A CONTROL SYSTEM FOR THE POWER MANIPULATION OF A BLUEBERRY WEEDER

Thesis for the Degree of M. S.

MICHIGAN STATE COLLEGE

Dwight Frederick Kampe

1953

This is to certify that the

thesis entitled

"A Control System for the Power Manipulation of a Blueberry Weeder"

presented by

Dwight F. Kampe

has been accepted towards fulfillment of the requirements for

M. S. degree in Agricultural Engineering

Walter M. Carleton
Major professor

Date May 25, 1953

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A CONTROL SYSTEM FOR THE POWER MANIPULATION OF A BLUEBERRY WEEDER

By

Dwight Frederick Kampe

AN ABSTRACT

Submitted to the School of Graduate Studies of Michigan State College of Agriculture and Applied Science in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

Department of Agricultural Engineering

Year 1953

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The cultural practice of setting bushes on a four by ten foot spacing used in the growing of blueberries has kept growers from satisfactorily mechanizing the weeding of the row area and has forced them to rely principally on hand hoeing to keep this area free of weeds.

A mechanical weeder was developed by Hall of Michigan State College to work in this area but the system for maneuvering the weeding head around bushes required a considerable amount of effort from the operator. As a result it was only partially satisfactory and this project was undertaken to work out a system of automatic controls for manipulating the head in the row area.

The method selected was to maneuver the head by means of a hydraulic cylinder which would be controlled by a bumper that contacted each bush as the weeder came to it. This system would retract the weeding head out of the row when the bumper contacted a bush and extend it back into the row again when the bumper had moved past the bush. This would maneuver the head around each bush and do it without any assistance from the operator.

The first control system tested utilized only two conditions for control of the weeding head. When the bumper was in contact with a bush the weeding head would be retracted out of the row and when the bumper moved away from the bush the head would extend back into the row again. This system was adequate to maneuver the weeding head without any assistance from the operator but, having only two positions, it would cycle between them and this cycling proved to be objectionable.

The depth regulation on Hall's weeder, on which the first system was tested, proved to be inadequate for automatic control and only a limited amount of test work could be done.

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A new weeder was built to overcome the difficulties that were encountered when using Hall's weeder with an automatic control and a second control system was developed that had a higher speed of retraction and also incorporated a hold position for improved stability. Some difficulty was encountered in achieving the additional stability due to overtravel of the weeding head but after making corrections to the system it was able to control the weeding head more smoothly than the first system.

The system, however, could not be operated above a tractor speed of 600 engine r.p.m. without becoming unstable due to the overtravel and had to be kept below this speed for satisfactory operation.

Either of these control systems was adequate to maneuver the weeding head around bushes but the one incorporating the hold position was more satisfactory as long as it was operated so that the factors affecting overtravel were not prominent enough to affect stability.

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The author wishes to express his sincere thanks to Doctor Walter Carleton, under whose guidance this project was conducted, for his counsel, encouragement, and helpfulness in making this project a reality.

He is also deeply indebted to Professor Arthur Farrall and the Agricultural Engineering Department of Michigan State College for making this investigation possible.

The author wishes to commend Doctor Carl Hall for his initial work on the blueberry hoe and to thank him for his most helpful counsel.

He also wishes to thank Mr. J. Levin and Mr. H. Gaston for their counsel and expresses his appreciation to Mr. H. Hootman and Mr. H. Gaston for making their facilities available for field testing.

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INTRODUCTION

Present Status of Blueberry Weeding

The mechanical weeding of blueberries has lagged behind the general trend in farm mechanization and to date only limited progress has been made in this field. This lag has been due to the fact that the blueberry culture presents a special weeding problem that cannot satisfactorily be handled by regular cultivating equipment and there has been no special equipment developed to fill this gap. This has left the grower with the necessity of using large amounts of hand labor to keep his planting free of weeds and he will be required to continue this practice until a satisfactory weeder can be developed that will meet the special requirements of this weeding problem.

Source of the Problem - Blueberry Culture

Nature of growth. The blueberry is a shallow rooted perennial that grows to a height of about four feet in eight years and may reach a height of six to eight feet at full growth. The bottom branches are from eight to twelve inches from the ground with the bush having approximately a hemispherical shape. The stump consists of several shoots forming a stump approximately six inches in diameter.

Blueberries in Michigan are grown on predominantly sandy soil with a pH 4.0 -5.5. The young plants are started in nursery beds and are set out into the field at about two or three years of age. Common practice is to

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Fig. 1. Typical planting of blueberries. Rows are ten feet apart and bushes are on four foot centers.

is to set them in rows 10 feet apart and with a spacing of 4 feet within the row (fig 1).

<u>The weeding problem.</u> The weeding problem consists of keeping the entire area free of weeds and unwanted plants. Part of this problem is the removal of a cover crop that is planted in the fall and removed the following spring.

The ten foot spacing between rows allows the grower to drive between rows with his tractor and any tillage implement he selects to work this area. The four foot spacing within rows, however, prevents the use of conventional tillage methods between bushes and requires that a band of soil be

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soil be left untouched that contains the row of bushes. The width of this band varies with the type of tillage used between the rows but it is in this area that growers have had to rely principally on hand hoeing for weed removal.

Although it is the most effective means of keeping the row of bushes free of weeds, the cost of this hand hoeing is $25 - $35 per acre and there has been considerable interest among growers in reducing this expense by some other means of weed removal.

Chemicals, fire, grazing, fallowing, and mulching are methods that have been advocated to reduce the cost of weed removal in the row area but these methods have not been very successful and growers still have to rely on mechanical working for most of their weeding.

Present Mechanical Weeding Methods

<u>The grape hoe.</u> One mechanical weeding method used in the row area consists of a special blade that is set so that as it is pulled down the row it scrapes the soil out of the row for one cultivation and pushes it back for the next. This implement, known as a grape hoe, is manipulated by a set of handles to move it out of the row, around the bush, and back into the row again after the bush has been passed (fig 2). This works

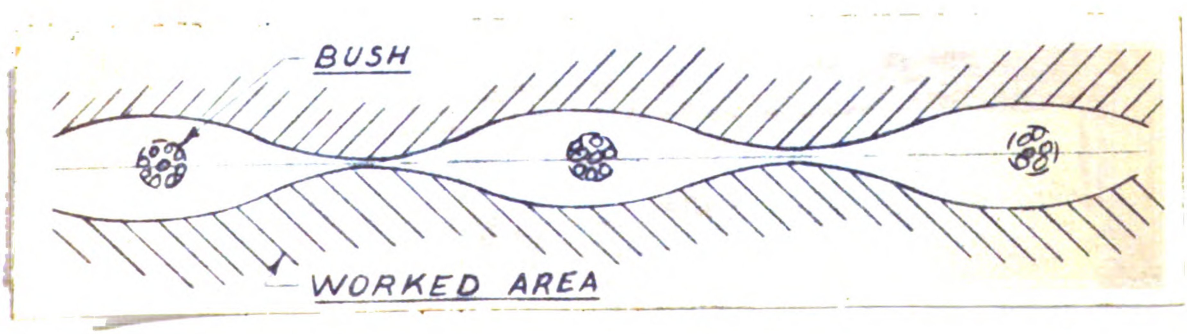

Fig. 2. Diagram of area worked by a grape hoe.

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part of the row area and cuts down on the required hand hoeing. At the present time this hoe is the standby of the blueberry growers but it still leaves a large area for hand hoeing and after prolonged use results in a definite hilling of the rows.

Experimental Equipment. In order to provide a weeder especially for the row area in blueberries, an experimental weeder was built by Hall of Michigan State College. This machine (fig. 3) consisted of a power driven weeding head (fig. 3,A) in the form of a cylinder with knives that were used to work the soil rather than rely on the forward motion of a blade. This head was driven by belts (fig. 3,B) from the tractor p.t.o. and was supported on a frame by means of a long horizontal shaft (fig. 3,C) that extended out to the side of the tractor. The head rotated on this shaft and was mounted so it could be moved in and out by means of cables

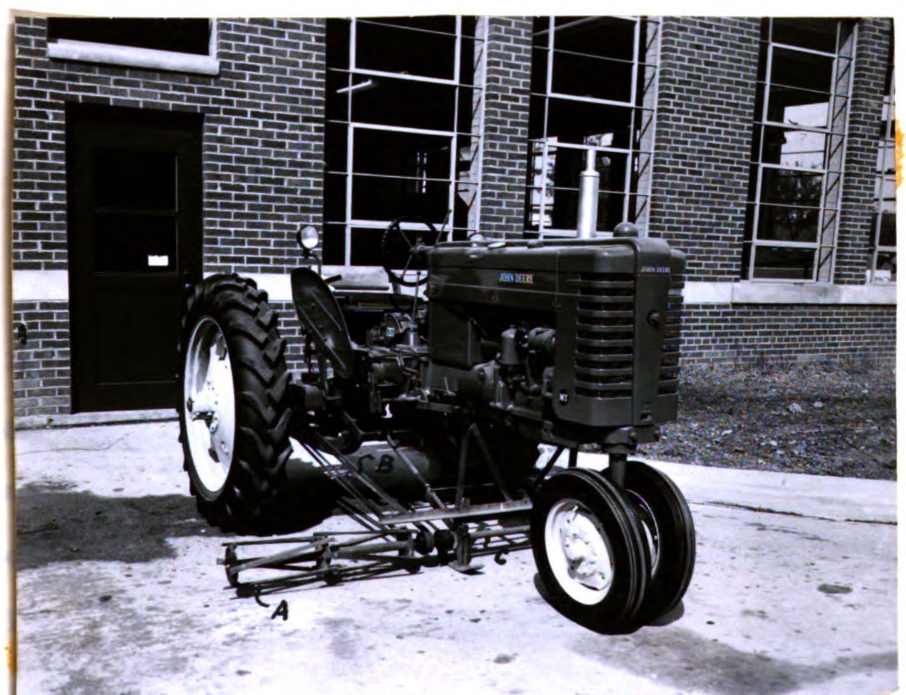

Fig. 3. Experimental blueberry weeder. Weeding head was moved in and out of the row by means of a hand lever (not shown).

