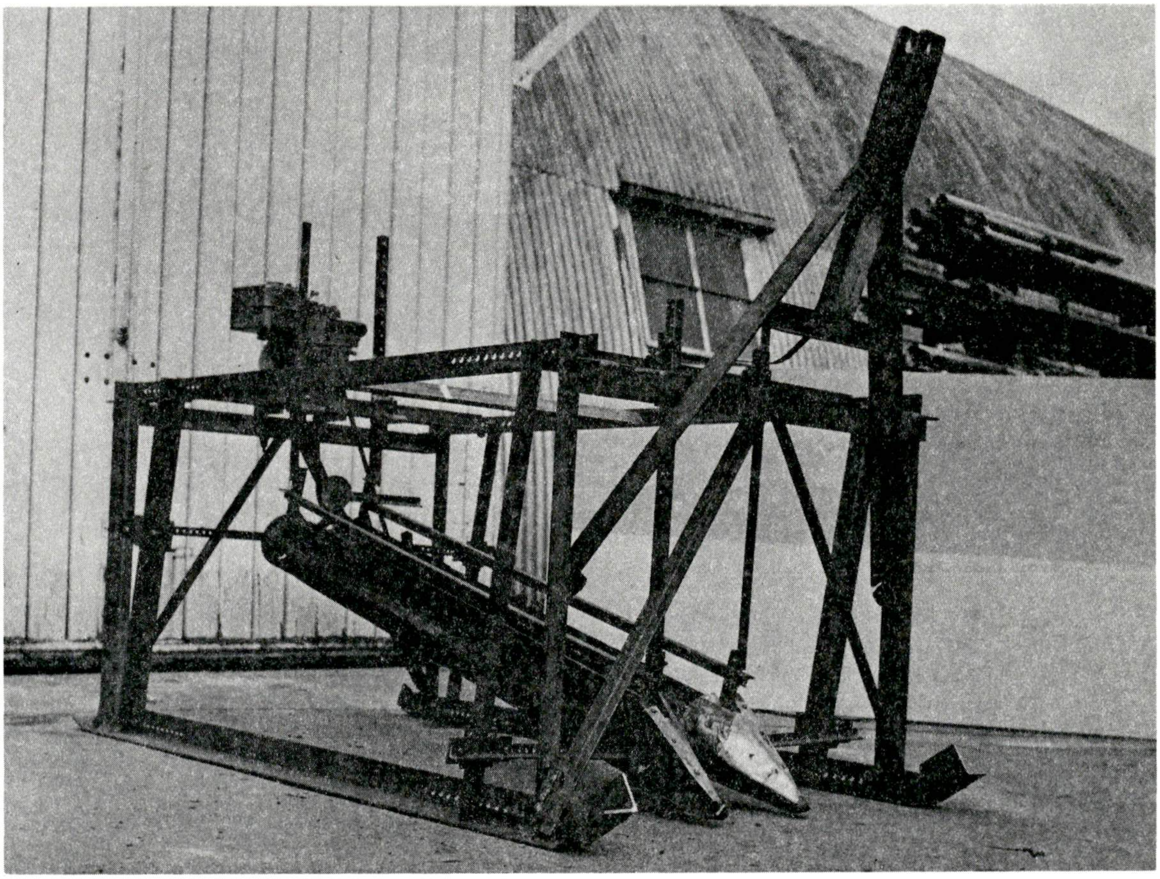

FIGURE 1

FRONT ISOMETRIC VIEW OF THE STRIPPING REEL UNIT

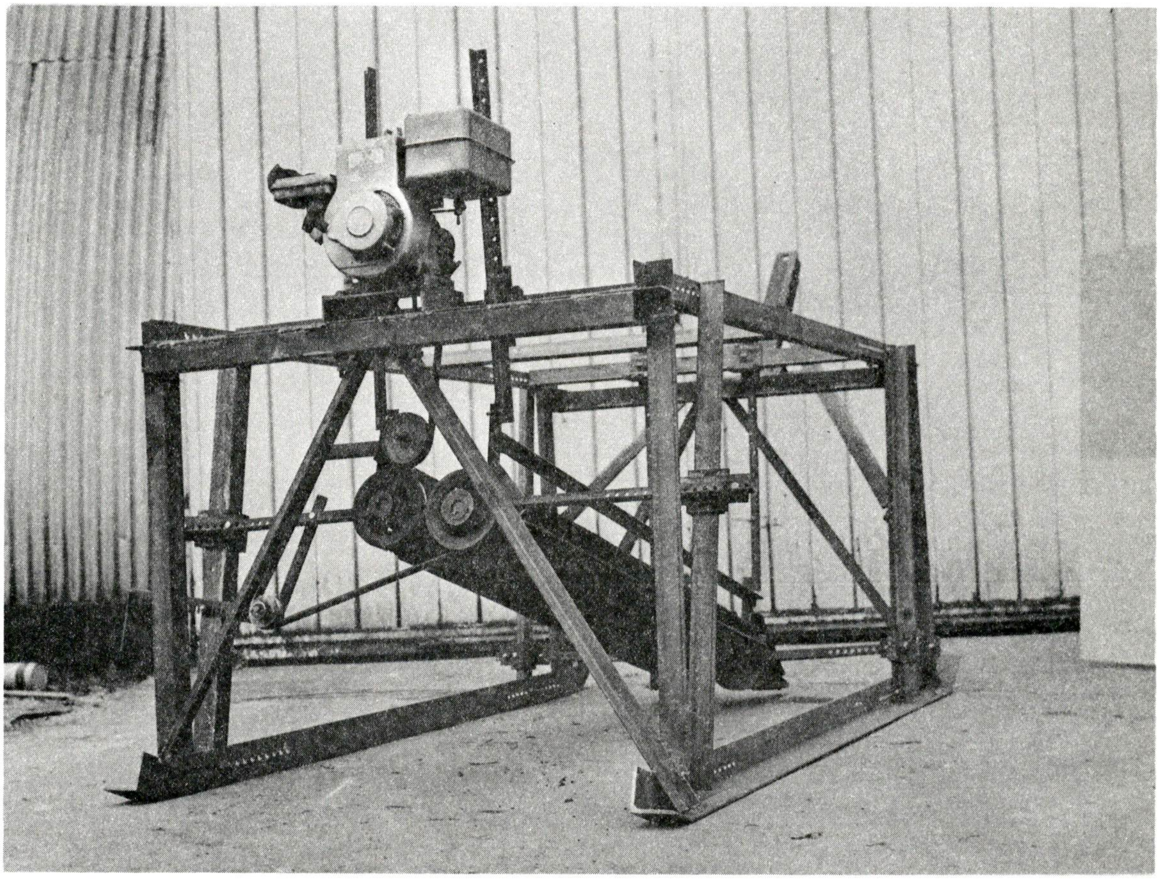

FIGURE 2

REAR ISOMETRIC VIEW OF THE STRIPPING REEL UNIT but only $1\frac{1}{2}$ inches were actually used to strip the beans. The nylon brushes and rubber ribs were easily detached from the reels by loosing several bolts in the shaft housing.

The reels were held in place by 1 x 1 x $\frac{1}{4}$ inch pieces of angle iron that were attached to the frame and reel bearings. The reels were free to rotate. Holes spaced three-fourths inch apart were drilled into the 1 x 1 x $\frac{1}{4}$ inch angle iron so the distance between the reels and their height above the ground could be varied.

Two six inch diameter pulleys were fastened on the shaft at the rear end of each reel. A three horsepower, four cycle, Briggs and Stratton gasoline motor was used to power the reels. A double V-belt was employed to link the motor pulley to the reel pulleys. Engaging and disengaging the reels to the motor was accomplished by an idler, which tightened or loosened the belt. The V-belt was placed around the reel pulleys in such a manner that the left reel rotated counter-clockwise and the right reel rotated clockwise.

Two cone shaped shields were constructed from one-sixteenth inch sheet metal and 1 x 1 x $\frac{1}{4}$ inch angle iron and fixed in front of the two stripping reels for the purpose of guiding the snap bean plants between the reels. These cone shields proved to be too rigid for adequate operation of the stripping reel unit. They became embedded in the ground, and the spacing between the front of the reels could not be adjusted close enough to the bean plants so the bottom beans could be stripped from the