# DESIGN AND TESTING OF AN AUTOMATIC HEIGHT CONTROL SYSTEM FOR A FLAIL-TYPE TOPPER

by

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# ABSTRACT

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Some Manitoba onion growers field top and windrow their onions in order to cut down the bin curing cost. A flail topper used at Portage la Prairie without automatic height control or a top-lifting device did not do an acceptable topping job.

Field tests were started in 1970 and the data were analysed. The correctly topped bulbs were only 19 percent while the damaged bulbs were 3 percent. The remaining 78 percent of the bulbs were either untopped or had tops which were too long. Another operation which cost the grower time and money was required.

An automatic height control system was fitted on this flail topper in 1971. A flow control valve with a sensor and hydraulic control cylinders was used. The topper was first tested on a laboratory test stand and then in the field. The automatic height control worked satisfactorily in the field.

The top-lifting cones tried were not suitable to lift the lodged onion tops. However for this flail topper 10 inch long flail hammers for the outside rows and 8½ inch long flail hammers in between the rows were found suitable to cut most of the green tops.

Field data were taken in 1971 with automatic height control and were analysed. Correctly topped bulbs amounted to 74 percent while damaged bulbs were only 2 percent. The untopped bulbs were only 7 percent and the bulbs with tops greater than 3 inches were 17 percent. Statistical analysis indicated that the onion topping with automatic height control was significantly better than the onion topping with manual height control.

There was a definite relationship between the topper travel speed and power take-off speed in order to do an efficient topping job. Power take-off speeds of 680 rpm and 880 rpm at a topper travel speed of 1.45 mph and 2.2 mph respectively were found adequate.

# ACKNOWLEDGEMENTS

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Laboratory and field testing of this project was an enormous job. I sincerely appreciate the help and efforts of Mr. A.E. Krentz, Mr. R.H. Mogan and Mr. W. Stettler. I would also like to acknowledge the assistance of summer students of the Agricultural Engineering Department during the collection of field data. Thanks are also due to Mrs. I.A. Hamel for her excellent job of typing and arranging the manuscript.

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# CHAPTER 1

# INTRODUCTION

An average of 650 acres of cooking onions (Allium cepa) are grown annually in the province of Manitoba. The annual production averages 10 million pounds. The approximate value of this vegetable crop is 0.4 million dollars representing about 20 percent of the total income from vegetables in Manitoba (13, 14)*.

The harvesting operation in Manitoba varies from a completely hand-labour operation to a fully mechanized opperation. Harvesting by hand labour is the most common method in Manitoba. The success of this harvesting method depends upon the availability of suitable labour and favorable weather conditions during the field curing period. The average labour costs for this harvesting method are $200 per acre. This represents approximately 50 percent of the total production costs (2). Unfavorable weather conditions that can occur during the harvest season can lead to costly storage losses due to the greater chance of onion infection by disease organisms.

Labour is the most expensive single input in vegetable production. The high cost of labour coupled with the acute shortage of labourers is the main driving force behind mechanized vegetable production. It is predicted that vegetables the production of which cannot be mechanized in the

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*Numbers in parentheses refer to appended references.

next ten years will be too expensive and will disappear from consumer's tables.

To reduce the direct harvest cost and shorten the harvest season, one grower at Portage la Prairie has used a flail-type topper to top the bulbs as they stand in the beds. This topper tops one onion bed at a time. Each onion bed has four rows of onions spaced 14 inches apart. After a few days of field curing the topped bulbs are dug and windrowed. A modified potato digger lifts the field cured bulbs from the windrow and delivers them to a truck for hauling to storage.

In the summer of 1970 field studies were started in order to determine the performance of this topper. The preliminary data were analysed. It was found that this topper was topping[a] only 19 percent of the bulbs. The bulb damage was 3 percent. The remaining 78 percent of the bulbs were either untopped or had tops which were too long (Table 1.1). Evidently precautions were taken to avoid bulb damage at the expense of a poor topping job.

The reasons for poor topping performance were investigated. Since 50 percent or more of the onion tops were lodged at harvest time and because the topper had no top-lifting device the topper simply passed over the bulbs without topping them. A second reason was that there was no automatic control of the cutting height. If the flail was

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[a] Bulbs with tops $\leq$ 2 inches were classifed as topped in 1970.

too low the bulbs were sliced and if the flail was too high the bulbs (and tops) were missed completely.

The objectives of this research project were:

1. To design and test an automatic height control system so that the topper would work at a preselected height above the onion bed irrespective of the changes in the ground contour.
2. To design and test a top-lifting device to lift the lodged onion tops so that topping can be done more efficiently.

Table 1.1

Onion Topping Results (1970)
(manual height control)

Location: Portage la Prairie

Condition of tops: green, lodged

Topper travel speed: 2.49 mph

Power take-off speed: 540 rpm

Topped bulbs[a] = 18.81%

Damaged bulbs = 2.71%

Bulbs with tops > 2 inches = 44.03%

Untopped bulbs = 34.45%

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[a] Bulbs with tops ≤ 2 inches.

# CHAPTER 2

# REVIEW OF LITERATURE

## 2.1 Manual Harvesting

Until recently nearly all of the onions grown in Manitoba have been harvested with hand labour. This harvesting method consists of four separate stages. These stages are:

i) Lifting and undercutting The bulbs are lifted either by hand or by a modified potato digger. The roots of the hand-lifted bulbs are removed using a long sharp knife.

ii) Initial curing and topping The initial curing period varies from 5 to 10 days depending upon the weather conditions. The objective is to dry the succulent onion tops in order to cut down the curing cost. After this initial curing period the tops are removed using a long sharp knife.

iii) Field curing The topped bulbs are put into bags and left in the field to cure. Depending upon the weather conditions 5 to 10 days is the general practice.

iv) Field loading Field cured bulbs are loaded and transported to storage buildings.

## 2.2 Development of an Onion Harvester

Manual harvesting costs average approximately 50 percent of the total production costs. Also the success of this harvesting method depends upon the availability of suitable labour and the occurrence of favorable weather conditions during the field curing period. If weather conditions during the harvesting period are unfavorable, the producer runs the risk of costly storage losses due to greater chance of onion infection. In order to reduce the direct harvest cost and shorten the harvesting period many attempts have been made to use various mechanical devices in the harvest operation.

Onion growers in Michigan have been using potato diggers for lifting bulbs but use different topping methods. These topping methods are:

i) Topping by hand labour.

ii) Counter-rotating rollers which pull the tops between the rollers and pinch them off (Figure 2.1).

iii) An air blast to lift the tops as the bulbs are elevated and the lifted tops are then removed using a rotary cutter positioned as shown in Figure 2.2.

iv) Counter-rotating cylinders which position the bulbs and have flights which direct the bulbs to a cutter (Figure 2.3).

A machine to harvest onions successfully should achieve the following general functions (not necessarily in this order):

i) Dig the bulbs from the soil.

ii) Lift the bulbs.

iii) Separate the bulbs from the soil and trash.

iv) Remove the tops.

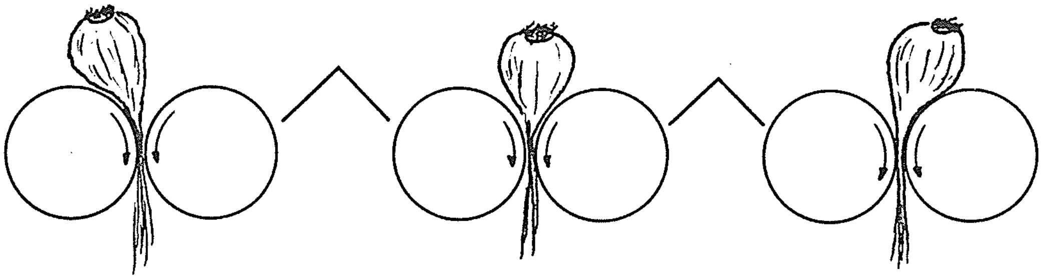

Figure 2.1 Schematic of a roller topper.

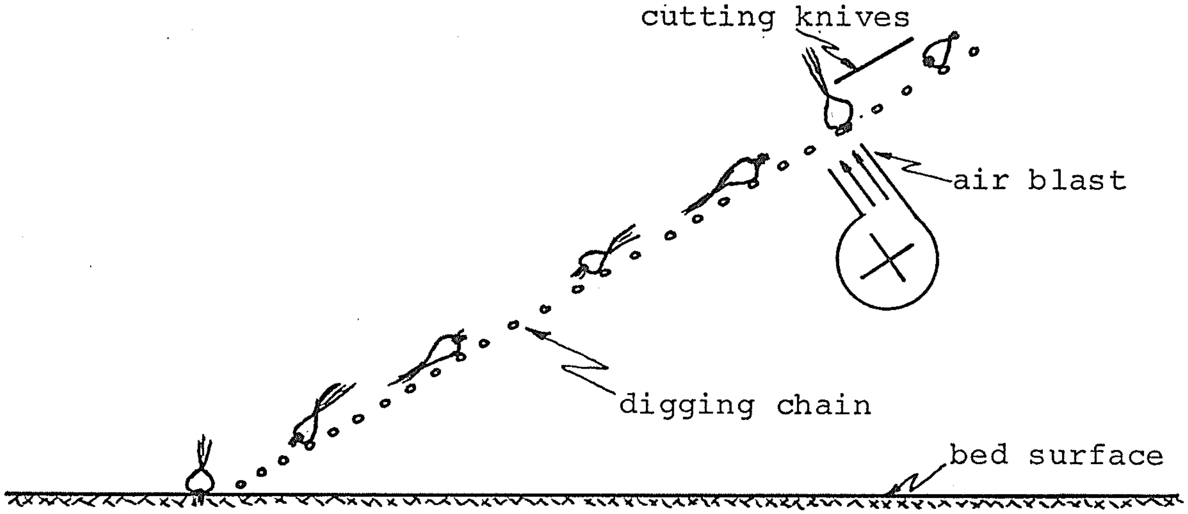

Figure 2.2 Schematic of an onion harvester using an air blast for top lifting.

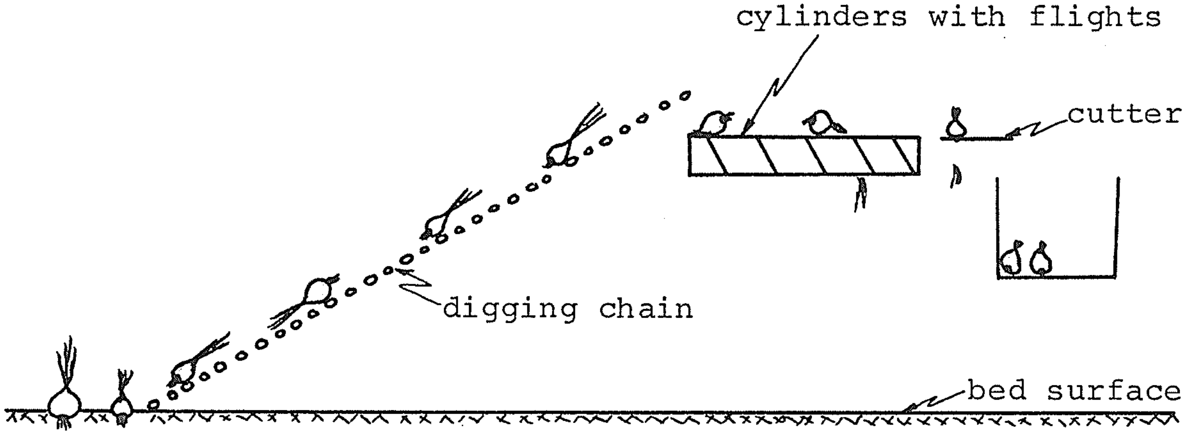

Figure 2.3 Schematic of a roller used with a cutter.

v) Convey the bulbs to a temporary storage.

An experimental machine using endless circular cross-section belts for lifting the bulbs was developed by Lorenzen in California (12). A narrow wedge-shaped digger and two endless belts were used to lift the bulbs. As soon as the digging blade cuts the roots of the bulbs and loosens the soil, the rubber belts lift the bulbs by grasping their tops. The bulbs are then elevated and guided to rotary topping discs. Topping was not uniform since the lifting belts cannot grasp all the bulbs at the same height above the neck. An additional function of picking up lodged tops was added to make the harvester more efficient. A similar machine for harvesting gladiolus corms was tested in Oregon by Cropsey (4). This method of harvesting has several advantages such as gentle handling of the bulbs, ease of separating the bulbs from clods, and ease of positioning the bulbs for topping.

LePori and Hobgood, at Texas Agricultural and Mechanical University, built an onion harvester in 1968 (10). They used the belt-lifting principle developed by Lorenzen and Cropsey because of its apparent advantages.