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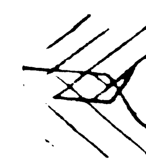

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and a hand lever. As the tractor moved along between the rows, the operator manipulated the head so that it worked in the row area between the bushes. When a bush was reached, the head was retracted out of the row until the bush was passed, and then returned to the row area again.

This power driven head did a more vigorous job of weeding and since no forward motion was necessary, the head could be maneuvered in close to the bush. The row was worked from both sides with an overlap in the center and when the operation was completed, only a small area remained unweeded at the base of each bush (fig. 4).

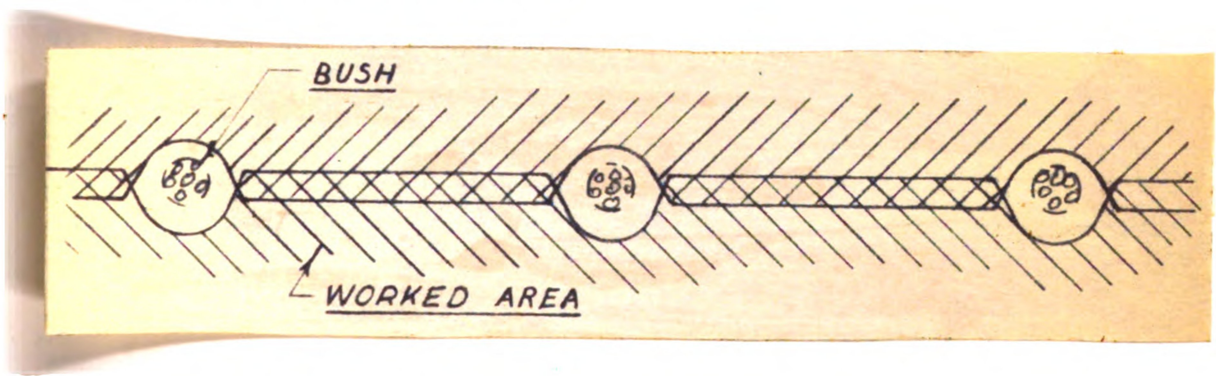

Fig. 4. Diagram of the area worked by Hall's experimental machine.

Need for a Power Operated Machine

The field test of Hall's machine proved that the basic principle of weeding was sound but that the hand lever as a means of moving the head in and out of the row was not satisfactory as moving the head required too much effort from the operator. Hall listed this as the outstanding limit of the weeder and recommended that a system of power operation be incorporated.

Since the system for maneuvering the weeding head in the row area was the limiting factor in the use of either of these weeders, this proje

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project was undertaken to work out a system of power operation for manipulating the head of Hall's machine that would make this weeder more satisfactory and could also serve as a basis for power operation of other machines of this type.

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Need for Automatic Control

The time factor. In the preliminary consideration of power operation it was necessary not only to consider a means of applying power to move the weeding head but to also consider the means of controlling this power and how power operation would fit into the use of the weeder. At 1 m.p.h. a tractor moving down a row would move past a bush on four foot centers each 2.7 seconds and move past the six inch stump in .3 second. Even at this slow tractor speed, the weeder would move between bushes so fast, and the time at the bush would be so short, that timing the operation would be a critical factor. Even with some form of power operation, manipulation by the operator with a hand control would make continuous operation difficult to achieve.

Ground coverage. Not only would it be difficult, by hand control, for the operator to cope with the speed at which the bushes would be passed but it would be equally difficult, at this speed, for him to maneuver the weeding head for good ground coverage so that only a small area would be left unweeded at the base of each bush. In order to avoid colliding with a bush, he would have to give it a wide berth and leave a large area unweeded around the base. Only after he became quite skillful could he work in close and do the best possible job.

Since inability to operate continuously down a row would reduce the capacity of any machine using this control system, and the poor ground

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coverage of a hand control would reduce it's effectiveness, it was decided to by-pass hand control by the operator and try to avoid these limitations with some type of an automatic control system. This automatic control system would take over the job of moving the weeding head out of the row, around the bush, and back into the row again. This would leave the operator with only the job of guiding the tractor and watching the weeder.

Requirements of an Automatic Control System

Sensing. If the control of the weeding head was to be automatic, the first requirement of the control system would be that it be able to sense each bush as the weeder came to it. This sensing would have to be accomplished regardless of the size, shape, or age of the bush and be of such a nature that it could be translated into the proper movement of the weeding head so as to move around each bush without damaging it.

Ground coverage. In translating the sensing of a bush into head movement the control system would have to perform so as to give the best possible ground coverage around the base of each bush. The control system would have to move the weeding head so as to be sure of clearing each bush but, at the same time, move out of the row only as far as necessary. The weeding head would have to be kept in the row as long as possible and, during retraction, be kept close to the base of the bush at all times.

Reliability. Both in sensing each bush and translating this sensing into head movement the control system would have to possess a high degree of reliability. Irregular shaped bushes, trash, dirt, stones, and other obstacles would have to be handled without difficulty. Since any failure to maneuver the head around a bush would result in serious damage to it, in no

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in normal operation the control system would have to perform with no chance of malfunction.

Durability. Along with the operating requirements of the control system would be the general requirement of durability. There are 1,089 bushes to an acre with four by ten spacing so the system would be required to perform 2,178 cycles for each acre in working both sides of the row. This would require a very durable system to stand up under extensive use and all components would have to be selected with this in mind.

The Basic Type of System

Type of power. In selecting the basic type of system to be built and tested the type of power was selected on the basis of how it could be used as the core for an intergrated automatic power control system. There were three ways, mechanical, electrical, and hydraulic generally available in which the power of the tractor could have been utilized. A mechanical system would have required some sort of clutching arrangment for control and, since these clutches would require a large force to operate them, a mechanical system did not lend itself to automatic control. An electrical system, although easy to control in small amperages, would have been difficult to control when supplying enough power to maneuver the weeding head and would have been hard to adapt to the in and out type motion that was needed. A hydraulic system using a cylinder would produce the type of motion that was needed and would be capable of all the power that was necessary. It's valves offered a fair ease of control so a hydraulic system was selected as the most likely means of utilizing the power of the tractor in an automatic control system.

Sensing method. Since control of the power source would be by means of a control valve, the method selected as the simplest means of sensing each bush and translating this sensing into head movement was to mount the valve on the weeding head so that the bush would operate it by making contact with a bumper that would act as the valve handle. This bumper would be mounted in front of the weeding head so that the forward motion of the weeder would bring it into contact with each bush and move the control valve so as to retract the head out of the row. This type of sensing would be positive for large bushes and would be limited only by the resistance of the shoots on small ones. Since blueberries have a rather stiff shoot, this system would require only that the load required to move the valve be kept low in order to make the system work on bushes of almost any size.

Details of the System

The control circuit. After selecting the type of power and the sensing method, the control circuit was selected to conform with the pattern of operation of the weeding head over the ground. Since the weeder would operate with the head fully extended into the row most of the time (fig. 4), power to move the head would be needed only when it was being retracted to maneuver around a bush. By using a spring to extend the weeding head and hold it in this position, the hydraulic system could be relieved of pressure while the head was extended which would be the greater part of the cycle. This pressure relief would be necessary in order to keep from generating too much heat within the oil by working the pump against pressure and doing no external work. The hydraulic

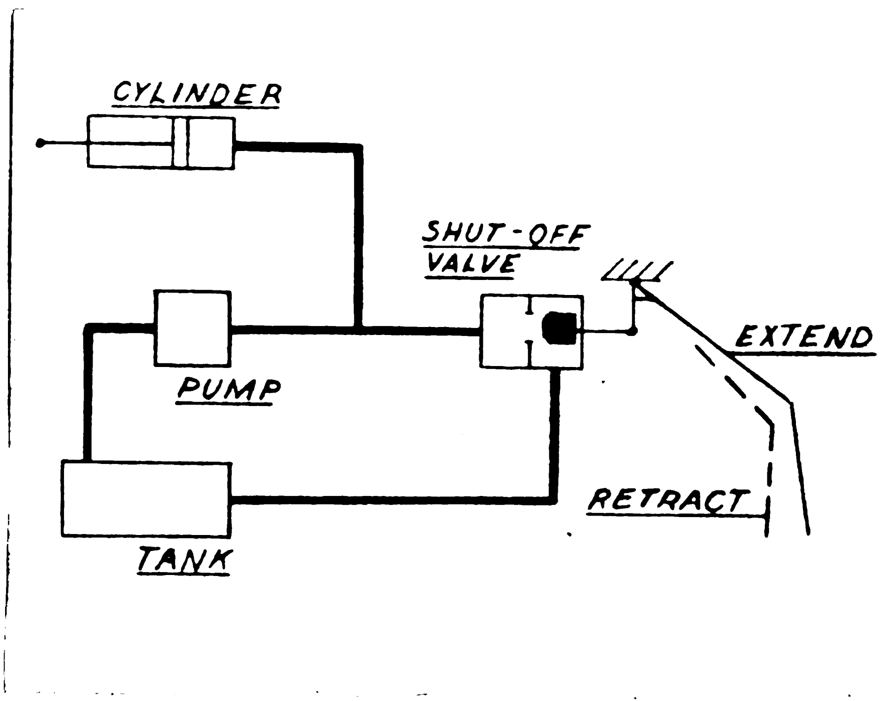

Fig. 5. Hydraulic circuit selected to control the weeding head.

cylinder, then, would be used to move the weeding head in only one direction. It would overcome the spring in retracting the head and this spring would supply the energy to extend the head back into the row again.