plant. Therefore, another type of shield was built using a 2 x $\frac{1}{4}$ inch flat metal foot. Metal rods were welded to this foot to guide the bean plants between the reels. The foot was bolted to the front of the reel to allow the shield to ride the surface of the ground. These guide shields removed the undesirable effects of the cone shields.

Stripping rod. A metal frame, built from 2 x 2 x $\frac{1}{4}$ inch angle iron, was constructed so that it could be attached to a three-point tractor hitch (Figure 3). A smaller frame, made from $1\frac{1}{2}$ x $\frac{1}{4}$ inch metal bars, was built to slide inside the larger frame. The smaller frame held the stripping rods in place.

Three sets of hollow pipes, each being approximately three inches long, were used to hold the stripping rods stationary in the smaller frame. Two pipes, at right angles to each other, made one set. A five-eights inch diameter steel rod was inserted into one of the pipes, which could slide along the rod for variable spacing. This rod was placed horizontally in the smaller frame. This method was used for each of the three five-eights inch rods. The stripping rod was placed inside the vertical hollow pipe and held in place by set screws. A one-fourth inch wide groove was cut the length of the five-eights inch rod so that the set screws in the horizontal pipes could be tightened into the groove, thus keeping the pipes from rotating about the rod.

The stripping rods were fixed in the small frame. When the bean plants passed between the three rods, the beans were larger than the open space between the rods and were removed from the plant. The stripping rods were inclined so the bean plant would pass through the rods gradually. The bottom beans were stripped before the top beans.