A schematic diagram showing the principles of lifting and topping for an experimental machine are shown in Figure 2.4. As the machine travels down the row, lodged tops are lifted by floating lifting shields in combination with rotating paddles. The shields lift and align the tops above the bulbs and the paddles direct the tops into the lifting

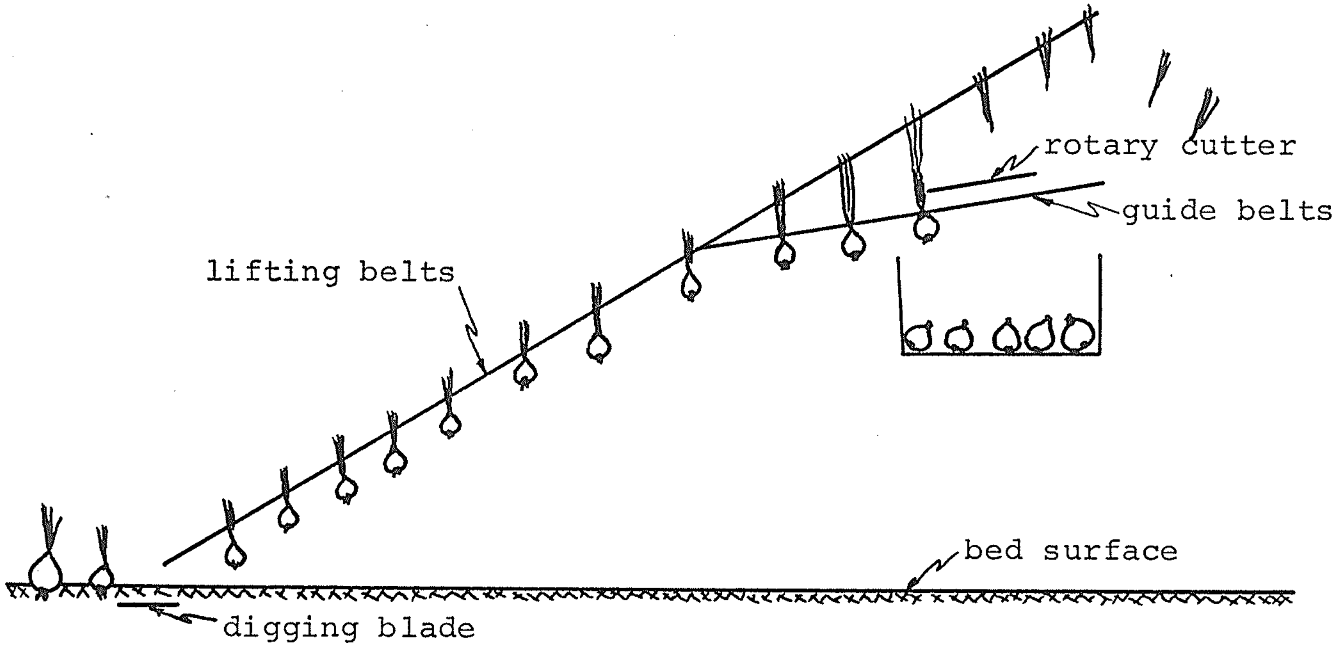

Figure 2.4 Schematic of an onion harvester with belt-lifting principle.

belts. A digging blade cuts the onion roots and loosens the soil as the lifting belts grasp the onion tops. With the onion tops held between the lifting belts, the bulbs are elevated at an angle of 30 degrees to the ground surface until they contact two guide belts. These belts position the bulbs for accurate topping by a rotary cutter placed above the belts. The topped bulbs are then loaded into bulkbins or wagons.

The addition of guide belts improved the topping characteristics because of the wedge action for positioning and guiding the bulbs. Harvesting efficiency generally exceeded 90 percent with less than 2.5 percent tops longer than 2 inches. However, automatic controls are needed to control the digging blade to avoid slicing of the bulbs.

## 2.3 Topper

Carson and Williams (3) at the University of Idaho worked on several steps to mechanize onion harvesting. They built a tined-wheel pickup unit to lift and align lodged tops so that they could be removed accurately by a horizontal rotary blade. Two tined wheels per row were used to pickup the tops. They were mounted so that they could ride on the ground with provisions for lifting when turning and backing.

Preliminary tests were conducted in August 1966. During these tests the tined wheels became plugged with tops. Another difficulty was experienced in locating the most desirable operating position for the top lifters. The lifters were operated at various angles in the direction of travel. The most acceptable job was done with the lifters making an angle of 25 degrees with the direction of travel and inclined away from the onion row at an angle of 5 degrees with the vertical.

These adjustments worked. But the problems of tops accumulating on the rear of the machine and on the lifter wheels reduced the field capacity of the topper to a level that demanded further research.

Another problem in the harvest trials was the inability to distinguish true machine damage from sources other than the lifter wheels and topping blades. As the tractor wheels and front gage wheels of the topper passed over the onion tops the onions were loosened and some were completely pulled out of the ground. A lifting action on these onions by the top-lifter wheels caused the onions to become entangled in the lifter tines. The result was a rapid buildup of tops in the wheels. The efficiency of the lifter wheels became unacceptably low.

The tined wheels provided a satisfactory method for picking up lodged onion tops. But the topper needs to be modified so that it can dispose of the tops better after they are removed.

The direct mechanical damage associated with this topper was about 2 percent.

## 2.4 Onion King

In the fall of 1971, Oppel Harvester Incorporated marketed a new mechanical onion harvester (15). Its trade name is Onion King. It is claimed that the topping efficiency is 97 percent with average length of cut tops 2 inches or less.

The Onion King lifts, tops and windrows two beds at a time or tops and windrows previously lifted onions. A rod-weeder type digger lifts the bulbs and a revolving paddle wheel keeps them from bunching ahead of the machine. Brushes positioned at the top of the primary digger chain trap rocks and clods and allow cleaned bulbs to settle gently onto the topping rolls while trash is dropped out. The tops of the bulbs flowing over the topping rolls are cut off by four rotary lawn mower type blades. A rear chute then places the topped bulbs in tight windrows.

# CHAPTER 3

# DESIGN AND ANALYSIS

## 3.1 Problem Stated

The biggest disadvantage associated with the flail-type topper used at Portage la Prairie was the lack of height control for the topping unit. If the topper wheels or the tractor wheels ran in a deep wheel rut the flail was lowered. The result was that the flail hammers started cutting the bulbs. If the topper wheels or tractor wheels passed over a bump, the flail moved up. The result was that the tops were missed altogether.

Another inherent disadvantage was that there was no top-lifting device. Since 50 percent or more of the tops were lodged at harvest time, they were left uncut when the topper passed over them.

## 3.2 Objectives

The objectives of this study were:

1. To design and test an automatic height control system for the flail-type topper.
2. To design and test a device to lift lodged onion tops so that topping can be done more efficiently.

## 3.3 Automatic Height Control System

The function of the automatic height control system is to enable the operator to top at a pre-selected height above the onion bed. With manual control the accuracy was often poor and the operator had to be alert to avoid onion damage. Carelessness resulted in the flail hammers digging into the ground and possibly damaging the topping unit.

Under field conditions the height of the topping flail was difficult to determine. It was impossible to maintain the desired topping height while travelling at fast field speeds. Topping too high and leaving most of the tops uncut requires another operation to remove the tops. This costs the grower time and money.

There are two areas of design for the height control system, the hydraulic components and the sensing linkage.

3.3.1 Hydraulic components The hydraulic circuit for height control consisted of a 4-way single spool valve and a pair of double-acting height control cylinders mounted on the topper frame as shown in Figure 3.1. The up and down movement of the spool directed oil to either side of the double-acting cylinders to raise or lower the topper.

A parallel cylinder circuit was used since the topper frame was rigid. The height control cylinders raised or lowered the topper uniformly irrespective of the fact that the weight on the left wheel was greater than the weight on the right wheel (Table 3.1).

3.3.2 Sensor design The design of the sensing linkage for sensing the height over the ground was equally as important as the hydraulic system in obtaining satisfactory height control. It senses the change in the ground contour

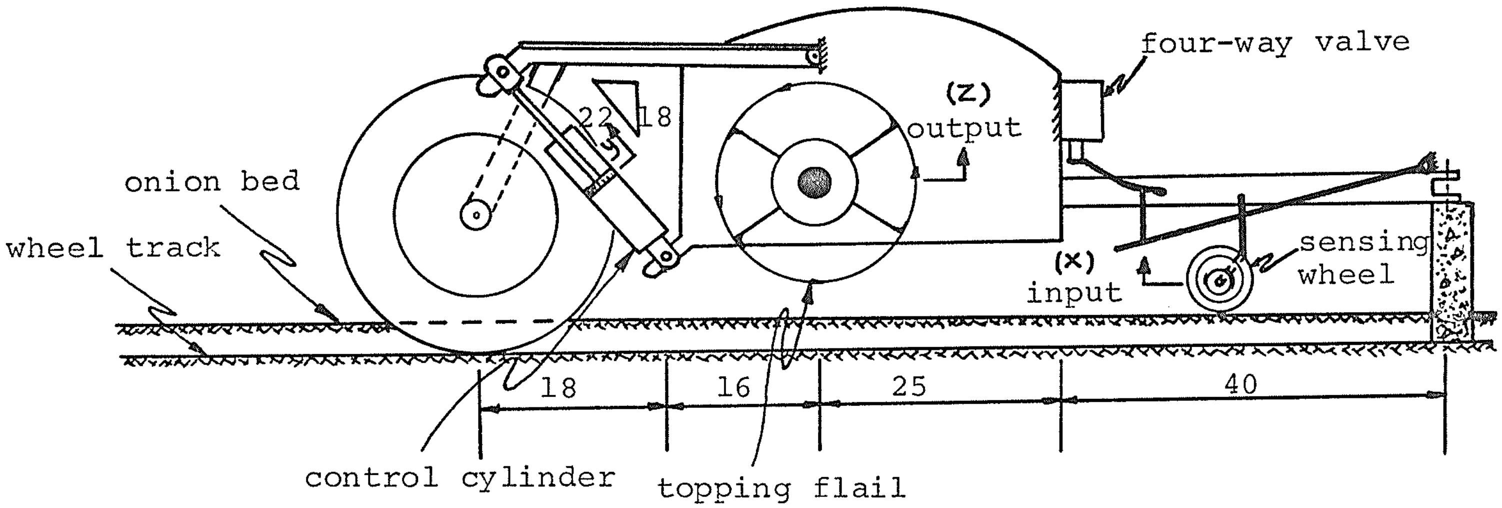

Figure 3.1(a) Schematic of the flail topper illustrating 4-way single spool valve and control cylinders.

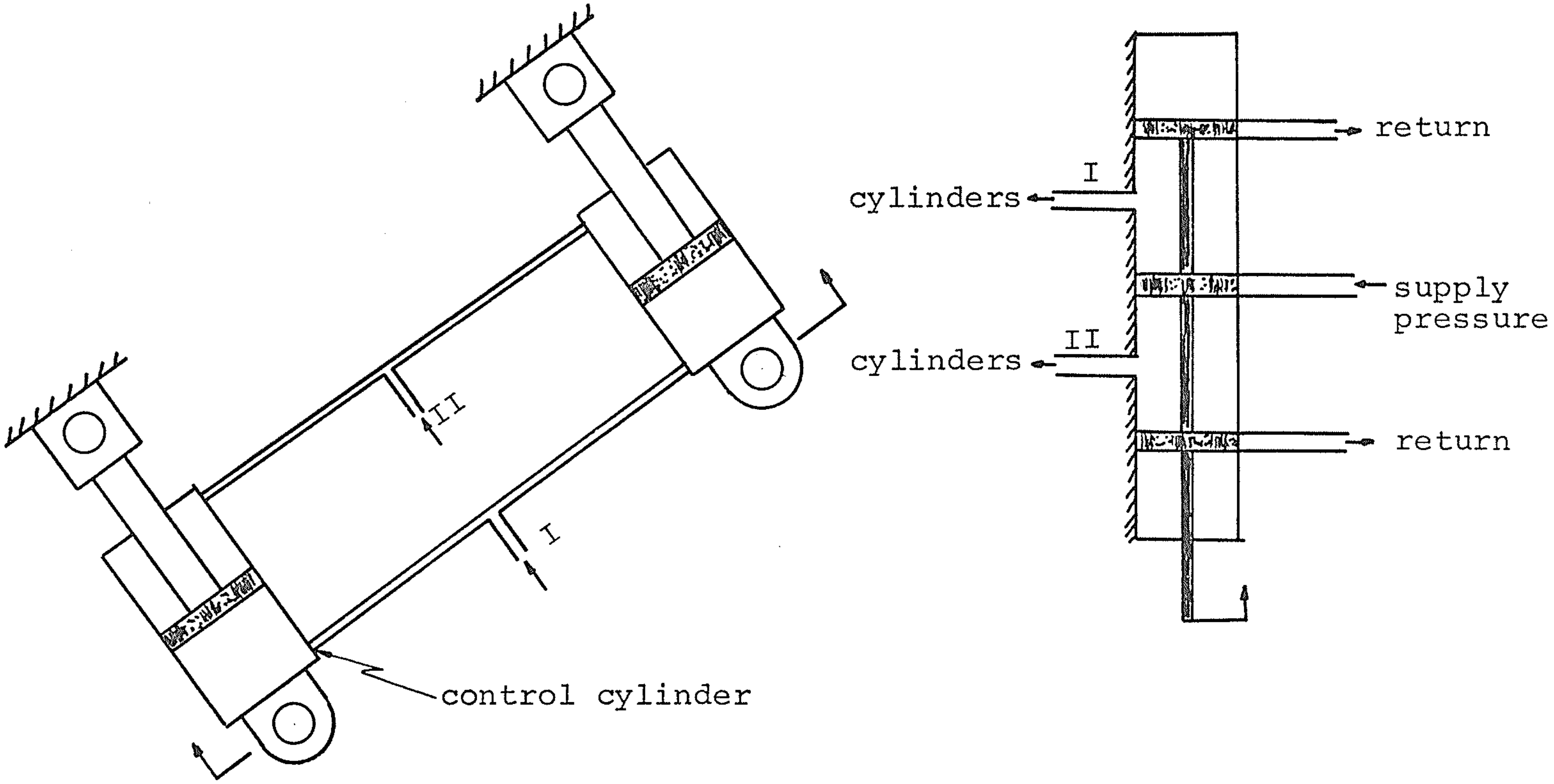

Figure 3.1(b) Schematic of the 4-way single spool valve and the parallel control cylinders circuit.

Table 3.1

| Weight of the Flail Topper | | |
|---|---|---|
| Weight on right wheel | = | 315 lbs. |
| Weight on left wheel | = | 433 lbs. |
| Weight at tongue | = | 559 lbs. |
| Total weight of the topper | = | 1,307 lbs |

and activates the spool valve to raise or lower the topper. The sensor was designed and mounted ahead of the flail as shown in Figure 3.1. The height between the ground and topping flail was sensed by a wheel that rode on the ground between two onion rows.

## 3.4 Analysis

When the sensing wheel receives an input as shown in Figure 3.1, the valve spool is moved upward and the oil flows to the upper side of the piston. The piston rod retracts and eventually raises the topper. To lower the machine, the spool is moved downward.

For a constant pressure drop across the valve, the rate of flow of oil to the piston is proportional to the area uncovered by the valve. Thus the flow of oil is proportional to the displacement of the valve spool. Therefore

$$q = k_v \cdot x \qquad (3.1)$$

where

$q$ = flow of oil, in$^3$/sec.

$x$ = displacement of the sensing wheel, in. (valve spool displacement is directly proportional to x)

$k_V$ = valve port coefficient, $in^2/sec$.

