DEVELOPMENT OF A MECHANICAL CABBAGE HARVESTER

By

Mohammed Yousry Hamdy

AN ABSTRACT

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

MASTER OF SCIENCE
in
Agricultural Engineering

Department of Agricultural Engineering

1962

Approved: ______________________

DEVELOPMENT OF A
MECHANICAL CABBAGE HARVESTER

By

Mohammed Yousry Hamdy

The objective of this investigation was to develop a mechanical cabbage (*Brassica oleracea* var. *capitata*) harvester utilizing some of the design principles of the Scott Viner beet harvester. The major conversion of the beet harvester to a cabbage harvester was accomplished at the Michigan State University Agricultural Engineering Laboratory under the supervision of Dr. B. A. Stout during the winter and spring of 1961 before this research was started.

The conversion primarily consisted of inverting the lifter shoe assembly and the drive sheaves. In this position the lifter shoes raised the cabbage heads and the belts grasped the cabbage plant by the root and elevated it to the trimming mechanism, which was a pair of revolving disc knives mounted on the shaft of the elevator belt sheaves. The belts retained a firm grip on the root as it passed through the cutting knives and discharged it behind the drive belt sheaves.

The harvested head and loose leaves, in contact with a fast moving overhead belt, were pushed rearward onto an inclined slowly-moving belt. The harvested head rolled down the incline to the elevator while the loose leaves were carried up the incline and dropped on the ground.

The author's efforts were devoted primarily to improving the pick-up mechanism. That was the major problem in the

machine and numerous approaches to solve it were tried. Steel fingers on the lower sheaves of the lifter belts solved the alignment, feeding, and lifting problems.

The cut roots presented a minor problem as they accumulated on the platform shielding the sheave driving mechanism. A paddle wheel of the proper dimensions moving at the proper speed completely eliminated this problem.

The quality of trimming the cabbage was improved to get a flush trim leaving one to three wrapper leaves on the head. This was accomplished by changing the geometry, suspension, and speed of the overhead belt, together with the position of the adjustable guides located in front of the disc knives. Appreciable improvement was obtained when cabbage was uniformly picked by the sheave fingers.

Physical measurements were made on cabbage to collect basic data needed to improve the performance of the machine. The vertical and horizontal forces required to remove the plant from the ground were measured. The gross weight of the plant, the weight of the center head, leaves, and roots were recorded. The alignment of the roots and the heads was estimated. The head size, root diameter, and plant stem length were also recorded.

DEVELOPMENT OF A MECHANICAL CABBAGE HARVESTER

By

Mohammed Yousry Hamdy

A THESIS

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

MASTER OF SCIENCE
in
Agricultural Engineering

Department of Agricultural Engineering

1962

ACKNOWLEDGMENTS

The author wishes to acknowledge all those who have helped make this investigation possible, particularly Dr. B. A. Stout, major professor during the first nine months of his graduate studies for providing encouragement and guidance. (Because of Far East travels, Dr. Stout was absent during the final phases of this study.)

The time, efforts, and suggestions of Dr. W. E. Buchele opened new horizons for investigation and improving the machine performance during the last two months of this investigation.

The assistance and suggestions of Dr. S. K. Ries of the Department of Horticulture and Mr. Thomas Burenga and his staff made the investigation possible and the tests meaningful.

Sincere thanks are due to Dr. F. H. Buelow and Dr. G. H. Martin, members of the Guidance Committee, for their many helpful suggestions.

Credit should be given to Messrs. James Cawood and Glenn Shiffer for their sincere interest and assistance in advising the author in machine shop work.

Appreciation is extended to Professors A. W. Farrall, M. L. Esmay, and J. S. Boyd and other department members who have contributed to the completion of the project.

TABLE OF CONTENTS

LIST OF FIGURES

Figure		Page

N.B.: All negatives are filed at Michigan State University Photographic Laboratory. The information services file number is 621901.

INTRODUCTION

Cabbage, one of the important vegetable crops in the United States, is grown commercially in about thirty-four states. An average of 130,000 acres was grown annually for fresh market in the ten-year period (1), 1950-59. The average production from this acreage for the above period was one million tons. The annual farm value of the cabbage produced for the fresh market averaged 40 million dollars.

An average of 14,000 acres was grown for sauerkraut during the same period with average production of 200,000 tons. The annual farm value of cabbage produced for sauerkraut averages 2-1/2 million dollars.

Cabbage is harvested by hand with little mechanical aid. In a study of costs and returns in producing sauerkraut at Cornell University (2), it was found that labor for hand harvesting costs about $31.59 per acre; the total growing and harvesting costs were $142.12 per acre. The development of a mechanical cabbage harvester has become necessary for the survival of the sauerkraut grower because of the unreliable source and high cost of hand harvest labor.

Cabbage production, and in particular that used for sauerkraut production, is not large in comparison to some

---

(1) Numbers in parenthesis following names correspond to references listed in the bibliography.

other vegetable crops. Farm machinery manufacturers have not been willing to undertake a development program for a cabbage harvester because of the limited potential market for a mechanical cabbage harvester. Because the producers of cabbage need a mechanical harvester, this development program was initiated in 1961 at Michigan State University and this thesis represents the author's participation in this program.

LITERATURE REVIEW

The most important work of direct concern to this research was done at the Michigan Agricultural Experiment Station under the name of "Project 651 - Basic Principles of Harvesting."

Stout reported (3) that the work was initiated in the Summer of 1960 by recording some physical measurements made on cabbage at the Turner farm located near Saginaw, Michigan. The same measurements were repeated in the Summer of 1961. Stout reported:

> Cabbage plants comprising twenty-head samples were randomly selected. A 100-pound capacity spring scale was fastened to the cabbage roots by means of an "S" hook. The plant was then pulled vertically from the ground and the scale indicator observed for its maximum reading. Other data taken included average root diameter, root length, head size, and head weight. The root diameter was measured at ground level. Root length represents the length of the underground main tap root not including the small portion of that root extending above ground. Head weight represents the weight of the center head.

The values reported were comparable to what was obtained by the author in the tests conducted at Michigan State University Horticulture Farm in the Summer of 1962.

In another part of his report, Stout said that the cabbage harvester was constructed at the Michigan State University Agricultural Engineering Laboratory during the Winter and Spring of 1961. The harvester was constructed by modifying a Scott Viner beet harvester (Figure 1).

Fig. 1. MSU experimental cabbage harvester in a field of head lettuce (1961).

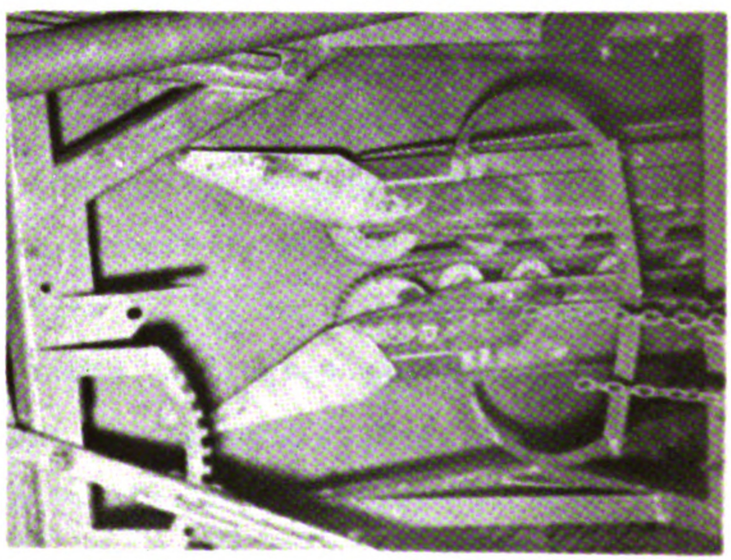


Fig. 2. Picking device of MSU. Experimental harvester (1961).

The same machine was used by the author in his tests and will be described in more detail in the chapter on the apparatus. The lifting shoes were a pair of two small streamlined shields with a comparatively small area sliding on the ground (Figure 2). They were not very successful in lifting the cabbage; they pushed it ahead of the machine in most of the tests. The cleaning device at the rear of the machine incorporated a wide, inclined belt placed perpendicular to the direction of travel and moved slowly upwards to the left (Figure 3). The harvested heads fell onto the belt and rolled down the incline where they were carried away to the right by the elevator while the loose leaves were carried up the incline and dropped onto the ground at the left side of the machine.

The root removing device was composed of two main elements: a square roller placed behind the disc knives to knock the cut-off roots down and a gathering chain under the drive belt sheaves (Figure 4) to drop them on the ground. The device was not successful, however, because it reversed the direction of motion of the roots. The incoming roots obstructed the cut roots, collected and choked the machine blocking the movement of incoming cabbage plants.

Stout presented also in his report an analysis of the economic feasibility of a mechanical cabbage harvester. In this analysis he considered two harvesters priced at $3,000 and $6,000, with a five-year useful life and 60 per cent field efficiency. He concluded that a cabbage harvester

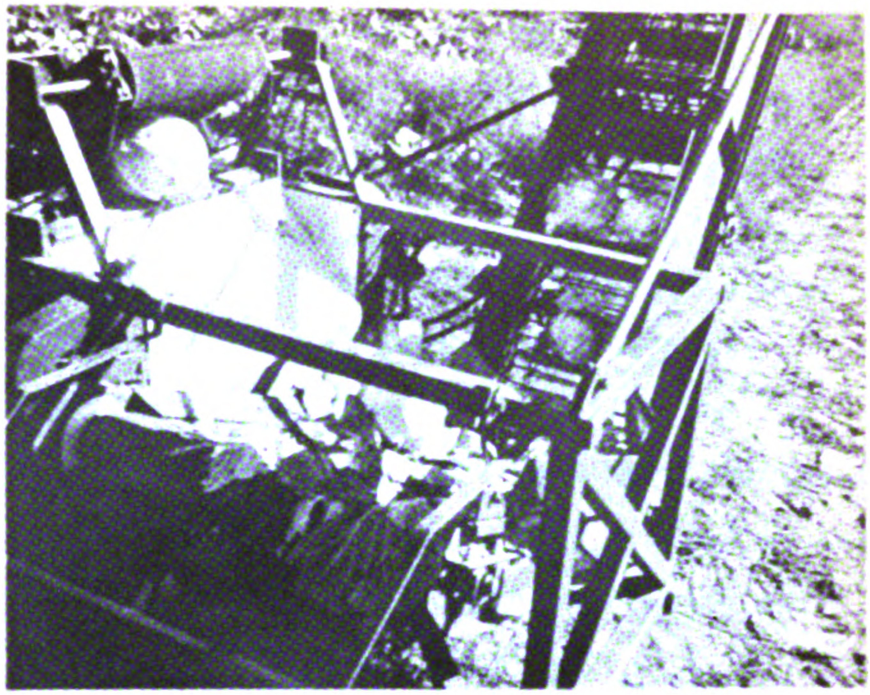


Fig. 3. MSU experimental harvester showing the cleaning belt and elevator (1961).

[illegible] MSU experimental [illegible] showing [illegible] [illegible] overhead belt [illegible] could favorably compete with hand harvesting. A profit over hand harvest will be expected with a $3,000 harvester used on a fifty-acre farm or a $6,000 harvester used on a 250-acre farm.

Another approach to mechanical harvesting of cabbage was made by Splinter and Wright at North Carolina State University. Their initial objective was to define the physical properties of cabbage which they felt were pertinent in the design of a mechanical harvester. They started in the Summer of 1961 by making measurements of the following properties:

1. Uniformity of heads.
2. Plant diameter.
3. Stem diameter.
4. Length of leaf stem (portion of stem where leaves are attached).
5. Force to cut stem (knife action).
6. Resistance to drop, etc.

They obtained more of the same measurements in the 1962 season and utilized the information of the previous year in the design of a field machine. The harvester was tractor-mounted. The cabbage heads were cut from the root by a band saw mechanism; the root or stalk of the cabbage plants were left in the ground. A conveyor system was used to convey cabbage to a cart. (No details regarding the operation of the machine were available at the time of writing this thesis.)

Some work was also done by Holmes at the University of Florida, but it was concentrated on the mechanical aids for cabbage harvesting.

A survey was conducted in April, 1962 by mailing questionnaires to sixteen leading sauerkraut packers. The objective of this survey was to find the practical answer to the following questions:

1. How should the cabbage head be cut? Is the height of cut critical? Is the angle of cut critical?
2. What size heads are preferred?
3. Is dirt a problem? What kind of washing process is used?
4. Is bruising a problem?
5. What is the price paid to the grower? Is the cost of harvesting available?

Answers received from eight companies can be summarized as follows:

1. The cabbage head should be cut as close to the base of the head as possible, with perhaps the outside wrapper leaves partially or wholly cut from the stem. The angle of cut should be as nearly square as possible so as to insure a good job of coring.
2. A cabbage head weighing five pounds and up is generally preferred for kraut.
3. Some surface dirt is not normally a problem, but any dirt that might get into the head would be a problem as the heads are not normally washed.
4. Minor bruising is not too serious, but rough handling that would cause breakage or loosening of leaves would result in more waste. Also, and especially important, if the cabbage is stored any length of time after it is harvested, rot would start in the bruised areas.
5. The average price of cabbage runs between $10 to $15 per ton, delivered. Harvesting costs run about $1.50 to $2.50 per ton.

PHYSICAL MEASUREMENTS

A knowledge of the force needed to pull the cabbage plant vertically or horizontally from the ground is necessary for designing a mechanical cabbage harvester. The gross weight of the plant and the net weight of the head would help the designer estimate the material handling arrangements for the different elements of the harvester.

A knowledge of the relative alignment of the plant root and plant head would help him evaluate the expected machine performance in the picking operation. The geometrical dimensions of the plant, such as the head size, the stem length, and the root diameter are also important factors to be considered when designing the harvester or checking the physical dimensions of a commercial harvester to determine if it can be used in a particular area.

The following information was obtained at the Horticulture Farm for the dates shown:

1. Force required to pull the plant vertically from the ground.
2. Force required to pull the plant horizontally from the ground.
3. Plant, gross weight.
4. Head, net weight.
5. Root, gross weight.
6. Distance between the root and a thread extended parallel and between the rows.

7. Distance between the head center and the same thread.

8. Head, mean diameter.

9. Root, mean diameter.

10. Stem length.

11. The average coefficient of friction between cabbage and some materials.

Tests 6 and 7 were repeated more frequently as it was believed that the alignment of the roots and of the heads seriously affects the picking operation which was the major problem of the machine.

Apparatus

The forces required to remove the plant from the ground were measured by a simple apparatus mounted on the left side of a tractor (Figure 5). A rope wound on a hand-rotated shaft and having the other end hooked to a 100-pound capacity spring balance was used to apply the pulling force. A system of pulleys served to double the spring balance capacity to indicate the extra high forces. The apparatus was designed with a mechanical advantage of 15 to avoid operator fatigue from the repeated tests. A pair of clamps was attached to the movable pulley and could be securely locked around the heads.

An arrangement to pull the plant horizontally was provided by a vertical beam (hidden behind clamps in Figure 6) with a pulley freely mounted at its lower end such that it laid below the movable pulley and almost touched the soil surface. An S-shaped hook was placed around the stem and

Fig. 5. Measurement of the vertical pulling force of cabbage (1962).

Fig. 6. Measurement of the horizontal pulling force of cabbage (1962).

pulled by a rope fixed to the movable pulley assembly. The clamps were kept on the apparatus during this test as the spring balance was calibrated to give a zero reading at no load with the clamps attached.

A 25-pound capacity table spring balance was calibrated and used to measure the gross weight of the plant and the net weight of the head. A 25-ounce spring balance was used to weigh the roots after the soil was removed.