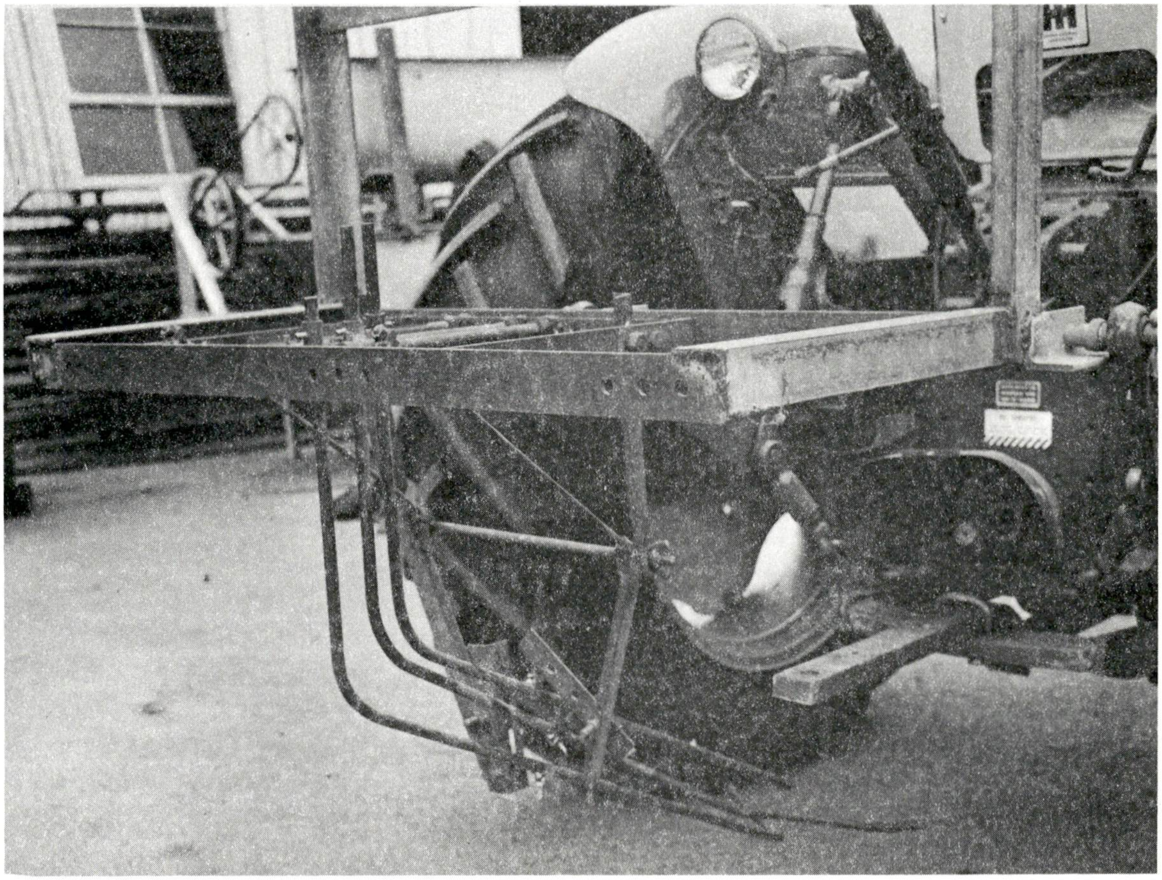

FIGURE 3

REAR ISOMETRIC VIEW OF THE STRIPPING ROD UNIT ATTACHED TO INTERNATIONAL HARVESTER TRACTOR BY THREE-POINT HITCH

II. PROCEDURE

Stripping reel test in the laboratory. The snap bean stripper, using the two Hesston reels, was tested in the laboratory prior to field testing. Snap bean plants were brought from the field to the laboratory and the plants mounted in growing position between two 1 x 4 inch wooden boards. Ten plants, spaced on two inch intervals, were passed through the reels to simulate actual field conditions. Reel speeds were varied to determine if the number and quality of beans removed from the plants were affected by this change. The front reel spacing was $1\frac{1}{4}$ inches between reels. This spacing permitted the plant to enter the space between the reels before the plant came in contact with the rotating nylon brushes and rubber ribs. The rear of the reels were touching. The spacing insured that all of the plant would pass through the rotating reels and become subject to being stripped.

The reel height above ground surface varied between one inch at the front of the reels to three inches over the top of the plant at the rear. This desirable height was dependent upon the variety of the bean and its lodging characteristics.

When the plants were pulled through the reels, the number of individual beans removed from the plant, beans left on the plant, beans broken, beans not broken, and the number of clusters that were stripped were recorded. If an entire plant was pulled loose, it was counted as a cluster. The reel speeds used in the laboratory were 730 and 850 revolutions per minute. When the reel speed was less than 730 revolutions per minute, the reels were stalled. Four replications were run for each reel speed. Laboratory trials were conducted with both the rubber ribs and the nylon brushes attached to the reels.

Stripping reel test in the field. The stripping reel unit was pulled in the field by a tractor at 1½ miles per hour. The rubber ribs were removed leaving only the nylon brushes to strip the beans from the plants in the first trial. The rubber ribs and the nylon brushes were both fastened to the reels in the second trial to parallel the laboratory tests.