The rate of flow q into the hydraulic cylinders is equal to the rate of change in volume of the cylinders. The volume is equal to the piston velocity times the effective area of the piston.

$$q = A.\dot{Y} \tag{3.2}$$

where

$q$ = flow of oil, $in^3/sec$.

$A$ = effective area of the piston, $in^2$

$\dot{Y}$ = velocity of the piston, in/sec.

Since the body of the valve is attached to the machine it also moves up to close the flow to the cylinders. The system then becomes a closed-loop system. Because of the geometry in Figure 3.1 the block diagram of the system becomes as shown in Figure 3.2.

The kinematics of the system were analysed since relative displacements of the sensing wheel and the topping flail were the input and output variables respectively. This approximate analysis was chosen to reduce the complexity of the solution of the second order differential equation of motion with complex roots. Laboratory testing of the system was used to verify the kinematic analysis.

The following set of equations is obtained:

$$(x-b)\frac{18}{22}\,\frac{65}{81}\,\frac{K_V}{AD} = Z \tag{3.3}$$

$$\frac{40}{65}\,Z = b \tag{3.4}$$

where

Z = output of the topping flail, in.

b = feedback signal, in.

D = operator symbol which indicates differentiation with respect to time

Eliminating b from the above equations gives:

$$(X - \frac{40}{65}Z)\,\frac{18}{22}\cdot\frac{65}{81}\,\frac{k_v}{AD} = Z \qquad (3.5)$$

$$\frac{Z}{X}(D) = \frac{65/40}{(2.48\,\frac{A}{k_v}\,D+1)} \qquad (3.6)$$

Equation 3.6 is compared with the standard first-order transfer function which is:

$$\frac{C}{R}(D) = \frac{k}{(\tau D+1)} \qquad (3.7)$$

where

$\tau$ (time constant) = $2.48\ A/k_v$ secs.

k (sensitivity or gain) = 65/40

In use the gain was adjusted to 1.0 through the mechanical linkages shown in Figure 3.1.

Since the system obtained is analogous to the first-order system, the transient response depends upon $\tau$, the time constant. If $\tau$ is small the system approaches its steady-state condition very fast and if $\tau$ is large more time is required to reach steady-state conditions (Appendix C).

Analysis also indicates that $\tau$ in turn depends upon A, the effective area of the piston and $k_v$, the valve-port coefficient. An increase in $k_v$ and a decrease

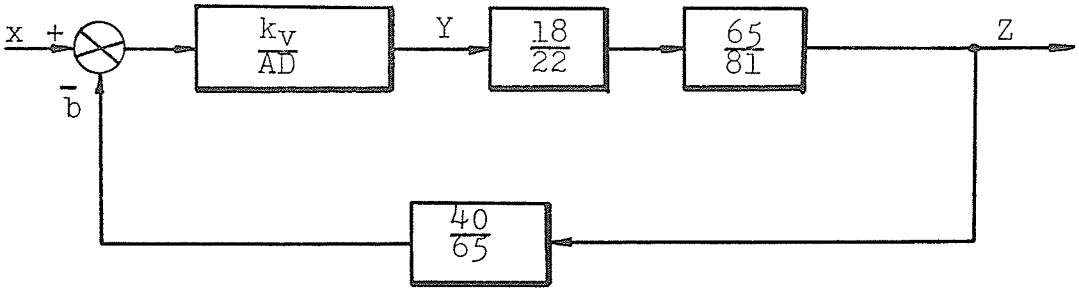

Figure 3.2(a) Block diagram of the closed-loop system with the 4-way valve.

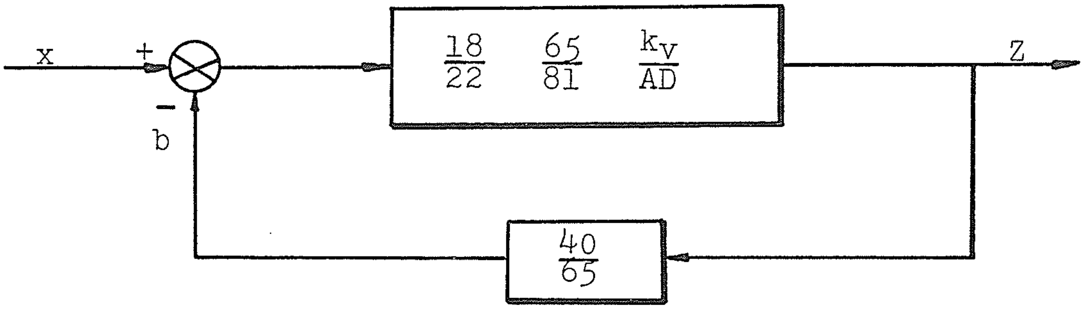

Figure 3.2(b) Combination of forwardpath transfer functions.

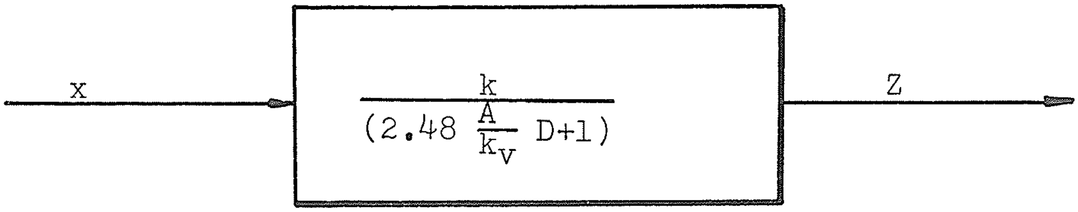

Figure 3.2(c) Simplified block diagram of the system.

in A results in a quick response. That is, anything done to decrease the absolute value of $A/k_V$ increases the rate at which transients approach zero. However, it must be noted that the steady-state operation is poorer for larger $k_V$. Therefore a compromise between these two conflicting factors was achieved. Control cylinders of 2 inch bore with 1 1/8 inch diameter rod were used.

## 3.5 Alternative Design

Another arrangement as shown in Figure 3.3 was tried. A 4-way valve with tapered lands was modified to work as a flow control valve. It used a signal from the sensing wheel and controlled the oil flow to the height control cylinders for automatic control.

The flow is directed to the control valve as shown in Figure 3.3 and across a tapered land in a fixed orifice. The oil then passes out of the control valve back to the reservoir.

The control cylinders were connected to the control valve as shown in Figure 3.3 but worked as single-acting cylinders in this case. A parallel circuit was used since the machine frame was rigid.

In the equilibrium condition the pressure in the valve chamber and in the control cylinders is the same. The operation of the mechanical linkage on the spool determines whether the oil goes to the control cylinders to raise the flail or back to the reservoir to hold or lower the flail. If the tapered land is forced into the fixed orifice, the

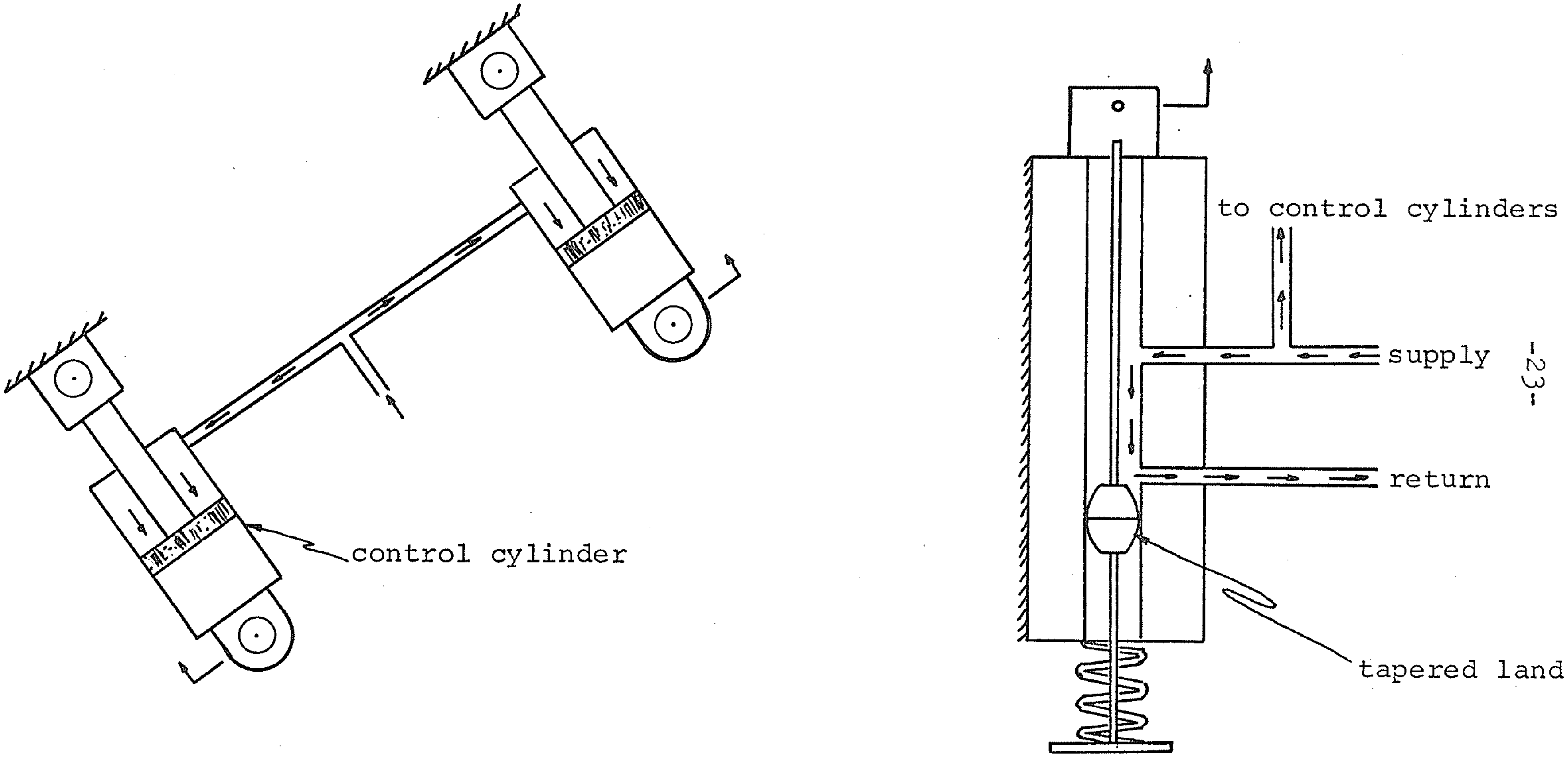

Figure 3.3 Schematic of the flow control valve and the parallel control cylinders circuit.

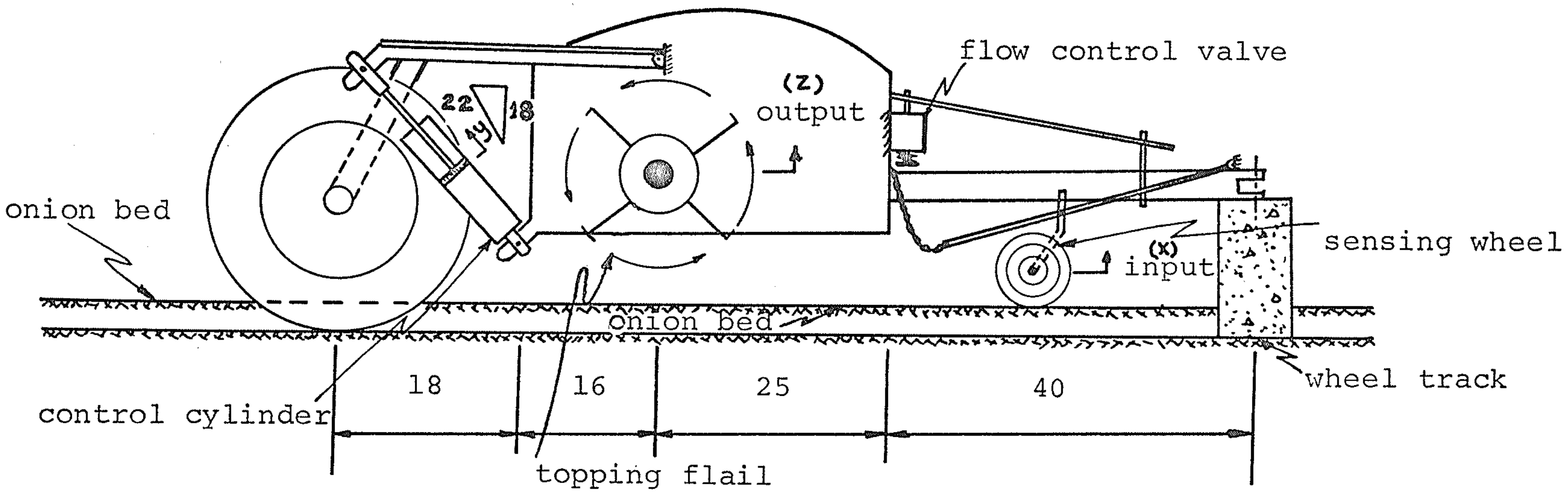

Figure 3.4 Schematic of the flail topper illustrating the flow control valve and control cylinders.

pressure builds up in the chamber of the control valve and forces oil to the cylinder line and eventually raises the flail. If the sensing wheel moves down, the tapered land moves down from the fixed orifice. The pressure drops in the valve chamber and the topping flail lowers. With the topping flail in a static condition and the sensing linkage engaging the spool, the tapered land moves into the orifice to a position creating the required pressure to balance the topping flail.

The rate of flow of oil into the control cylinders is proportional to the displacement of the tapered land in the orifice.

$$q = c_f \cdot x \qquad (3.8)$$

where

$q$ = flow of oil, in$^3$/sec.

$c_f$ = coefficient of flow control valve, in$^2$/sec.

$x$ = displacement of the sensing wheel, in. (valve spool displacement is directly proportional to x)

The rate of flow q into the control cylinders is equal to the rate of change in volume of the cylinders. The volume is equal to the piston velocity times the effective area of the piston.

$$q = A \cdot \dot{Y} \qquad (3.9)$$

where

$q$ = flow of oil, in$^3$/sec.

$A$ = effective area of the piston, in$^2$

$\dot{Y}$ = piston velocity, in/sec.