A large caliper was built and used to measure the head diameter while a commercial one was used to measure the root diameter. The alignment of the roots was determined by stretching a string between two stakes placed at the mid-point between the rows and measuring the distance between the string and root side and string and head center.

A 10-pound spring balance was calibrated and used to estimate the coefficient of friction between cabbage and some of the commonly used engineering materials. The balance was fastened with an "S" hook to the cabbage at a point close to the surface of contact to prevent any rolling. The balance was then pulled and both the static and dynamic frictional forces were measured and recorded along with the head weight.

Results

The results of tests and physical measurements conducted on samples of cabbage from Michigan State University Horticulture Farm are listed in Tables I, II, III, IVa, and IVb (Appendix I). The variety was Glory and planted on May 2, 1962. The tests were conducted between September 27 and

October 7, 1962.

Table I lists the measurements made to investigate the alignment of the roots of five samples varying in size from 30 to 35 heads each. A statistical analysis was conducted on the samples, assuming that cabbage population is normally distributed around the mean (4). It yielded the following:

	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
Sample size (No. of heads)	35	35	29	31	33
Max. dist. to thread (in.)	21.5	22	21	22	24
Min. dist. to thread (in.)	16.5	15	18	18	18
Mean dist. to thread (in.)	18.7	18.6	20.2	19.6	21.8
Max. deviation from mean (in.)	2.8	3.6	2.2	2.4	3.8
Standard deviation (in.)	1.09	1.25	0.72	1.12	1.62
95% of population is expected to lie within	±2.2	±2.52	±1.47	±2.28	±3.3

A similar analysis was made on the values listed in Table II giving the distance between the thread and the head.

	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
Sample size (No. of heads)	35	35	29	31	33
Max. dist. to thread (in.)	22	24	23	25	26
Min. dist. to thread (in.)	16	15	14	19	15
Mean dist. to thread (in.)	18.2	18.7	17.5	22.2	20.7
Max. deviation from mean (in.)	3.8	5.3	5.5	3.2	5.7
Standard deviation (in.)	1.38	2.56	1.96	1.92	2.78
95% of the population is expected to lie within (in.)	±2.8	±5.2	±4.0	±3.9	±5.6

The same analysis was repeated on the head size, root diameter, and stem length which are listed in Table III.

	Head Size		Root Dia.		Stem Length	
	Sample 1	Sample 2	Sample 1	Sample 2	Sample 1	Sample 2
Sample size (heads)	31	33	31	33	31	33
Max. value (in.)	11.5	11.5	1.2	1.2	3.6	4.0
Min. value (in.)	7	6	0.8	0.6	2.4	1.5
Mean value (in.)	8.5	8.2	0.95	0.98	2.74	2.62
Standard deviation (in.)	0.95	1.4	0.1	0.16	0.3	0.6
Expected limits for 90% of population	10.1 6.9	10.6 5.9	1.13 0.78	1.25 0.71	3.25 2.23	3.6 1.6

A more simple analysis was conducted on the contents of Tables IVa and IVb:

	Forces to remove cabbage from the ground			
	Vertical Force (lb.)		Horizontal Force (lb.)	
	Sample 1	Sample 2	Sample 1	Sample 2
Sample size (heads)	16	16	15	16
Maximum force (1 pound)	94	78	112	100
Minimum force (1 pound)	56	35	45	42
Average force (1 pound)	74	59	85	65

	Weight percentage of plant elements					
	Net Head		Leaves		Roots	
	Sample 1	Sample 2	Sample 1	Sample 2	Sample 1	Sample 2
Max. Percent.	74	83	38	38	10.6	11.5
Min. Percent.	55	54	20	9	6.9	6.5
Ave. Percent.	65	71	27	20	7.6	9

The results of the tests conducted to estimate the coefficient of friction between cabbage and some engineering materials can be summarized as follows:

	Static Coefficient	Dynamic Coefficient
Steel plates	0.52	0.47
Zinc-coated steel plates	0.50	0.45
Paper (hard board)	0.62	0.57
Wood (rough)	0.65	0.60
Wood (finished)	0.48	0.43

Discussion

In the alignment test we were actually interested in investigating how far and how frequently the cabbage roots and heads deviated from the virtual centerline of the row. The results of our investigation may be stated as follows:

> . . . 95% of the cabbage roots are expected to grow in a 5-inch wide band and 95% of the center of heads are expected to lie in a 10-inch wide band.

The above statement depends to some extent on the type and make of the planter used to plant the cabbage, and on the surface and condition of the soil. But the probability factors which determine in which direction the plant will grow are the major variables.

The physical dimensions of the plant have a smaller effect on the design of the machine. The maximum and minimum head size, root diameter, and stem length may suggest some of the plant criteria that the machine has to accommodate. It is true that they will change from field to field depending on the variety planted, the plant spacing, the soil, the moisture, the amount and kind of fertilizer used, the temperature, etc., but they will not change much in a single field. Since the machine can be adjusted to handle one field condition, the analysis was presented together with the statistical inference to estimate how seriously these changes are in a single field.

Tables IVa and IVb list the force required to remove the plant from the ground, either vertically or horizontally. The pairing technique was used in pulling the heads by both methods to get a more accurate estimate of the ratio between them. This technique reduces the possibility of misleading results in case of any change in properties along the row from which the sample was taken. The magnitude of these forces varied over a relatively wide range, which was not unexpected. The conclusion of the test is as follows:

> The horizontal force required to remove the plant from the ground is about 10 per cent higher than the vertical force required to pull it from the ground.

Combining this result with the estimated coefficients of friction reveals one of the basic principles of mechanical harvesting of cabbage:

> Cabbage cannot be dragged out of the ground by a horizontal frictional force produced by a reaction on the rubbing surface equal to the force by which it is anchored in the ground.

In fact, this frictional force will be less than half of the horizontal force required to pull the cabbage from the ground. However, it should be stated that cabbage was freed horizontally from the ground in actual field tests due to direct mechanical push or due to the accumulation of soil ahead of the machine which released the plant before the machine touched it.

The same tables also list the gross weight of the plant and the weights of the head, leaves, and roots. The absolute values of these weights express the same concept of the plant dimensions as discussed previously, but the relative values may show a new concept which is important for the performance of the machine. These relative values show the amount of material that must be handled by each machine element. The machine capacity as such was not investigated at this point. The following was concluded:

> The expected head weight, leaf weight, and root weight are 67 per cent, 27 per cent, and 8 per cent, respectively, of the total plant weight.

More accurate measurements could have been obtained; however, the error resulting from the accuracy of the spring balances was definitely less than the unavoidable error resulting from the soil, dirt, and accumulated water in the leaves of the plant. The error resulting from using the extended thread to estimate the alignment of the plant was less than the error made to determine the part of the root to be contacted or the exact center of the head. It was believed, however, that the harvester will not move in a better straight line than that of the thread, and we are actually interested in the alignment of the plant relative to the machine travel. Since this relative alignment could not be measured, the absolute alignment was measured and used instead of as an estimate.

APPARATUS

Description of the Machine

The Scott Viner sugar beet harvester was modified by changing some of the machine elements to harvest cabbage. Some initial elements were removed and new ones were added. The following description gives the features and the function of the basic components labeled in the order by which they handled the plant as shown in the assembly drawing (Appendix III).

Lifter shoes (1) were constructed to align and raise the head from the ground, orient it toward the lifter V-belts, and hold it there until it was gripped and lifted. The shoes shown on the drawing are one of the tested designs, however, no final decision was made regarding the best design as will be discussed later. A pair of slides were located under the lifter assembly; it carried a portion of the weight of the lifter assembly, the lifted heads and the thrust resulting from the pulling forces. The other portion of the weights and thrust was counterbalanced by a tension spring. The lifter assembly (carried on the slides) followed contours of the ground. In some of the designs the slides had a plowing action that pushed about three inches of soil aside and left the plant on a middle ridge which provided a better approach and grip on the stem for the V-belts.

The lifter assembly (2) consisted of two hinged beams that were moved in a vertical plane. Each beam carried free-rotating eight-inch diameter sheave at its lower end which supported the lifter V-belts. The gap between the sheaves could be adjusted by a pair of lifter shoe spreaders located under the bottom surface of the hinged beams. Each beam had also a set of four-inch spring-loaded idler pulleys hinged to the inner edge which supported and forced the V-belts against each other. The V-belts were thus able to continuously retain a firm grip on the plant from the lifter shoes to the trimming disc knives (4).

A pair of adjustable guides (3) was placed just before the disc knives. The overhead belt (5) pressed the cabbage against these guides which changed the grip position on the stem in order to locate the plant at the proper height relative to the disc knives for trimming.

The disc knives (4) were mounted on the lifter belt drive shafts, cut the roots and outer leaves from the plant. One of the knives had a plain edge and the other was serrated to insure positive feeding of the stem between them.

An overhead belt (5), moving at 1.15 times the speed of the lifter V-belts, pushed the trimmed heads and the loose leaves over the root deflecting shield (7) to the cleaning belt (8) at the rear of the machine. Its lower end could move up and down and was spring loaded to control the contact pressure between the belt and the cabbage. Two small rollers located at the lower third of the belt made the space taper from front to rear to accommodate different head sizes. The belt was run at a particular speed in order to cause the angle of trim to be at right angles to the vertical axis of the head.

The root thrower (6) was a 12-inch diameter by 9-inch wide paddle wheel with seven separate compartments, each 3-inches deep. It was placed below the disc knives to catch the cut-off roots and throw them backwards. The wheel was driven with a circumferential speed 1.5 times the V-belt speed to produce a centrifugal force great enough to keep the root in contact with the lower surface of the deflecting shield (7). The shield ended at a position where the root could be released to fall to the ground behind the driving mechanism.

The trimmed heads and loose leaves fell onto an inclined cleaning belt (8) which moved slowly upwards. The heads rolled down the incline to the step incline (10) where the elevator (11) carried them to a truck moving along the right side of the machine. The loose leaves were carried up the incline and dropped on the ground. The head deflector (9) oriented the heads to the elevator side and helped to loosen the cut-off leaves which might still be wrapped around the head.

Field Tests

After the research work conducted on the machine during the 1961 season, it seemed that this approach to mechanical cabbage harvesting was sound. There were, however, four unsolved problem areas in the machine as follows:

1. Lifting.--The machine did not lift the cabbage satisfactorily. In most cases the lifter shoes and lifter belts pushed the plants ahead, collected a large amount of soil, trash, and broke the roots at the throat between the belts.

2. Root removal.--A few approaches had been tried to remove the cut-off roots (at a rate equal to the harvesting rate), but none gave satisfactory results.

3. Head trimming.--The angle and location of trimming were not satisfactorily controlled. Frequently the machine discharged a head cut into halves or a head with none of the external leaves removed. The heads were not "square trimmed" in most cases.

4. Loose leaf dropping.--The cleaning belt, having been placed perpendicular to the direction of travel (Figures 1, 3), dropped the loose leaves on the left side of the machine. The leaves fell on an unharvested row that would be subsequently harvested.

When the author started to work on this project, he was informed about the nature of these problems and was supplied with photos showing what had been done. It was quite evident that the lifting problem was the primary problem to be solved; the other three could not be evaluated until a sufficient supply of lifted heads was lifted. The author, therefore, concentrated on lifting until reasonable results were obtained; then he considered the other problems.

The details of the field tests, together with the necessary photos, are given in Appendix II. These tests, however, are summarized in the following tables.

TESTS ON LIFTING DEVICES

Test No.	Date 1962	Page	Fig. No.	Description	Results
1	6-11	42	--	Two flat inclined plates	Accumulated soil
2	6-12	42	--	Curved inclined plates	Accumulated soil
3	6-12	42	--	Small sliding runners	Accumulated soil
4	6-13	43	2	Curved small shoes	Accumulated soil
5	6-18	43	7	Moldboard plows & gathering bars	Dug into soil
6	6-21	43	8	Curved large plates	Choked cabbage flow
7	6-25	43	8	Curved large plates	Satisfactory, needed manual help
8	6-27	45	--	Two sliding runners	Pushed cabbage, no soil problem
9	6-28	45	9	Flat plates and runners	Pushed then lifted cabbage
10	6-29	47	9	Same shoes with wider gap	Pushed then lifted cabbage
11	7-5	47	--	Similar shoes, but smaller	Pushed cabbage and soil
12	7-13	47	--	Strong sliding runners only	Pushed cabbage, no soil problem
13	7-31	48	10	Gathering V-belts and runners	Pushed cabbage
14	8-2	49	10	Above device with modifications	Did not work
15	8-8	49	11	Strong curved shields	Did not work
16	8-9	51	8	Device of test 7	Pushed, then lifted cabbage

TESTS ON LIFTING DEVICES (continued)

Test No.	Date 1962	Page	Fig. No.	Description	Results
17	8-15	51	12	Strong curved shields	Pushed and lifted cabbage
18	9-6	52	12	Above shoes at higher speed	Pushed cabbage
19	9-11	52	12	Paddle wheel and above shields	Pushed cabbage, paddle speed too slow
20	9-12	53	12	Above device at higher paddle speed	Better results, still pushed cabbage
21	9-17	54	12	Same device at faster travel speed	Pushed cabbage
22	9-21	55	13 14	Stronger paddles, New slides, no slip clutch	Rough operation, paddles damaged
23	9-25	57	14	The same device, wider throat	Better performance, still pushed soil
24	9-26	57	15	Faster paddle speed, larger slip force	Equally well, paddles too fast
25	9-27	58	16	Overhead floating rubber tire	Pushed cabbage, did not work
26	9-28	60	16	Same device with refinements	Did not work
27	10-2	60	17	Smaller, rigid, floating paddle-wheel	Moderate performance
28	10-5	60	18	Floating rubber-lined paddle-wheel	Poor performance
29	10-9	62	19	Same device with plowing slides	Better performance

TESTS ON LIFTING DEVICES (continued)

Test No.	Date 1962	Page	Fig. No.	Description	Results
30	10-11	62	20	Steel fingers on left sheave	Better performance
31	10-31	64	21	Steel fingers on on both sheaves	Excellent performance

TESTS ON ROOT REMOVAL, TRIMMING, AND CLEANING DEVICES

Test No.	Date 1962	Page	Fig. No.	Description	Results
1	9-17	64	22	Steep inclined shield below disc knives to drop roots	Did not work & was clogged
2	9-21	66	23	Paddle-wheel below knives and shield	Partially successful, needed modifications
3	9-25	68	24	Same paddle and a double-deck shield	Paddle-wheel very successful
		68	25	Taper entrance for overhead belt	Trimming poor
4	9-26	70	--	Faster paddle-wheel	Effective root removal, angled trimming & bruising of cabbage
5	10-2	70	26	Slower overhead, spring-suspended belt	Less bruising and inclined trimming
6	10-9	70	27	Spring-suspension modified, trimming efficiency estimated.	Less bruising, better trimming, efficiency 96%

TESTS ON ROOT REMOVAL, TRIMMING (continued)

Test No.	Date 1962	Page	Fig. No.	Description	Results
7	10-24	72	28	Cleaning belt added (new lifting positive feed)	Cleaning belt clogged, satisfactory trimming due to better picking
8	10-31	73	--	Faster cleaning belt	Better cleaning, satisfactory trimming and root removal

Because of the action of the plowing runners, a force analysis was conducted to study the stability of the lifting shoes. Special care was taken to prevent unstable conditions which would damage the machine. Such a condition results because the greater the plowing resistance, the deeper the plowing action which, in turn, creates greater resistance.