During both trials the front of the stripping reels were one inch above the ground surface, and the rear of the reels was fifteen inches above the ground surface. The reel speed was approximately 800 revolutions per minute in each trial. When the sled was pulled down a bean row, the reel height varied with the moisture content of the soil. The sled rode higher on a dry soil than on wet soil. Each row of Cornelli 14 variety of snap beans was approximately 150 feet long. Samples were taken over a row length of 4½ feet. Each sample consisted on the number of individual beans removed from the plants, beans left on the plants, beans broken, beans not broken, and the number of clusters that were stripped. Whole plants that were pulled from the ground were counted as clusters. An analysis of variance was conducted to see if there was any significant difference between the treatments (nylon brushes versus nylon brushes with rubber ribs).

Stripping rod test in the field. When the first attempt was made to strip snap beans in the field with the stripping rods, three seven-sixteenths inch diameter rods were fastened in the metal frame. The rods were so arranged that the beans would pass between the three rods in a manner to strip the beans from the plant. The stripping unit was attached to a tractor by the three-point hitch. The rods were inclined at an angle of twenty-two degrees with respect to the ground surface. The forward speed was one-half mile per hour. The front vertical spacing between the top and the middle rod was the same as between the bottom and the middle rod. The front vertical rod spacing was varied from one-half inch to two inches at a point where the bean plants entered the rod arrangement. The spacing was not constant throughout the length of the rods; only the front vertical spacing remained constant. The middle rod was offset slightly to one side to apply a force on the bean plant as it passed between the stripping rods. This sequence of events was termed the first trial.

Observations were made as to how the stripping rods reacted when they came in contact with the bean plants for every trial. Whether any beans were removed was also noted and recorded.

The second trial was carried out exactly as the first trial except the diameter of the rods was changed to one-half inch to determine whether this added thickness would increase the rigidity of the rods.

A third trial was performed using three one-half inch rods inclined at a thirteen degree angle with respect to the ground surface.

The vertical spacing between each rod was again varied from one-half inch to two inches. The forward speed was one-half mile per hour.

Using longer rods, the angle of inclination was changed to eighteen degrees in the fourth trial. Greater support was added to strengthen the frame. This support minimized the separation of the rods that occurred when the bean plants came in contact with the rods. The length of the rods was increased so the bean plants would encounter a more gradual slope along the stripping rods. Three seven-sixteenths inch diameter rods were fixed in the stripping frame and were spaced three-fourths inch apart vertically. The forward speed was again one-half mile per hour.

The middle rod was changed to a nine-sixteenths inch diameter while the two outer rods remained seven-sixteenths inch in the fifth trial. Spacing between rods varied from one-fourth inch to one inch. The angle of inclination remained at eighteen degrees and the forward speed at one-half mile per hour.

The rods were rearranged in the sixth trial so all three were nine-sixteenths inch diameter. The vertical spacing of the front of the rods was varied from one-fourth inch to two inches. The angle of the rods with respect to the ground surface was eighteen degrees, and the forward speed was one-half mile per hour.

Stripping rod test in the laboratory. When the stripping rods were tested in the laboratory, the metal frame was placed horizontally in a vise and the rods were arranged as desired. Four trials were run in which the vertical and horizontal placement of the rods were varied. The front ends of the rods were held in place by hand so they could not spread, which was the case in the field test. Four replications were run for trial one; three replications in trial two; and seven replications in trials three and four. When some beans were stripped from the plant, more replications were performed than when it became apparent that no beans could be removed to inadequate arrangement of the stripping rods. Each replication consisted of one bean plant being pulled through the stripping rods by hand. The top and bottom rods were always in a vertical line, but the middle rod was moved to one side of the center line in an effort to obtain a better combination for stripping. The horizontal and vertical spacings were with respect to a line along the bean row toward the stripping rods.

In the first trial, the middle rod was spaced one-half inch horizontally from the center line, one inch vertically from the top rod, and one-half inch vertically from the bottom rod. These measurements were made at the front of the rods where the plants came in contact with the rods.

The middle rod was spaced one-fourth inch horizontally from the center line in the second trial and one inch vertically from both the top and bottom rods.

The vertical spacing of the middle rod was kept at one inch between the top and bottom rods in the third trial. The middle rod was extended out so that it was spaced one-half inch from the center line.

In the fourth trial, the middle rod was kept at a horizontal distance of one-half inch from the center line. The vertical distance of this middle rod was rearranged so it was one-half inch from the top rod and one inch from the bottom rod.

The data recorded for each trial consisted of the number of individual beans removed and the number of beans left of the plant. Also the number of broken beans, unbroken beans, and the number of clusters stripped from the plant were recorded.

CHAPTER IV

RESULTS AND DISCUSSION

Stripping real test in the laboratory. Harvest King snap beans were used in the experiment. Two different reel speeds were used to determine if reel speed affected the quantity or quality of snap beans removed from the plants. The data are recorded in Table VI in the Appendix showing the number of individual beans removed from the plants, beans left on the plants, beans broken, beans not broken, and the number of clusters removed from the plants. The number of beans on the clusters were not counted; therefore, only the individual beans removed from the plants were considered in the analysis. Table I shows the percentage of individual beans removed from the plants and the percentage of beans broken for reel speeds of 730 and 850 revolutions per minute.