Since the body of the valve is attached to the topper frame (Figure 3.4) the system becomes a closed-loop system.

Because of the geometry in Figure 3.4 the block-diagram representation of the system is shown in Figure 3.5. The following set of equations is obtained.

$$(x-b)\,\frac{18}{22}\,\frac{65}{81}\,\frac{c_f}{AD} = Z \tag{3.10}$$

$$\frac{40}{65}Z = b \tag{3.11}$$

Eliminating b from the above equations gives:

$$\left(x - \frac{40}{65}Z\right)\frac{18}{22}\,\frac{65}{81}\,\frac{c_f}{AD} = Z \tag{3.12}$$

The operational transfer function of the system is

$$\frac{Z}{x}(D) = \frac{65/40}{\left(2.48\frac{A}{c_f}D+1\right)} \tag{3.13}$$

where

Z = output of the topping flail, in.

b = feedback signal, in.

D = operator symbol which indicates differentiation with respect to time.

In use the gain, k, was adjusted to 1.0 through the mechanical linkages shown in Figure 3.4. Since the system obtained is analogous to the first-order system, the analysis shown in Appendix C holds. It was noted that for quick response A, the effective area of the piston must be kept small. Therefore the same cylinders of 2 inch bore with 1 1/8 inch diameter rod were used.

The mechanical linkage between the control valve and sensing wheel was designed with a minimum of spring action

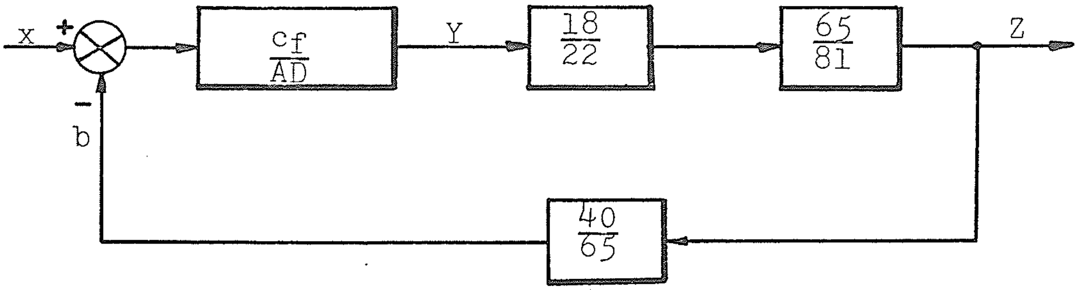

Figure 3.5(a) Block diagram of the closed-loop system with the flow control valve.

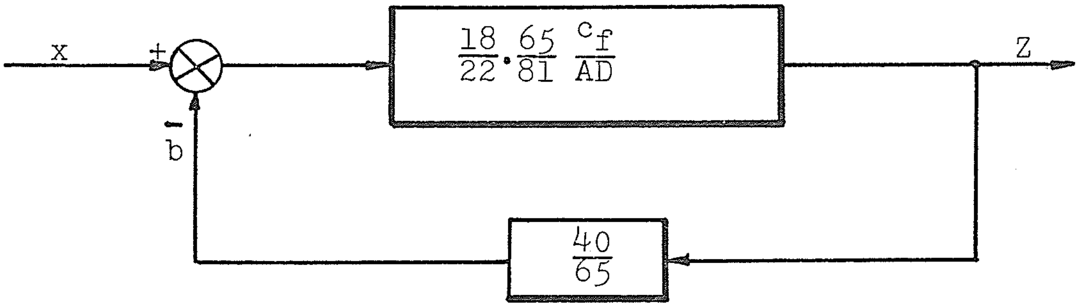

Figure 3.5(b) Combination of forwardpath transfer functions.

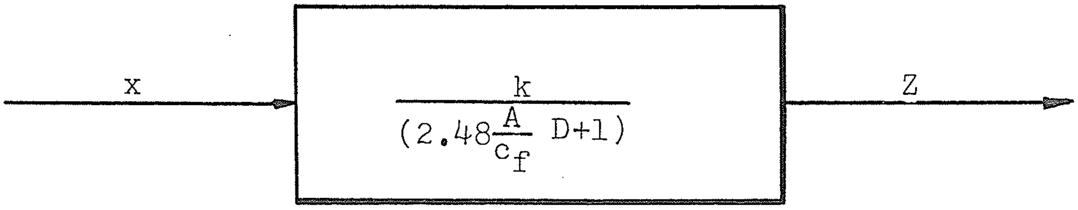

Figure 3.5(c) Simplified block diagram of the system.

to give a smooth and positive action on the control valve for a better response. A preloaded spring was mounted between the sensor linkage and valve linkage to take care of override. For underride protection a chain was used.

### 3.6 Design of Top-lifting Device

As bulbs reach maturity, the neck weakens at a point about one inch above the bulb and the top eventually falls over. Frequently growers use "50 percent tops down" as a sign that the field is mature enough for harvest. Any topper that removes the tops while the bulbs are still in the ground will need a device to pick up lodged tops so that topping can be done efficiently.

Lorenzen (12) used two-bladed flippers and fins at the front of the machine to pick and guide tops into lifting belts. Their axes of rotation were inclined forward at an angle of 30 degrees with the vertical and their directions of rotation were indicated by the arrows.

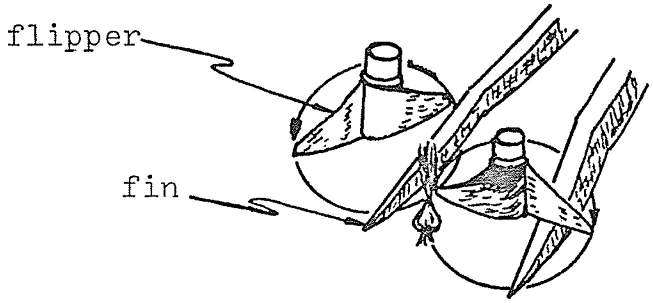

Figure 3.6 Flippers and fins for top lifting.

For a forward speed of 1 mph of tractor, the flippers rotate at 300 rpm giving the tips a peripheral speed of 2200 fpm. The vector diagram in Figure 3.7 shows the angle of the average plane of the paths of the flipper tips. This angle is about 40 degrees with the horizontal and shows that in operation the onion tops were lifted and moved back toward the throat of the machine. This pickup device worked satisfactorily and was the most important element in making the machine a practical unit.

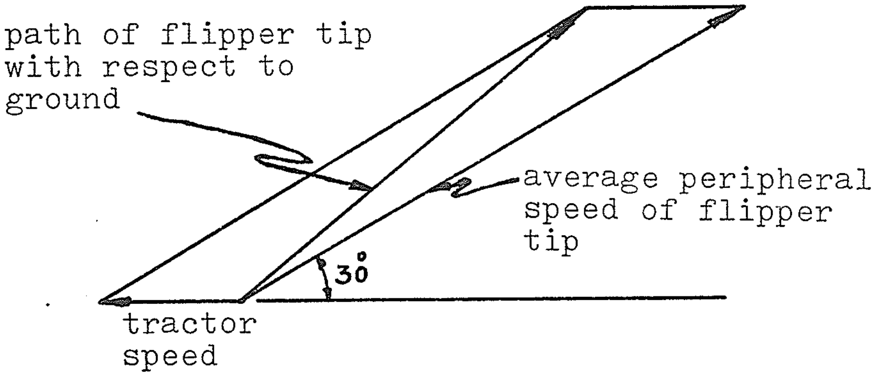

Figure 3.7 Vector diagram of top pickup device at the throat of the machine.

An air blast directed from below the rod digger chain has been used to lift the tops. A rotary cutter removes them as they are elevated. Topping performance was satisfactory and resulted in making the harvester a commercial unit (10).

Carson and Williams used tined wheels to pick up lodged onion tops. The lifters were operated at various angles in the direction of travel. The most acceptable topping job was done with the lifters making an angle of 25 degrees with the direction of travel and inclined away from the onion row at an angle of 5 degrees with the vertical (3).

LePori and Hobgood used rubber fingers in combination with lifting rods for the 1968 machine. The fingers were positioned at an angle on each side of the row with their plane of rotation perpendicular to the ground surface. By rotating fingers at a higher peripheral speed than the machine speed, tops are directed into the throat of the lifting belts. The fingers did not assist in picking up the lodged tops except in good conditions[a].

For the 1969 machine, floating lifting shields in combination with rotating paddles were used. The shields lift and align the tops over the bulbs and the paddles direct them into lifting belts. Field tests proved that this combination was superior to the first one (10).

To avoid any extra cost and power requirements the simplest type of cones were designed to lift and align the lodged tops. They had a down row component of velocity equal to that of the tractor. Because of the angle they made with the horizontal, the tops were lifted as shown in the vector diagram (Figure 3.8).

Two pairs of cones with cone angles of 25 degrees and 30 degrees were built. The cones were tested on one row. They were mounted on the topper ahead of the topping flail.

---

[a] Tops green in colour and free from any disease.

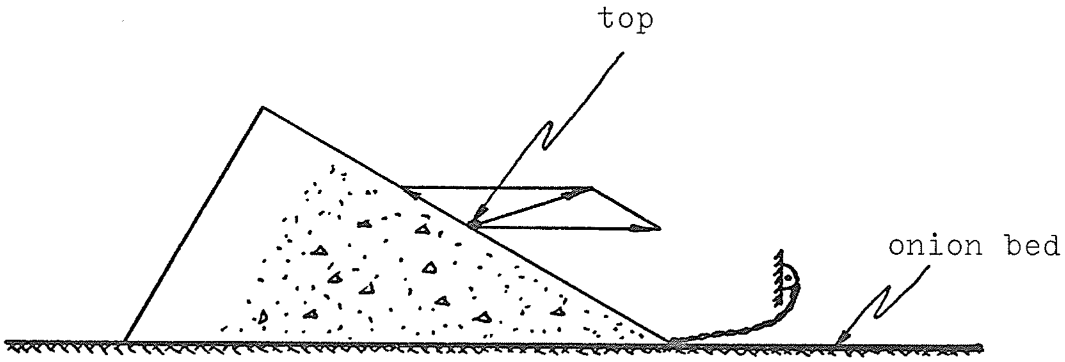

Figure 3.8 Top-lifting cones with a vector diagram of top-lifting action.

# CHAPTER 4

## EXPERIMENTAL METHODS AND EQUIPMENT

### 4.1 Onion Damage Study

The following sampling technique was used to study the topping performance of the flail topper. This topper tops one onion bed at a time (Figure 4.1). Each onion bed has four rows of onions spaced 14 inches apart.

An onion bed was chosen at random and all four rows were sampled. Three samples were taken from every row. Each sample consisted of all the onions of marketable size in a 30 foot long section of the row selected at random.

A wooden gage as shown in Figure 4.2 was used to measure the length of the top above the bulb neck.

For the 1970 field tests a bulb was classified as topped if the top above its neck was less than 2 inches. For the 1971 field tests about six onion beds were topped according to the above topping definition. Although the topping job was better than the previous year some bulbs were damaged due to the greater variation in bulb size in 1971. The grower was not satisfied with the results. The bulbs that were damaged were jumbo size. These were the bulbs which had greater market value. He was willing to tolerate a few longer tops rather than the damaged bulbs. Hence the grower changed the topping definition and it was decided to work 3 inches above the bulb neck. Therefore for the 1971 field tests a topped bulb had a 3 inch top above

Figure 4.1 A topped onion bed showing four rows of onions spaced 14 inches apart.

Figure 4.2(a) A wooden gage shown was used to measure the length of the top above the bulb neck.

Figure 4.2(b) Damaged bulbs.

its neck instead of 2 inches. Topped, damaged, top greater than 3 inches and untopped bulbs were counted in each sample. Counts were recorded on the data sheet shown in Table 4.1.

Table 4.1

Flail Topping

Location: Portage la Prairie

Condition of tops:

Topper travel speed: ________ mph

Power take-off speed: ________ rpm

______ Manual control

______ Automatic control

| | 1 | 2 | 3 |
|---|---|---|---|
| i) Topped bulbs[a] | | | |
| ii) Damaged bulbs | | | |
| iii) Bulbs with tops $> 3$ in. | | | |
| iv) Untopped bulbs | | | |

NOTE: Three samples were taken at random from a topped onion row. Each sample consisted of a 30 foot long onion section selected at random in the row.

[a] Bulbs with tops $\leq 3$ inches.

## 4.2 Laboratory Testing of Automatic Height Control

The topper was set up stationary in the laboratory. To simulate field conditions blocks were put under the tongue to bring it to a drawbar height of 14½ inches above the ground.

To simulate the ground contour a movable ramp was built with a 2½ inch rise in 5 feet (Figure 4.3). A winch was used to pull the ramp which ran on a track under the topper as shown in Figure 4.4 to simulate ground travel of the topper. The winch was fitted with a variable speed drive to simulate different ground speeds.

Two ground speeds of 2½ mph and 3½ mph were simulated in the laboratory. These speeds were selected on the basis of the 1970 topper travel speed of 2.49 mph.

A Brush 220 recorder was used to record the input to the sensing wheel and output of the topping flail. Displacement transducers using cantilever beams and strain gages were built and calibrated. A graph of the beam deflections versus displacements of the recording pen was plotted. It was found that the deflection was linear up to 2 inches (Appendix D).

One transducer was mounted on the sensing wheel to measure the input (Figure 4.5) and the other was mounted on the topping flail to measure the output (Figure 4.6).

A hydraulic pump of 3.00 gpm capacity was used in the laboratory experiment.

## 4.3 Power Take-off Speed

A Smiths' tachometer was used to gage power take-off speed. Power take-off speeds of 540 rpm, 680 rpm and 880 rpm were used in the field tests.

Figure 4.3 Ramp shown was used to simulate ground contour.