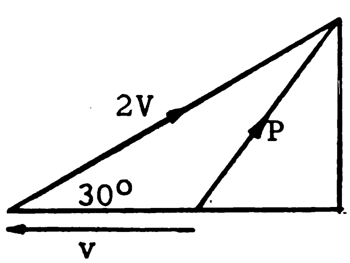


Fig. i. Velocity diagram.

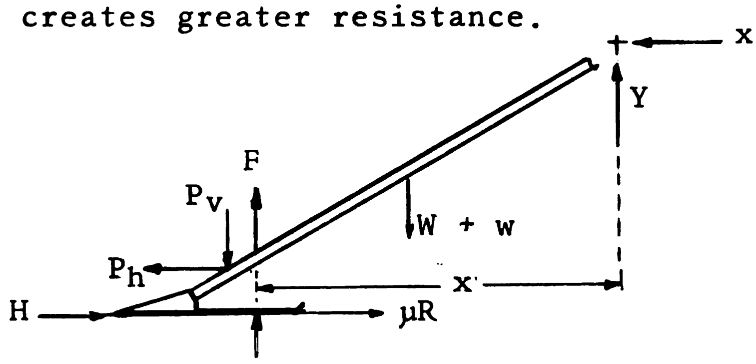


Fig. ii. Forces acting on lifter assembly.

The lifting V-belts run at twice the travelling speed V (Fig. i). The root displacement and the pulling force, therefore, are along the direction P. The action of the pulling force on the shoes has two components, P_v and P_h

(Fig. ii). The other forces acting on the lifter assembly are:

H = horizontal plowing resistance = 2 btp

Where: b = width of each furrow

t = depth of the furrow

p = soil resistance

F = spring force = $F_o + kt$

Where: F_o = force when runners are at ground level

k = spring constant

R = soil reaction

μR = soil friction

W = weight of the lifter assembly

w = weight of lifted heads, equally distributed

X & Y = reactions at the hinge

A summation of the moments of the forces around the hinge, to which the relative moment arms are as shown follows:

$(F + R)\,x - P_v\,(1.1x) - (W + w)\,0.6x + P_h\,(0.64x) - (H + \mu R)\,0.7x = 0 \;\therefore\; R\,(1 - 0.7\mu) = 0.6\,(W + w) + 0.7H + 1.1\,P_v - 0.64\,P_h - F$

Assuming:

$\mu = 0.5$

$W + w = 400$ lb.

$H = 2btp = 10\ pt$

$P_v = 0.8\ P = 64$ lbs.

$P_h = 0.6\ P = 48$ lbs.

$F = F_o + kt = 180 + kt$

$\therefore$ 0.65 R = 240 + 7 p·t + 70 - 30 - F_o - kt

= (7 p - k)t + 280 - 180

= (7 p - k)t + 100

$\therefore$ R = (10 p - 1.5k)t + 150,

The unstable conditions occur if R increases with the increase in depth which increases the plowing resistance H and, consequently, R. To avoid this 10p - 1.5k should be negative

$\therefore$ k > 6.5p

In average soils, p = 7 --> 8 psi

$\therefore$ k $\gtrsim$ 60 lbs./unit deflection.

This average was obtained with proper leverage of the links carrying the lifter assembly. The sliding runners were also designed to carry up to 500 pounds soil pressure which is greater than the maximum expected value, 150 pounds.

Discussion

The results of the preliminary tests (tests 1-5) conducted on the machine revealed that the major problem was failure of the lifting mechanism to lift cabbage. The importance of the problem was not in the value of one lost head of cabbage to every fifty or sixty heads successfully harvested, but rather that the operator of the tractor will not notice that blocking has started until a mass of cabbage, soil, and trash had developed. He has to stop the machine, clean it, and start again. The cleaning of the machine takes more time than would be spent harvesting fifty or sixty heads. Lifting was subdivided into its basic phases.

The approach used was to solve each subdivision separately:

1. Contact with the soil cannot be avoided if the machine is required to operate close to the ground and grasp the short cabbage stem. A sliding runner was designed to carry a share of the lifter assembly weight, the lifted plant's weight, and the down thrust resulting from the pulling forces. Knowledge of the average values of pulling forces and weight of plants reveals the force to be transmitted to the soil and the area of contact. The shape of the runner, both the sliding and the leading parts, is determined by the performance required, whether sliding on the ground surface or cutting a passageway into the soil.
2. A gathering element was definitely required. It should work to align the scattered cabbage heads, raise them from contact with the ground to give the lifter-belts room for grasping the stem, and to direct the plant, within limits, to the V-belts. The different types of gathering devices were:
   a. Curved sheet metal shields.
   b. Straight and curved bars.
   c. Loop overhanging elements.
   d. Power-driven belts.
   e. Steel fingers on sheaves.

   The first three types could gather cabbage, the fourth one failed. The curved shields, however, accumulated soil and trash, the straight bars caused frequent breakage of stems. The loop type and the steel fingers were the most successful.

3. Since in cabbage harvesting short stems and a comparatively heavy vegetative growth at the top are handled, there is little probability that the stem could be gripped without external help. The gathering device does half of the job; it orients the plant to the throat of the lifter belts. The second half of keeping the plant in place against the pressure of the traveling machine was left to the soil. But the soil resistance is limited, and this explains why cabbage was pushed ahead in an accumulated mound of soil in most of the tests. A positive feeding device is a must for continuous uniform operation of the machine. The different types tested were:

    a. The gathering belts.
    b. Overhead paddle.
    c. Overhead tire.
    d. Steel fingers on sheaves.

   The paddle and the fingers were successful because of their positive mechanical action. The fingers, however, had the advantage of eliminating the meshing problem and feeding the stem perpendicular to the lifter belts which resulted in square trimming.

The second problem in the machine was how to get rid of the cut-off roots at the same rate they came into the machine. A properly designed paddle wheel and root deflector completely eliminated the problem after a few trials and modifications.

The third problem was the proper trimming. The force holding the disc knives against each other was increased such that no heads came through partially trimmed. The location of cut was effectively controlled by the guides placed before the knives and the new design and suspension of the overhead belt.

The angle of trim was effectively improved to a square trim when the steel fingers were mounted on the sheaves. The lifter belts gripped the stem almost perpendicularly and the proper speed and suspension of the overhead belt kept this grip until the cabbage reached the disc knives.

The last problem was the dropping of the cut-off leaves on the row which will be subsequently harvested. The design solution as presented in the assembly drawing (Appendix III) appears as a reasonable alternative to the design adopted in tests (6) and (7). It can handle rather uniformly a continuous flow of cabbage and even provide a better removal of leaves as it has a longer length of contact. However, it has the disadvantage of moving the heavy elevator about two feet backwards which affects the maneuverability of the machine.

CONCLUSIONS

The application of the principles of the Scott Viner beet harvester to cabbage harvesting was a sound approach. After considerable modification, the experimental machine performed satisfactorily. The basic problems of the machine were solved as follows:

1. Continuous uniform lifting of cabbage was secured under the test conditions encountered at the end of the harvest season (October 31 and November 7, 1962). The machine successfully handled different varieties of cabbage under different weather conditions.
2. The root removal problem was completely eliminated.
3. A square trim was uniformly obtained with a 96 per cent trimming efficiency.
4. The cleaning belt removed the loose leaves from the heads and dropped them behind the machine; however, more adjustments are desirable.
5. It was also observed that the harvested heads were free from surface dirt.

The physical properties of cabbage were measured; the data obtained were comparable to that gathered by previous research workers.

RECOMMENDATIONS FOR FUTURE STUDY

1. The Literature Review revealed a lack of information on the mechanical properties of cabbage. A study of the vertical and horizontal pulling forces, the bending strength of the roots, coefficient of friction with different materials, the bruise-producing pressure, and a weight survey for different varieties and their average dimensions would help in the design of a cabbage harvester.
2. New types of picking and lifting devices utilizing different shapes of steel fingers and new sliding runners are recommended for additional study. A depth gage wheel may be a good substitute for the sliding runners.
3. The overhead belt should be tested with a concave steel backing to keep the head in the center and help maintain, with the proper speed relative to the lifter belts, a square cut at the desirable position.
4. The field capacity of the machine at various speeds should be investigated. An economic analysis based on actual figures would help to predict its economic feasibility.
5. Evaluation of different cabbage varieties to find the suitable ones for mechanical harvesting, and which can be used for fresh market or sauerkraut production. Trimming may be difficult for both.

6. Study of changing the cultural practices to grow cabbage on a central ridge. This change may provide better lifting and cleaner handling for the machine.
7. Bulk handling methods of cabbage should be studied to accommodate the introduction of the mechanical harvester.
8. An information exchange with North Carolina State University regarding their approach to mechanical cabbage harvesting is needed to establish a comparative evaluation of the two approaches.
9. The machine should be tested on cabbage treated with gibberillic acid. This acid increased the stem length in previous tests. Probably, plowing can be eliminated and still a good grip on the stem is available.

BIBLIOGRAPHY

1. *Agricultural Statistics*, 1960. USDA.

2. Pincock, M. G. "Costs and Returns in Producing Processing Cabbage," Department of Agricultural Economics, Cornell University, 1958.

3. Stout, B. A. Report on Project 651 - Basic Principles of Harvesting. Part III - Cabbage Harvester. For 1961 Agricultural Experiment Station, Michigan State University.

4. Dixon and Massey. *Introduction to Statistical Analysis*. New York: McGraw-Hill Book Company, 1957.

APPENDIX

APPENDIX I

TABLE I

Alignment of Roots Measured at Michigan State University Horticulture Farm

Head No.	Distance to thread (in.)				
	Test 1 9-27-62	Test 2 9-27-62	Test 3 9-28-62	Test 4 10-7-62	Test 5 10-7-62
1	17	17	19	20	20
2	18	19	20	19.5	18
3	18	17.5	19	20	21
4	18.5	18	20	20.5	24
5	17.5	17	20	22	21
6	19.5	20	20	19	22
7	19	17	20	19	23
8	19	19.5	20	20	23
9	19.5	17	21	18	22
10	19	17	22	19	21
11	19.5	17.5	20	19	22
12	20	15	20.5	19	24
13	19.5	16	20.5	22	24
14	20	19	21	18.5	23
15	18.5	20	20	22	23
16	16.5	15	20.5	19	22
17	19	18	20.5	19	22
18	19	15	21	19.5	22.5
19	19	17	21	19	22
20	20	21	20	19	24
21	21.5	20	20	21	22
22	20	18	20	18	24
23	19	19	20	19	22
24	19	18	20	20	23
25	19.5	19	20	21	21
26	19	18	20	18.5	23
27	17.5	17	20	21	20
28	18	16	20	19	23
29	18	19	18	20	--
30	19	16	--	19	20
31	18	19	--	18.5	--
32	18	20	--	--	19
33	18	20	--	--	19
34	16.5	22	--	--	20
35	17.5	20	--	--	20

TABLE II

Alignment of Cabbage Heads Measured at Michigan State University Horticulture Farm

Head No.	Distance to thread (in.)				
	Test 1 9-27-62	Test 2 9-27-62	Test 3 9-28-62	Test 4 10-7-62	Test 5 10-7-62
1	17	22	18	22	19
2	18	17	18	22	17
3	19	17	17	24	20
4	18	15	17	24	25
5	17.5	16	14	25	20
6	19	19	14	22	21
7	19	17	17	22	23
8	19	20	16	24	25
9	17	18	20	21	18
10	17	20	21	21	16
11	19	14	15	21	22
12	19	18	16	22	25
13	20	17	16	25	26
14	19	16	18	21	22
15	18	20	14	26	22
16	15	24	17	21	22
17	18	15	17	20	22
18	19	17	19	22	21
19	18	15	19	22	21
20	19.5	18	18	22	22
21	22	24	20	24	20
22	20	20	17	19	24
23	17	21	21	21	19
24	19	19	19	22	21
25	19	20	18	22	19
26	19	20	19	19	22
27	17.5	15	16	27	17
28	18	18	20	21	24
29	18	20	17	22	--
30	19	17	--	19	19
31	18	20	--	22	--
32	18	20	--	--	15
33	18	20	--	--	18
34	16	23	--	--	18
35	17.5	20	--	--	18

TABLE III

Physical Measurements Made on Cabbage at Michigan State University Horticulture Farm on 10-7-62

Head No.	Head Size (in)		Root Dia. (in)		Stem Length (in)	
	Test 1	Test 2	Test 1	Test 2	Test 1	Test 2
1	9	9	0.9	0.9	2.5	2.1
2	7.5	9.5	0.8	1.0	2.7	2.1
3	7	9	0.8	1.2	2.5	2.9
4	8.5	10	0.9	1.1	2.9	2.3
5	9	7.5	0.9	1.2	3	2.7
6	7.5	9.5	0.8	1.0	2.9	2.6
7	8	9.5	0.9	1.0	2.7	2.6
8	8.5	9	0.9	1.0	2.8	2.5
9	9	7	1.0	1.2	2.5	2.5
10	9.5	9.5	0.9	1.1	2.7	2.7
11	8.5	8	1.0	1.0	2.6	2.8
12	9	6	0.9	1.1	2.5	2.9
13	7.5	7	1.0	1.1	2.5	2.7
14	7	9	1.1	0.9	2.9	3.0
15	9	8.5	1.1	1.0	3.6	2.7
16	8	8.5	1.0	1.1	2.4	2.5
17	11.5	8	1.2	1.0	2.5	2.6
18	9	10	1.0	1.1	2.5	1.8
19	8	6	1.1	0.8	2.5	2.2
20	9.5	11.5	1.1	1.0	2.4	2.0
21	9	8	0.9	0.8	2.8	4.0
22	9	10	0.9	1.1	2.6	3.2
23	9	6	0.8	0.9	3.0	3.5
24	8.5	7	0.9	1.0	2.6	2.9
25	7.5	7	1.1	1.0	2.7	3.1
26	8.5	7	1.0	0.9	2.6	2.2
27	9.5	6	0.8	0.7	3.1	3
28	9.5	7.5	1.0	0.9	2.7	2.7
29	9	9.5	1.0	0.9	2.9	2.5
30	7	7.5	0.9	1.2	3.5	1.5
31	8.5	7.5	0.9	0.6	2.8	3.1
32	--	7.5	--	0.7	--	3.2
33	--	7.5	--	0.7	--	3.4

TABLE IVa

Physical Measurements Made on Cabbage at Michigan State University Horticulture Farm on 10-7-62

Head No.	Pulling Force (lb)		Gross	Net Head			Root		Leaves	
	Vert.	Horz.	Wt. (lb)	Dia. (in)	Wt. (lb)	Wt. %	Wt. (lb)	Wt. %	Wt. (lb)	Wt. %
1	70	--	10	9	6.5	65	.75	7.5	2.7	27
2	--	45	6.5	7.5	4.5	69	.5	7.7	1.5	23
3	56	--	6.7	7	4.5	67	.6	9.0	1.6	22
4	--	88	9.0	8.5	5.5	61	.6	6.7	2.9	32
5	62	--	10.4	9	6.3	61	.8	7.7	3.3	31
6	--	90	7.5	7.5	4.5	60	.5	6.7	2.5	33
7	70	--	9.8	8	5.9	60	.6	6.1	3.3	34
8	--	74	9.0	8.5	6.0	67	.6	6.7	2.4	26
9	60	--	8.7	9	5.6	64	.6	6.9	2.5	29
10	--	110	9.5	9.5	7.0	74	.6	6.3	1.9	20
11	72	--	9.0	8.5	6.0	67	.6	6.7	2.4	26
12	--	65	9.0	9	6.0	67	.6	6.7	2.4	26
13	90	--	9.0	7.5	6.0	67	.6	6.7	2.4	26
14	--	102	8.2	7	4.5	55	.6	7.3	3.1	38
15	87	--	13.2	9	9.1	69	.95	10.5	4.1	21
16	--	76	7.5	8	5.0	67	.8	10.6	1.7	23
17	92	--	13.0	11.5	9.0	69	.9	6.9	3.1	24
18	--	92	8.2	9	5.6	68	.7	8.5	1.9	23
19	70	--	8.8	8	5.8	66	.7	8.0	2.3	26
20	--	90	9.1	9.5	6.1	67	.7	7.7	2.3	25
21	62	--	9.5	9	6.2	65	.75	7.9	2.5	27
22	--	82	8.1	9	5.5	68	.75	9.3	1.8	23
23	94	--	11.3	9	6.3	58	.8	8.9	4.2	35
24	--	80	9.1	8.5	6.1	67	.7	7.7	2.3	25
25	60	--	8.1	7.5	4.6	57	.6	7.4	3.0	35
26	--	112	8.5	8.5	5.7	67	.9	10.6	1.9	22
27	77	--	11.5	9.5	7.5	66	1.1	9.6	2.9	24
28	--	87	10.0	9.5	6.1	61	.8	8.0	3.1	31
29	66	--	10.2	9	7.1	70	.9	8.9	2.2	21
30	--	74	8.5	7	4.7	55	.6	7.7	3.2	37
31	86	--	9.9	8.5	6.0	61	.8	8.0	3.1	31