This arrangment of using the hydraulic cylinder only for retracting the weeding head permitted the use of a single acting cylinder and a simple two-way circuit (fig. 5) was selected to control it. This circuit consisted of a pump and a shut-off valve, acting as a control valve, with the cylinder connected by a tee between them. With the bumper free and the valve open, oil from the pump would flow through the valve and back to the tank. As soon as the bumper contacted a bush and the head would have to be retracted, the bumper would close the valve, stop the flow of oil to the tank, force the oil to back up into the cylinder, and retract the head. When the bumper moved past the bush, it would again be free,

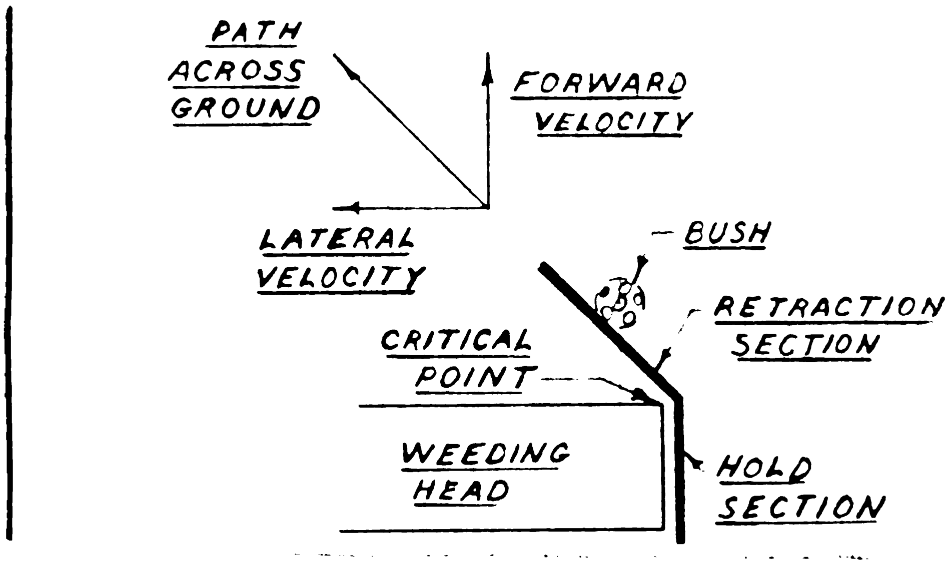

Fig. 6. Diagram showing how the path of the weeding head across the ground would determine the bumper's location and shape.

the valve would open, the oil would be released from the cylinder, and the spring would extend the weeding head back into the row again.

Shape of the bumper. Since the movement of the weeding head would be controlled directly by the bumper, the type of movement necessary to maneuver the head around a bush determined it's location and shape. When the weeding head was being retracted out of the row, it's path across the ground would be the resultant of the forward motion of the tractor and the lateral motion of retraction (fig. 6). Any point on the weeding head would follow this path, so if the front corner of the head was to clear the bush, retraction had to be started soon enough so that it's path would take it out of the row before it came abreast of the stump. This meant that the bumper would have to be located at an angle and in front of a line drawn from this front corner along the path of motion. Regardless of where the bush contacted the bumper, then, retraction would start soon enough so the front corner would clear the bush.

After retracting the head so the front corner would clear, it would be necessary to hold the head in the retracted position until the rear corner was past the bush. This meant that the bumper would have to extend back to the rear corner and end somewhere in back of this point. The bumper, then, would consist of an angular section in front of the weeding head for retraction and a straight section parallel to the row across the end of the weeding head to hold the head in the retracted position until it was completely past the bush.

Operation of the system. In operation, a weeder with this control system would move down the row with the end of the head extended just past the center line. With the bumper free, oil would flow from the pump through the control valve, and back to the tank. The extension spring would hold the head in place. When the bumper came in contact with a bush, it would close the valve, direct oil into the cylinder (fig. 5) and retract the head. The head would continue to retract as long as the bumper kept the valve closed. Since the bumper would be attached to the head, however, retracting the head would tend to erase the bumper's action on the valve by moving the head away from the bush. When the head had moved away far enough to open the valve, retraction would stop. This would keep the bumper in contact with the bush and the weeding head would follow it around a bush.

Since this circuit had only two positions for the control valve, the head would have to alternate between retraction with the valve closed and extension with the valve open. This would mean that the head would hunt between these two positions while following the bumper around a bush and would come to equilibrum only when the bumper had moved past the bush and the head moved to the fully extended position. This hunt would be most noticeable when the bush was in contact with the straight section of the bumper across the end of the head. During retraction, if ideal conditions prevailed such that the bumper followed the exact line of travel and there were point contact with the bush, the bumper would hold the valve closed during the full time the bush was in contact with the retraction section. After passing the corner, however, the head would move away from the bush until the bumper no longer would hold the valve closed. The head would then start extending until it would move the bumper into the bush and close the valve again. The system would cycle between these two conditions until the bumper would move past the bush and the head could extend the full distance back into the row. Since ideal conditions could not be obtained on the retraction section, the head would follow this pattern of cycling throughout the entire length of the bumper.

Although this cycling, or hunt, would not be desirable, it was an outgrowth of the simple circuit and the simple two position control valve. To eliminate it would have required a more complex circuit and since there was no way of knowing actually how detrimental this cycling would be without test, it was decided to use this circuit and add refinements only if field test indicated they were needed.

THE FIRST EXPERIMENTAL MACHINE

Preliminary Considerations

In order to field test the proposed automatic control system, it was decided to modify Hall's machine to incorporate the necessary elements for adding the automatic control. This modification would be simplified by the fact that the John Deere MT tractor with which the weeder was used was well adapted to the proposed type of control system. The hydraulic pump on the tractor had a capacity of 7.0 g.p.m. at 1650 r.p.m. and was driven directly from the engine. The ground speed in low gear was 1.75 m.p.h. at 1650 r.p.m. which was lower than most tractors. This combination of a high capacity hydraulic pump and a low ground speed was favorable for working out the ratio of forward motion to lateral motion without resorting to unusual features to obtain the necessary retraction speed. Having the pump driven directly from the engine would keep the power available regardless of ground travel and since there would be no control except by means of the bumper, this arrangment was considered mandatory.

Design of the Control Elements

Bumper shape and pivot point. Since the bumper had to match the forward and lateral movement of the weeding head and would be correct for only one set of conditions, it's shape was worked out on the basis of operation in low gear and the use of a 1-3/4 inch diameter hydraulic cylinder. At 900 r.p.m. the hydraulic pump would move this ram at the rate of 6.2 inches per second while the tractor would move forward at the rate of 18.3 inches per second. The use of a three to one lever arm between the hydraulic cylinder and the weeding head would bring this ratio into a more favorable condition so that the head would move at the rate of 18.6 inches per second. Since the full stroke of the weeding head was 12 inches, this ratio would correspond to 12 inches of forward travel to the 12 inches of lateral travel for full movement.

It was decided to try one bumper with exactly this ratio on the retraction section and one bumper with the inner end moved forward to correspond to a 15 to 12 ratio. This second bumper would start retraction sooner all along it's length and would provide a factor of safety proportional to the distance the head had to retract.

The pivot point for the bumper was set at 9 inches in from the front corner of the head and 6 inches in front. Assuming that the head would operate 3 inches beyond the center line of the row, this would provide a minimum of a 6 inch lever arm the entire time the bush was in contact with the bumper.

Control valve. Since the force required to operate it had to be kept small, the control valve was designed especially for this control circuit. This valve consisted of a two land spool operating in a bore with the inlet and outlet ports entering the bore between the two lands (fig. 7). With the valve open, the oil would enter through one port and leave from the other. With this arrangment, the area exposed to the oil would be the same on both lands and the force exerted by the oil would be the same in both directions. In closing the valve, the large land on the spool would move across the outlet opening and close it off but the

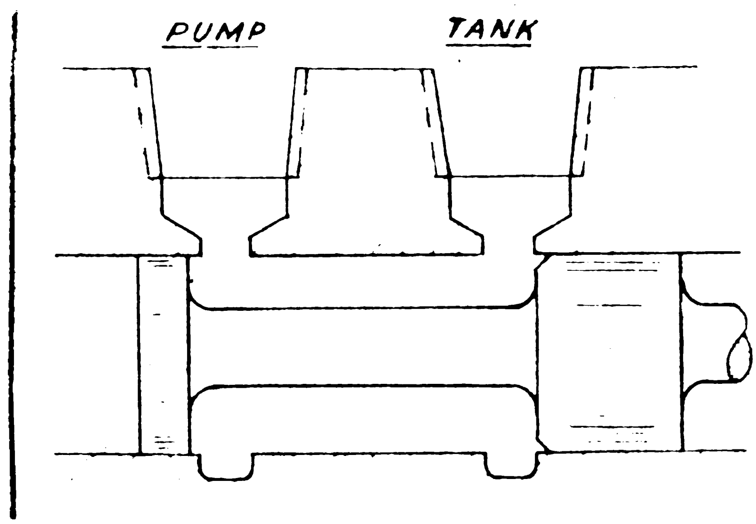

Fig. 7. Diagram showing pressure balance on the control valve.

pressure load on the spool would still remain balanced on the two lands. This valve would remain balanced at all times and could be moved with a small force regardless of any change in pressure that might occur in the hydraulic circuit.