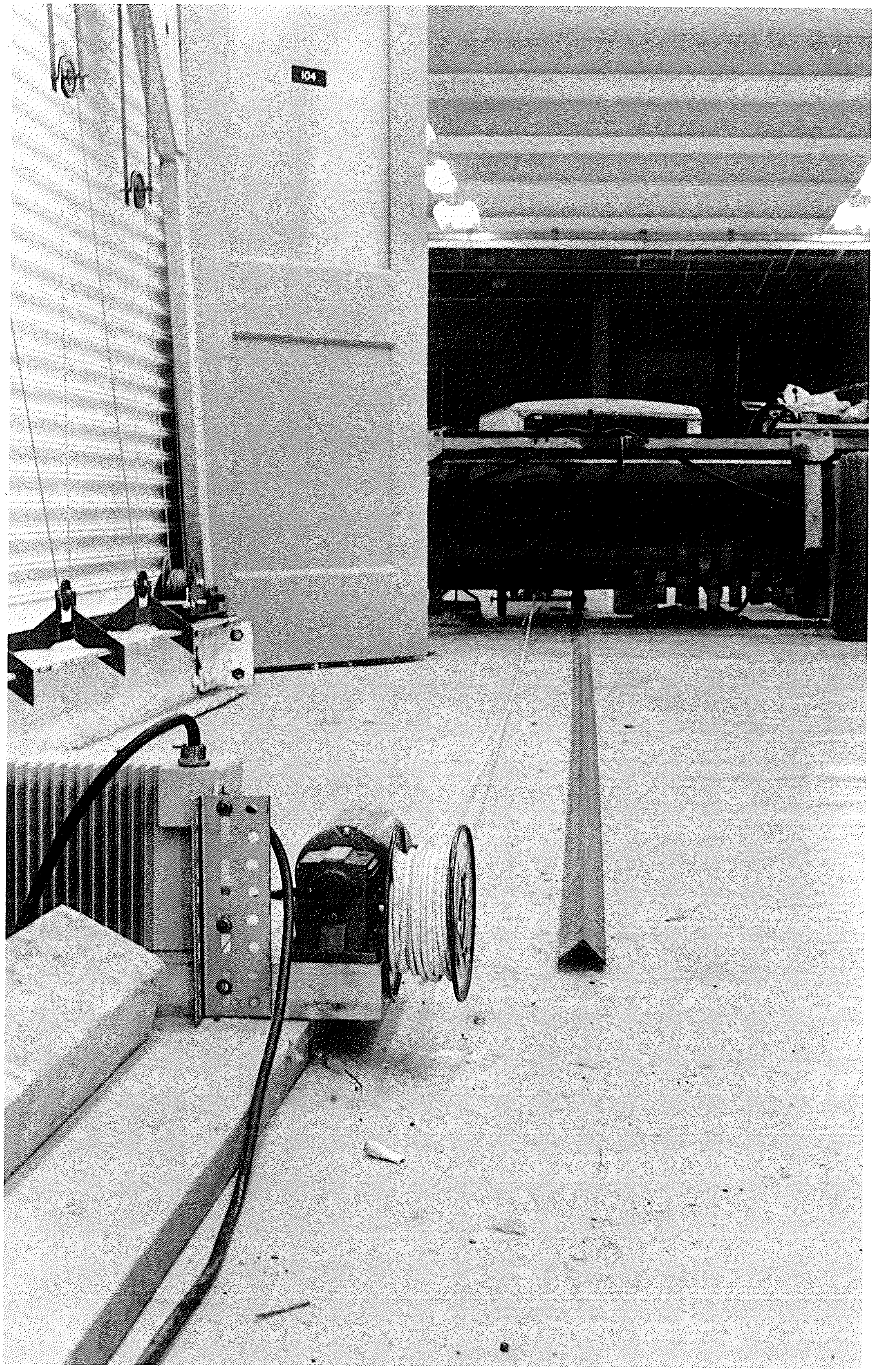

Figure 4.4 Winch shown was used to pull the ramp.

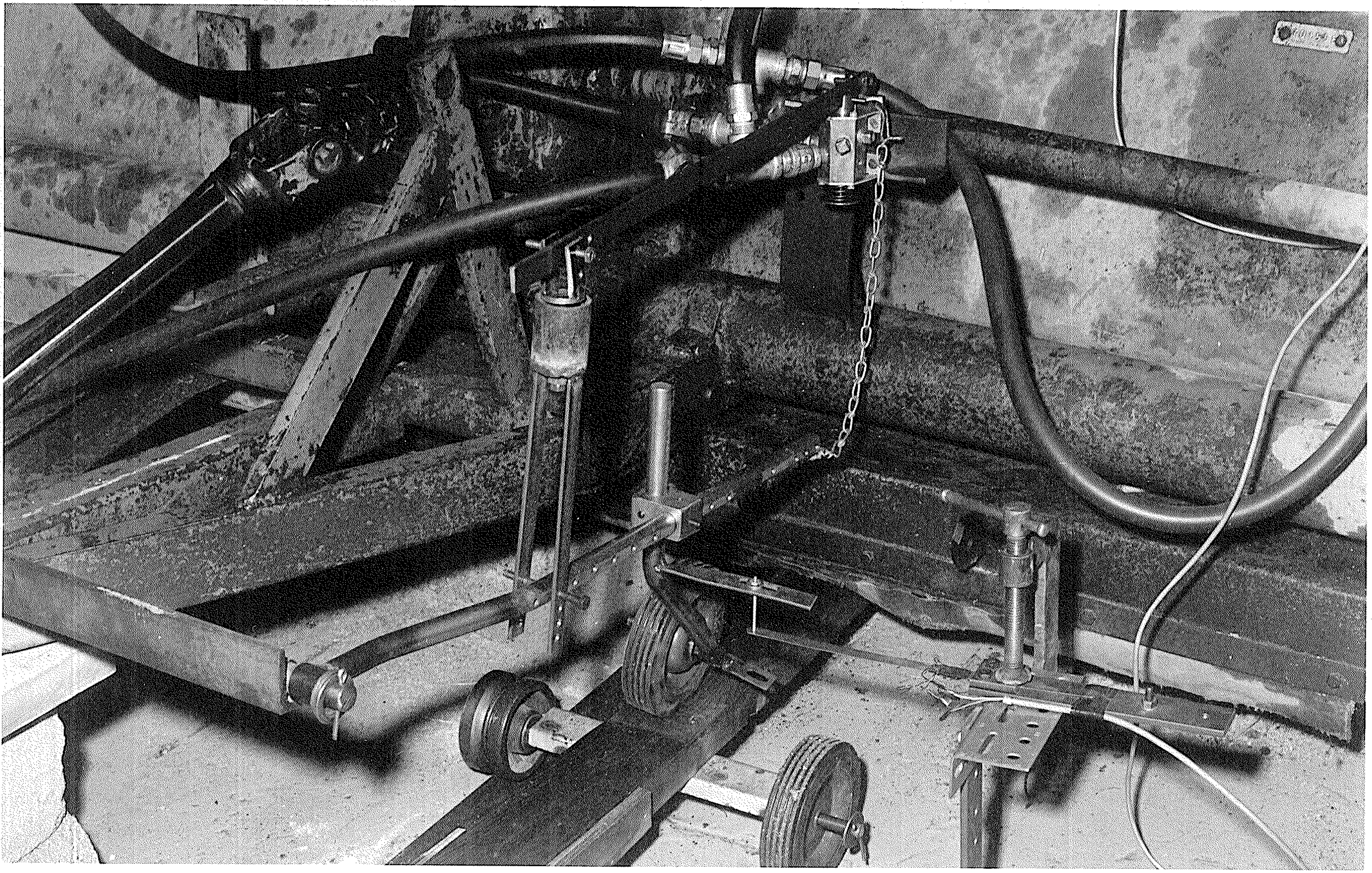

Figure 4.5 Displacement transducer to measure the input to the sensing wheel.

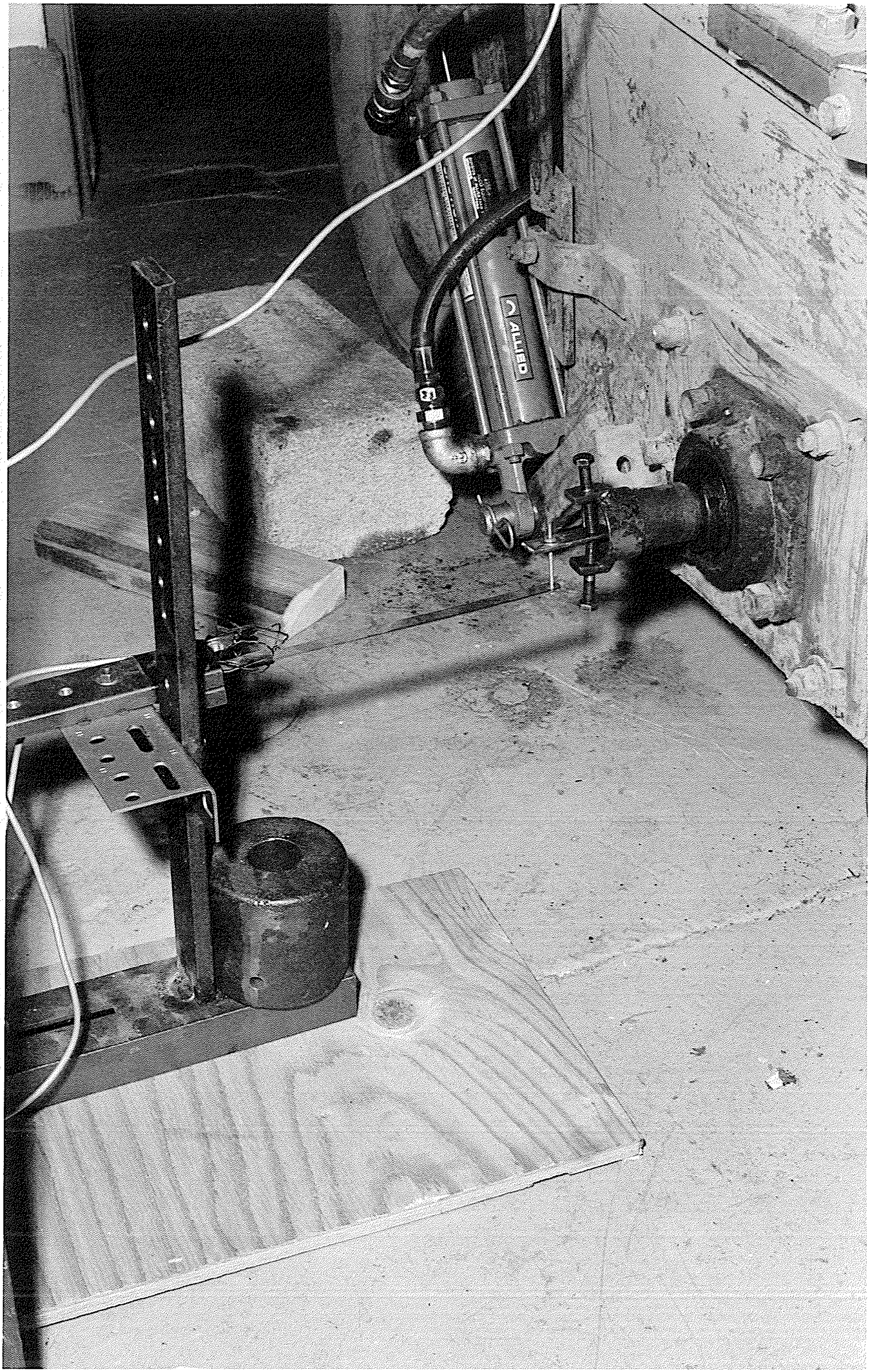

Figure 4.6 Displacement transducer to measure the output of the topping flail.

# CHAPTER 5

# RESULTS AND DISCUSSION

## 5.1 Automatic Height Control Laboratory Testing Results

5.1.1 Four-way Gresen valve[a] Cantilever beam displacement transducers were mounted on the sensing wheel and on the topping flail to measure the input to the sensing wheel and the output of the topping flail respectively. From the recorded results it was found that for a 2½ inch ramp input in 5 feet at a travel speed of 2½ mph the valve took 1.92 seconds to start lowering and 1.44 seconds to start raising the machine (Appendix E). The reason for these delays was that the valve had a dead band before it started to open. The lowering dead time was greater than the raising dead time. The two dead zones were therefore not symmetrical. Since this dead time was too great, it was concluded that this valve was not suitable. A more sensitive 4-way valve[b] was tried next. With this valve hunting became a problem.

5.1.2 Flow control valve From the recorded results it was found that for 1½ inch ramp input in 5 feet at travel speeds of 2½ mph and 3½ mph the valve took 0.49 seconds to start lowering and 0.96 seconds to start raising the machine (Appendix F). It was noted that at steady-state the steady-state error approached zero.

---

[a] SP 4 — 4-way single spool valve.

[b] Becket servo valve (Type VI A) with tapered lands and blocked centre with nominal zero lap.

Lowering and raising operations were quite smooth. Since this valve controlled topper height successfully in the laboratory tests it was decided to field test the system.

## 5.2 Field Testing Results

5.2.1 Automatic height control The automatic height control worked satisfactorily in the field. It was sensitive enough to sense deep ruts and bumps. One difficulty was experienced when the sensing wheel either hit the bulbs due to incorrect steering or passed over the thick mat of lodged onion tops (Figure 5.1). The topping flail moved up which was not desirable.

Another problem occurred when the right wheel rut was much deeper than the left wheel rut. Onion damage occurred in the rows near the right wheel rut. This shows that the sensing wheel located left of the hitch point was not able to sense the right wheel rut inputs.

5.2.2 Top-lifting device A pair of sheet-metal cones with a cone angle of 25 degrees were tried for one row. The pair were mounted on the topper ahead of the topping flail. The tops were unusually long and heavy in 1971. Where the tops were badly lodged and tangled the cones collected and trailed many tops. This resulted in pulling the bulbs out of the soil. This was highly undesirable.

Longer flail hammers (10 inch) were tried in between the rows and on the outside of the outside rows. Although

Figure 5.1 Lodged onion tops.

they helped top most of the green tops, they were too long to work at any lower height. Therefore shorter flail hammers ($8\frac{1}{2}$ inche) were substituted in between the rows. For the outside rows 10 inch long hammers were found to work satisfactorily (Figure 5.2).

An increase in power take-off speed to 880 rpm with a decrease in travel speed to 2.2 mph was tried. These changes provided sufficient suction to lift most of the tops and the topper did a good topping job.

## 5.3 Onion Topping Results

5.3.1 1970 onion topping results with manual height control The tops were green and about 50 percent of them were lodged. The topper was operated at 2.49 mph with a power take-off speed of 540 rpm. The height of the topping flail was controlled manually.