An analysis of variance for each reel speed showed there was no significant difference between the treatments with respect to the percentage of individual beans removed from the plants or the percentage of beans broken. This analysis showed that the change in reel speeds had no significant affect on the quantity or quality of individual beans stripped from the plants. The results of the statistical analysis are given in Tables X and XI in the Appendix.

Stripping reel test in the field. The first trial of the field test was conducted with the rubber ribs removed from the reels leaving

TABLE I

COMPARISON OF TWO REEL SPEEDS SHOWING PERCENTAGE OF INDIVIDUAL BEANS REMOVED FROM PLANTS AND PERCENTAGE OF BEANS BROKEN BY STRIPPING REELS IN THE LABORATORY

		Per Cent of Individual Beans	
R.P.M.	Reps	Beans Removed From Plants	Beans Broken
730	1	85.71	90.74
	2	90.10	87.80
	3	87.50	78.57
	4	81.48	68.18
	Mean	86.20	81.32
850	1	93.61	84.09
	2	78.04	90.62
	3	72.85	92.15
	4	77.77	90.47
	Mean	80.57	89.33

only the nylon brushes to strip the bean plants. The stripping reel unit harvested three rows of Cornelli 14 variety of snap beans at a forward speed of 1½ miles per hour. Four samples of harvested beans were gathered per row. Table VII in the Appendix shows the data for this trial. Table II shows the percentage of individual beans removed from the plants and the percentage of beans broken in this trial.

Both the rubber ribs and the nylon brushes, in the second trial, were fastened to the reels for stripping the bean plants. Three rows of Cornelli 14 variety of snap beans and four samples per row were also used in this trial. The forward speed in this trial was 1½ miles per hour. The stripping reel unit moving along a row are shown in Figure 4. The data for this trial are recorded in Table VIII in the Appendix. Table III shows the percentage of individual beans removed from the plants and the percentage of beans broken during this trial.

During both trials of the field test, data were collected to show the number of individual beans removed from the plants, beans left on the plants, beans broken, beans not broken, and the number of clusters removed from the plants. An analysis of variance showed there was no significant difference between the treatments with brushes alone versus brushes with ribs for the percentage of individual beans removed from the plants. There was a significant difference between treatments at the 5 per cent level of probability for the percentage of beans broken. Tables XII and XIII in the Appendix show the statistical analysis.

TABLE II

PERCENTAGE OF INDIVIDUAL BEANS REMOVED FROM PLANTS AND PERCENTAGE OF BEANS BROKEN USING ONLY NYLON BRUSHES ON STRIPPING REELS IN THE FIELD

Reps	Samples	Per Cent of Individual Beans: Beans Removed From Plants	Per Cent of Individual Beans: Beans Broken
1	1	88.18	64.28
	2	84.53	65.85
	3	73.95	49.29
	4	81.37	66.26
	Mean	82.07	61.42
2	1	69.36	61.03
	2	74.28	75.96
	3	80.40	67.22
	4	76.27	64.44
	Mean	75.07	67.16
3	1	79.76	68.65
	2	58.10	79.06
	3	68.42	69.23
	4	91.22	62.50
	Mean	74.37	69.86
Treatment	Mean	77.15	66.15

FIGURE 4

VIEW OF THE STRIPPING REELS AND SNAP BEAN PLANTS USING NYLON BRUSHES AND RUBBER RIBS TO STRIP THE PLANTS

TABLE III

PERCENTAGE OF INDIVIDUAL BEANS REMOVED FROM PLANTS AND PERCENTAGE OF BEANS BROKEN USING NYLON BRUSHES AND RUBBER RIBS ON STRIPPING REELS IN THE FIELD

		Per Cent of Individual Beans	
Reps	Samples	Beans Removed From Plants	Beans Broken
1	1	51.94	80.00
	2	68.86	94.52
	3	71.75	94.68
	4	79.16	90.35
	Mean	67.92	89.88
2	1	68.00	82.35
	2	66.22	89.00
	3	76.75	88.02
	4	80.98	93.18
	Mean	72.98	88.13
3	1	73.33	83.11
	2	66.17	88.88
	3	83.33	92.50
	4	80.21	91.09
	Mean	75.76	89.89
Treatment	Mean	72.22	89.30

The treatment using only nylon brushes on the reels broke an average of 66.15 per cent of the individual beans removed from the plants. An average of 89.30 per cent of the individual beans removed from the plants were broken in the treatment employing both the nylon brushes and the rubber ribs on the reels. The trial using only the nylon brushes stripped an average of 77.15 per cent of the individual beans removed from the plants while the trial employing both the nylon brushes and rubber ribs stripped an average of 72.22 per cent of the beans.

The beans that were not removed from the plants were observed to be the lower beans on the plants. The tops of the plants were almost null of any beans, Figure 5. Even though the rubber ribs and nylon brushes were within one inch of the ground, these lower beans were not removed due to the $1\frac{1}{4}$ inch horizontal front space between the reels. This opening permitted the bottom beans to pass under the rotating reels before contact was made.

