MECHANIZING LETTUCE PRODUCTION

BY

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ABSTRACT

Economic analyses, which indicated a need for reducing lettuce production costs, were the basis for feasibility studies of mechanizing some production processes. These processes are the thinning and weeding operations. Thinning can be eliminated by precision seeding while weeding can be reduced or eliminated by using a suitable mulch layer. Mechanization of these processes requires development of a mulch layer applying machine and a precision seeder capable of seeding through the mulch.

A model of the precision seeder was designed, fabricated and tested. Test results were below the minimum acceptable performance level of the machine. Weaknesses in the model were obvious and modifications are recommended. These modifications should bring the model to an acceptable performance level.

A model of the mulch layer applier was also designed and fabricated. Field testing was not completed, however, expected problems are discussed and alternatives are recommended.

The practical feasibility of both these machines cannot be completely evaluated until the models have been thoroughly field tested.

ACKNOWLEDGEMENTS

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TABLE OF CONTENTS

TABLE OF CONTENTS (Continued) PAGE

LIST OF FIGURES

LIST OF FIGURE (Continued) PAGE

LIST OF TABLES

1. GENERAL INTRODUCTION

In an effort to overcome low profit margins, agriculture, like many industries, has increased production to increase profits. The result is usually a lower unit profit, but more units, increasing the return. The net result, however, is often a surplus which lowers the product value. Marketing boards have been formed to limit this production but have not been too successful when the product can be imported. Surpluses and their resulting problems will cause a shift in emphasis from the traditional increased volume production to efforts to directly lower unit production costs.

This study investigates the feasibility of lowering unit lettuce production costs in the Cloverdale area of British Columbia. The thesis is divided into three main sections. The first section determines the needs and limitations for mechanization of lettuce production within economic guidelines. The second section details the design, development and testing of a precision seeder, while the third section discusses the design and development of a mulch layer applier. Development of these two machines were a direct result of the economic feasibility study.

1.1 Project Feasibility Study

The first objective was to determine how lettuce production costs were distributed. The economic study by Dorling (1)[1] on the costs of mid-season lettuce production

1 Numbers in parenthesis refer to the appended references.

in the Cloverdale area of British Columbia was used as a basis for the economic analysis. The information contained in this report was reorganized to group associated production costs for a more physical presentation of work distribution and according to each production phase.

This enabled the analysis of separate production costs as part of a total system and determined where the largest expenditures occurred. The production phases resulting in largest expenditures were analysed in detail to determine methods of cost reduction.

The total production system is a series of interdependent operations where any change made in one operation will affect the remaining operations. It follows that a high cost operation occurring earliest in the total production system should be analysed first, followed by the next highest in the total production sequence.

2. ECONOMIC AND THEORETICAL FEASIBILITY

2.1 Introduction

The report by Dorling (1) indicates a very low profit margin for lettuce growers in the Cloverdale area. Any drop in the price of lettuce due to competition or over supply could result in operating losses for the producers. Similarly, any increase in labour costs would eliminate the profit margin. An arbitrary increase in the lettuce price is difficult due to market competition. The only solution appears to be a reduction of operating costs. Labour costs are certain to increase and as a result, the labour intensive sections of lettuce production must be modified first.

For the above reason, the study on mechanization of lettuce production is divided into two phases. The first phase is the mechanization of the labour intensive weeding and thinning operations. The second phase is the mechanization of labour intensive harvesting and packaging, and investigations into the high material costs associated with marketing. In the following discussion all costs reported are on a per-acre basis.