Forty-five samples were taken to evaluate the topping performance. The correctly topped bulbs were only 18.81 percent. Damaged bulbs were 2.71 percent. The remaining 78.48 percent bulbs were either untopped or had tops greater than 2 inches (Table 5.1).

5.3.2 1971 onion topping results with manual height control The tops were unusually long and heavy in 1971. More than 50 percent of the tops were completely lodged and very tangled. The topper was operated at 3.19 mph with a power take-off speed of 880 rpm.

Ten inch long flail hammers were used in between the

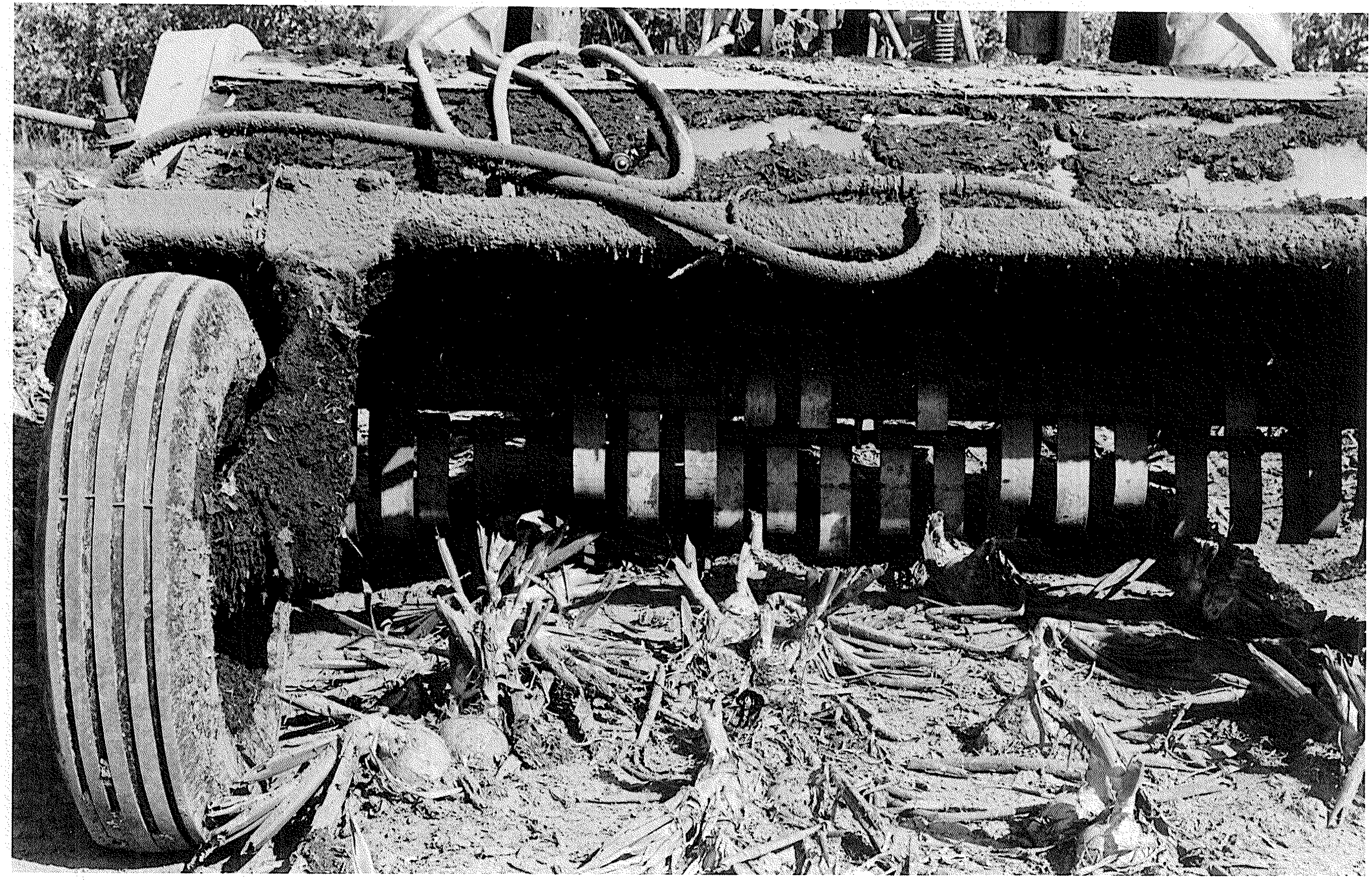

Figure 5.2(a) Showing longer flail hammers in between the rows and on the outside of the outside rows.

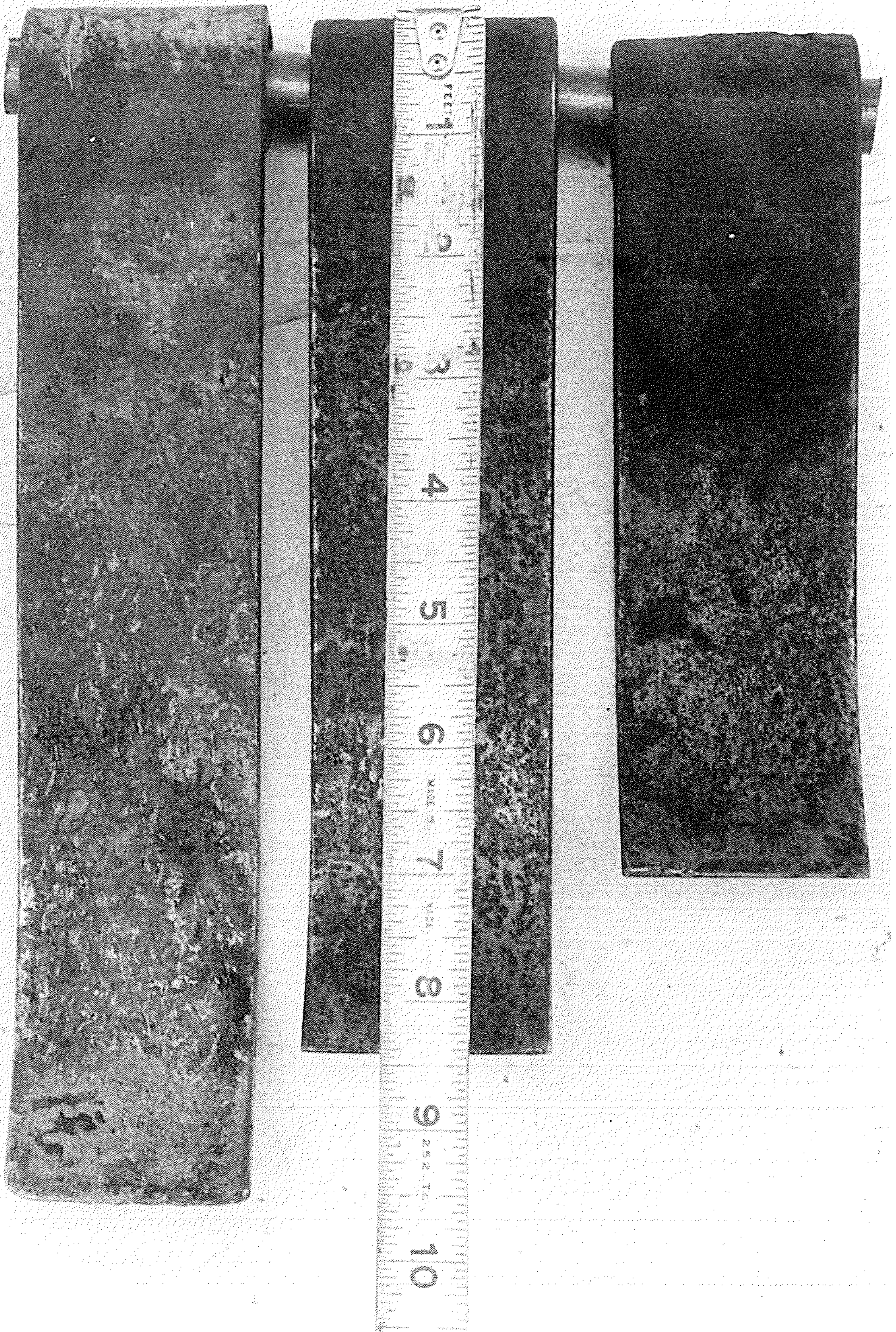

Figure 5.2(b) Showing flail hammers of 7 inch, 8½ inch and 10 inch length.

Table 5.1

---

Onion Topping Results (1970)
(manual height control)

---

| | |
|---|---|
| Location: | Portage la Prairie |
| Condition of tops: | green, lodged |
| Topper travel speed: | 2.49 mph |
| Power take-off speed: | 540 rpm |

| | |
|---|---|
| Topped bulbs[a] = | 18.81% |
| Damaged bulbs = | 2.71% |
| Bulbs with tops > 2 in. = | 44.03% |
| Untopped bulbs = | 34.45% |

---

[a] Bulbs with tops $\leq$ 2 inches.

rows and on the outside of the outside rows. Thirty samples were taken to evaluate the topping performance. Table 5.2 shows that only 21.15 percent of the bulbs were topped while 2.1 percent were damaged. The remaining 76.75 percent of the bulbs were either untopped or had tops greater than 3 inches.

Although the height was controlled manually the increased power take-off speed provided sufficient suction to do a comparatively better topping job. Unfortunately a faster travel speed was used and the tops did not have time to be lifted before the topper had passed over them. There is a definite relationship between the power take-off and the travel speed in order to do an acceptable topping job.

Table 5.2

Onion Topping Results (1971)
(manual height control)

| | |
|---|---|
| Location: | Portage la Prairie |
| Condition of tops: | green, lodged |
| Topper travel speed: | 3.19 mph |
| Power take-off speed: | 880 rpm |

Topped bulbs[a] = 21.15%

Damaged bulbs = 2.10%

Bulbs with tops > 3 in. = 32.28%

Untopped bulbs = 44.47%

---

[a] Bulbs with tops $\leq 3$ inches.

5.3.3 <u>1971 onion topping results with automatic height control</u> To compare automatic height control with manual height control seventy-two samples were taken with automatic height control under two modes of operation. In the first test the tops were green and more than 50 percent of them were lodged. The topper was operated at 1.45 mph with a power take-off speed of 680 rpm.

Twenty-four samples were taken. Table 5.3 shows the topping results. The correctly topped bulbs were 72.85 percent. Damaged bulbs were 0.55 percent. Bulbs with tops greater than 3 inches were 16.92 percent and untopped bulbs were only 9.70 percent.

In the second test the topper was operated at 2.2 mph with a power take-off speed of 880 rpm. The power take-off speed used was the same as for the manual height control

Table 5.3

Onion Topping Results (1971)
(automatic height control)

| | |
|---|---|
| Location: | Portage la Prairie |
| Condition of tops: | green, lodged |
| Topper travel speed: | 1.45 mph |
| Power take-off speed: | 680 rpm |

| | |
|---|---|
| Topped bulbs[a] = | 72.85% |
| Damaged bulbs = | 0.55% |
| Bulbs with tops > 3 in. = | 16.90% |
| Untopped bulbs = | 9.70% |

[a] Bulbs with tops ≤ 3 inches.

but lower travel speed was used. This reduction in travel speed provided better suction.

The tops were partially dry and yellowish-green in colour. About 70 percent of the tops were completely lodged.

Forty-eight samples were taken. Table 5.4 shows the topping results. The topped bulbs were 73.82 percent while damaged bulbs were 1.96 percent. Bulbs with tops greater than 3 inches were 17.83 percent and untopped bulbs were only 6.79 percent.

### 5.4 Comparison of Onion Topping Results (Automatic Control versus Manual Control)

The results listed in Table 5.2 were compared with the results listed in Table 5.4. The results of automatic height control are significantly better than the results of manual height control (Table 5.5).

The damage was not high in either of the tests. Special precautions were taken with the manual height control to avoid onion damage even at the expense of a poor topping job. There was no difference statistically in the amount of damage done with automatic control or manual control.

Table 5.4

Onion Topping Results (1971)
(automatic height control)

Location: Portage la Prairie

Condition of tops: yellowish-green, badly lodged.

Topper travel speed: 2.2 mph

Power take-off speed: 880 rpm

Topped bulbs[a] = 73.82%

Damaged bulbs = 1.96%

Bulbs with tops $> 3$ in. = 17.43%

Untopped bulbs = 6.79%

---

[a] Bulbs with tops $\leq 3$ inches.

Table 5.5

Statistical Comparison of Automatic Height Control Versus Manual Height Control

| | Automatic height control | Manual height control | Test Statistic | Critical Region | Conclusion |
|---|---|---|---|---|---|
| 1. Topped bulbs | 73.82% | 21.15% | $Z = 43.1157$* | $Z_{0.01} > 2.33$ | Topping with auto. is better than manual. |
| 2. Damaged bulbs | 1.96% | 2.10% | $Z = -0.4057$ | $Z_{0.01} < -2.33$ | No difference. |
| 3. Bulbs with tops > 3 in. | 17.43% | 32.28% | $Z = -14.1012$* | $Z_{0.01} < -2.33$ | Auto. leaves fewer bulbs with tops > 3 in. than manual. |
| 4. Untopped bulbs | 6.79% | 44.4% | $Z = -35.9127$* | $Z_{0.01} < -2.33$ | Auto. leaves fewer bulbs untopped than manual. |

*Significant at one percent level.

# CHAPTER 6

# CONCLUSIONS

The following conclusions were drawn from the results of this project:

1. The 4-way Gresen valve was not suitable for use with this sensing device for automatic height control of this topper.
2. The flow control valve with the sensor can be used for automatic height control.
3. Onion topping with the automatic height control was significantly better than onion topping with manual height control.
4. There was a definite relationship between the topper travel speed and power take-off speed in order to do an efficient topping job. Power take-off speeds of 680 rpm and 880 rpm at a topper travel speed of 1.45 mph and 2.2 mph respectively were found adequate for this purpose.
5. The top-lifting cones were not suitable to lift lodged onion tops. However for this flail topper 10 inch long flail hammers for the outside rows and 8½ inch long flail hammers in between the rows were suitable to cut most of the green tops.