TABLE IVb

Physical Measurements Made on Cabbage at Michigan State University Horticulture Farm on 10-7-62

Head No.	Pulling Force (lb)		Gross	Net Head			Root		Leaves	
	Vert.	Horz.	Wt. (lb)	Dia. (in)	Wt. (lb)	Wt. %	Wt. (lb)	Wt. %	Wt. (lb)	Wt. %
1	--	65	9.4	9	5.1	54	0.7	7.5	3.6	38
2	73	--	10.2	9.5	7.8	76	0.9	8.8	1.5	15
3	--	60	8.2	9	4.7	57	0.7	8.5	3.8	34
4	68	--	10.4	10	7.6	73	1.2	11.5	1.6	16
5	--	62	7.1	7.5	4.9	69	0.7	9.8	1.5	21
6	74	--	10.4	9.5	7.6	73	0.9	8.7	1.9	18
7	--	56	7.2	9.5	4.2	58	0.7	9.8	2.3	32
8	52	--	8.7	9	5.5	63	0.6	6.9	2.6	30
9	--	74	8.0	7	4.5	56	0.6	7.5	2.9	36
10	50	--	9.2	9.5	5.7	62	0.7	7.6	2.8	30
11	--	90	8.2	8	5.5	67	0.6	7.3	2.1	30
12	40	--	7.5	6	5.0	67	0.6	8.0	1.9	25
13	--	56	7.1	7	4.0	56	0.6	8.5	2.5	35
14	78	--	9.4	9	7.8	83	0.7	7.5	0.9	9
15	--	42	9.2	8.5	5.2	57	0.6	6.5	3.4	36
16	61	--	9.0	8.5	6.1	68	0.9	10	2.0	22
17	--	70	8.1	8	5.1	63	0.6	7.4	2.4	29
18	74	--	11.0	10	8.1	74	0.9	8.2	2.0	15
19	--	90	5.1	6	3.6	70	0.4	7.8	1.1	22
20	64	--	11	11.5	7.6	69	0.9	8.2	2.5	22
21	--	100	4.5	8	3.5	78	0.5	11.0	0.5	11
22	58	--	11.5	10	7.5	68	1.1	9.6	2.9	22
23	--	66	4.7	6	2.7	58	0.7	15.0	1.3	27
24	54	--	7.5	7	4.5	60	0.8	10.7	2.3	29
25	--	64	6.1	7	4.2	69	0.7	11.5	1.2	19
26	52	--	8.0	7	4.7	59	0.6	7.5	2.7	33
27	--	44	5.3	6	3.1	58	0.6	11.3	1.6	30
28	54	--	7.1	7.5	5.1	72	0.6	8.5	1.4	19
29	--	55	5.6	7.5	4.0	71	0.5	8.9	1.1	20
30	54	--	12.1	9.5	7.1	59	0.8	6.6	4.2	34
31	--	53	5.8	7.5	4.1	71	0.5	8.6	1.2	20
32	35	--	7.2	7.5	4.3	60	0.6	8.3	2.3	31

APPENDIX II

I. Tests on Lifting Device

Test (1), June 11, 1962

The first test of a series of four preliminary tests was conducted to illustrate the problem. Two flat plates about three-feet long each, inclined 15^{o} from the vertical and 10^{o} from the direction of travel and separated by six inches at the back lower corner, were used to lift the cabbage. Large quantities of soil were accumulated at the throat between the plates which completely choked the flow of cabbage. The belts were running directly on the ground.

Test (2), June 12, 1962

The above plates were curved and their rear-lower quarter removed to allow the accumulated soil to escape. They were not satisfactory because the leading edge did not follow the surface but dug into the soil. When the counter-balancing spring was tightened the leading end ran high above the ground and into the heads. The heads that escaped the blades were caught in the accumulated soil and their stems were broken.

Test (3), June 12, 1962

A pair of small plates covering the belt sheaves with a small sliding area was tested. They were not strong enough to support the lifter assembly weight and dug into the ground. The cabbage was pushed ahead and the stem was broken.

Test (4), June 13, 1962

The curved shoes of the previous season (Figure 2) were placed on the machine and demonstrated for the Scott Viner personnel. They were no better than the above plates.

Test (5), June 18, 1962

A pair of small moldboard plows was placed in front of the sheaves (Figure 7) to push the soil aside and provide a furrow for the V-belts to operate in. A two-foot inclined bar extended over each plow to align the cabbage, raise them from the ground, and orient them toward the V-belts. The device failed as there was nothing to support the lifter assembly weight. The plows dug deep into the ground and pushed the soil and cabbage ahead of the machine.

Test (6), June 21, 1962

Two large curved plates were mounted on two large slides (as those shown in Figure 8). The plates aligned the cabbage but the inner edge was too high and pulled them from the ground. The gap between the plates was comparatively wide and caused some side wedging of cabbage which increased the frictional forces between the plates and cabbage and pushed the plant ahead. Less soil and trash accumulation was noted.

Test (7), June 25, 1962

The same device used in the previous test was used again but with some modifications (Figure 8). The plates were lowered relative to the sheaves such that the inner edge

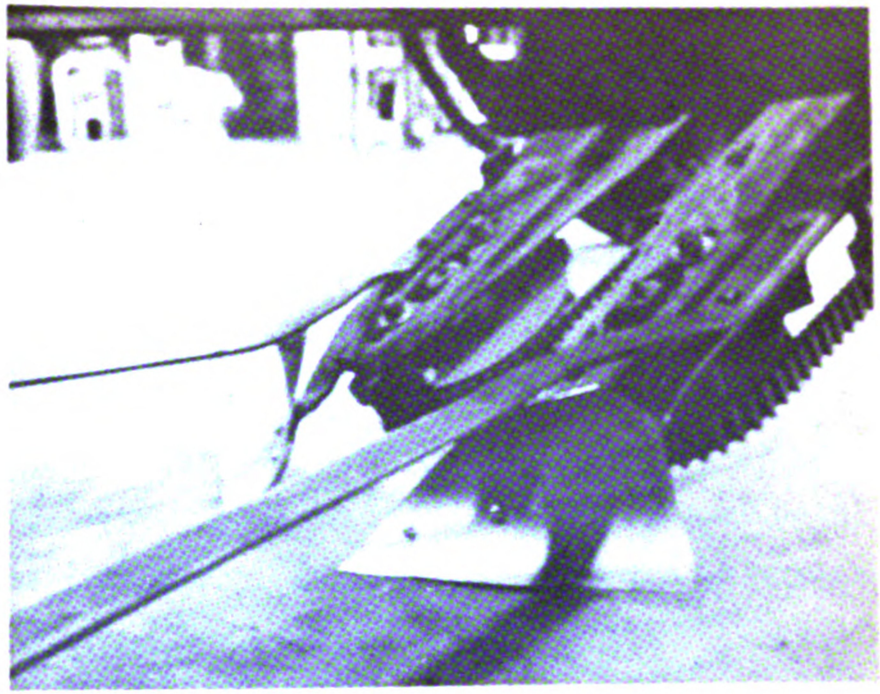


Fig. 7. Lifter shoes of test (5) showing plows and gathering bars.

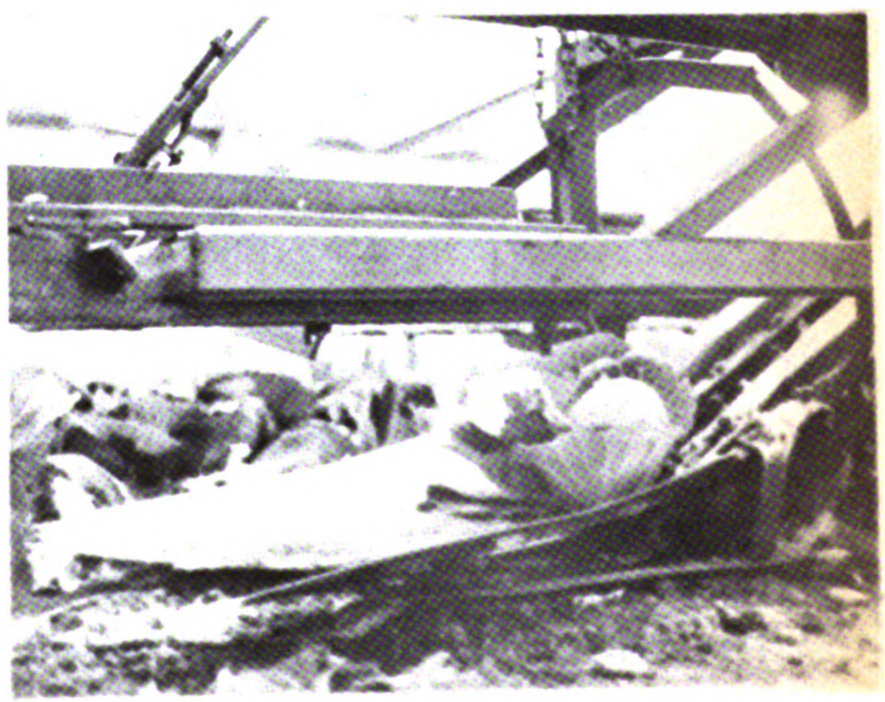


Fig. 8. Lifter shoes of test (7) showing slides and curved shields

touched the ground at the front and was not higher than two inches at the rear. The gap between the plates was reduced to four inches at the front and three inches at the rear. The performance was very promising with no soil accumulation. The cabbage flowed smoothly to the V-belts and was lifted uniformly. Some plants, however, were small and not sufficiently anchored in the ground or had relatively short stems which caused them to be pulled from the ground before being caught by the belts. When the plants had an additional help by hand to keep them in place, the machine was able to harvest a 40-foot row without stoppages.

Test (8), June 27, 1962

This test was to find out whether a pair of slides eliminating the problem of soil accumulation was sufficient as a basis for a picking device. Two slides very close to the bottom face of the sheaves and bent from the front to shield them were tested. They completely eliminated the soil problem and the belts ran clean on plain soil. However, they failed to gather cabbage and it was struck by the assembly and pushed ahead of the machine. A streamlined deflector proved to be necessary.

Test (9), June 28, 1962

The slides of the previous test were kept on the machine. New flat plates, curved to smoothly deflect cabbage up the lifter assembly (Figure 9) were mounted on the assembly lower end. They also protected the sheaves from

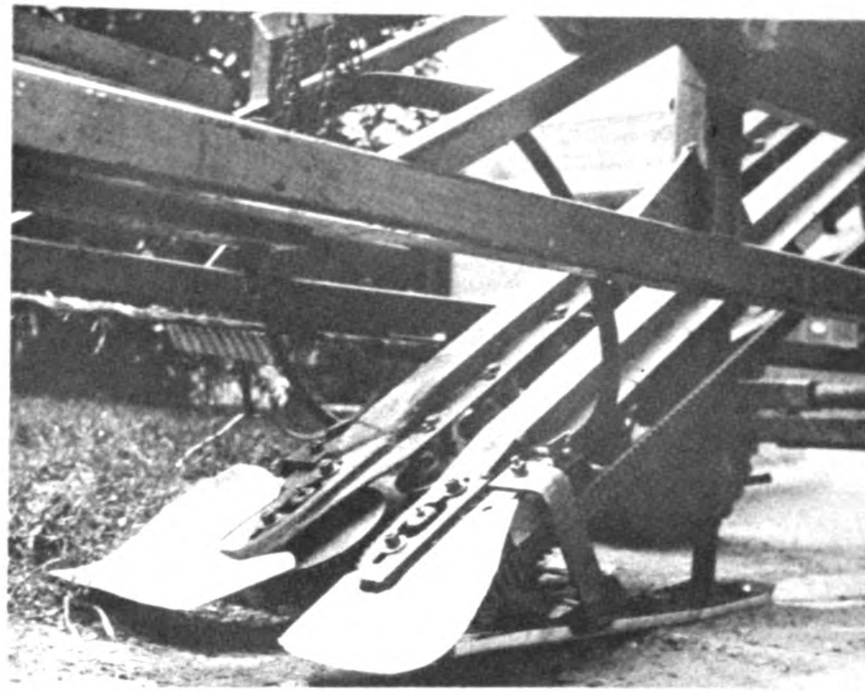
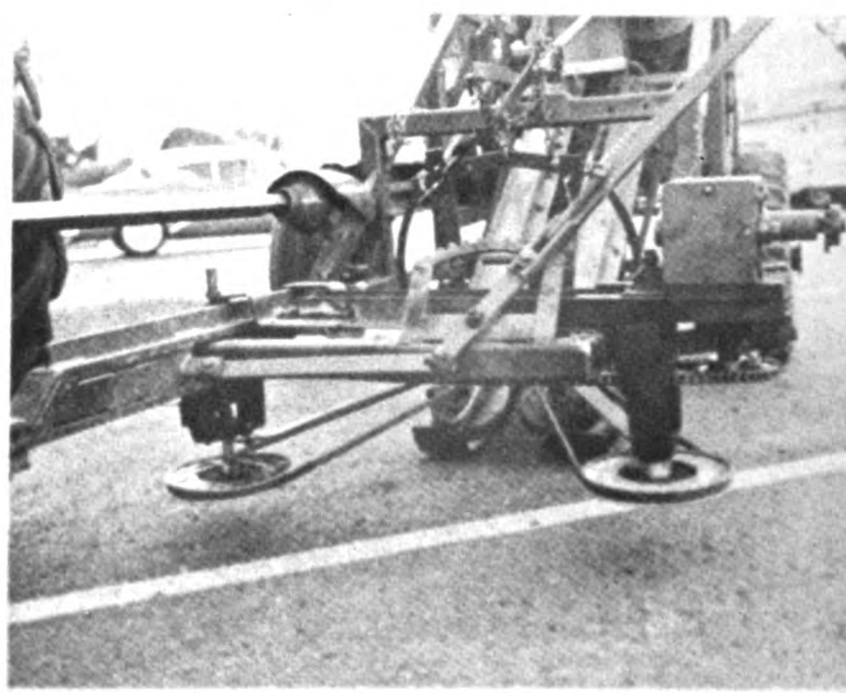


Fig. 9. Lifter shoes of test (9) showing slides and curved plates.



[illegible] (13)

soil. The device was partially successful. It lifted cabbage continuously without any external help and did not accumulate much soil. However, each head was pulled from the ground, pushed ahead until it struck the next head, and was forced into the throat, then it was gripped by the lifter V-belts. It seemed that some modification of the profile might help.