Incorporation of the Control Elements

Bumper and valve. The most significant change made in Hall's machine (fig. 8) in order to incorporate the control elements was the addition of a hood (fig. 8,A) over the weeding head. This hood was necessary to provide a mounting place for the bumper that would move with the weeding head and it also provided a shield for the weeding knives.

The bumper pivot (fig. 8,B) consisted of a triangular plate with the bumper (fig. 8,C) attached to the forward point. A link to the valve (fig. 8,D) was attached to one rear point and a spring to hold the bumper out and the valve open (fig. 8,E) was attached to the other rear point. This external spring was the only means of holding the valve open when the

Fig. 8. Hall's weeder with the automatic control elements incorporated.

bumper was free and was made adjustable to compensate for the inertia of the bumper and variances in the stiffness of the bush shoots. The link to the valve was positioned so there would be 1 inch between control positions and the straight section of the bumper would be parallel to the row just before the valve would close.

<u>Cylinder, return spring, and lever arm.</u> The hydraulic cylinder (fig. 8,F) was attached to the base frame and extended out to the lever arm (fig. 8,G). The extension spring (fig. 8,H) was located directly above it. The pivot point for the lever arm was also attached to the main frame and the lever arm and links were proportioned so that when the end of the head was 3 inches past the center line of the row the tractor would be centered between the rows.

Circuit connections. The tractor hydraulic system was tapped at the control valve under the seat with the pressure line running to a tee (fig. 8,J) at the base of the cylinder. The circuit was completed by running a line to the valve (fig. 8,K) and back to the filler connection on the reservoir.

Preliminary Test

After modifying the weeder, it was given a preliminary test by setting up stakes and driving the weeder past them the same as it would be driven past a blueberry bush. This preliminary test was used only to verify that the automatic control system was functioning as planned and was capable of retracting the head and taking it around an object.

Field Test

Conditions of the test. The machine was given a Field test Oct. 6, 1951 at the Boo-Hoot Blueberry Farm, Holland, Michigan. The weather was clear and the soil damp from a recent rain. The bushes were about ten years old and were set out on a four by ten spacing. The rows were hilled from the use of a disc and grape hoe. There were few weeds.

Performance of the weeder. The field operation of the control system paralleled very closely the projected operation set forth in planning the system. The tractor was driven between the rows so that the end of the weeding head was about three inches past the center line of the row (fig. 9). The bumper retracted the head at each bush (fig. 10) and after it was passed, the spring extended it back into the row again (fig. 11). After working both sides (fig. 12), the row area was almost completely worked (fig. 13) with all maneuvering of the head being done by the automatic control system.

Fig. 9. Weeder positioned between the rows.

Fig. 10. Path of retraction on the approach side of a bush.

Fig. 11. Path of extension on the back side of a bush.

Fig. 12. Weeder working the second side of the row with an overlap at the center.

Fig. 13. Row area after working both sides.

With the weeder operating in the soil, the head would make from two to four reversals due to the two position circuit before moving completely past a bush.

The chief difficulty encountered during field operation was keeping the weeding head operating at the proper depth. Since the depth regulating shoe and the head were widely separated (fig. 9), ground irregularities would make the head lift out of the ground or bury itself until the bush could not move the bumper. Only when the contour of the ground was quite uniform could the machine be operated for any distance without adjusting the depth shoe.

In order to evaluate the shape requirements of the bumper both bumpers were tested along the same row. The bumper shaped exactly to the angle of the path of motion did not retract the head soon enough to clear the bush without forcing it's way past. The other bumper was more satisfactory, however, and only occasionally was there any evidence of forcing while maneuvering around a bush.

Evaluation of the Machine

The control system. The performance of the control system in itself was generally satisfactory since it was able to maneuver the head around each bush with no assistance from the operator. The bumper proved to be a satisfactory sensing method, the control circuit functioned as planned, and the two worked well together.

The inherent instability of the system, although apparently not detrimental to the operation, was objectionable to watch. The hunt while maneuvering around a bush seemed to make the machine erratic and was very noticable.

Since the head would follow the bumper around a bush, the 15 to 12 ratio bumper represented too low a retraction speed in relation to the forward speed and left a long point of ground unweeded on the approach side of each bush.

The small diameter on the bumper had a tendency to bark the plants although this did not occur often.

The complete weeder. The performance of the weeder as a complete automatic controlled unit was not as satisfactory as the performance of the control system alone. The unit could not be considered reliable since ground irregularities might bury the head and jam up the control system at any time. Constant adjustment of the depth shoe was necessary and if the rows were hilled excessively the weeder could not be used at all.

The 12 inch stroke of the weeding head was not adequate for automatic control. If a bush was out of line the head could not retract far enough to clear and this could not be detected until a collision actually occurred.

THE SECOND EXPERIMENTAL MACHINE

Preliminary Considerations

The successful working of the control system on the first machine indicated that automatic control of the weeding head was feasible so it was decided to continue working with this type of control system and to carry the work into a second machine. Since the first experimental machine using Hall's weeder could be used only when conditions were ideal for depth regulation, it was also decided to build a new weeder with which to carry on the control system testing. This new weeder would have the depth shoe closer to the weeding head, have a greater lateral movement, and have it's own hydraulic system devoted exclusively to the control of the weeding head.

There were two phases of the control system that needed improvement. Modifications in the circuit were needed to eliminate the hunt while the head was being maneuvered around a bush and more retraction speed was needed in order to reduce the long point on the approach side of the bush.

The New Weeder

Frame and drives. The frame of the new weeder (fig. 14) was basically a vertically pinned four bar linkage that was used to support the weeding head and still allow it to move laterally in and out of the row. The shaft of the weeding head (fig. 14,A) served as one bar of the linkage with two curved arms (fig. 14,B) running forward to an upper frame member (fig. 14,C) that formed the fourth bar. These arms were connected to the upper frame

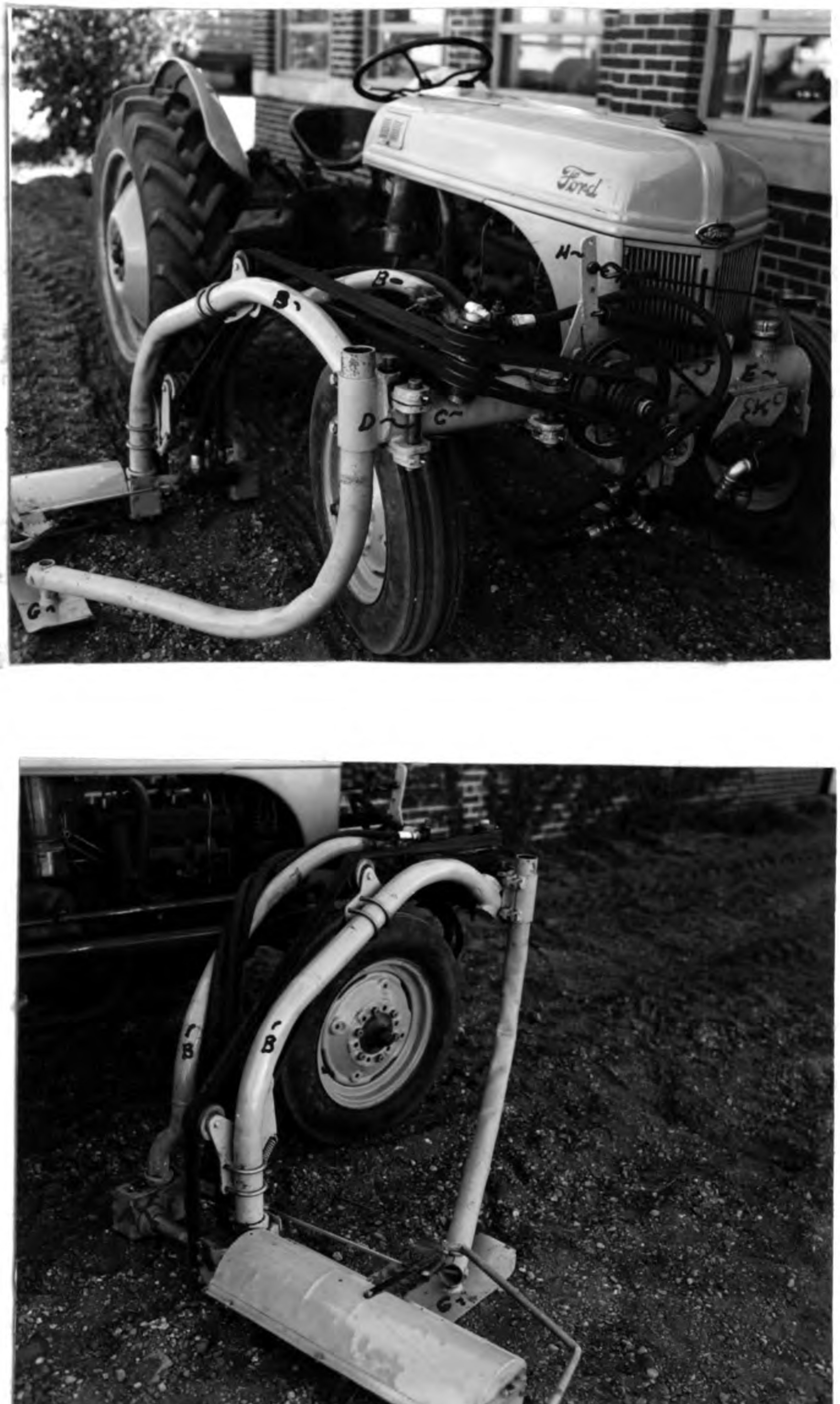

Fig. 14. New weeder used for testing the automatic control system. Top - Front quarter view. Bottom - Rear quarter view.

member by means of yokes and vertical pins (fig. 14,D) so that the head could swing in and out but could not move vertically. This upper frame member, then, would support the weeding head and was attached at the inner end to a central frame section (fig. 14,E) that was rigidly attached to the tractor. This upper frame member was attached to the center section by means of a horizontal pivot (fig. 14,F) so that the outer end could move up or down but could not swing back. Since the weeding head and this upper frame member would move as a unit, the depth shoe (fig. 14,G) was positioned in front of the weeding head and was attached to the outer end of this upper frame member. As the shoe moved the outer end of the frame up or down, the weeding head would move up or down with it. This would allow the shoe to regulate depth immediately in front of where the head was working and still allow it to move freely in and out of the row.