# CHAPTER 7

# RECOMMENDATIONS

In reality the flail topper was not built specifically to field top onions. It was designed primarily as a potato vine beater. It was used to top potato vines in order to kill the vines prior to harvesting. It was also used successfully for trimming the foliage of turnips and carrots to check excessive growth so that the roots did not become too large and woody. This topper can probably field top onions no better than at present. Therefore further research work to improve or modify the flail topper to field-top onions would not be worthwhile.

Recent developments in onion harvesters indicate that commercial machines are becoming available.

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# APPENDIX A

## Onion Topping Field Data (1970)
(manual height control)

| | |
|---|---|
| Location: | Portage la Prairie |
| Condition of tops: | green, lodged |
| Topper travel speed | 2.49 mph |
| Power take-off speed: | 540 rpm |

| Sample No. | Topped bulbs $x_1$ | Damaged bulbs $x_2$ | Bulbs with tops > 2 inches $x_3$ | Untopped bulbs $x_4$ | Total $N = \sum_{i=1}^{4} x_i$ |
|---|---|---|---|---|---|
| 1 | 26 | 0 | 69 | 62 | 157 |
| 2 | 49 | 1 | 72 | 30 | 152 |
| 3 | 42 | 2 | 63 | 71 | 178 |
| 4 | 13 | 0 | 57 | 92 | 162 |
| 5 | 1 | 0 | 65 | 84 | 150 |
| 6 | 25 | 62 | 20 | 51 | 158 |
| 7 | 5 | 0 | 54 | 62 | 121 |
| 8 | 12 | 0 | 86 | 83 | 181 |
| 9 | 25 | 2 | 61 | 33 | 121 |
| 10 | 4 | 0 | 30 | 40 | 74 |
| 11 | 5 | 0 | 45 | 63 | 113 |
| 12 | 2 | 0 | 46 | 59 | 107 |
| 13 | 19 | 0 | 91 | 11 | 121 |
| 14 | 58 | 0 | 35 | 14 | 107 |
| 15 | 10 | 0 | 98 | 26 | 134 |
| 16 | 23 | 0 | 69 | 18 | 110 |
| 17 | 24 | 2 | 94 | 41 | 161 |
| 18 | 32 | 3 | 55 | 28 | 118 |
| 19 | 6 | 0 | 71 | 0 | 77 |
| 20 | 36 | 2 | 31 | 5 | 74 |
| 21 | 56 | 2 | 28 | 6 | 92 |
| 22 | 9 | 0 | 44 | 39 | 92 |
| 23 | 22 | 1 | 25 | 42 | 90 |
| 24 | 35 | 5 | 33 | 32 | 105 |
| 25 | 28 | 3 | 35 | 54 | 120 |
| 26 | 2 | 1 | 19 | 60 | 82 |
| 27 | 2 | 0 | 21 | 53 | 76 |
| 28 | 86 | 1 | 16 | 1 | 104 |
| 29 | 0 | 0 | 94 | 11 | 105 |
| 30 | 28 | 10 | 62 | 13 | 113 |
| 31 | 90 | 25 | 12 | 4 | 131 |
| 32 | 0 | 0 | 38 | 64 | 102 |
| 33 | 0 | 0 | 72 | 25 | 97 |
| 34 | 0 | 0 | 18 | 99 | 117 |
| 35 | 8 | 0 | 42 | 23 | 73 |
| 36 | 2 | 0 | 38 | 62 | 102 |
| 37 | 7 | 0 | 51 | 28 | 86 |
| 38 | 6 | 0 | 86 | 23 | 115 |

APPENDIX A continued...

| | | | | | |
|---|---|---|---|---|---|
| 39 | 30 | 12 | 47 | 1 | 90 |
| 40 | 0 | 0 | 42 | 68 | 110 |
| 41 | 28 | 1 | 52 | 29 | 110 |
| 42 | 25 | 0 | 39 | 35 | 99 |
| 43 | 2 | 0 | 32 | 72 | 106 |
| 44 | 7 | 1 | 59 | 23 | 90 |
| 45 | 68 | 2 | 26 | 15 | 111 |
| | $\sum X_1=958$ | $\sum X_2=138$ | $\sum X_3=2243$ | $\sum X_4=1755$ | $\sum N=5094$ |

# APPENDIX B

## ESTIMATION OF ONION DAMAGE

i) Topped bulbs $= \frac{\Sigma X_1}{\Sigma N}$

$= \frac{958}{5094} \times 100 = 18.81\%$

ii) Damaged bulbs $= \frac{\Sigma X_2}{\Sigma N}$

$= \frac{138}{5094} \times 100 = 2.71\%$

iii) Bulbs with tops $>$ 2 inches $= \frac{\Sigma X_3}{\Sigma N}$

$= \frac{2243}{5094} \times 100 = 44.03\%$

iv) Untopped bulbs $= \frac{\Sigma X_4}{\Sigma N}$

$= \frac{1755}{5094} \times 100 = 34.45\%$

where

$\sum X_1$ = sum of topped bulbs in 45 samples.

$\sum X_2$ = sum of damaged bulbs in 45 samples.

$\sum X_3$ = sum of bulbs with tops greater than 2 inches in 45 samples.

$\sum X_4$ = sum of untopped bulbs in 45 samples.

$\sum N$ = total number of bulbs in 45 samples.

# APPENDIX C

The transfer function of the first-order system in Laplace transform is

$$\frac{z}{x}(s) = \frac{1}{(\tau s + 1)} \qquad (1.1)$$

A terminated-ramp input is applied to the system. Since the Laplace transform of the terminated-ramp function is $\left(\frac{1}{s^2} - \frac{e^{-s}}{s^2}\right)$ substituting $x(s) = \left(\frac{1}{s^2} - \frac{e^{-s}}{s^2}\right)$ into Eq. (1.1)

$$z(s) = \frac{1}{(\tau s + 1)} \left(\frac{1}{s^2} - \frac{e^{-s}}{s^2}\right) \qquad (1.2)$$

Expanding into partial fractions

$$z(s) = \frac{1}{s^2} - \frac{\tau}{s} + \frac{\tau^2}{\tau s+1} - e^{-s} \left(\frac{1}{s^2} - \frac{\tau}{s} + \frac{\tau^2}{\tau s+1}\right) \qquad (1.3)$$

Taking inverse Laplace transform of Eq. (1.3)

$$z(t) = t - \tau + \tau\, e^{-t/\tau} - [(t-1) - \tau + \tau\, e^{-t-1/\tau}] \quad (1.4)$$

Simplifying Eq. (1.4) gives:

$$z(t) = 1 + \tau\, e^{-t/\tau} (1 - e^{-1/\tau}) \quad (t>1) \qquad (1.5)$$

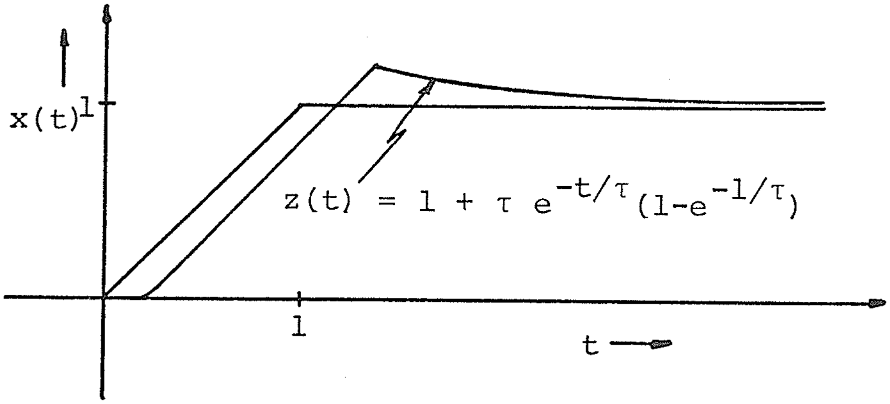

Figure C.1 Terminated-ramp response of the first-order system.

where

$\tau$ = time constant of the system

It may be seen from Eq. (1.5) that the transients tend to approach zero as time approaches infinity because the exponent of the complementary function is negative. The larger the value of the negative exponent and the smaller the value of $\tau$, the constant multiplier, the faster the complementary function approaches zero. To achieve this objective $\tau$ must be kept small. Therefore the smaller the time constant the faster the response.

# APPENDIX D

## Part I

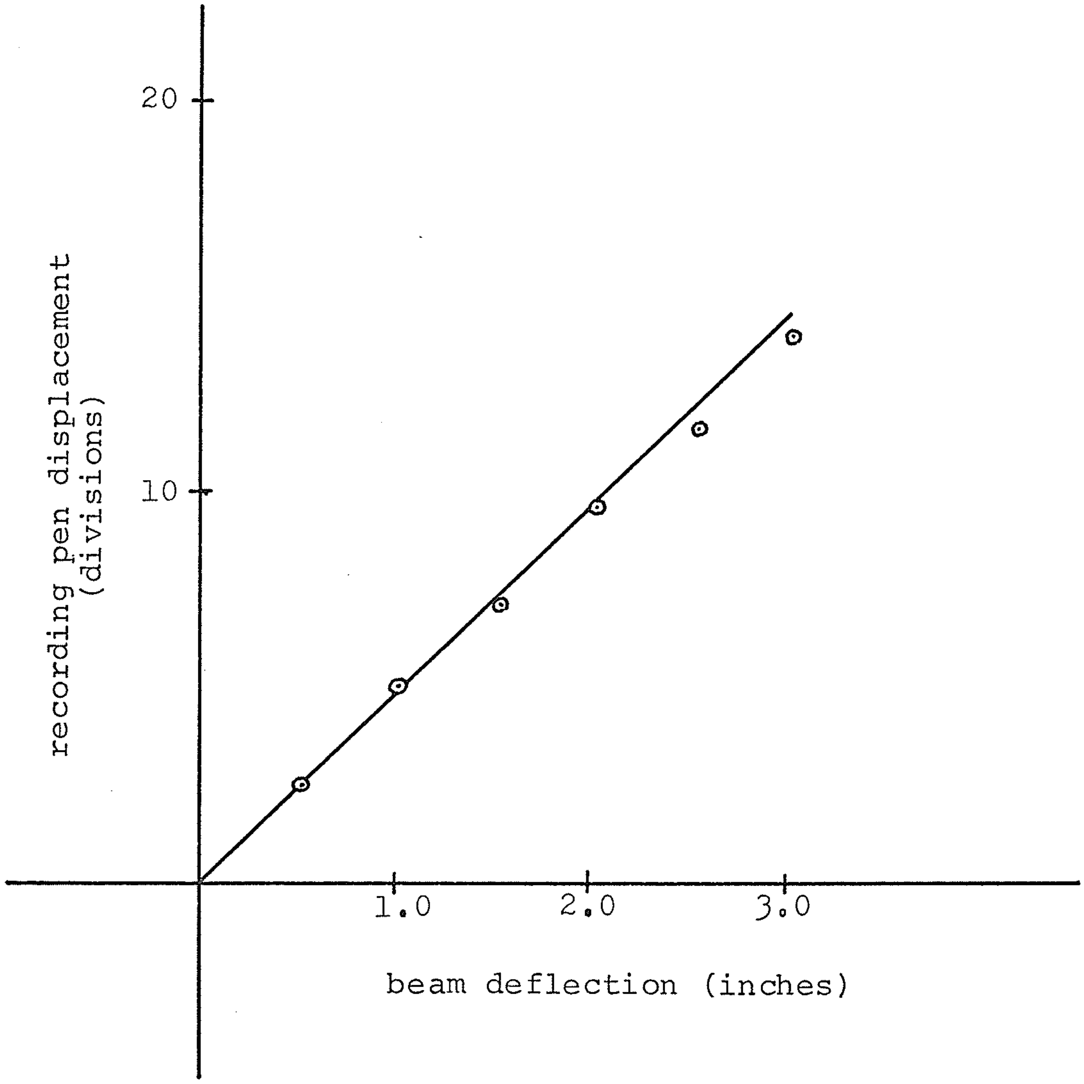

Figure D.1 Calibration curve of the input displacement transducer (beam deflection versus recording pen displacement).

# APPENDIX D

## Part II

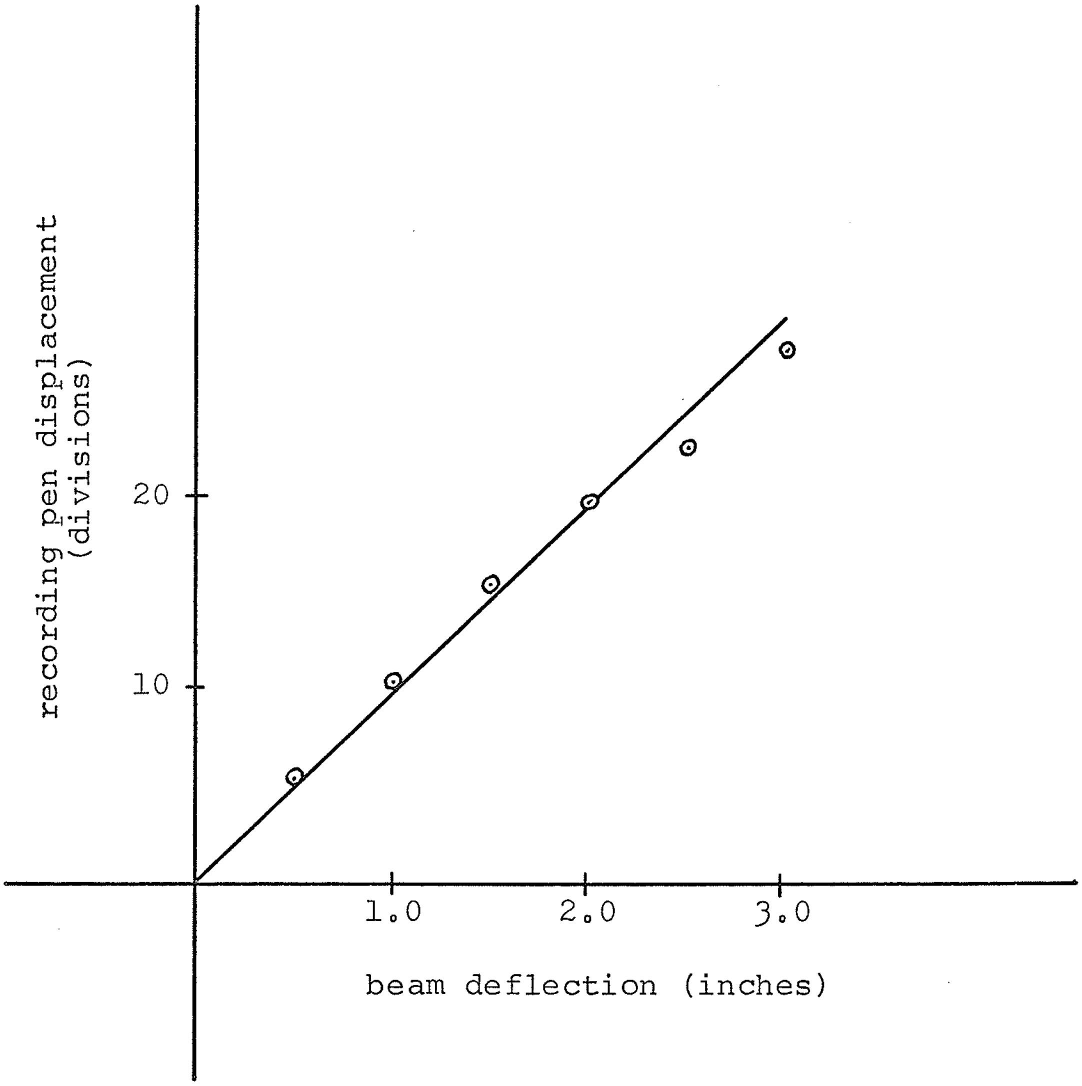

Figure D.2 Calibration curve of the output displacement transducer (beam deflection versus recording pen displacement.