Test (10), June 29, 1962

The same plates were used, but the gap in between was increased to give the lifter V-belts a better chance of gripping the stem before the plant would be pushed. The plate size was reduced and the inner edges were lowered. The performance was not better than test (9), but some information on the effect of changing the profile was obtained.

Test (11), July 5, 1962

New plates, similar to those used in Test (9), were constructed with the leading edge more curved and the inner edge lower. The external edge was also curved to give some desirable alignment to the plant. No improvement was noticed in performance and a plate was destroyed when an underground stone was hit.

Test (12), July 13, 1962

Comparatively rigid runner slides were constructed with a built-in simple profile at the front to direct the plant to the lifter V-belts. The area of contact with the ground was increased to 8-inches x 30-inches per slide. The device was unsuccessful and pushed the cabbage with its relatively high leading edge. However, as in Test (8), the soil accumulation was eliminated on plain soil.

Test (13), July 31, 1962

A new approach to the problem was tried with a pair of ground-driven horizontal belts (Figure 10). They were designed to align the plant and feed it to the lifter V-belts. Each was set at 22.5° angle with the direction of travel and had a velocity component along this direction equal to 1.02 times the ground speed. Their rear sheaves were spring loaded to hold the cabbage with a proper force and feed it to the lifter belts. The belts were tightened by a system of links, allowing a small swing to accommodate differences in cabbage size and alignment. The link carrying the rear sheave was hinged close to the shaft of the driving front sheave and to the lifting mechanism of the lifter assembly. It was not directly connected to the lifter assembly in order to provide an escape for any leaves of the plant that might get under the gathering belt. Since it was hinged to the lifting mechanism, it closely followed the contours of the ground and it was automatically raised clear of the ground with the lifter assembly when not in operation.

The device did not work properly due to some mechanical troubles, slack chains jumping over sprockets, and insufficient belt speed. The height of the horizontal chain was too low; it hit the tops of the large unharvested cabbage. The spring loading of the rear sheave was not sufficient.

Cabbage was still pushed by the machine and even by the gathering device. No soil problem was noted as the slides of previous tests were used and no cabbage leaves reached the lifter assembly to start soil accumulation.

Test (14), August 2, 1962

The above device was tested again after checking the mechanical troubles. On-the-spot adjustments were made concerning the geometry of links, the angles of belts, the spring force at the rear idle sheave, etc. No improvement, however, was noted in the performance of the device over the last test results. It seemed that holding the plant by the side to feed it to the lifting V-belts was not the right approach since the outer leaves were involved. Some other holding place should be tried, such as the top of the plant or the stem. The gathering belts were a failure.

Test (15), August 8, 1962

A new strong pair of shields was formed from 1/8-inch steel plating (Figure 11). They worked on a principle close to that of the plates used in Tests (9), (10), and (11). However, the shields had a considerable curvature at the external side to collect the plant and orient it to the lifting V-belts. The inner rear surface was curved inwards for the same objective. The runner slides of Test (12) were kept on the machine. The device did not work at all and failed to pick one head of cabbage. It pushed cabbage ahead and accumulated a mass of cabbage and soil.

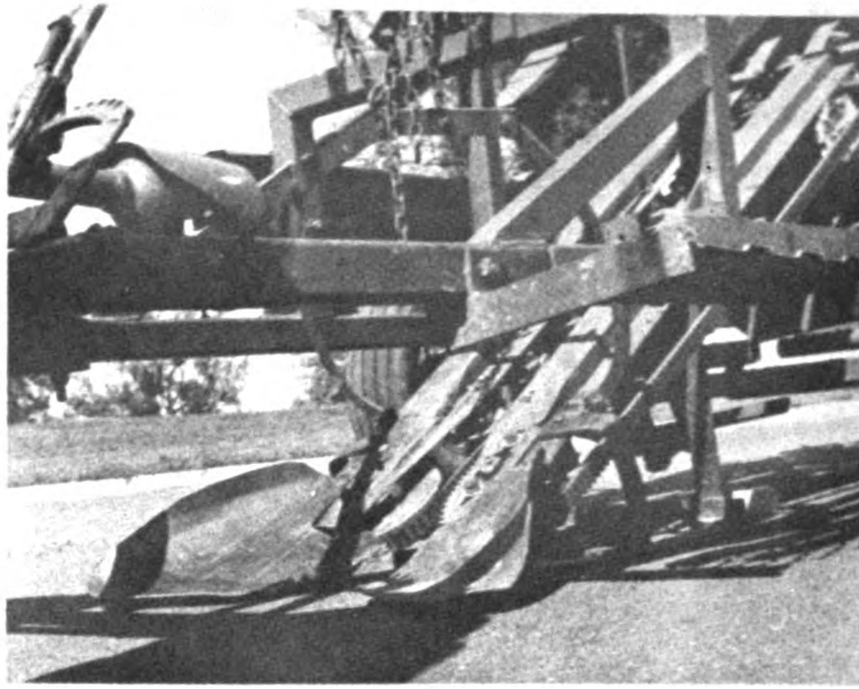
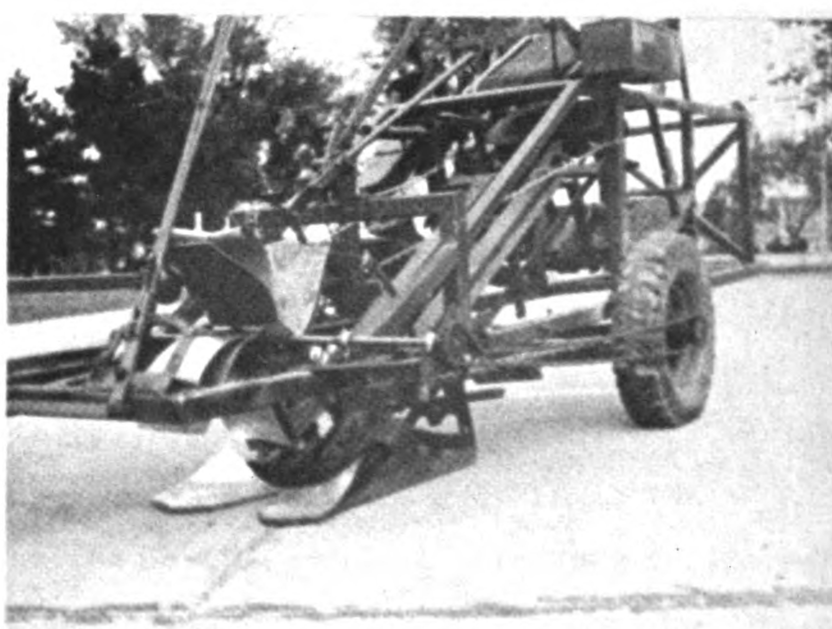


Fig. 11. Lifter shoes of test (15) showing slides and the strong shields.



[illegible]

Test (16), August 9, 1962

The same device used in Test (7) was again mounted to evaluate the effect of the new variety of large cabbage heads upon the design of lifter shoes. Cabbage was larger, heavier, more scattered, and with longer and thicker roots. At 1.5 mph, the device worked equally well if not better than in Test (7). No manual help was required to keep cabbage in place as this variety was more strongly anchored in the ground and had longer stems than earlier varieties. Steering was necessary since the heads were scattered and the gap between the plates at the front was narrow. Whenever the lifter V-belts failed to hold a cabbage plant, a mass of pushed cabbage and soil developed. Positive feeding was definitely needed.

Test (17), August 15, 1962

A new, strong pair of shields and runner slides was constructed and mounted on the lifter assembly (Figure 12). The inner sharp edge was eliminated and the curved edge was made. The shield profile was constructed close and nearly parallel to the ground to avoid raising the heads. A 1/8-inch steel plating reinforcement was placed at the front edge and welded to the rugged frame of the shoe to withstand any possible shock. The shoes worked as well as the previous device at the same speed, but with much less steering trouble.

Test (18), September 6, 1962

The same device of previous test was tested at a 2.5 mph traveling speed. It performed similarly, but the V-belts failed more frequently to grip a plant. When this happened, a mass of cabbage and soil developed. The seriousness of the problem increased as the speed increased. A positive powered picking device was clearly needed.

Test (19), September 11, 1962

A ground-driven paddle wheel was constructed (Figure 12) and the shoes of the previous two tests were kept on the machine. The paddle was built from 1/16-inch galvanized steel plating and was faced with longer rubber pieces to prevent bruising of cabbage. The steel blades were curved forward to facilitate "meshing" between the heads. The wheel width was ten inches and the outer edges were bent to eliminate sharp edges, thus providing a sufficiently wide and safe approach to the cabbage. The paddle was also protected by a slip clutch which was released when the tangential force at the blade tip exceeded twelve pounds. The paddle, as a whole, could be described as being flexible enough to handle small variations in working conditions.

The design parameters of the paddle were: cabbage height, plant spacing in row, diameter, and applied force. They were estimated, as an average, to be ten inches, eighteen inches, ten inches, and twelve pounds, respectively. Four blades seemed to be a reasonable number; they would not obstruct cabbage motion when gripped and lifted by the V-belts and travelled at a much higher speed.

The paddle wheel diameter was chosen as 24-inches and the rubber facing diameter as 30 inches. The circumferential distance between two successive blades, 18.8 inches, was longer than the average plant spacing of the cabbage and, of course, provided enough room for one plant. The paddle/ ground speed ratio was made 1.11; the machine travel per quarter turn of paddle was 17 inches. This was slightly less than the average plant spacing (pitch) to push the cabbage and feed it to the lifter V-belts. The paddle shaft, located at 18 inches high from ground level, placed the lowest point of the paddle circle 6 inches above the ground level. This provided a quasi-horizontal force to the plant as it passed close to the head center.

The device performed satisfactorily in the test. It kept the heads in place and forced them into the V-belts. However, the paddle seemed to rotate at a too low a speed and the 12-pound releasing force of the clutch was insufficient. Besides, trouble was encountered with the variety of cabbage which grew small auxiliary heads at ground level in addition to the main head. (No one, of course, would expect the lifter belts to be able to grip such a plant.)

Test (20), September 12, 1962

The same paddle was used with some modifications. The clutch releasing force at blade tip was increased to 25 pounds. The steel blade diameter was increased from 24 to 26 inches. Thus the distance between two successive blades was increased from 18.8 inches to 20.4 inches, and the level of force application was lowered from six to five inches high above the ground. The results were very promising; four rows of cabbage 60 feet long each, totalling about 140 heads, were successfully harvested.

The cabbage head and a little amount of soil, however, were pushed slightly ahead of the lifter assembly until the head hit against the next one. Then the plant, which had been raised slightly above its original position, had enough support from the next head and the paddle to force it into the throat of the lifter belts and was thus harvested. This process was continuously repeated, but in the extreme cases the head actually flowed on soil, turned upside down, and came over the top of the lifter belts. In these cases the lifter belts could not grasp the root and the machine was blocked.

Root removing problem was noted for the first time as sufficient flow of harvested plants came up to the trimming knives. The cut-off roots accumulated very rapidly on the machine platform and had to be removed after every row. Some plans to solve the problem were considered and will be discussed later on.

Test (21), September 17, 1962

The above device was tested again, the sliding runners were inclined 5^{o} with the horizontal to give them some sweeping action to prevent soil accumulation. The test was conducted at a higher speed. Trash and soil accumulation problems were not solved; on the contary, they developed with higher speed until they clogged the lifting device. The paddle rode against the incoming block of cabbage heads and was bent inward.

It seemed that the problem of feeding the cabbage into the V-belts could be solved if the trash and soil problem was eliminated. The first test on root removing was also conducted, as will be discussed later.

Test (22), September 21, 1962

New types of runner slides and gathering devices were built (Figure 13). The slides were made from 1/8-inch steel plating and curved at the front to completely protect the sheaves. Moreover, they were completely separate to provide an unobstructed, upward passage for the roots. The gathering device consisted of a pair of triangular loops made of one-inch steel tubing. Their inner overhanging part raised the cabbage to the level of the lifter belts. The loop provided a reasonable solution for soil accumulation in case it might develop as soil would be dropped through the loop to the ground and the slides could easily move over that soil. Sharp edges were completely eliminated. A new, much stronger, ground-driven paddle wheel was constructed from 1/4 x 1-1/2-inch steel sections and 1-inch tubing at the outer side. It had the same dimensions of the previous wheel and was driven at the same speed; besides, the outer tube was curved in the tangential plane to help align the heads. The rubber facing was used, but it was reduced in length. No slip clutch was

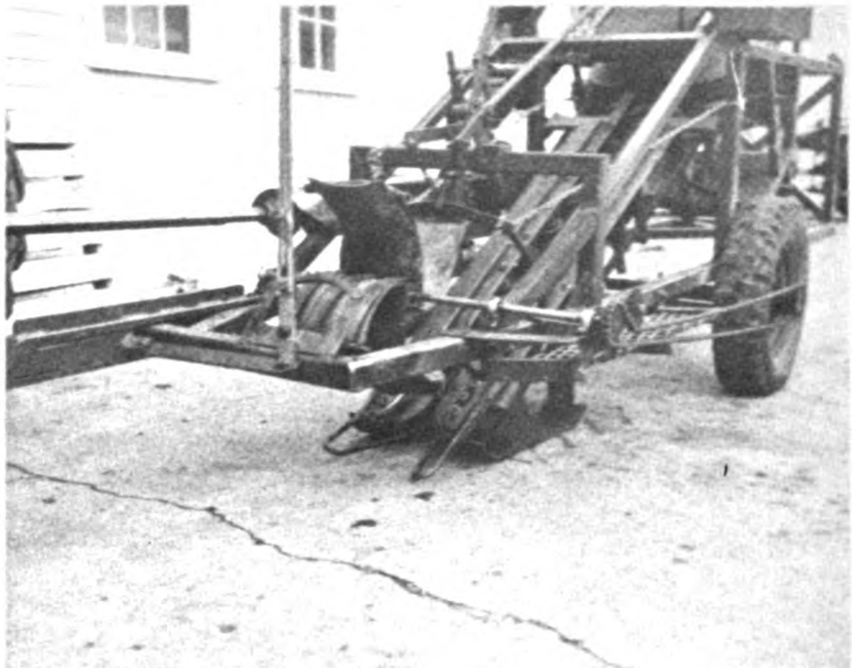
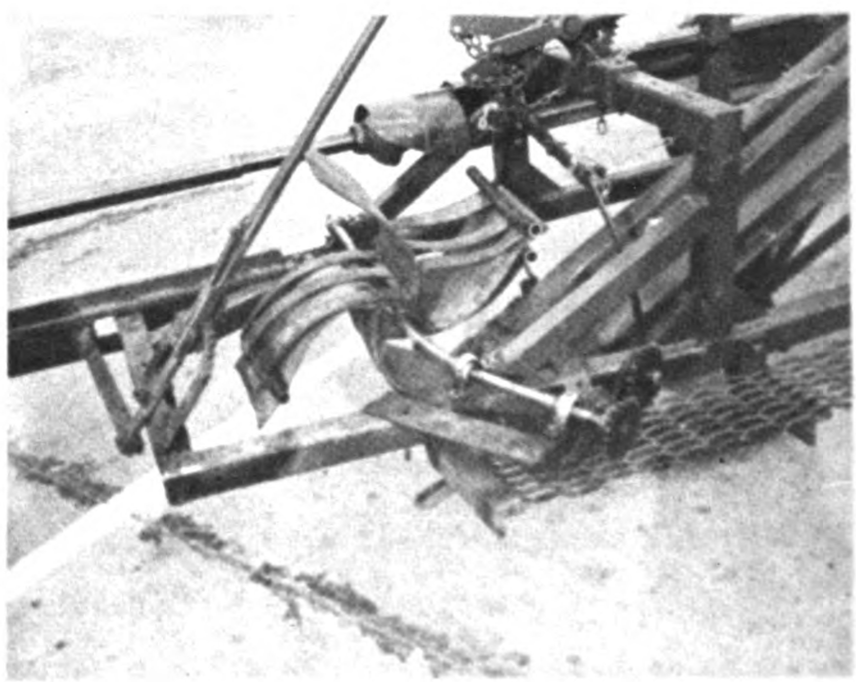


Fig. 13. The lifter shoes and paddle wheel [illegible] test (22).