An arm (fig. 14,H) was attached to this upper frame member with a cable running to the tractor lift to swing the head up for transport.

The central frame section served as a mount for the belt drive to the weeding head (fig. 14,J). This belt drive originated at the front of the engine, ran over to the frame pivot, along the outer curved arm, and down to the weeding head.

<u>The weeding head.</u> The weeding head (fig. 15) of the new machine remained the same with the exception of the front edge of the hood which was raised to provide a larger opening.

<u>Control elements.</u> The hydraulic pump (fig. 14,K) was mounted on the central frame section and was driven from the front of the engine with the same drive that was used for the weeding head. This central frame section was hollow and served as the oil reservoir.

Fig. 15. Weeding head of the new machine.

Fig. 16. Upper section of the frame showing the hydraulic cylinder and the springs used to extend the head.

The control valve (fig. 15,A) was moved from it's position on the weeding head to a position between the two curved arms but it was still operated by a link (fig. 15,B) directly from the bumper.

One end of the hydraulic cylinder (fig. 16,A) was attached to the outer end of the upper frame member and the other end was attached to the inner one of the two curved head support arms. The extension springs (fig. 16,B) were similarly located but were attached to the bottom of the upper frame member to make room for the head drive belts. Attaching the hydraulic cylinder to the inner support arm allowed the outer arm to carry most of the weight of the head and the inner arm to carry the load of retracting the head out of the row.

The New Control System

The control circuit. The new control circuit (fig. 17) was the same basic type that was used on the first machine in that control action would be initiated by shutting off the flow to the tank and forcing the oil to back up into the cylinder. In this circuit, however, the oil would enter the cylinder over a check valve so it could not be forced out as soon as the pump line was opened to tank again. This would allow the head to be stopped and held in place rather than reversing it's motion when the bumper moved away from a bush. When the head was to be extended, oil would be released through a separate line to the control valve that could be controlled separately from the tank shut-off.

The control valve contained the regular shut-off for the pump-to-tank line and an additional shut-off for the cylinder-return line. Both of these shut-offs were balanced and were arranged so that as the valve

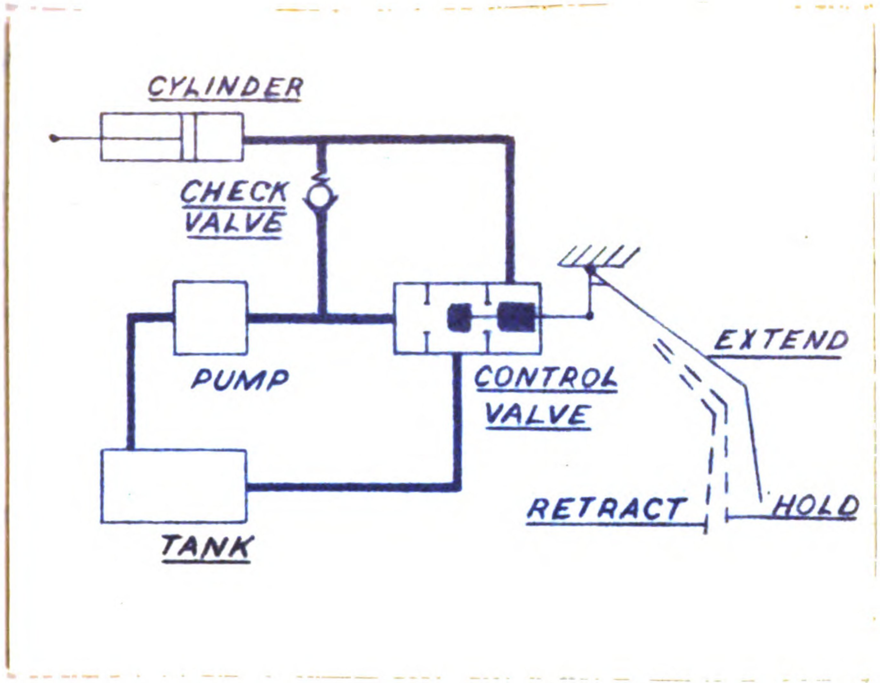

Fig. 17. New circuit incorporating a hold position used to control the weeding head.

was moved from the open position the cylinder return shut-off would occur first. As the valve spool continued to move, this line would remain shut off and the tank shut-off would occur after the spool had moved farther on it's travel.

This would give the control valve three positions. With both sections of the valve open and the bumper free, the head would be allowed to extend it's full length. With both sections of the valve shut off, oil would be forced into the cylinder and would not be able to escape. This would put the control valve in the retract position. Between these two positions would be the third position with the pump line open but the cylinder return line closed. This would provide a hold position since no oil would be forced into the cylinder but none could escape.

In operation, with the bumper free and the valve open, this circuit would allow oil to flow from the pump, through the control valve, and back to the tank with the spring holding the head in the extended position. When the bumper contacted a bush it would move the control valve through the hold position and into the retract position. As the head retracted it would carry the bumper away from the bush and move the control valve back to the hold position. This would stop the head movement by opening the pump line to tank but the head would not start to extend because the cylinder return line would still be blocked. If further retraction were needed, the bumper would move the valve into the retract position again and back into the hold position when the head tended to move away from the bush.

As soon as the bumper would move completely past the bush it would swing free and move the control valve into the extend position allowing the oil to escape by the cylinder return line.

This circuit would allow the head to remain stationary when the straight section of the bumper was in contact with the bush instead of cycling between the retract and extend conditions.

Shape of the bumper. The same 1-3/4 inch diameter hydraulic cylinder was used on the new machine and was attached to the head support arms (fig. 16,A) so as to produce a 6:1 ratio of movement between the cylinder and the weeding head. With a ground speed of 1.66 m.p.h. and a pump capacity of 6.0 g.p.m. at 900 r.p.m. this arrangement produced a ratio of 10 inches of forward travel for the 18 inches of lateral travel for the full stroke of the weeding head. By keeping the same 3 inch advance on the inner end, the bumper was shaped to correspond to a 13 to 18 ratio.

The link was attached to the bumper support plate so there would be 1 inch between control positions and the bumper was set so the straight section would be parallel to the row just before the valve would enter the retract position.

The new bumper had a diameter of 1 inch in place of the 1/2 inch diameter one used on the first machine.

Preliminary Test on Stakes

Difficulties encountered. After completing the machine, it was given it's first trial by using stakes in the same manner as the first machine. The first indication of this test was that the stability that was supposed to be gained by the circuit change was not present and the weeding head would hunt for position the same as the first machine. Instead of holding when it moved away from the stake, the head would reverse, move back into the stake, and cycle between the retract and extend conditions. After three or four cycles the head would settle down and hold but in regular operation the weeding head would be past the stake before this would occur.

Close observation while the control system was working indicated that the head was moving far enough after the flow of oil to the cylinder was stopped to carry the bumper through the hold position and into the extend position.

Exploratory tests. In order to have a basis for evaluating corrective measuries for this overtravel condition a marker was attached to the outer end of the weeding head (fig. 18) and the machine was driven past the stakes at three selected speeds. Overtravel and hunting occurred in all cases. It was present when the tractor was operated a 400 engine r.p.m. (.74 m.p.h.) but it was not pronounced (fig. 19,top). At 600

Fig. 18. Weeding head showing marker and string attached to the bumper.

engine r.p.m. (1.11 m.p.h.) it became quite prominant (fig. 19,cen.) and at 900 engine r.p.m. (1.66 m.p.h.) the head was completely unstable (fig. 19, bot.).

A string was tied to the bumper so the valve could be held in the retract position and the weeder was driven over open ground at the same three speeds to get a trace of the head over it's full retraction stroke. Instead of moving across the ground in a straight line, there was a definite bend in the trace in all three cases (fig. 20). This bend occurred close to the outer end of the stroke at 400 r.p.m. (fig. 20,top), farther in at 600 r.p.m. (fig. 20,cen.), and still farther in at 900 r.p.m. (fig. 20,bot.).