The Cornelli 14 variety has the characteristic of producing beans low on the plant with many of them touching the ground. This undesirable characteristic is a distinct disadvantage to mechanical harvesting.

All the beans stripped from the plant were not counted, because many beans were thrown out of their row. Only those beans and clusters that fell between the tracks of the sled were coulted; therefore, the percentage of individual beans removed was actually greater than that calculated.

FIGURE 5

VIEW OF STRIPPED SNAP BEAN PLANTS USING NYLON BRUSHES AND RUBBER RIBS TO STRIP THE PLANTS

Stripping rod test in the field. This test employed three stripping rods and six rod arrangements with different diameters and angles of inclination. Wadex snap beans were harvested in this test. Vertical distances between the front of the rods were varied. Data were recorded to determine the effects of the rods and bean plants when the stripping rods encountered the bean plants. These data are listed in Table IV.

No analysis of variance was conducted for the trials because no snap beans were removed from the plants. The three rods either became embedded in the ground or spread apart. The bean plants slipped through the rods or became clogged between them.

Stripping rod test in the laboratory. Four different rod arrangements were used in the laboratory test when testing the stripping rods. Harvest King snap bean plants were pulled through the rods by hand while the rods were held so they could not spread. Only one plant was stripped at a time; and data recorded were the number of individual beans removed from the plant, beans left on the plant, beans broken, beans not broken, and the number of clusters removed from the plant. Data for this test are shown in Table IX in the Appendix. Table V shows the percentage of individual beans removed from the plant and the percentage of beans broken for each trial of this test.

All the beans that were stripped from the plants in the laboratory test were pulled off as a result of the beans becoming wedged between two of the rods. If more than one plant had passed

TABLE IV

COMPARISON OF SIX ROD ARRANGEMENTS SHOWING FINAL RESULTS WHEN STRIPPING RODS ENCOUNTERED BEAN PLANTS IN THE FIELD

	Results of Rods			Results on Bean Plants		
Trial	Remained Stationary	Spread Apart	Embedded in Ground	Wedged Between Rods	Slipped Between Rods	Beans Removed
1	-[a]	x[b]	-	x	-	-
2	-	x	-	x	-	-
3	-	x	x	x	-	-
4	-	x	x	-	x	-
5	-	x	-	-	x	-
6	x	-	x	x	-	-

[a]Denotes no effect.

[b]Denotes effect.

TABLE V

COMPARISON OF FOUR ROD ARRANGEMENTS SHOWING PERCENTAGE OF INDIVIDUAL BEANS REMOVED FROM PLANTS AND PERCENTAGE OF BEANS BROKEN BY STRIPPING RODS IN THE LABORATORY

		Per Cent of Individual Beans	
Trials	Reps	Beans Removed From Plant	Beans Broken
1	1	0	0
	2	0	0
	3	0	0
	4	0	0
	Mean	0	0
2	1	25.00	100.00
	2	0	0
	3	0	0
	Mean	25.00	100.00
3	1	0	0
	2	14.29	100.00
	3	11.11	100.00
	4	0	0
	5	22.22	50.00
	6	0	0
	7	30.77	75.00
	Mean	11.19	81.25
4	1	20.00	100.00
	2	41.67	60.00
	3	22.22	100.00
	4	14.29	100.00
	5	0	0
	6	25.00	100.00
	7	33.33	66.67
	Mean	22.36	87.78
	Test Mean	13.96	89.68

through the rods, as in the field conditions, the remaining plants would have become lodged between the rods, rendering the apparatus ineffective.

CHAPTER V

SUMMARY AND CONCLUSIONS

An investigation was performed to determine the effectiveness of two types of snap bean harvesting units. One stripper employed a Briggs and Stratton, three horsepower, gasoline motor that rotated two nylon brush stripper reels in opposite directions at approximately 800 revolutions per minute. The second unit consisted of three sets of inclined metal rods that were moved down a bean row to strip off the beans. This stripper apparatus was mounted on a three-point tractor hitch.

When the stripping reels were tested in the laboratory, the treatments consisted of reel speeds of 730 and 850 revolutions per minute. Bean plants were passed between the reels to simulate actual field conditions. The number of individual beans removed from the plant, beans left on the plant, beans broken, beans not broken, and the number of clusters that were stripped were recorded. There was no significant difference between treatments with respect to the percentage of individual beans removed from the plants and the percentage of beans broken when nylon brushes and rubber ribs were attached to the stripping reels.

The stripping reels were composed of detachable nylon brushes and rubber ribs attached to a shaft. Trials were conducted using only nylon brushes and nylon brushes with rubber ribs attached to the reels in the field test using the stripping reel apparatus. The trial using only the nylon brushes on the reels stripped an average of 77.15 per cent of the individual beans removed from the plants and broke an average of 66.15 per cent of the individual beans removed. The trial employing both the nylon brushes and rubber ribs stripped an average of 72.22 per cent of the individual beans removed from the plants, but broke an average of 89.30 per cent of the individual beans stripped. An analysis of variance showed there was no significant difference between the treatments of brushes versus brushes with ribs for the percentage of individual beans removed from the plants. When the percentage of beans broken was analyzed, there was a significant difference between treatments at the 5 per cent level of probability.