2.2 Labour Distribution

An average of 393.1 man-hours is required to produce one acre of lettuce using existing methods. This labour represents 44.1% of total production costs. The total costs may be divided among four general operations. Three of these operations involve distinct inputs of labour and materials

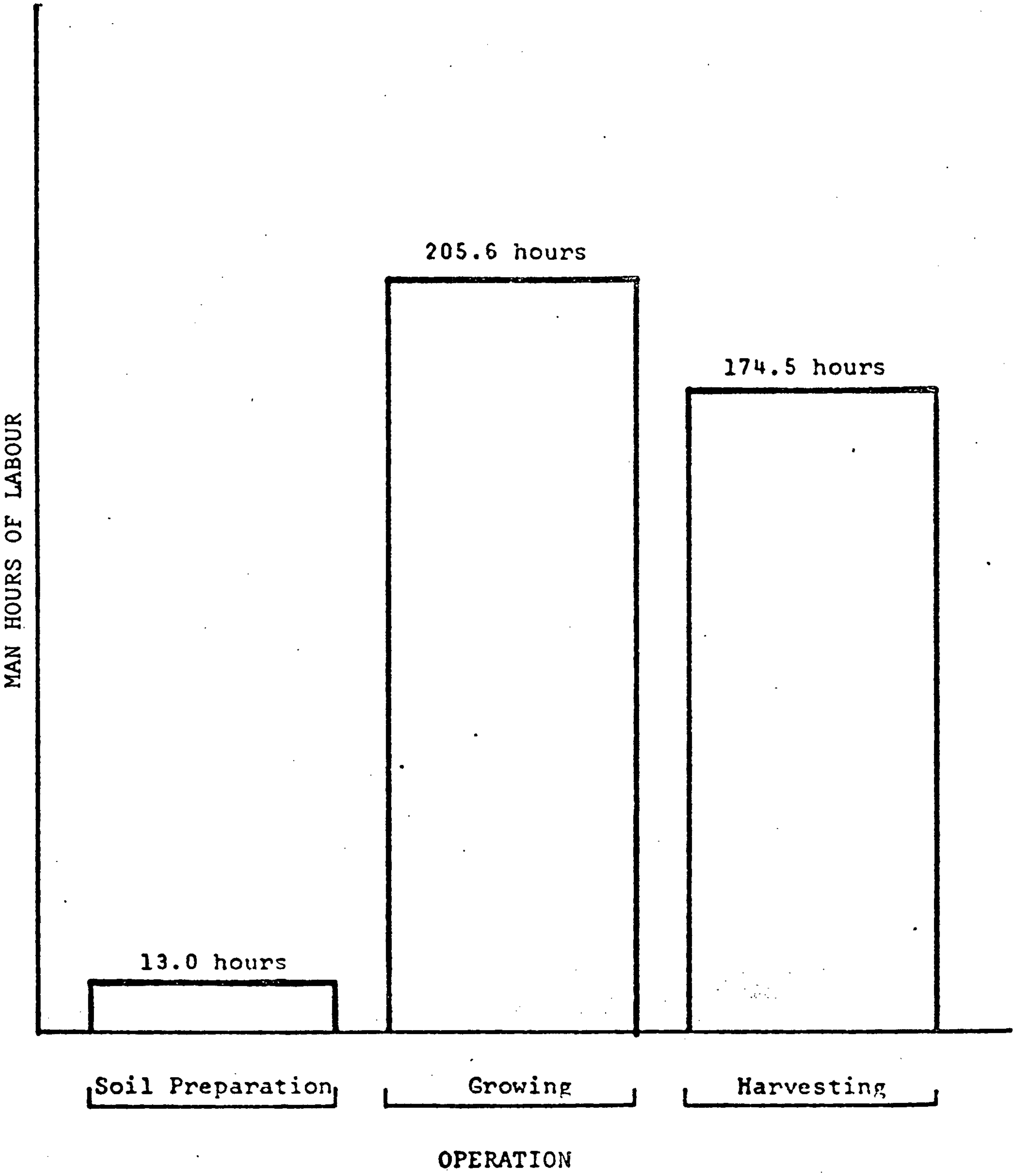


FIGURE 1. Labour distribution in producing one acre of lettuce

while the fourth is made up of primarily fixed costs to which no direct operation can be charged.

Figure 1 indicates the labour distribution for one acre of land. This distribution is:

Labour associated with soil preparation	13.0 hrs.
Labour associated with growing	205.6 hrs.
Labour associated with harvesting and distribution	174.5 hrs.
TOTAL:	393.1 hrs.