The shape of this trace indicated that the first energy supplied to the cylinder was being stored somewhere in the frame due to deflections

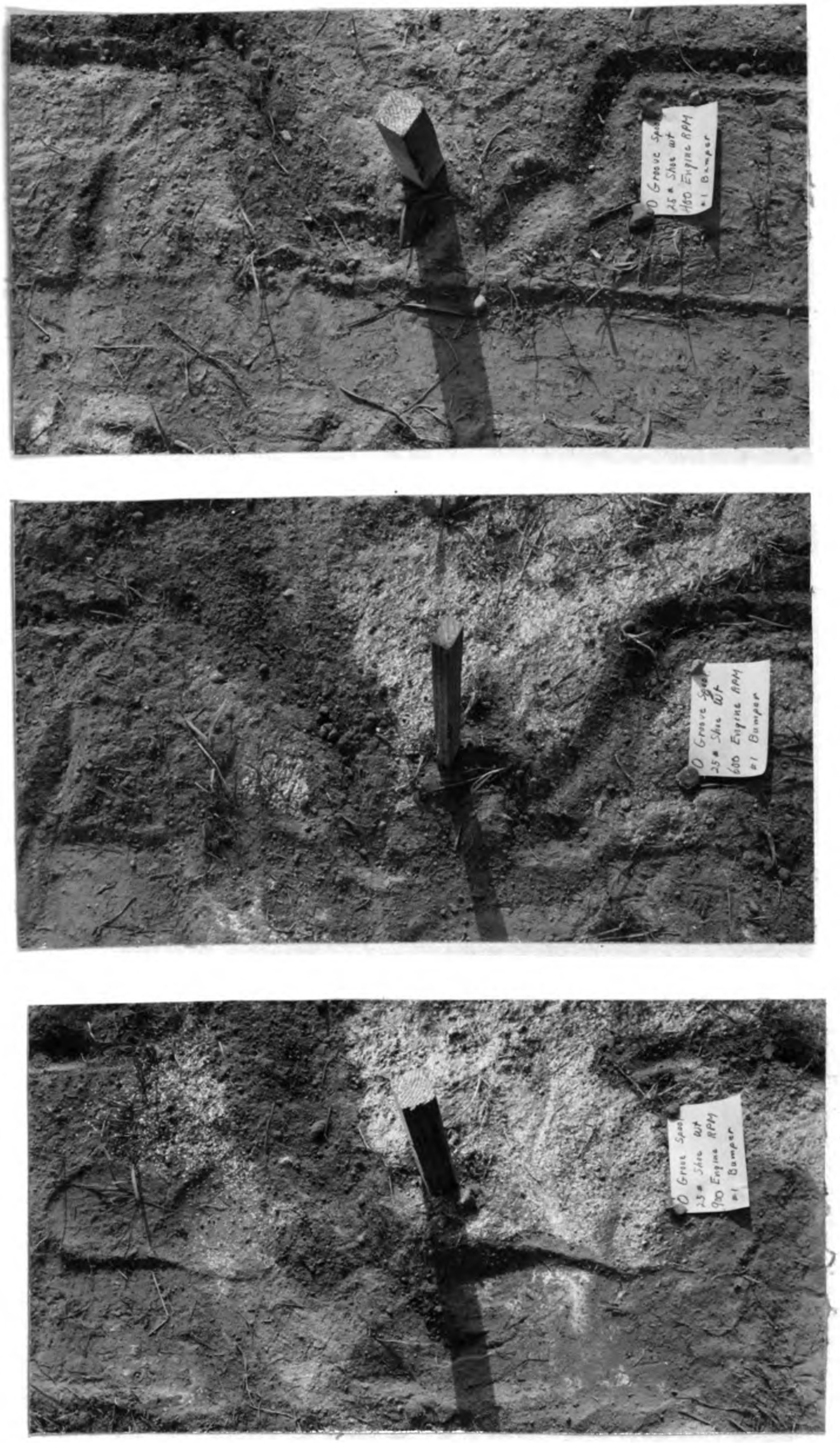

Fig. 19. Trace made by marker on the weeding head while maneuvering around a stake with machine in original condition. Top - 400 r.p.m. Center - 600 r.p.m. Bottom - 900 r.p.m.

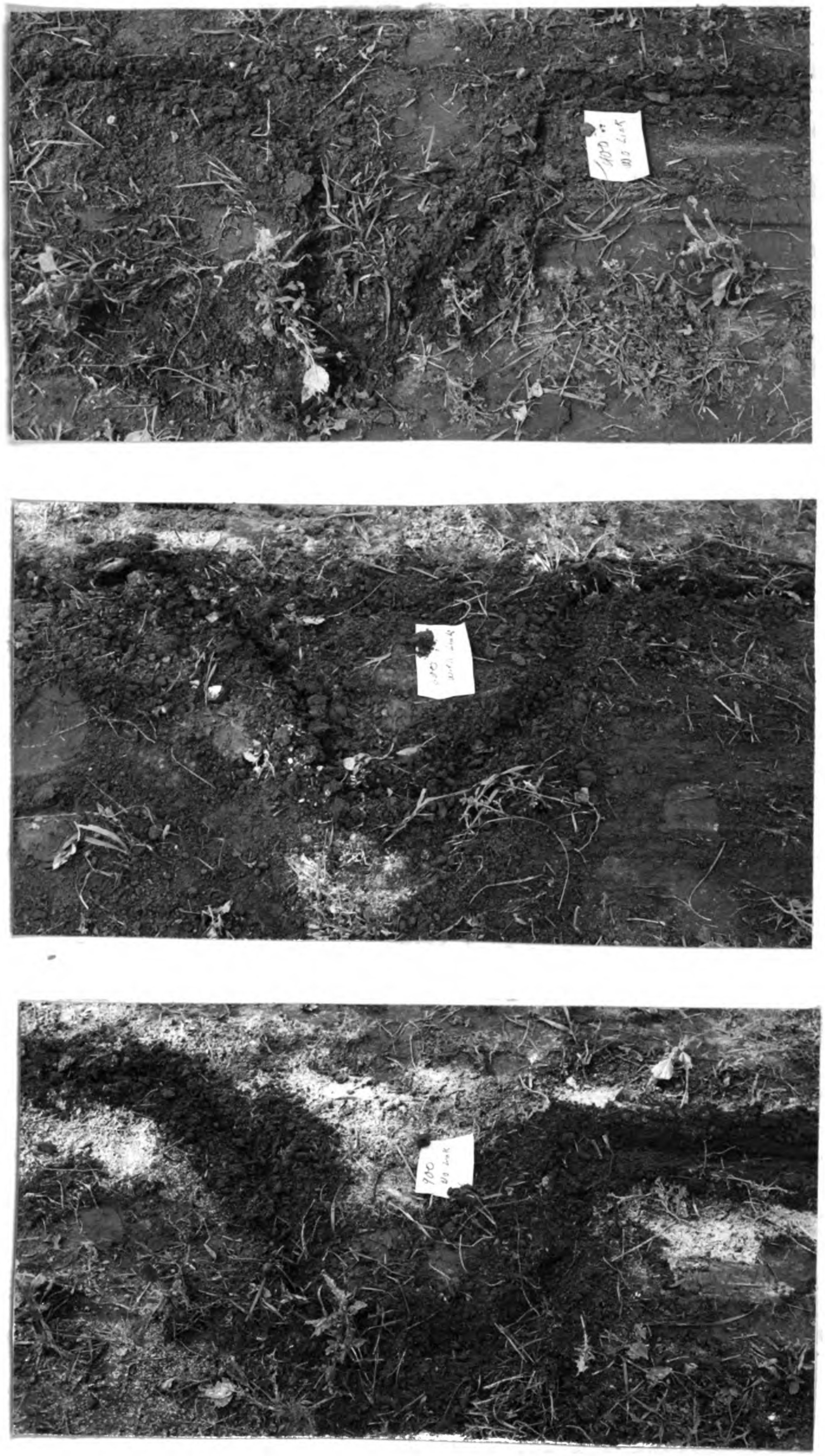

Fig. 20. Trace made by marker on the weeding head during a full retraction stroke. Top - 400 r.p.m. Center - 600 r.p.m. Bottom - 900 r.p.m.

in the arms, hydraulic lines, or some other place and was being released during the first part of the stroke so as to increase the lateral speed during this period. This condition corresponded to having a half wave of the natural frequency of vibration of the head and frame superimposed on the steady state motion. Since the absolute speed of retraction was high (23"/sec.) even at 400 r.p.m., it was quite possible to be in the range of the natural frequency of the head support arms.

This meant that the release of this stored energy from the frame was contributing to the overtravel as well as the kinetic energy of the head that would always be present and tending to carry the head past the point where the retracting force was shut off.

Corrective measures. One condition noted in these early test was that the depth shoe would lift off the ground when the head started to move and would drop back as soon as the head was under motion. Since the pivot for the head support linkage was above the head the inertia of starting would move the head outward and upward. The head would move back downward and inward just about the same time that it would be required to stop moving away from the stake. This condition was a possible source of energy storage so the weight on the depth shoe was increased from 25 pounds to 100 pounds and the runs on the stakes repeated.

Some improvement was shown by this move (fig. 21) but it was slight and under these conditions the depth shoe would bury itself in a very short distance.