[illegible]

used with this wheel.

The slides and gathering loops did a good job when tested on plain soil. No soil accumulation developed, but when the machine was tested on cabbage, the paddle worked very roughly without the slip clutch and was damaged when some heads accumulated in front of the lifter assembly (Figure 14).

The gap between the lifter-belts at the throat of the lower sheaves seemed to be insufficient to allow the roots to pass in to the throat and be lifted.

Test (23), September 25, 1962

The paddle wheel was repaired and mounted on a new shaft and bearings. The slip clutch was also used and adjusted to slip at 35-pounds tangential force at the blade tip. The gap at the throat between the lower sheaves of the lifter belts was increased to 1-1/4 inches. In the test, the machine worked more satisfactorily with much less soil accumulation and harvested three rows. A new after-lifting trouble was noticed when the lifter assembly cut into the bottom of the cabbage heads. Moreover, the paddle seemed to move too slowly.

Test (24), September 26, 1962

The machine was tested with the same shoes and paddle, but the clutch releasing force was increased to 45 pounds. The paddle/ground speed ratio was increased from 1.2 to 1.4. Two steel shields were also welded to the lifter assembly to prevent the sharp edges from cutting into the cabbage by providing a curved guide sloping slightly upward to raise the cabbage (Figure 20).

The machine performed equally as well as in previous test (Figure 15). The protecting curved shields did a good job since no cutting of cabbage was noticed. However, the paddle wheel ran too fast and could not uniformly accommodate the plant pitch. Apparently its speed was too fast. Another after-lifting trouble in the machine was detected. One of the V-belts was moving faster than the other which caused the slower belt to buckle in various places and thus it released the cabbage. Speed difference was believed to be due to an accumulation of dirt on the driving sheaves that apparently changed their effective pitch circle diameters.

Test (25), September 27, 1962

A new lifting defice was built, an overhead floating rubber tire with a concave surface (Figure 16). It was ground-driven at a 1.23 tire/ground speed ratio. It was hoped that the tire would support the heads as the paddle wheel did, but eliminate the "meshing" problem of the paddle. New gathering points, made of curved steel tubing, were used instead of the triangular loops. The lifter V-belts driving sheaves were also cleaned to prevent the belts from buckling.

In the test, the tire failed to feed the heads into the V-belts, instead, it pushed them ahead (Figure 16). The new gathering points could not be evaluated, and the lifter belts did not buckle again.

Fig. 15. The cabbage harvester during operation showing the paddle wheel.

Fig. 16. Floating rubber tire to help lift the cabbage (test 23).

Test (26), September 26, 1962

The above device was used again, the tire rubber surface was covered with high-friction conveyor material to increase the frictional force applied to cabbage. The tire/ground speed ratio was tested at 1.05, 1.25, and 1.8 values. In spite of all possible adjustments made on the machine elements, the device failed to pick one head. The new gathering points accumulated more trash and soil and failed to give any better results.

Test (27), October 2, 1962

A small, four-blade, 23-inch diameter, rigid paddle wheel was mounted in place of the tire (Figure 17). It was ground-driven at 1.06 paddle/ground speed ratio. The gathering points of Test (22) were remounted. The machine performance, after many trials and adjustments, was comparable to Tests (20) and (21), although it missed a head of cabbage more frequently.

Test (28), October 5, 1962

The rubber-lined paddle wheel of Test (21) was mounted on a floating suspension (Figure 18). Some changes in the frame were made to fit the new modifications. The paddle was ground-driven at 1.04 paddle/ground speed ratio. The clutch releasing force was adjusted to 40 pounds.

The machine performance in the test was not as good as was expected. The paddle/ground speed ratio was apparently too low and probably the new variety of cabbage was heavier heads and thicker and shorter roots affected the performance.

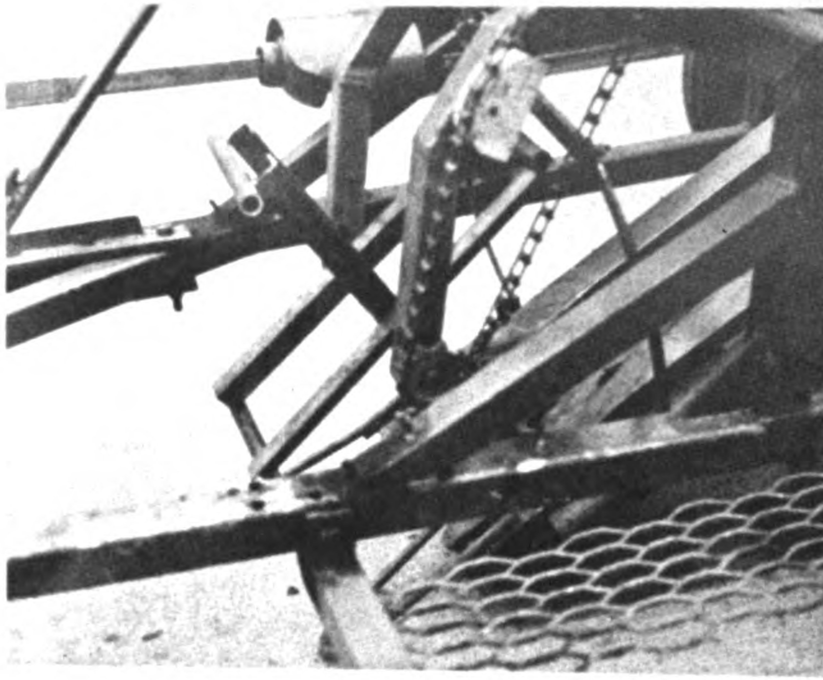


Fig. 17. Floating rigid paddle (test 27).

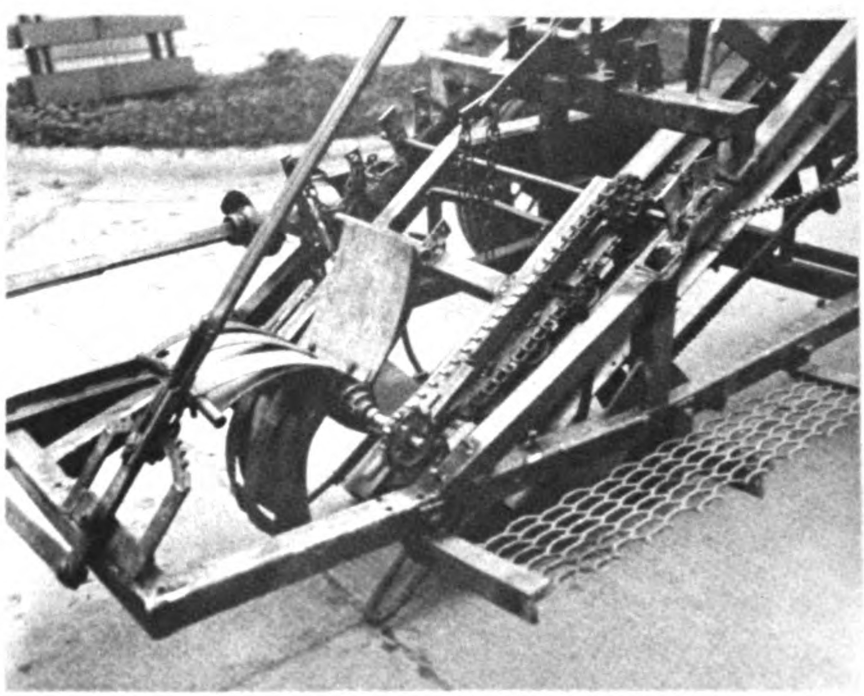


Fig. 18. Floating flexible paddle with slip [illegible] and rubber lining (test [illegible]).

Test (29), October 9, 1962

A new type of sliding runners was built with a small plow located at the front to plow the soil aside to provide a passageway for the belts. The plants were thus left on a small (2-inch high) ridge. This enabled the belts to grasp and handle short stems (Figure 19). The paddle/ground speed ratio was increased to 1.25. The machine worked quite satisfactorily and harvested five rows without many stoppages. A sixth row was harvested without the paddle wheel and was also harvested with no stoppages. The plowing action to provide a furrow on each side of the ridge where the V-belt could operate seemed promising if the V-belts could stand running in some dirt.

Test (30), October 11, 1962

The left sliding runner was removed and four steel fingers were fixed on the bottom face of the left sheave (Figure 20). They provided positive feed of the cabbage into the V-belts. Although the fingers shook the plant slightly before the V-belts gripped it, the machine performed satisfactorily; in fact, the operation was as good as the best previously obtained results. The new approach of forming a central ridge of soil and cutting a passageway for the sheaves into the soil seemed very promising. Moreover, the steel fingers reduced the ridge width to a minimum and provided positive feeding of the plants. Yet, it should be mentioned that, in few cases, the fingers broke the stem when it was pressed against the other sheave or when the

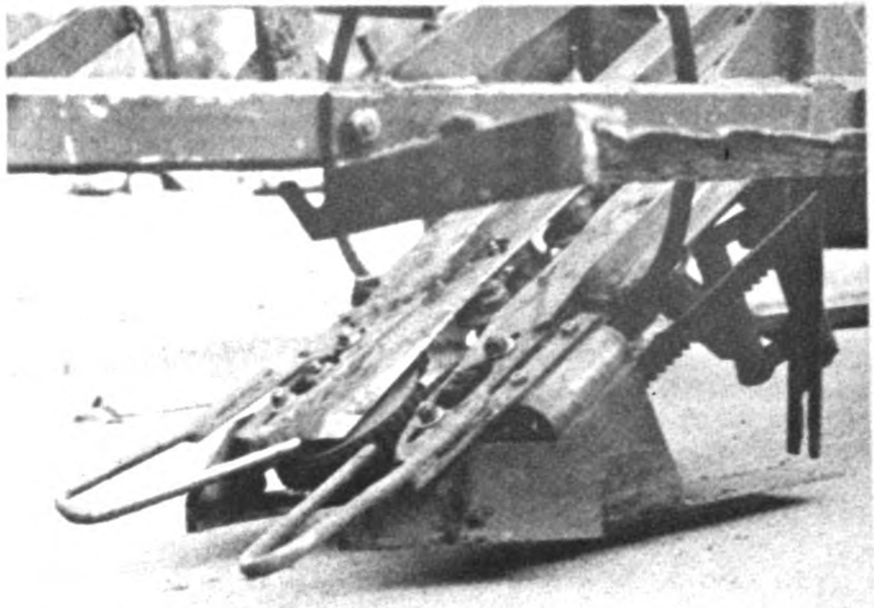
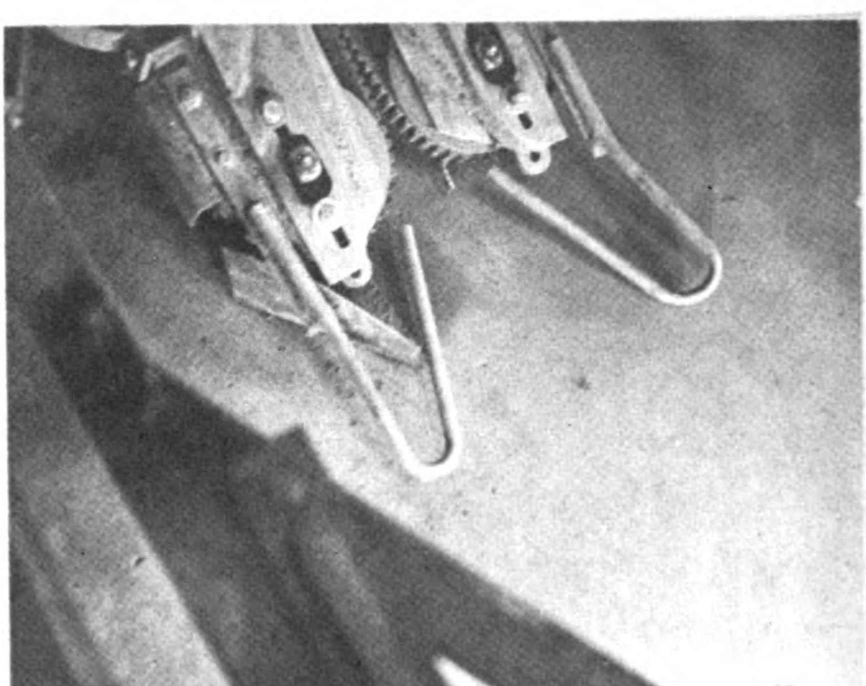


Fig. 1[illegible]. Lifter shoes of test (24) showing the plowing edge.



[illegible]

V-belts failed for one reason or another to grip the plant. Another set of fingers placed on the other sheave at a different level would probably improve the performance. The shape of the fingers and their position on the sheaves should be studied further to improve their action.

Test (31), October 31, 1962

The shoes of test (29) were modified to accommodate the steel fingers of test (30) and another set of fingers were fastened to the upper face of the other sheave (Figure 21). The machine worked very satisfactorily and the shoes were capable of lifting cabbage continuously from a 300-feet row (200 heads). The two sets of sheave fingers worked together to align and feed the cabbage into the V-belts. They were so effective that, when the loop gathering device was removed, the machine performed equally well. The test was conducted at 1.5 mph and precise steering of the machine was required. It was also noticed that the V-belts continuously operated in the soil.

II. Tests on Root Removing, Trimming, and Cleaning Devices

Test (1), September 17, 1962

A simple sheet metal incline was constructed and mounted on the machine below the disc knives (Figure 22). It had two high sides and was inclined 76^{o} with the horizontal to provide a steep, smooth, unobstructed escape passage for the cut-off roots. The device did not work. An unexpected extra period of time was required for the cut root to fall

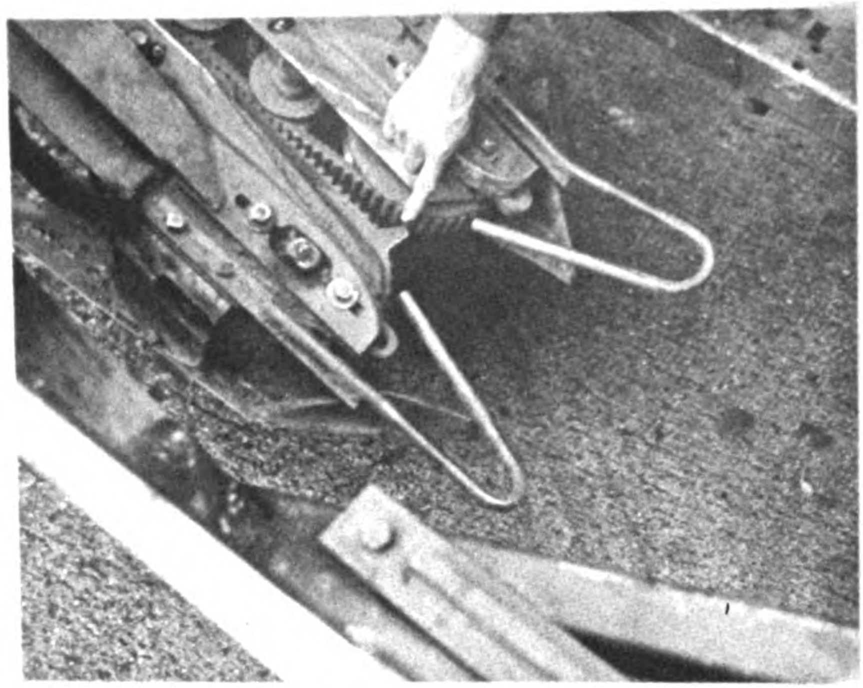


Fig. 21. Lifter shoes of test (31) showing the set of fingers on the top of the right sheave.