As can be seen, labour costs for soil preparation are negligible while the labour involved in growing and harvesting is significant enough to justify a more detailed analysis of these operations. Figure 2 presents a detailed breakdown of labour and material input for the three operations. A detailed look at the growing operation shows that thinning and weeding account for 81.5% of the total labour and material cost of this operation. The labour cost alone is $305.21 per acre. Harvesting and packaging labour costs are $280.38 per acre accounting for 46.9% of the total cost of this operation. Packaging materials represent 50% of the cost for harvesting and distribution and account for 20.5% of the total production costs, indicating the need for further study in this area.

2.3 Material Distribution

The average material cost for each acre of lettuce produced is $444.46, representing 30.5% of the total production

OPERATION

Labour Breakdown - $1.57/hr ($)		Operation		Material Breakdown ($)	
Floating & Marking	6.44	1. Soil Preparation		$12.58	Lime
Discing	3.45			21.17	Manure
Ploughing	1.89			60.00	Fertilizer
Liming	3.14				
Fertilizing	2.36				
Manuring	3.14	$20.42	$93.75		
Sub Total		$ 114.17			
Blocking	16.80	2. Production Operations & Maintenance		$10.72	Seed
Thinning & hand weeding	232.36			21.45	Seed Coating
Cultivating (wheel hoe)	46.63			15.33	Spray
Cultivating (basket weeder)	4.71			4.21	Drainage
Big weeds (pulling)	4.71				
Spraying	5.49				
Irrigation	9.42				
Seeding	2.67	$322.79	$51.71		
Sub Total		$ 374.50			
Cutting, Packing, Stapling & Loading	262.23	3. Harvesting Packaging Distribution		$299.00	Cartons & Staples
Hauling	18.75				
Making Cartons	18.15	$299.13	$299.00		
Sub Total		$ 598.13			
		4. Misc. Expenses Overhead			
		$ 369.22			
TOTAL COST		$ 1,456.02			

FIGURE 2. Existing cost to produce one acre of lettuce.

cost. Figure 2 indicates the general distribution of the material costs for the various operations, while Figure 3 details the material cost distribution. As mentioned previously the purchase of packaging materials (staples and cartons) represents the largest single cost item for materials. The packaging containers are therefore of some concern and a desired objective would be to replace the cartons with a less expensive container, preferably one that could be collapsed and recycled.

Another aspect of the material costs (Figure 2) is the cost of seed coating. Seed coating costs were approximated as follows: The cost of uncoated lettuce seed is approximately $6.00 per pound while coated seed sells for $9.00 per pound. Since the artificial seed coat weighs about twice as much as the individual seeds, one pound of coated seed consists of 2/3 lb. of coating material and 1/3 lb. of actual seed. On this basis, the seed cost of $32.17/ acre (Figure 2) is composed of $21.45 for coating and $10.72 for seed. This figure becomes significant if the 525 acres growing lettuce in the Lower Mainland area are seeded by precision seeders requiring coated seeds. Seed coating would cost $11,261.00 per year. This seemingly insignificant cost item alone indicates the value of a precision seeder not requiring seed coating for operation.

2.4 Land Use

An acre of lettuce produces an average of 733 cartons. On the basis of 24 heads per carton, this represents