Since the lifting of the depth shoe was not contributing appreciably to the overtravel of the head, other corrective measures were taken. Provision was made to increase the spread between control positions at the

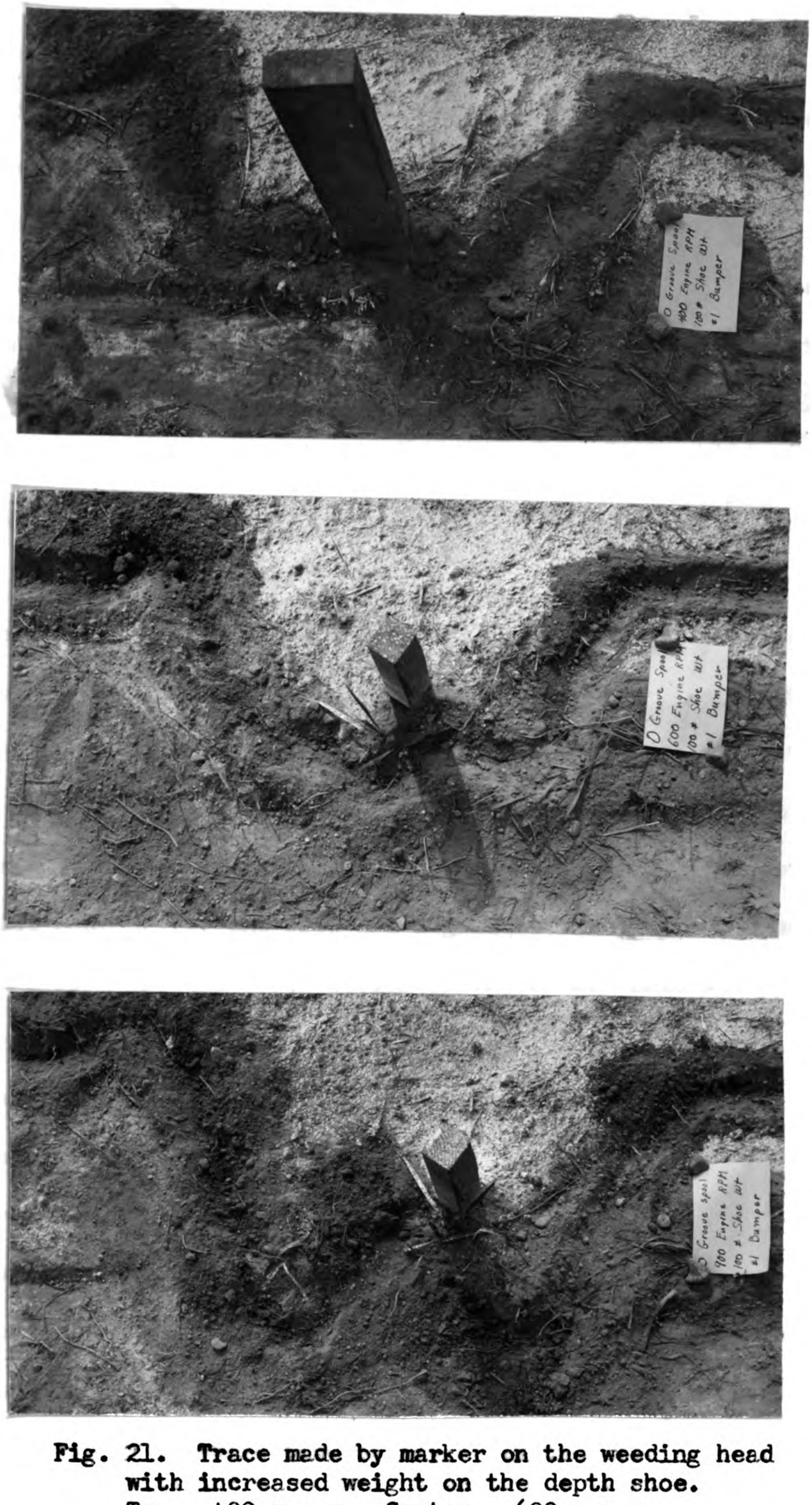

Fig. 21. Trace made by marker on the weeding head with increased weight on the depth shoe. Top - 400 r.p.m. Center - 600 r.p.m. Bottom - 900 r.p.m.

bumper from 1 to 2 inches to allow more distance for the springs to absorb the kinetic energy of the head without affecting the control valve and a stronger set of extension springs was made up (fig. 16,B) in order to absorb the kinetic energy sooner. These new springs had a load corresponding to 60 pounds at the weeding head when it was fully extended and a load of 240 pounds when it was fully retracted. The original springs were the same as the spring on the first machine and had a load corresponding to 20 pounds at the weeding head when it was extended and 80 pounds when it was retracted. These new springs were capable of absorbing all the kinetic energy of the head within the 2 inch spacing of the control positions anywhere during the stroke and at any speed up to 900 r.p.m.

The control valve was modified to incorporate tapered metering slots on the shut-off edges of the spool lands instead of the sharp edge that was first used. Instead of shutting off instantly, these slots would allow a gradual shut off of the flow and a gradual build up of pressure so as to produce a more gradual acceleration of the head. This would allow more of the first energy supplied by the cylinder to go into head movement and less into storage within the frame. These slots were arranged so they would become effective after the first 1/4 of the travel between positions, and were of such a size that at 900 r.p.m. the pressure drop through them would overcome the lowest load of the extension springs as soon as the slots became effective. One spool was made up with 4 metering slots to correspond to the light return springs and one spool was made up with 2 metering slots to correspond to the heavy springs.

The weeder was driven past the stakes again using the heavy springs, the two groove spool, and the extended bumper positions (fig. 22). At

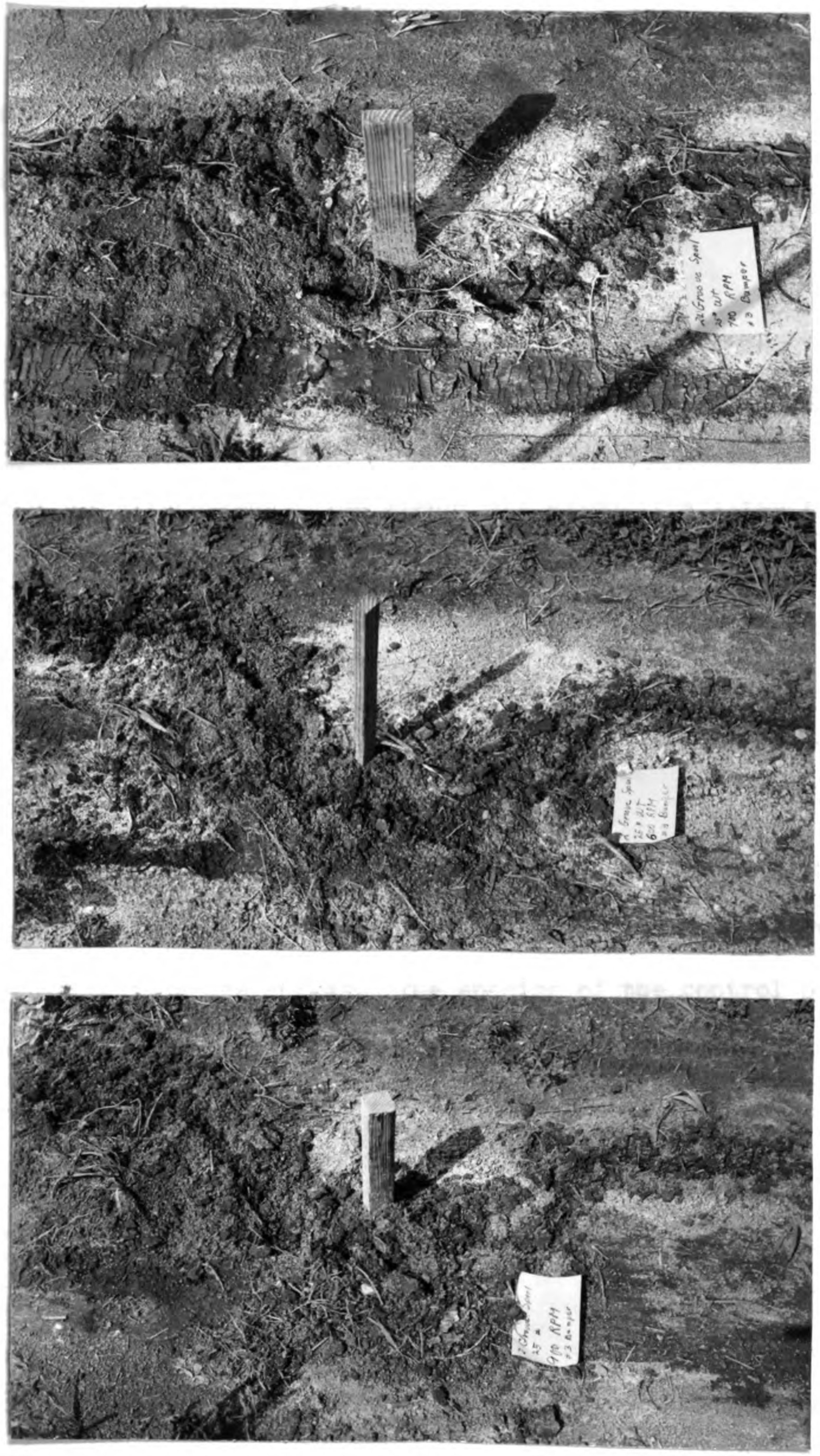

Fig. 22. Trace made by marker on the weeding head with increased spread on the control positions, metering slots in the valve spool, and increased load in the extension springs. Top - 400 r.p.m. Center - 600 r.p.m. Bottom - 900 r.p.m.

400 r.p.m. the control action was smooth with no sign of overtravel (fig. 22,top). At 600 r.p.m. the control action was still (fig. 22,cen.) smooth. At 900 r.p.m. there was some overtravel (fig. 22, bot.) on the initial retraction but it was not far enough to move through the hold position and the head did not cycle.

First Field Test

Conditions of the test. The weeder was given it's first field test on Aug. 23, 1952 at the Triangle Blueberry Farm, South Haven, Michigan. The weather was clear and the soil was dry. The rows were moderately hilled and were quite weedy.