# APPENDIX E

## SYSTEM RESPONSE WITH THE GRESEN VALVE

Response time $= \frac{\text{chart distance lag}}{\text{speed of the chart}}$

a) Time delay for raising $= \frac{3\text{ mm}}{125\text{mm/min}}$

$$= \frac{3\ \cancel{\text{mm}}}{1} \times \frac{1\text{ min}}{125\cancel{\text{mm}}} \times \frac{60\text{ secs}}{1\cancel{\text{min}}}$$

$$= \frac{3 \times 60}{125}\text{ secs}$$

$$= 1.44\text{ secs}$$

b) Time delay for lowering $= \frac{4\text{ mm}}{125\text{mm/min}}$

$$= \frac{4\cancel{\text{mm}}}{1} \times \frac{1\cancel{\text{min}}}{125\cancel{\text{mm}}} \times \frac{60\text{ secs}}{1\text{min}}$$

$$= \frac{4 \times 60}{125}\text{ secs}$$

$$= 1.92\text{ secs}$$

# APPENDIX F

## SYSTEM RESPONSE WITH THE FLOW CONTROL VALVE

Response time $= \frac{\text{chart distance lag}}{\text{speed of the chart}}$

a) Time delay for raising $= \frac{2\text{ mm}}{125\text{mm/min}}$

$$= \frac{2\cancel{\text{mm}}}{1} \times \frac{1\ \cancel{\text{min}}}{125\cancel{\text{mm}}} \times \frac{60\text{ sec}}{1\ \cancel{\text{min}}}$$

$$= \frac{2 \times 60}{125}\text{ secs}$$

$$= 0.96\text{ secs}$$

b) Time delay for lowering $= \frac{1\text{ mm}}{125\text{mm/min}}$

$$= \frac{60}{125}\text{ secs}$$

$$= 0.48\text{ secs}$$

# APPENDIX G

## Part I

### Onion Topping Field Data (1971)
(manual height control)

| | |
|---|---|
| Location: | Portage la Prairie |
| Condition of tops: | green, lodged |
| Topper travel speed: | 3.19 mph |
| Power take-off speed: | 880 rpm |

| Sample No. | Topped bulbs $x_1$ | Damaged bulbs $x_2$ | Bulbs with tops > 3 inches $x_3$ | Untopped bulbs $x_4$ | Total $N = \sum_{i=1}^{4} x_i$ |
|---|---|---|---|---|---|
| 1 | 17 | 0 | 38 | 49 | 104 |
| 2 | 70 | 34 | 22 | 33 | 159 |
| 3 | 36 | 1 | 19 | 22 | 78 |
| 4 | 11 | 0 | 12 | 6 | 29 |
| 5 | 32 | 0 | 45 | 26 | 103 |
| 6 | 0 | 1 | 15 | 8 | 24 |
| 7 | 60 | 3 | 29 | 20 | 112 |
| 8 | 25 | 2 | 30 | 6 | 63 |
| 9 | 35 | 0 | 26 | 7 | 68 |
| 10 | 4 | 0 | 48 | 64 | 116 |
| 11 | 9 | 0 | 43 | 71 | 123 |
| 12 | 6 | 0 | 30 | 75 | 111 |
| 13 | 17 | 0 | 22 | 67 | 106 |
| 14 | 7 | 0 | 40 | 70 | 117 |
| 15 | 4 | 0 | 27 | 60 | 91 |
| 16 | 1 | 0 | 28 | 66 | 95 |
| 17 | 13 | 0 | 46 | 60 | 119 |
| 18 | 7 | 0 | 48 | 86 | 141 |
| 19 | 12 | 0 | 30 | 53 | 95 |
| 20 | 10 | 0 | 50 | 80 | 140 |
| 21 | 36 | 3 | 76 | 26 | 141 |
| 22 | 11 | 0 | 33 | 96 | 140 |
| 23 | 18 | 1 | 20 | 77 | 116 |
| 24 | 31 | 2 | 7 | 49 | 89 |
| 25 | 76 | 4 | 38 | 21 | 139 |
| 26 | 7 | 0 | 33 | 80 | 120 |
| 27 | 18 | 14 | 41 | 62 | 135 |
| 28 | 64 | 0 | 24 | 21 | 109 |
| 29 | 14 | 0 | 43 | 4 | 61 |
| 30 | 3 | 0 | 35 | 10 | 48 |
| | $\sum X_1=654$ | $\sum X_2=65$ | $\sum X_3=998$ | $\sum X_4=1375$ | $\sum N=3092$ |

# APPENDIX G

## Part II

### Onion Topping Field Data (1971)
(automatic height control)

| | |
|---|---|
| Location: | Portage la Prairie |
| Condition of tops: | green, lodged |
| Topper travel speed: | 1.45 mph |
| Power take-off speed: | 680 rpm |

| Sample No. | Topped bulbs $X_1$ | Damaged bulbs $X_2$ | Bulbs with tops > 3 inches $X_3$ | Untopped bulbs $X_4$ | Total $N = \sum_{i=1}^{4} x_i$ |
|---|---|---|---|---|---|
| 1 | 60 | 0 | 10 | 11 | 81 |
| 2 | 63 | 1 | 23 | 8 | 95 |
| 3 | 20 | 0 | 2 | 1 | 23 |
| 4 | 30 | 0 | 7 | 9 | 46 |
| 5 | 40 | 0 | 13 | 3 | 56 |
| 6 | 55 | 0 | 10 | 3 | 68 |
| 7 | 24 | 0 | 7 | 4 | 35 |
| 8 | 17 | 0 | 5 | 2 | 24 |
| 9 | 73 | 1 | 12 | 6 | 92 |
| 10 | 75 | 1 | 4 | 1 | 81 |
| 11 | 40 | 0 | 6 | 3 | 49 |
| 12 | 42 | 0 | 11 | 3 | 56 |
| 13 | 40 | 0 | 9 | 22 | 71 |
| 14 | 30 | 0 | 1 | 3 | 34 |
| 15 | 53 | 1 | 11 | 8 | 73 |
| 16 | 22 | 0 | 10 | 11 | 43 |
| 17 | 33 | 0 | 6 | 4 | 43 |
| 18 | 36 | 3 | 10 | 7 | 56 |
| 19 | 18 | 0 | 1 | 0 | 19 |
| 20 | 9 | 0 | 1 | 2 | 12 |
| 21 | 72 | 0 | 24 | 5 | 101 |
| 22 | 42 | 0 | 25 | 7 | 74 |
| 23 | 28 | 0 | 8 | 2 | 38 |
| 24 | 17 | 0 | 3 | 0 | 20 |
| | $\sum X_1=939$ | $\sum X_2=7$ | $\sum X_3=218$ | $\sum X_4=125$ | $\sum N=1289$ |

## APPENDIX G

### Part III

### Onion Topping Field Data (1971)<br>(automatic height control)

| | |
|---|---|
| Location: | Porgate la Prairie |
| Condition of tops: | partially dried and yellowish-green, badly lodged |
| Topper travel speed: | 2.2 mph |
| Power take-off speed: | 880 rpm |

| Sample No. | Topped bulbs $x_1$ | Damaged bulbs $x_2$ | Bulbs with tops > 3 inches $x_3$ | Untopped bulbs $x_4$ | Total $N = \sum_{i=1}^{4} x_i$ |
|---|---|---|---|---|---|
| 1 | 35 | 0 | 3 | 6 | 44 |
| 2 | 70 | 0 | 1 | 3 | 74 |
| 3 | 24 | 0 | 1 | 2 | 27 |
| 4 | 45 | 0 | 0 | 2 | 47 |
| 5 | 40 | 1 | 6 | 3 | 50 |
| 6 | 59 | 3 | 1 | 3 | 66 |
| 7 | 70 | 0 | 1 | 1 | 72 |
| 8 | 68 | 0 | 3 | 4 | 75 |
| 9 | 45 | 7 | 1 | 0 | 53 |
| 10 | 50 | 19 | 1 | 1 | 71 |
| 11 | 33 | 10 | 1 | 4 | 48 |
| 12 | 49 | 4 | 3 | 1 | 57 |
| 13 | 32 | 8 | 3 | 2 | 45 |
| 14 | 34 | 6 | 2 | 0 | 42 |
| 15 | 80 | 3 | 1 | 3 | 87 |
| 16 | 62 | 3 | 1 | 0 | 66 |
| 17 | 45 | 0 | 46 | 4 | 95 |
| 18 | 68 | 0 | 14 | 14 | 96 |
| 19 | 19 | 0 | 20 | 6 | 45 |
| 20 | 18 | 0 | 11 | 25 | 54 |
| 21 | 54 | 0 | 15 | 4 | 73 |
| 22 | 73 | 0 | 5 | 8 | 86 |
| 23 | 41 | 0 | 19 | 1 | 61 |
| 24 | 89 | 5 | 17 | 5 | 116 |
| 25 | 82 | 0 | 3 | 2 | 87 |
| 26 | 67 | 0 | 40 | 7 | 114 |
| 27 | 49 | 0 | 32 | 3 | 84 |
| 28 | 53 | 0 | 18 | 10 | 81 |
| 29 | 65 | 0 | 9 | 5 | 79 |
| 30 | 35 | 0 | 16 | 10 | 61 |
| 31 | 53 | 0 | 40 | 7 | 100 |
| 32 | 63 | 0 | 5 | 6 | 125 |
| 33 | 52 | 0 | 33 | 11 | 96 |
| 34 | 64 | 0 | 44 | 5 | 113 |
| 35 | 77 | 0 | 9 | 5 | 91 |

APPENDIX G Part III continued...

| | | | | | |
|---|---|---|---|---|---|
| 36 | 37 | 0 | 5 | 3 | 45 |
| 37 | 56 | 0 | 14 | 7 | 77 |
| 38 | 78 | 0 | 29 | 13 | 120 |
| 39 | 70 | 0 | 22 | 3 | 95 |
| 40 | 95 | 1 | 7 | 3 | 106 |
| 41 | 43 | 0 | 10 | 6 | 59 |
| 42 | 101 | 0 | 17 | 6 | 124 |
| 43 | 78 | 1 | 0 | 1 | 80 |
| 44 | 29 | 0 | 3 | 0 | 32 |
| 45 | 23 | 0 | 1 | 1 | 25 |
| 46 | 48 | 0 | 2 | 0 | 50 |
| 47 | 65 | 0 | 24 | 15 | 104 |
| 48 | 78 | 0 | 19 | 14 | 111 |
| | $\sum X_1=2664$ | $\sum X_2=71$ | $\sum X_3=629$ | $\sum X_4=245$ | $\sum N=3609$ |

# APPENDIX H

The hypothesis under test was $H_o: \hat{p}_a = \hat{p}_m$

The alternative hypothesis was that topping with automatic control was better than manual control $H_1: \hat{p}_a > \hat{p}_m$

where

$\hat{p}_a$ = proportion of topped bulbs with automatic control

$\hat{p}_m$ = proportion of topped bulbs with manual control

Significance level, $\alpha = 0.01$

Test statistic $$Z = \frac{(\hat{p}_a - \hat{p}_m)}{\sqrt{\bar{p}\bar{q}\left(\frac{1}{N_a} + \frac{1}{N_m}\right)}}$$

$$\hat{p}_a = \frac{\Sigma x_{1a}}{\Sigma N_a} = \frac{2664}{3609} = 0.7382$$

$$\hat{p}_m = \frac{\Sigma x_{1m}}{\Sigma N_m} = \frac{654}{3092} = 0.2115$$

$$\bar{p} = \frac{\Sigma x_{1a} + \Sigma x_{1m}}{\Sigma N_a + \Sigma N_m} = \frac{2664 + 654}{3609 + 3092} = \frac{3318}{6701}$$

$$\bar{q} = 1 - \bar{p}$$

$$= 1 - \frac{3318}{6701} = \frac{3383}{6701}$$

$$Z = \frac{(0.7382 - 0.2115)}{\sqrt{\frac{3318}{6701} \times \frac{3383}{6701}\left[\frac{1}{3609} + \frac{1}{3092}\right]}}$$

$$Z = 43.1157$$

Critical region $Z_{0.01} > 2.33$

Conclusion: Rejected $H_o$ and concluded that the topping with automatic control was better than manual control.

where

$\Sigma x_{1a}$ = sum of topped bulbs in 48 samples with automatic control

$\Sigma x_{1m}$ = sum of topped bulbs in 30 samples with manual control

$\Sigma N_a$ = total number of bulbs in 48 samples with automatic control

$\Sigma N_m$ = total number of bulbs in 30 samples with manual control