The gasoline motor performed adequately at 800 revolutions per minute at a forward speed of 1½ miles per hour. When the forward speed was increased, the reel speed was reduced. A motor with a greater horsepower rating would have more effective. The drive belt slipped under heavy loads.

Six stripping rod arrangements were used when the stripping rod unit was tested in the field. Three rods with various diamenters and angles of inclination were employed in an attempt to strip snap beans from the plants. No stripping action was observed in any of the six trials. The front of the rods spread and became embedded in the ground when the bean plants encountered the rods. The bean plants either slipped through the rods or became wedged between them.

Four rod arrangements were utilized in testing the stripping rod unit in the laboratory. An average of only 13.96 per cent of the individual beans were stripped from the plants when one plant at a time was pulled through a rod arrangement. An average of 89.68 per cent of the individual beans removed were broken. The individual beans that were stripped from the plants resulted from wedging between two of the rods as the plant was pulled through.

Based upon the results of the two experiments, the following conclusions were made: the stripping reels definitely could be used to remove snap beans from their plants. Only the nylon brushes should be used on the reels to minimize snap bean breakage of stripped snap beans, using the type equipment tested. The stripping rods proved to be inadequate for satisfactory harvesting results.

The following areas are suggested for additional analysis and study:

1. Additional tests should be performed using larger brushes on the rotating reels and a chain drive used to prevent reel slippage.

2. Test employing various reel speeds and forward speeds, providing data for statistical analysis, should be conducted.

3. Experiments utilizing cone shaped reels instead of cylindrical reels would provide additional information toward the development of an improved snap bean harvester.

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APPENDIX

TABLE VI

COMPARISON OF TWO REEL SPEEDS SHOWING NUMBER OF BEANS LEFT ON PLANTS, INDIVIDUAL BEANS REMOVED FROM PLANTS, BEANS BROKEN, BEANS NOT BROKEN, AND NUMBER OF CLUSTERS REMOVED FROM PLANTS BY STRIPPING REELS IN THE LABORATORY

		Number of Individual Beans				
R.P.M.	Reps	Left on Plants	Removed from Plants	Broken	Not Broken	No. of Clusters
730	1	9.00	54.00	49.00	5.00	10.00
	2	9.00	82.00	72.00	10.00	8.00
	3	4.00	28.00	22.00	6.00	15.00
	4	5.00	22.00	15.00	7.00	10.00
	Mean	6.75	46.50	39.50	7.00	8.25
850	1	3.00	44.00	37.00	7.00	12.00
	2	9.00	32.00	29.00	3.00	9.00
	3	19.00	51.00	47.00	4.00	6.00
	4	12.00	42.00	38.00	4.00	12.00
	Mean	10.75	42.25	37.75	4.50	9.75

TABLE VII

NUMBER OF BEANS LEFT ON PLANTS, INDIVIDUAL BEANS REMOVED FROM PLANTS, BEANS BROKEN, BEANS NOT BROKEN, AND NUMBER OF CLUSTERS REMOVED FROM PLANTS USING ONLY NYLON BRUSHES ON STRIPPING REELS IN THE FIELD

		Number of Individual Beans				
Reps	Samples	Left on Plants	Removed from Plants	Broken	Not Broken	No. of Clusters
1	1	15.0	112.0	72.0	40.0	10.0
	2	15.0	82.0	54.0	28.0	10.0
	3	25.0	71.0	35.0	36.0	2.0
	4	19.0	83.0	55.0	28.0	5.0
	Mean	18.5	87.0	54.0	33.0	6.75
2	1	34.0	77.0	47.0	30.0	5.0
	2	36.0	104.0	79.0	25.0	4.0
	3	29.0	119.0	80.0	39.0	9.0
	4	28.0	90.0	58.0	32.0	5.0
	Mean	31.75	97.5	66.0	31.5	5.75
3	1	17.0	67.0	46.0	21.0	3.0
	2	31.0	43.0	34.0	9.0	2.0
	3	30.0	65.0	45.0	20.0	3.0
	4	10.0	104.0	65.0	39.0	7.0
	Mean	22.0	69.75	47.5	22.25	3.75
Treatment Mean		24.08	84.75	55.83	28.92	5.42

TABLE VIII

NUMBER OF BEANS LEFT ON PLANTS, INDIVIDUAL BEANS REMOVED FROM PLANTS, BEANS BROKEN, BEANS NOT BROKEN, AND NUMBER OF CLUSTERS REMOVED FROM PLANTS USING NYLON BRUSHES WITH RUBBER RIBS ON STRIPPING REELS IN THE FIELD