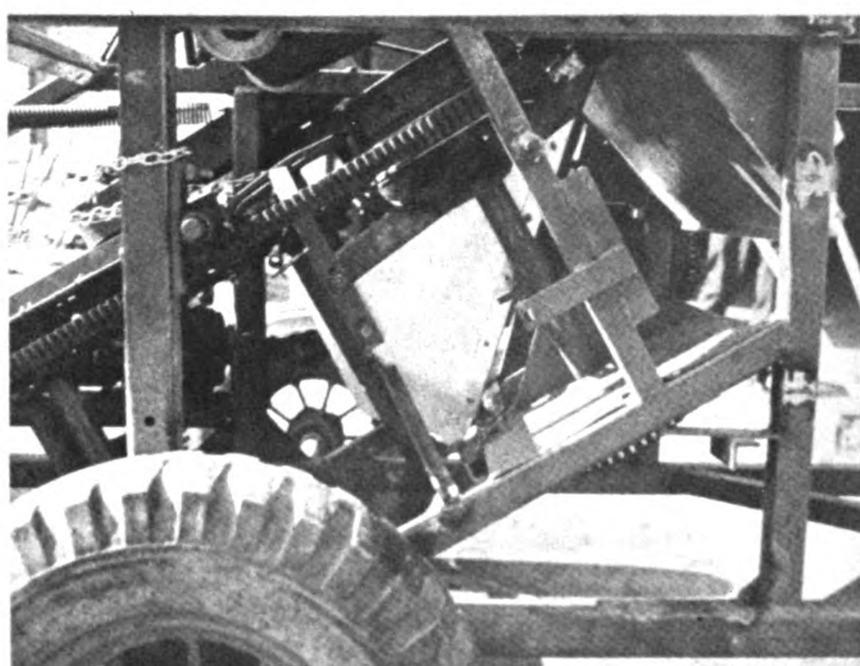


Fig. [illegible]. Sheet metal steep [illegible] [illegible] cut-off [illegible].

out of the way of the new incoming root. The time period required by a cut-off root traveling upwards to come to a stop, reverse its direction and slide down the incline a distance sufficient to provide clear space for a new coming root was less than the time period between cutting two successive roots. A trial was made to change the incline direction backwards. It also failed since, in this case, the angle of inclination was about 30° to the horizontal and the roots stopped and accumulated on the incline after sliding a short distance.

Test (2), September 21, 1962

A 12-inch power-driven paddle wheel was constructed from sheet metal and mounted below and slightly behind the disc knives (Figure 23). The paddle was nine inches wide and had seven partitions making seven compartments each three inches deep. The driving gear of the harvester was modified to energize this paddle. Its peripheral speed was 1.17 times the V-belt's speed. The paddle was designed to accommodate the roots after being cut off, rotate them through a 90° angle, and throw them from its compartments. The induced centrifugal force on the roots held them against a curved deflecting shield (removed from the machine in Figure 23) during their rotation to the proper position where the deflector was terminated, then this force threw them from the paddle compartments to the ground. A lower incline was built to keep the dirt, roots, and trash out of the driving mechanism. The device worked very effectively, but it could

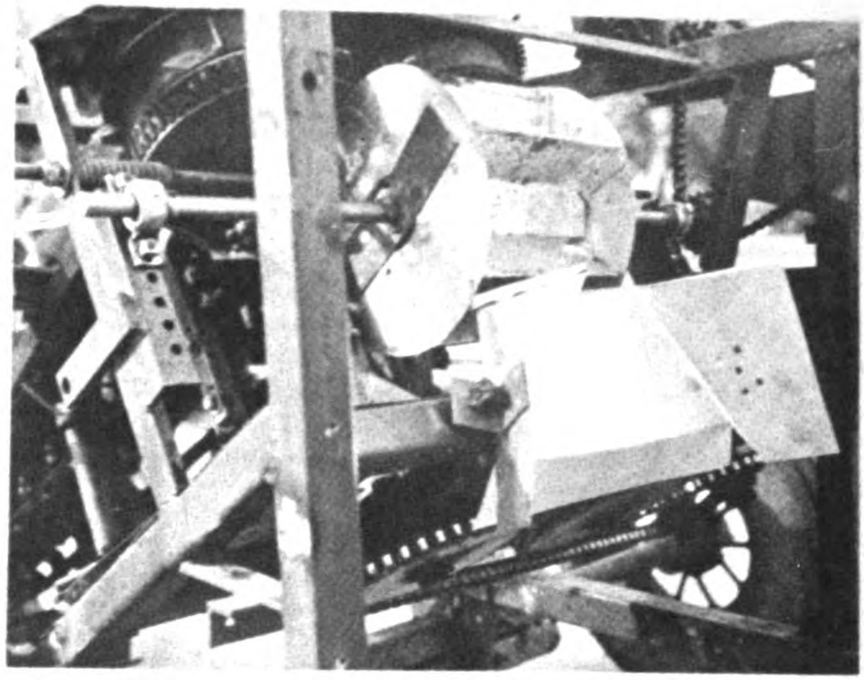


Fig. 23. Root-throwing paddle wheel.

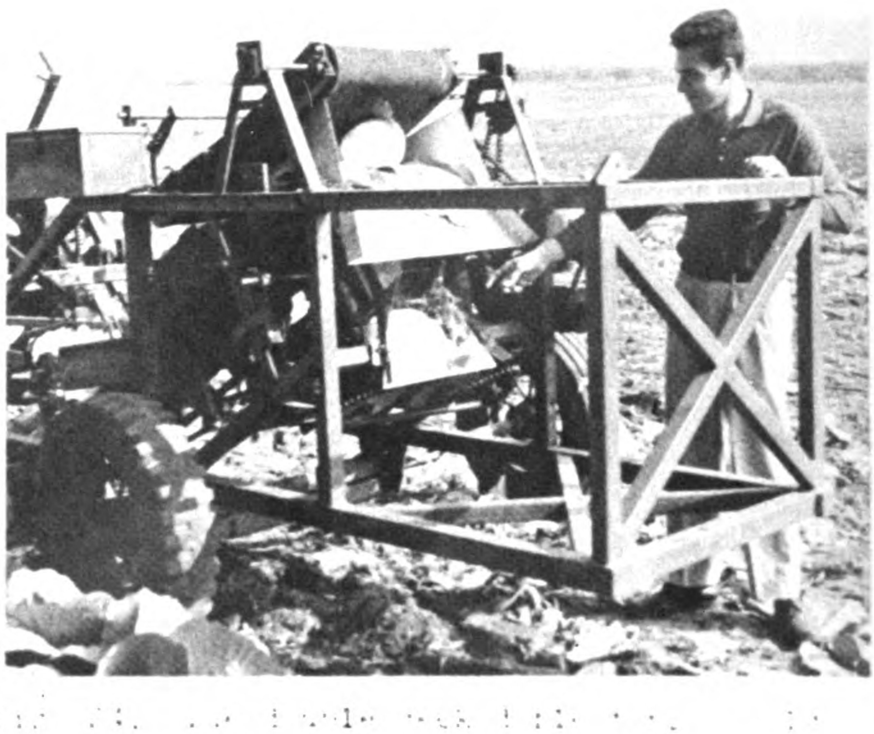


Fig. 24. [illegible]
[illegible]

not handle a continuous flow of roots. The deflecting shield was too close to the paddle at its lower end, thus choking the passage of the roots.

Test (3), September 25, 1962

An upper double-deck deflecting shield was built so that it enclosed the paddle wheel (Figure 24). The shield was a single piece with walls at the upper deck to prevent any loose leaves from falling on the platform protecting the driving mechanism. It had also straight walls around the paddle (Figure 25) to prevent any trash from escaping and falling on the driving gear.

The spring force holding the disc knives against each other was increased to help the knives trim the extra-large heads of the new cabbage varieties. The overhead belt was extended another 12 inches and two rollers were placed at the lower third point of the belt (Figure 25). This provided the belt with a tapered entrance to handle cabbage heads from five to twelve inches size. The change was made as the older construction (Figures 2 and 3) was incapable of handling extra-large heads unless the belt was pre-raised in which case it could not press against small heads. The forward end of the frame was carried by two checker chains at the front to facilitate its up and down motion.

The root removing device performed successfully in this test. Yet, a root failed once to leave a paddle compartment sufficiently fast and caused some damage to the lower deck. No difficulty was encountered in the disc

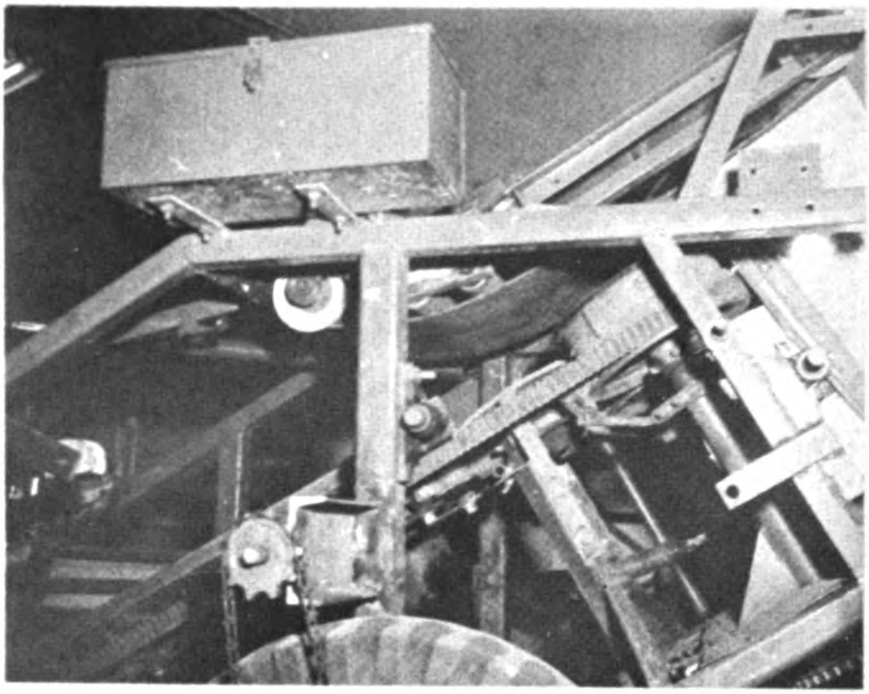
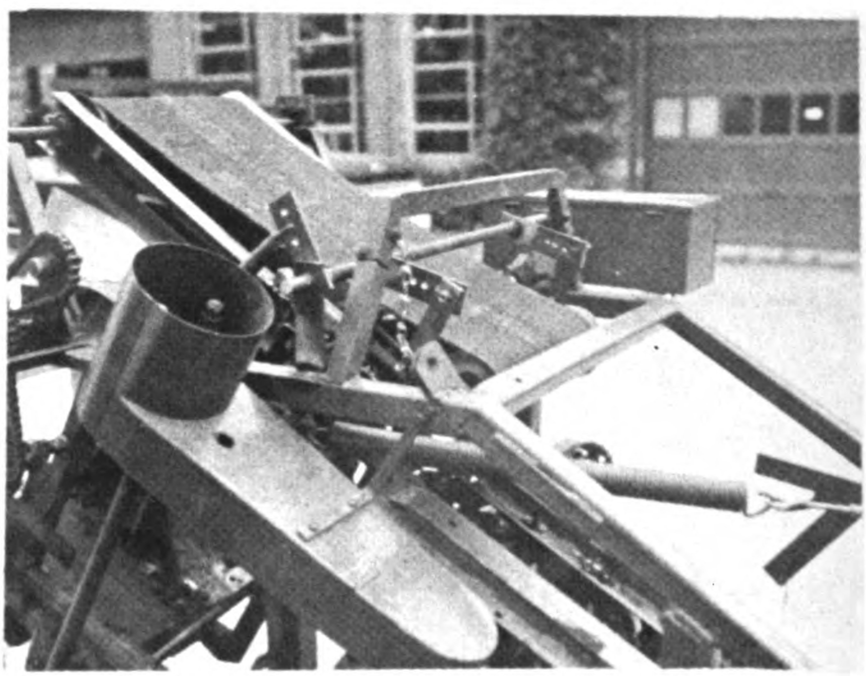


Fig. 2[illegible]. The overhead belt showing its tapered entrance.



[illegible] spring [illegible] and [illegible] knives in trimming large heads and the entrance of the overhead belt did not obstruct the cabbage.

Test (4), September 26, 1962

The damage to the deflecting shield was repaired and the paddle/V-belt peripheral speed ratio was increased from 1.17 to 1.53. (The ratio was 1.5 as measured by the tachometer.) Since no trouble from the root-removing device developed, no further changes were made. Some bruises were noticed at the top of the cabbage which were caused by incorrect action of the overhead belt. Traces of cabbage leaves are visible on the middle section of the belt (Figure 26). Besides, inclined trimming was frequently noted.

Test (5), October 2, 1962

A new, spring-loaded front suspension was constructed to carry the weight of the overhead belt (Figure 26). The overhead belt speed was reduced from 1.3 to 1.1 times the V-belt's speed. These modifications were required to reduce the top bruises. They proved effective in the test as bruises were reduced. Yet, bruises were still serious with large cabbage. The root removing paddle wheel was very satisfactory.

Test (6), October 9, 1962

A new spring-loaded suspension was built to allow for a wider range of movement and counterbalance (Figure 27). The results were satisfactory and the bruises on the large heads were effectively reduced. There were still, however,

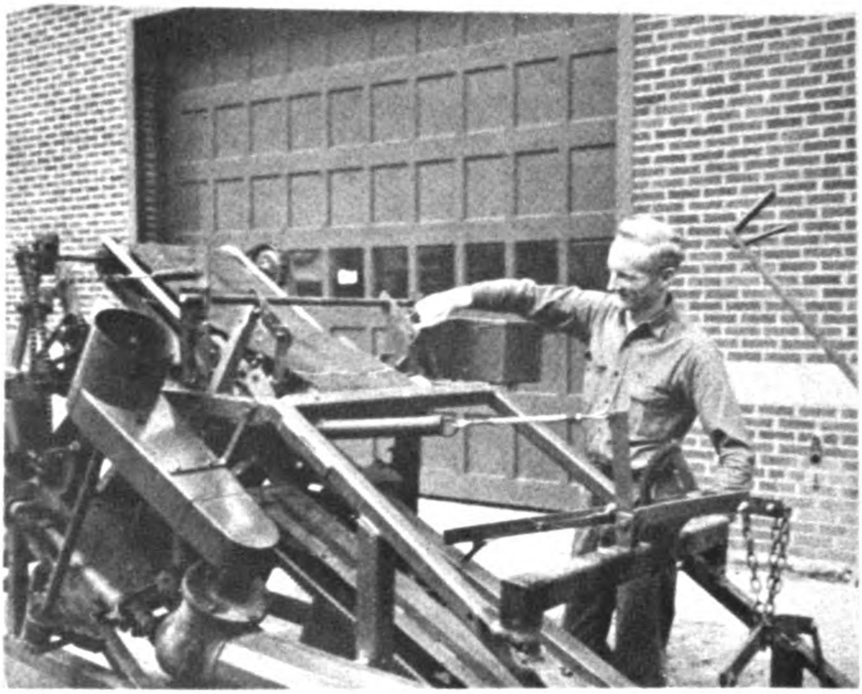
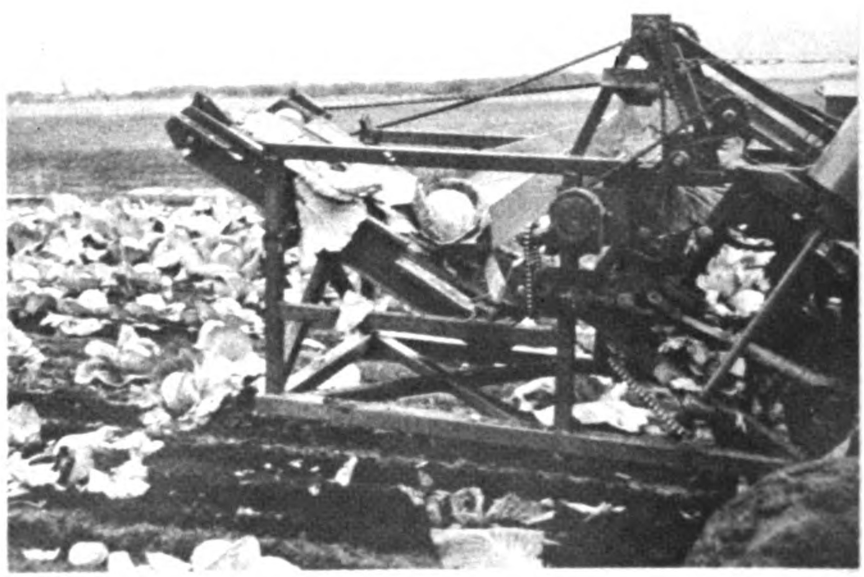


Fig. 27. Spring-loaded suspension of the overhead belt, allowing wider swinging.