Performance of the weeder. The weeder was first operated with the light springs, the four groove spool, and the 1 inch spacing of the control positions. Operation with the weeder working in the soil provided a damping effect on the system and the cycling was not as severe as it was in the test on the stakes. The spacing of the control positions was increased to 2 inches and a noticable decrease in the cycling resulted. If the tractor speed was kept below 600 r.p.m. the control system would move the head around the bushes about half the time without overtraveling enough to reverse the head.

The presence of weeds in the row during these tests gave a better indication of the ground coverage characteristics of this weeder with the new control circuit. The tractor was driven between the rows with the depth shoe traveling just beside the stumps (fig. 23). Before any weeding was done the row was well filled with weeds (fig. 24). Going one way (fig. 25) cleaned out one side and the reverse pass (fig. 26) completely cleaned out the row area.

Fig. 23. The new weeder being driven between rows of bushes.

Fig. 24. Row area before any weeding was done.

Fig. 25. Row area after being weeded from one side.

Fig. 26. Row area after being fully weeded.

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Fig. 27. Path of the weeding head on the approach side of a bush showing the improved ground coverage.

With the increased retraction speed the head would move in much closer on the approach side and leave a smaller area unweeded at the base of the bush (fig. 27).

Not only were the light springs inadequate to keep the head from cycling but they tended to be slow in extending the head back into the row after the bush had been passed. Substitution of the heavy springs and the two groove spool completely stopped the cycling of the head but provided a more severe extension action at the same time. This severe extension would often push the head into the bush as the end of the bumper moved past the outermost shoots. This condition was caused by the fact that as the bumper left the outermost shoots it would move forward as well as outward. This would take the bumper away from the rear corner of the hood and leave this area without a bumper to hold the head away from the bush. As long as the extension speed was moderate or slow the head would pass the bush without hitting it but the heavy springs would move the head too fast to clear the bush in all cases.

Second Test on Stakes

Since the first field test indicated that one set of extension springs was too light for proper operation of the weeding head and the other set was too heavy, an intermediate set was made up that had a load of 30 pounds with the head extended and a load of 120 pounds with the head retracted. A new valve spool was also made up with the metering slots proportioned for these springs and a new bumper was made up that had a section turned in toward the tractor at the rear corner of the hood to extend the point at which the bumper would swing free.

This arrangement was checked on the stakes in order to compare it to the other arrangements (fig. 28). At 400 r.p.m. (fig. 28,top) and 600 r.p.m. (fig. 28,cen.) the control system worked as smoothly as it had with the heavy springs. At 900 r.p.m. (fig. 28,bot.), however, the system was not as stable and there was some cycling.

Second Field Test

Conditions of the test. The weeder was field tested again at the Triangle Blueberry Farm, Aug. 30, 1952 one week after the first test. The field conditions were the same as in the previous test.

Performance of the weeder. The weeder was first tested with the intermediate springs and valve and the extended bumper (fig. 29). This arrangement provided almost perfect control of the weeding head as long

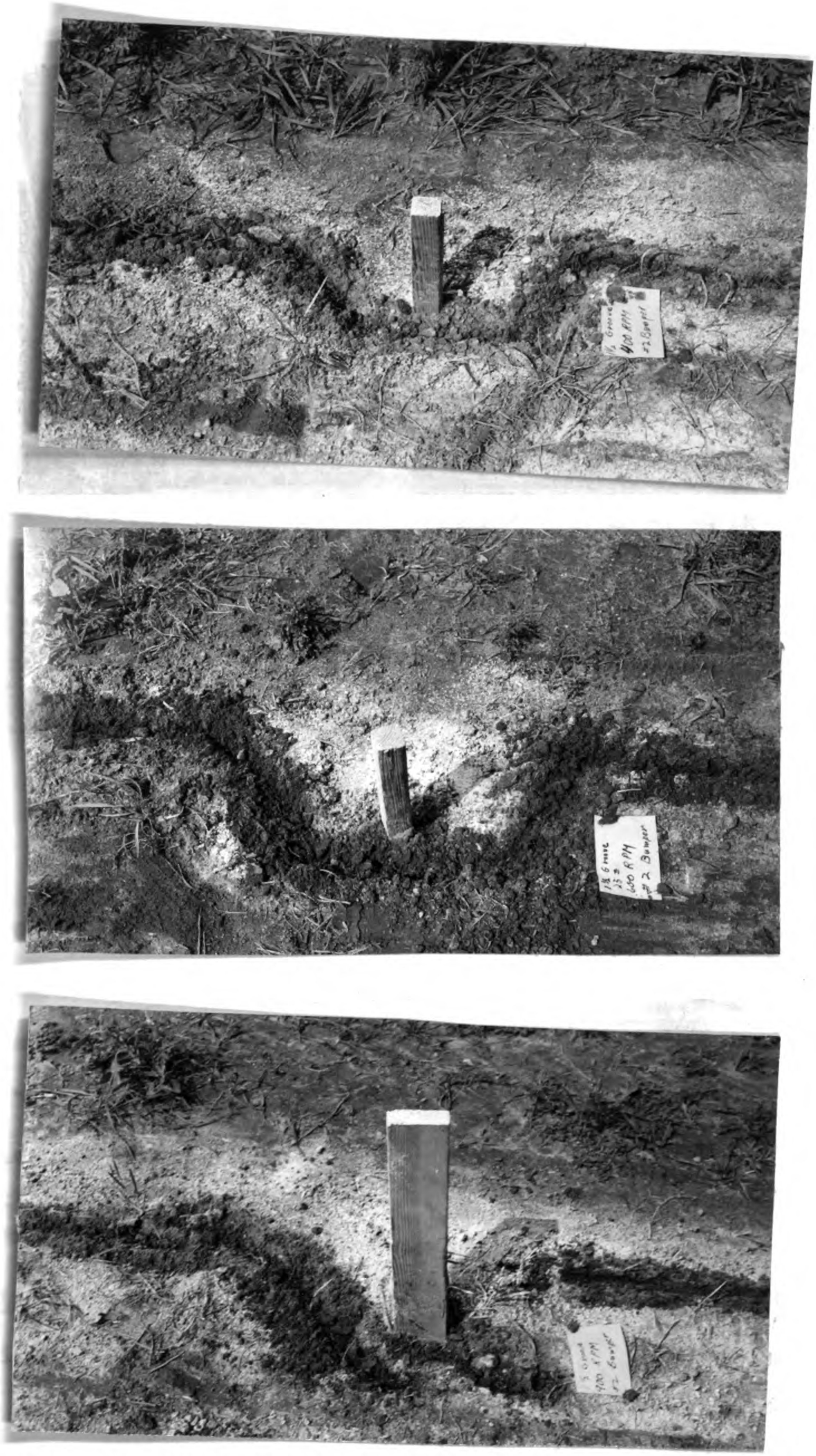

Fig. 28. Trace made by the marker on the weeding head with intermediate springs and metering slots. Top - 400 r.p.m. Center - 600 r.p.m. Bottom - 900 r.p.m.

Fig. 29. Weeder being operated with the extended bumper.

as the tractor was operated below 600 r.p.m. The tractor could not be operated above this speed, however, without the control system becoming unstable and cycling starting to occur.

The heavy springs were tested with the extended bumper but it did not completely keep the head from being pushed into the bushes.

Evaluation of the Machine

<u>Control system.</u> After the proper corrective measures had been taken, observations indicated that the new control system with the hold position provided much improved control. The higher retraction speed produced better ground coverage and the control system changes were satisfactory within the limited operating range of idle to 600 r.p.m.

The larger diameter bumper did not bark the bushes even though the hold out spring had to be stronger because of the higher weight and inertia.

The complete weeder. The weeder as a unit could only be considered partially successful since there was a definite limit on the speed at which it could be operated. The performance of the control system was more responsive to speed changes than to changes in the control elements which indicated that the source of the overtravel was tied very closely to the weight of the weeding head and the natural frequency of the head and frame as a unit.

The depth regulation system was very effective and no trouble could be ascribed to this source.

The 18 inch total movement of the head proved to be adequate especially since the depth shoe served as an indicator for keeping the weeder properly oriented between the rows.

SUMMARY

Conclusions

Although two different weeders were used for testing them, the two control systems were of the same basis type and evaluation of their performance in the field leads to the following conclusions:

1. An automatic control system can be made to satisfactorily maneuver the weeding head around bushes without assistance from the operator.

2. Either of the control systems developed in this investigation is adequate to maneuver the weeding head around bushes but the control system incorporating the hold position, although more complex, is more satisfactory and should be used unless the application will not warrant the additional expense.

3. In order to have satisfactory ground coverage, the retraction speed of the weeding head should be equal to or greater than the forward speed of the tractor.

4. Accurate depth control is necessary to keep the bumper out of the dirt and the system functioning properly.

5. The sensing bumper must be provided with means for retracting the head sooner than theoretically necessary in order to compensate for lag in the control system.

6. When using the control system incorporating the hold position, the inertia of the weeding head and the flexability of the frame both contribute to overtravel and unstability in the system and must be considered when planning the application and setting limits for it's use.

Recommendations for Further Study

Since there was a limit to the speed at which the second control system would give smooth control of the weeding head, future study should be directed toward the requirements for raising this limit so that a weeder using this system could be operated at a higher speed. The weight of the weeding head, the stiffness of the frame, and the damping effects of the soil are factors that should be evaluated for their effect on the control system's stability.

A control system based on a double acting cylinder could provide a more positive control of the hydraulic cylinder and should be investigated.

Different types of weeding heads and their effect on the control system is another area where further study should be made.

Since it did not always function properly on irregular shaped bushes, future study is needed on the requirements of the bumper as a sensing element. Greater length, more surface area, and other systems of mounting are possible approaches.

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