		Number of Individual Beans				
Reps	Samples	Left on Plants	Removed from Plants	Broken	Not Broken	No. of Clusters
1	1	37.0	40.0	32.0	8.0	0.0
	2	33.0	73.0	69.0	4.0	1.0
	3	37.0	94.0	89.0	5.0	1.0
	4	30.0	114.0	103.0	11.0	2.0
	Mean	34.25	80.25	73.25	7.0	1.0
2	1	24.0	51.0	42.0	9.0	2.0
	2	51.0	100.0	89.0	11.0	2.0
	3	43.0	142.0	125.0	17.0	7.0
	4	31.0	132.0	123.0	9.0	2.0
	Mean	37.25	106.25	97.0	11.5	3.25
3	1	28.0	77.0	64.0	13.0	4.0
	2	46.0	90.0	80.0	10.0	7.0
	3	24.0	120.0	111.0	9.0	9.0
	4	36.0	146.0	133.0	13.0	3.0
	Mean	33.5	108.25	97.0	11.25	5.75
Treatment Mean		35.0	98.25	88.33	9.92	3.33

TABLE IX

COMPARISON OF FOUR TRIALS SHOWING NUMBER OF BEANS LEFT ON PLANT, INDIVIDUAL BEANS REMOVED FROM PLANT, BEANS BROKEN, BEANS NOT BROKEN, AND NUMBER OF CLUSTERS REMOVED FROM PLANT BY STRIPPING RODS IN THE LABORATORY

		Number of Individual Beans				
Trials	Reps	Left on Plants	Removed from Plants	Broken	Not Broken	No. of Clusters
1	1	6.0	0.0	0.0	0.0	0.0
	2	8.0	0.0	0.0	0.0	0.0
	3	7.0	0.0	0.0	0.0	0.0
	4	10.0	0.0	0.0	0.0	0.0
	Mean	7.5	0.0	0.0	0.0	0.0
2	1	12.0	4.0	4.0	0.0	2.0
	2	10.0	0.0	0.0	0.0	6.0
	3	8.0	0.0	0.0	0.0	0.0
	Mean	10.0	3.33	3.33	0.0	2.67
3	1	9.0	0.0	0.0	0.0	0.0
	2	6.0	1.0	1.0	0.0	0.0
	3	8.0	1.0	1.0	0.0	0.0
	4	6.0	0.0	0.0	0.0	0.0
	5	7.0	2.0	1.0	1.0	0.0
	6	10.0	0.0	0.0	0.0	0.0
	7	9.0	4.0	3.0	1.0	0.0
	Mean	7.86	1.14	0.86	0.28	0.0
4	1	4.0	1.0	1.0	0.0	1.0
	2	7.0	5.0	3.0	2.0	3.0
	3	7.0	2.0	2.0	0.0	2.0
	4	6.0	1.0	1.0	0.0	1.0
	5	3.0	0.0	0.0	0.0	0.0
	6	3.0	1.0	1.0	0.0	1.0
	7	6.0	3.0	2.0	1.0	2.0
	Mean	5.14	1.86	1.43	0.43	1.43
Test Mean		7.66	1.58	1.41	0.18	1.03

TABLE X

ANALYSIS OF VARIANCE OF PERCENTAGE OF INDIVIDUAL BEANS REMOVED FROM PLANTS BY STRIPPING REELS IN THE LABORATORY

Source of Variation	Degrees of Freedom	Sum of Squares	Estimated Variances	F Test
Total	7	346.6932		
Between Treatments	1	63.3938	63.3938	1.2291 N.S.[a]
Between Replications	3	128.5731	42.8577	0.8309 N.S.
Error	3	154.7263	51.5754	

[a]Not significant.

TABLE XI

ANALYSIS OF VARIANCE OF PERCENTAGE OF BEANS BROKEN BY STRIPPING REELS IN THE LABORATORY

Source of Variation	Degrees of Freedom	Sum of Squares	Estimated Variances	F Test
Total	7	477.6428		
Between Treatments	1	128.3202	128.3202	1.6147 N.S.[a]
Between Replications	3	110.9251	36.975	0.4652 N.S.
Error	3	238.3975	79.4658	

[a]Not significant.

TABLE XII

ANALYSIS OF VARIANCE OF PERCENTAGE OF INDIVIDUAL BEANS REMOVED FROM PLANTS BY STRIPPING REELS IN THE FIELD

Source of Variation	Degrees of Freedom	Sum of Squares	Estimated Variances	F Test
Total	23	1,921.1806		
Between Treatments	1	145,7308	145.7308	1.1068 N.S.[a]
Between Replications	2	5.2145	2.6072	0.0198 N.S.
Between Treatments x Replications	2	263.3347	131.6673	1.5727 N.S.
Between Samples	18	1,506.9006	83.7167	

[a]Not significant.

TABLE XIII

ANALYSIS OF VARIANCE OF PERCENTAGE OF BEANS BROKEN BY STRIPPING REELS IN THE FIELD

Source of Variation	Degrees of Freedom	Sum of Squares	Estimated Variances	F Test
Total	23	3,995.7437		
Between Treatments	1	3,126.112	3,126.112	62.9955*[a]
Between Replications	2	55.5615	27.7807	0.5598 N.S.[b]
Between Treatments x Replications	2	99.2488	49.6244	1.2495 N.S.
Between Samples	18	714.8214	39.7123	

[a]Significant difference at 5 per cent level of probability.

[b]Not significant.