[illegible]

some bruises. Probably the diameter of the intermediate roller is too small or the speed ratio should be changed.

An estimation of the "trimming efficiency" was made by building a sixteen cubic feet box at the rear of the machine. It collected the harvested heads and leaves while the roots were picked by hand from the ground. The weight of the different parts of the trimmed cabbage was recorded; the trimmed heads were checked by hand and the undesirable leaves or stem were removed. The following table gives the weight of the parts of trimmed cabbage before and after hand checking:

	Heads Wt. (lb.)	Leaves Wt. (lb.)	Roots Wt. (lb.)
Machine trimming	210	85	25
After hand trimming	202	93	25
Machine trimming efficiency	0.962	0.915	1.00

If the ratio between the net cabbage weight to the discharged trimmed heads weight is defined as the "trimming efficiency," then the machine would have a 96.2 per cent trimming efficiency. However, it had only removed 91.5 per cent of the leaves that should have been removed or 93.2 per cent of all that should have been removed, including the roots.

Test (7), October 24, 1962

The cleaning belt was mounted on the rear of the machine (Figure 28). The root deflecting shield was slighly changed to transfer the trimmed heads and leaves to the belt. An arrangement was provided to discharge the trimmed heads from the side of the machine where the elevator would be mounted.

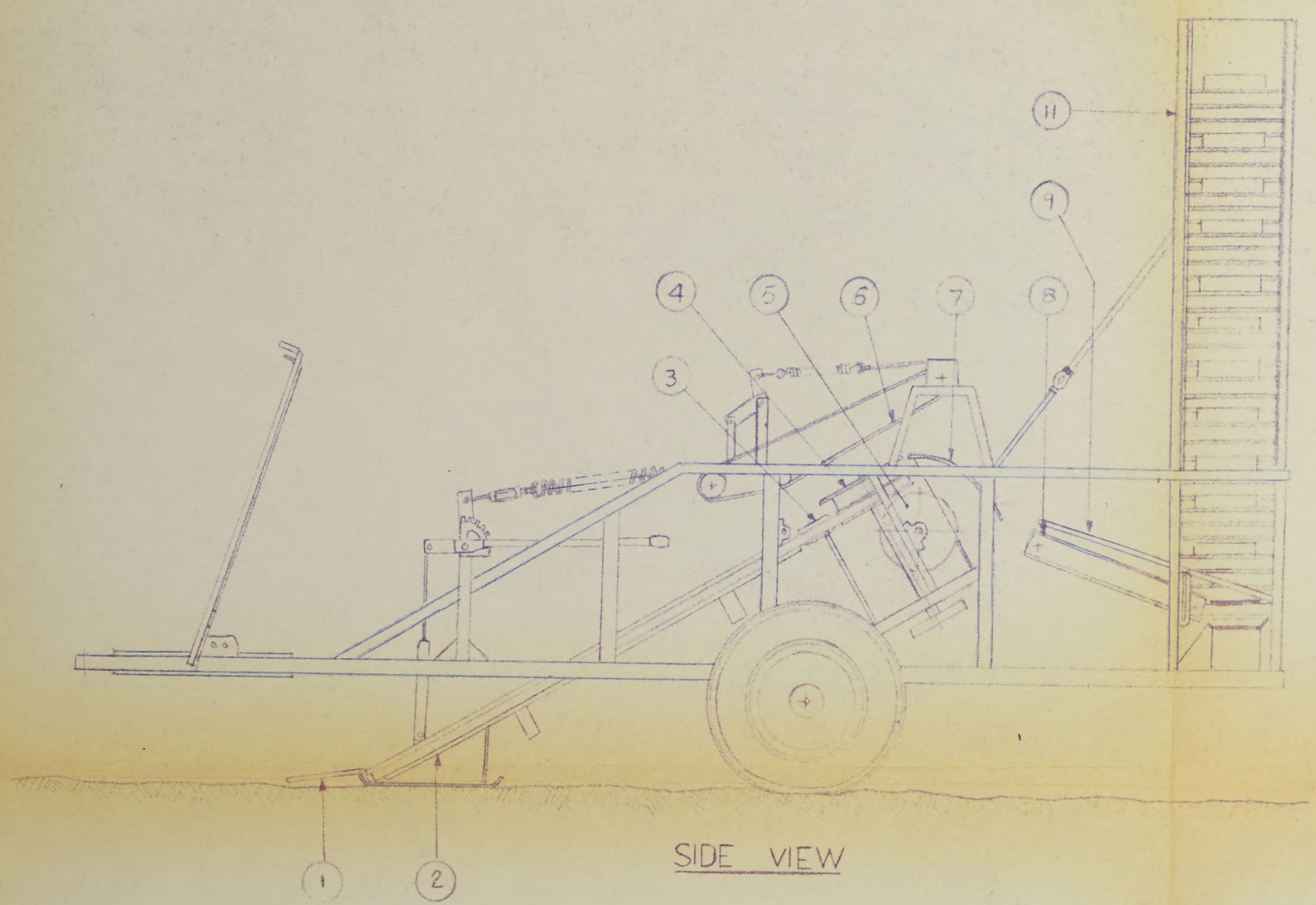
The belt was not very successful; it seemed to be too slow. The leaves were not carried away fast enough, such that the heads were obstructed and could not be discharged. The continuous flow of the heads coming from the trimming device added to the problem and the belt finally clogged. The trimming was satisfactory. This improvement was gained because the steel fingers of the lifting device forced the cabbage with its root almost perpendicular into the lifting belts.

Test (8), October 31 and November 7, 1962

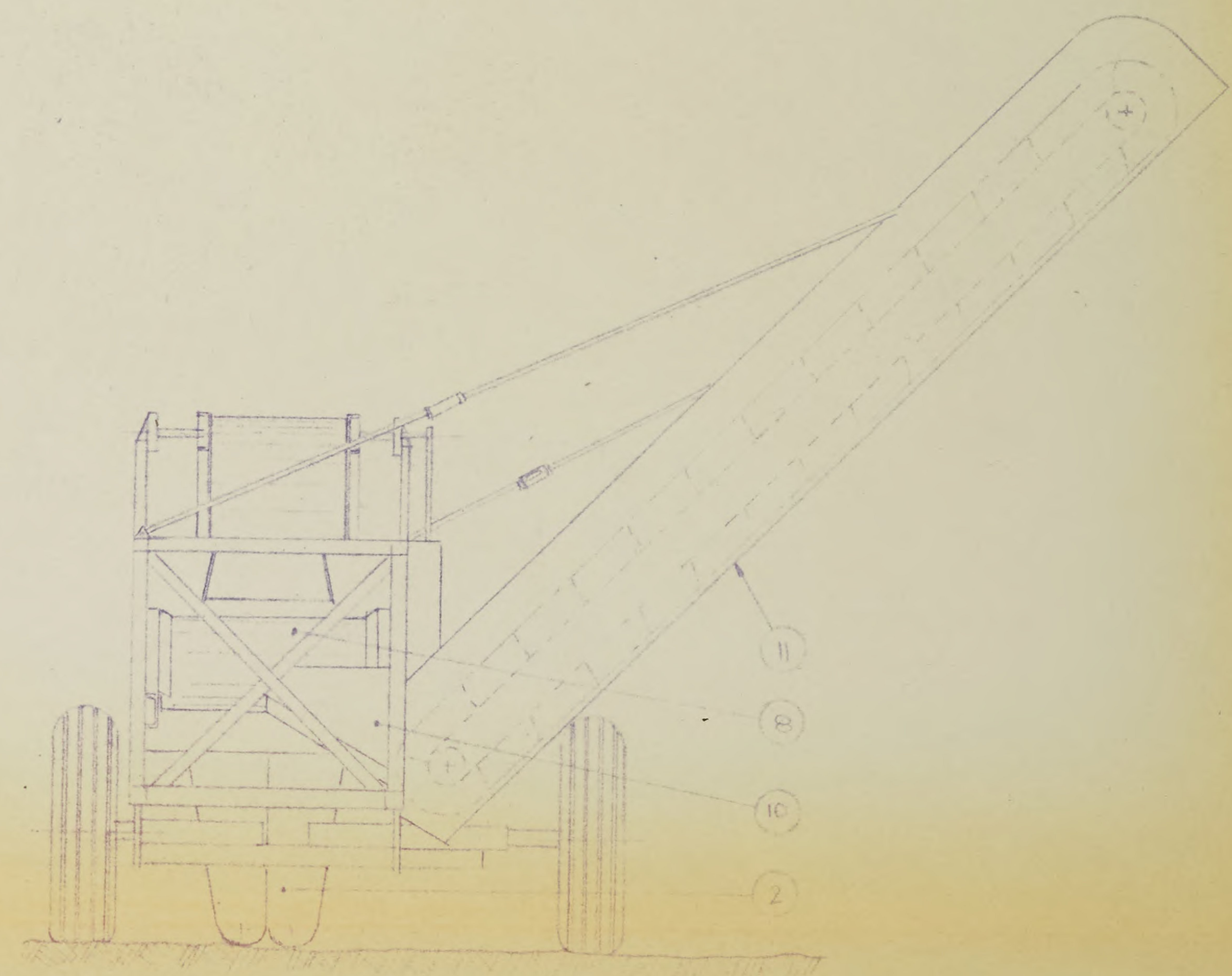
The speed of the cleaning belt was increased and the slope of the deflecting shield was also increased. It was hoped that this modification would help carry away the loose leaves sufficiently fast.

The cleaning belt did not perform as was desired; it carried most of the heads and discharged them rearwards. Besides, the cut-off roots that fell on the front portion of the belt below the deflecting shield were carried up and wedged under the shield.

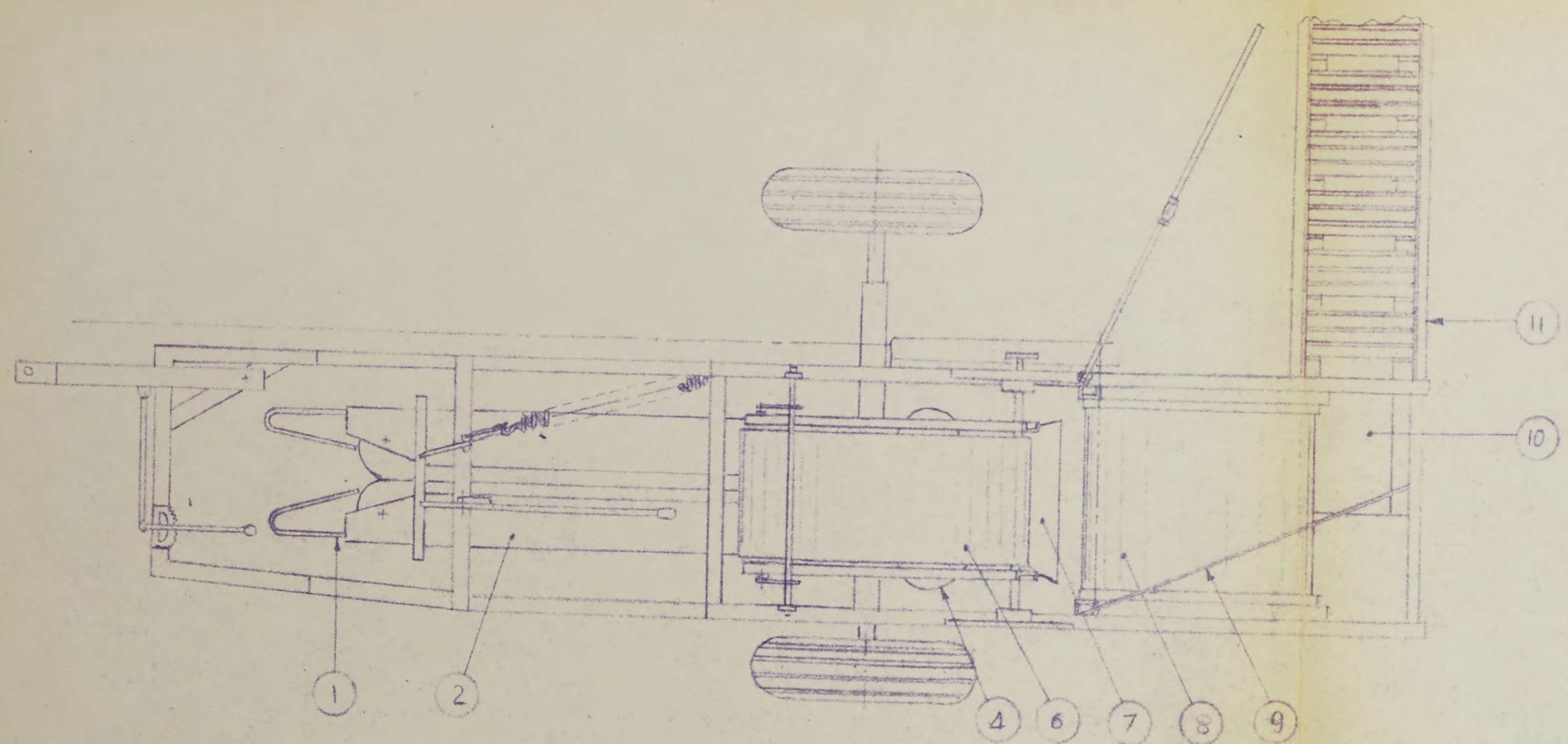
It was clear that the heads should not be discharged from the side of the cleaning belt.



SIDE VIEW



END VIEW



PLAN

Pos. no	Part Name
1	Picking device
2	Lifter shoe assembly
3	Adjustable guides
4	Disc knives
5	Root thrower
6	Overhead belt
7	Root deflector
8	Cleaning belt
9	Head deflector
10	Step incline
11	Elevator
Drawn	Mohammed Y. Hamdy
Scale	1 : 20 Date October 17, 1962

CABBAGE HARVESTER