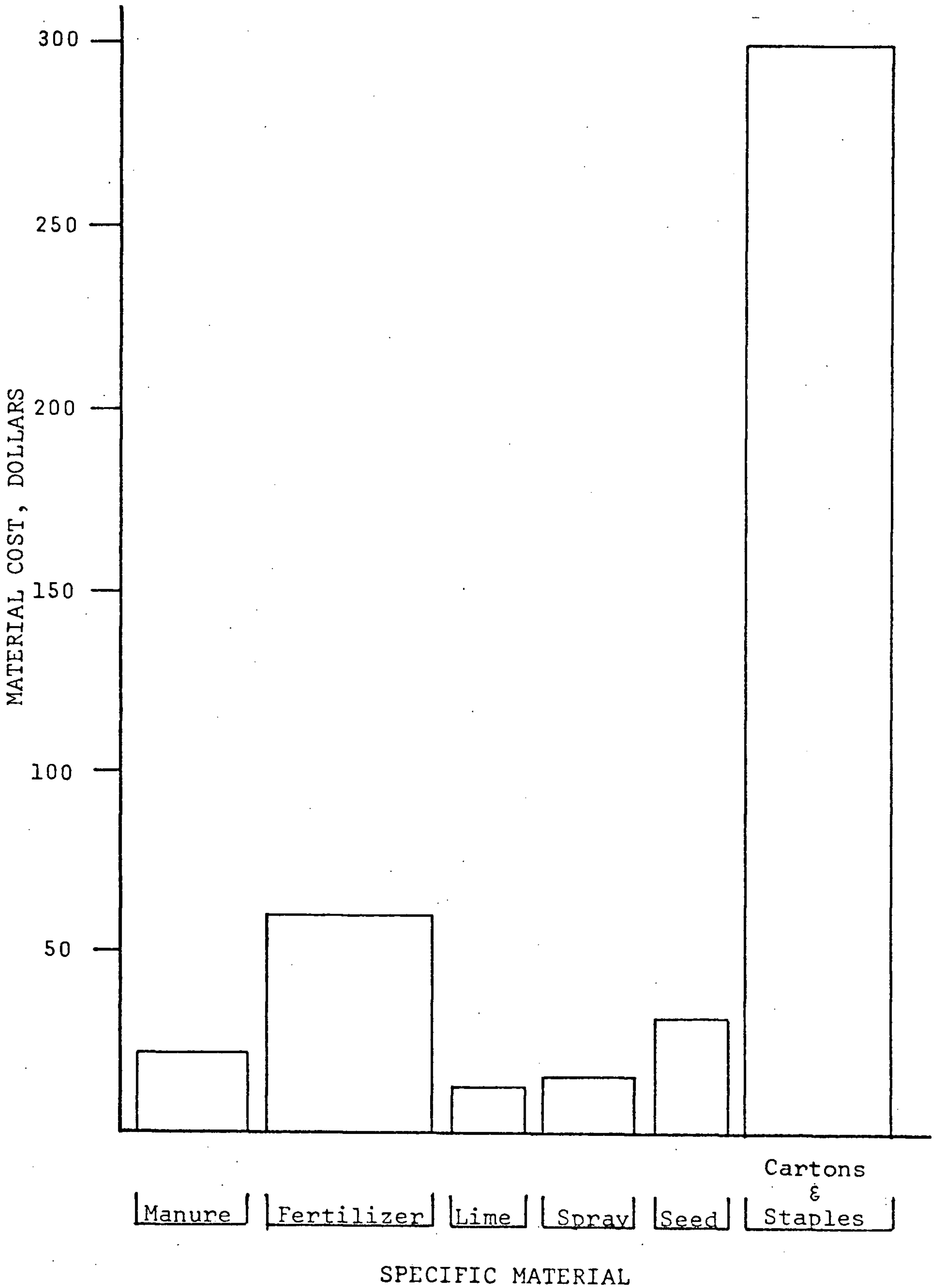


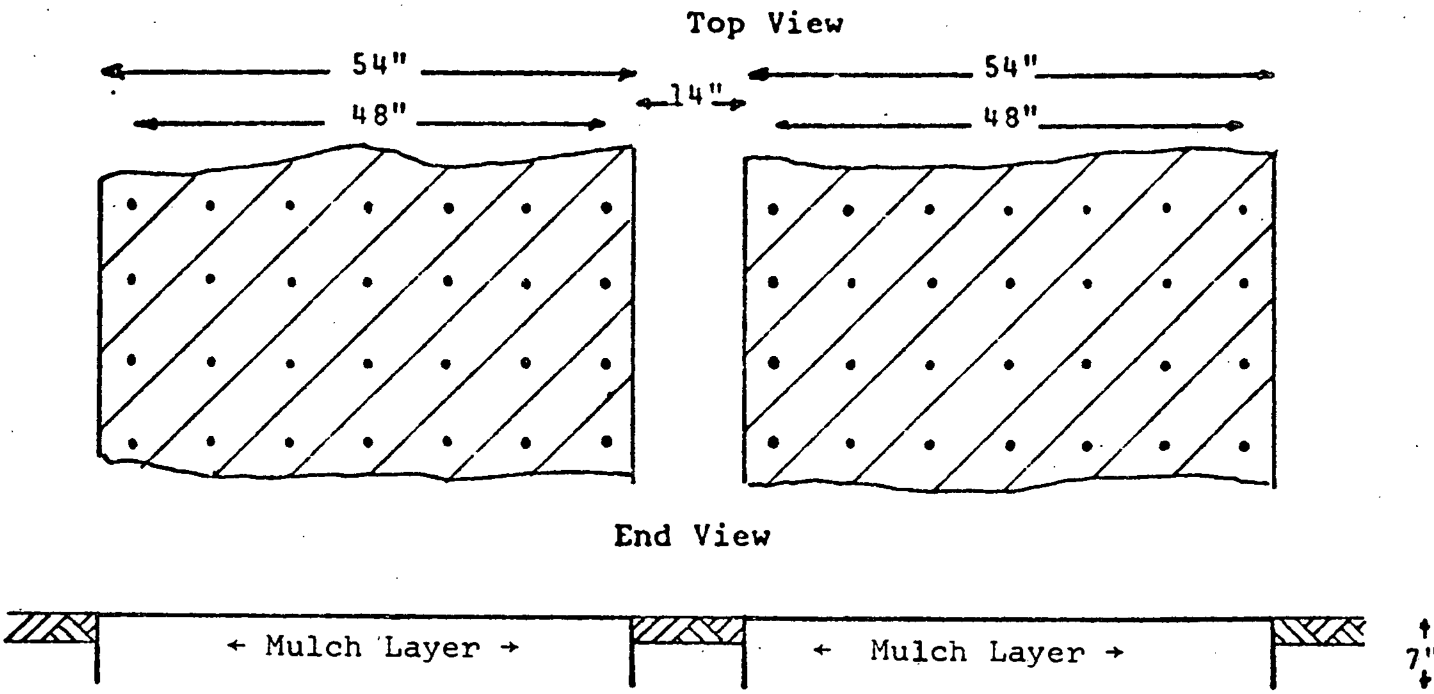
FIGURE 3. Material cost distribution in producing one acre of lettuce

a yield of 17,592 heads per acre. Each marketed head of lettuce therefore utilizes 2.48 square feet of field area. On the assumption that only 50% of the original plants in a field are actually marketed, each lettuce plant utilizes 1.24 square feet of field area. Assuming an average six inch head diameter, each lettuce plant however occupies only 0.20 square feet of field area.

At present, lettuce is planted in 48 inch wide beds. Each bed contains four rows of lettuce and individual beds are spaced at 14 inches. Modifying this system (Figure 4) so that each bed contains seven rows, with individual plants spaced at 8 inch centres, results in the utilization of only 0.44 square feet by each plant. An individual plant would therefore utilize a field area 2.26 times greater than the area it occupies. (Figure 4 also illustrates a proposed newsprint mulch layer, to accommodate the new row configuration, which is discussed later).

The effective land utilization with the modified planting configuration is illustrated with the following example. Figure 5 shows a square plot with a one acre surface area. Allowing 10 feet wide headlands at both ends of the beds, effective row length is 188.7 feet. Each bed and space between occupies a 68 inch width, giving a total of 36 beds per acre. The total effective bed length is 6,793 feet. At 8 inch spacing the potential number of lettuce heads is 71,328. If, as in the previous example, only 50% of the

PROPOSED CONFIGURATION INCLUDING MULCH LAYER



EXISTING CONFIGURATION

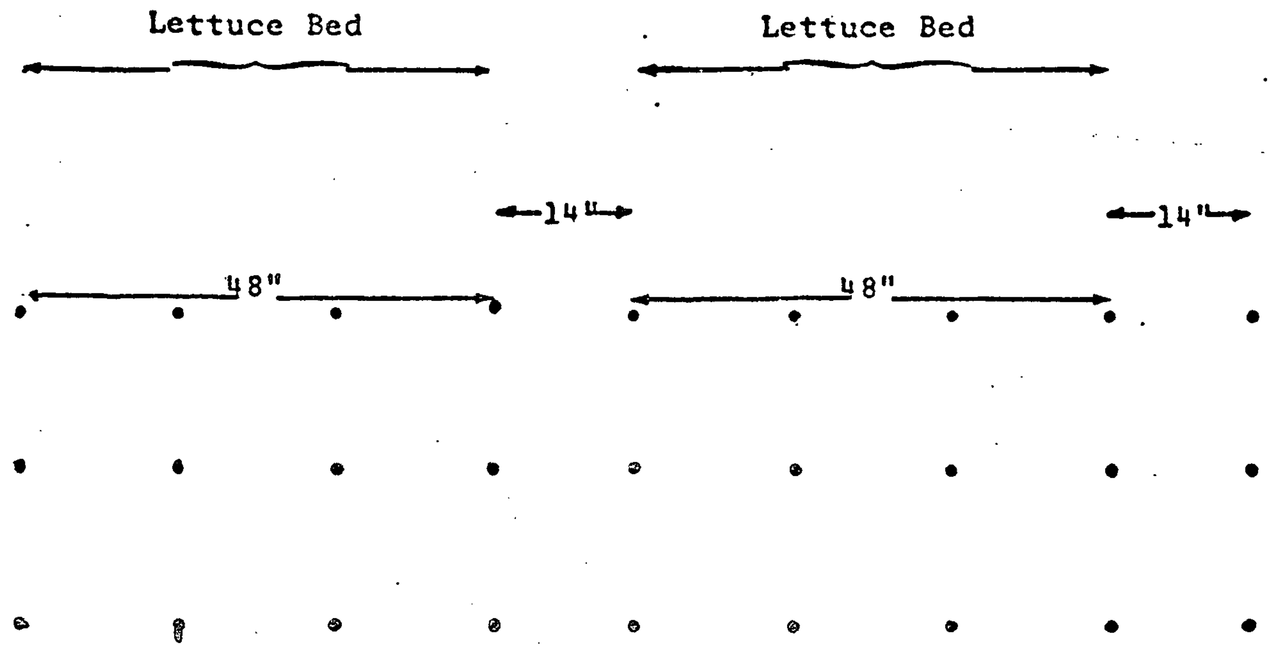


FIGURE 4. Proposed and existing lettuce bed configurations

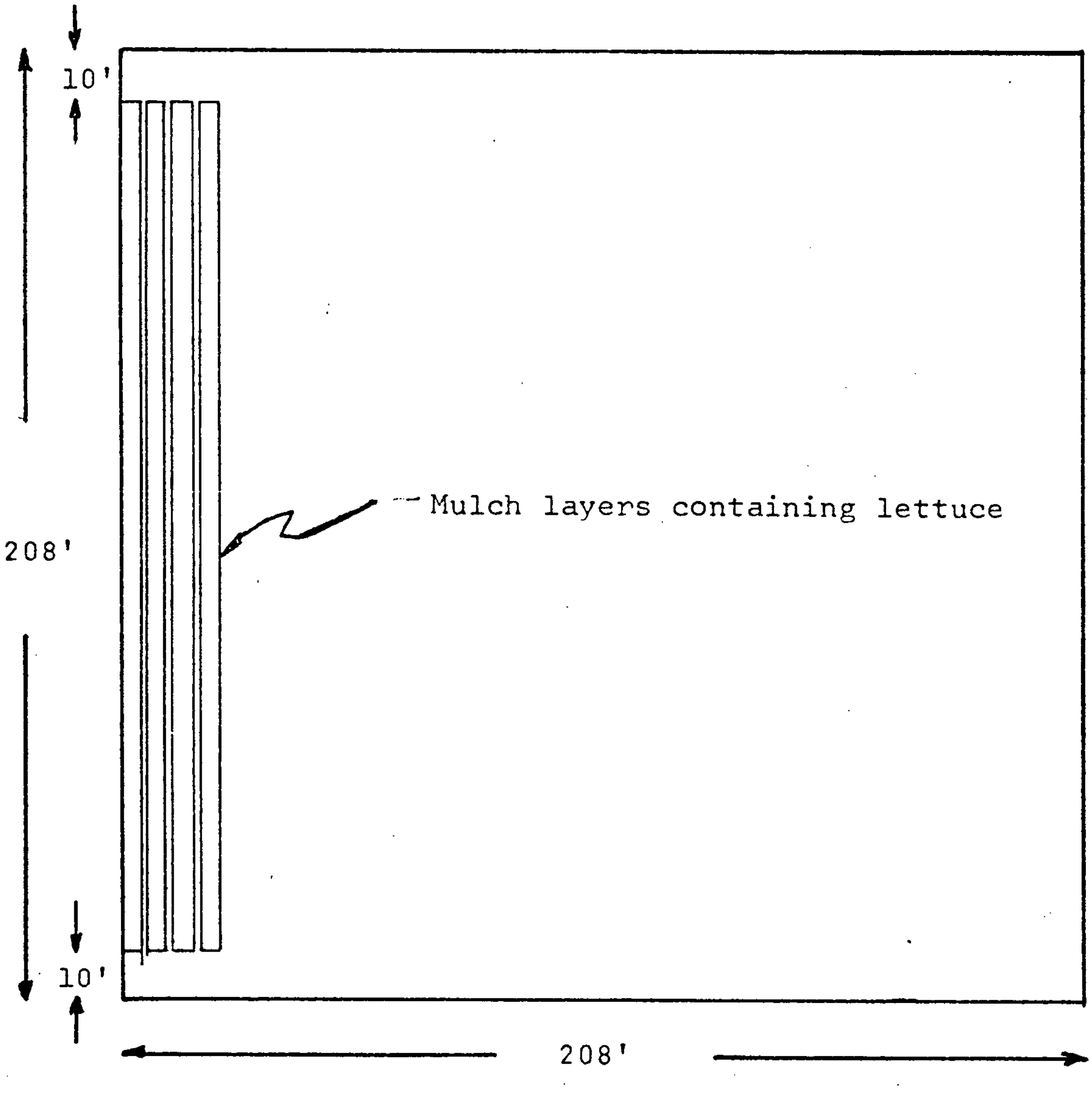


FIGURE 5. Land use

heads are marketable and it is further assumed that yield is reduced an additional 15% due to closer planting, the resultant increase in production is 142%. The above figures give a rough indication of the value of fitting new machines to the crop rather than spacing the crop to fit existing machines.

2.5 Discussion of Results

It is noted that labour is the largest single expense followed by material costs. A breakdown of the labour costs indicates that growing operations are the largest expense followed by harvesting and distributing operations. The growing operations occur first in chronological order and require the largest portion of labour. An analysis of labour distribution indicates that thinning and weeding operations account for the largest portion of labour cost in the growing operation. Thinning costs can be reduced by using either an automatic thinning machine or a precision seeder, while one of the easier ways to control weeds is by the use of a mulch layer. The final decision to develop a mulch layer applier was made because mulch layers are a proven weed deterrant, they aid in moisture conservation and they should result in increased yield. With all the system components being interdependent, a thinning machine would be useless if a mulch layer were applied and a mulch layer is, in turn, useless if no machine is available to plant seeds through it.

The decision to develop a mulch layer applying machine necessitates the need for a precision seeder capable of seeding through the mulch. Some thought was given to modifying a commercial seeder using coated seed, but a rough cost estimate of seed coating indicated that adapting a simpler precision seeding technique might be more advisable. The principles used in a precision seeder developed at U.B.C. in 1970-71 for containerized seedling production in reforestation have been thoroughly tested (2). This technique for single seed selection has proven itself satisfactory for greenhouse seeding and is considered suitable for seed selection for precision planting through a mulch layer. The seed selection device does not require coated seeds. The only requirements is that a seed be relatively symmetrical about one axis. This symmetry need only be relative to the extent that if one axis is large compared to the other two then these two form essentially a symmetry about the long axis. Of course, true symmetry irrespective of relative axis length is ideal. Thus the initial study on the feasibility of reducing lettuce production costs becomes a feasibility study of a combined mulch layer applier and precision seeding machine.

Considering that some mulch effects are known and that the seed selection concept is essentially developed and tested, the problem reduces to designing a suitable precision seeder and a mulch layer applier. Before designing these in detail further feasibility study is required. This is a comparison between the estimated labour savings and the estimated increase in materials and equipment costs.

2.6 Proposed Mechanization Procedure

The proposed development for mechanizing lettuce production may be divided into two distinct phases.

2.6.1 Phase 1: The first phase is the development of a mulch laying machine to place a cover over the soil to reduce weeding costs. A modified version of an existing precision seeder will be incorporated in this machine to eliminate thinning costs and seed coating costs. Modifications include an additional device for seeding through the mulch and the use of a seed selection nozzle suitable for lettuce. These proposed machines are discussed, in some detail, below. Their proposed design and feasibility are discussed before estimating their manufacturing and operating costs.

2.6.2 Phase II: After completion of phase 1, development should be directed toward reducing the intensive labour costs in the harvesting operation. This may be accomplished by the design of a suitable mechanical harvester. Finally, the material costs for containers should be studied and better handling techniques should be recommended.

The above order of development is proposed because the largest possible savings will probably occur in phase I. Completion of phase I should result in higher yields due to more complete land utilization and will result in savings due to labour reduction.

2.7 Detailed Description of Phase I

Performance characteristics of the original seeder, which are presented in reference (2), establish the expected performance limits of the modified version when it operates with the mulch laying machine.

The control system on the mulch applier is the critical aspect of the machine. It is physically impossible to remove paper mulch from a roll and place it on the ground with zero stress remaining in the paper. The reason for this is variation in the forward speed due to variable slip of the drive wheels on the prime mover. For instance, a paper roll drive mechanism driven directly from the tractor transmission will place an excess of mulch on the ground if tractor slip increases beyond the design value. Similarly, if slip decreases below the assumed value, the paper will not be removed fast enough and the difference must be compensated for by strain in the mulch paper. This strain will be accompanied by corresponding stresses. Alleviation of the stresses will occur through further strain (creep) and this may result in a torn mulch layer. Similarly, if excess mulch is applied, tearing may occur due to wind action.

In order to overcome these problems a paper roll control mechanism is required. The control device must sense the mulch paper tension between the paper feed mechanism and the point of application to the soil. Feedback from the control device is sent to a variable speed unit to allow the paper to be applied to the soil surface at a uniform tension, independent of tractor drive wheel slip.

As paper tension increases above a predetermined value, the paper discharge speed is increased while a decrease in paper tension results in a decrease in the speed of paper discharge. The variable speed unit should be capable of varying the speed of paper discharge in a range of 0 to 100% of some selected base speed. The force required to activate the control system must not exceed the maximum allowable tension in the mulch paper.

It is proposed that regular newsprint paper will be used as the mulch layer for two reasons. Newsprint is readily available and is economical. Secondly, a machine capable of placing a newsprint layer will be satisfactory for almost any other mulch material. The present retail price of newsprint in Vancouver is \$165.00/ton. Considering a density of 50 lb/cubic foot, a 0.0025 inch thick layer costs only 0.086¢/ft^2, while an 0.003 inch thick layer costs 0.10¢/ft^2.

The newsprint applying machine must also be capable of limiting stress conditions due to soil surface irregularities. A roller and a slider, mounted in front of and under the newsprint, respectively, could be used to smooth out soil surface irregularities, preventing stress concentrations in the newsprint. The slider would not only assist in smoothing the soil but would also excavate the sides of the bed to allow the edges of the newsprint to be placed below the soil surface. The slider would also pack the inside edges so that when the paper is covered, compaction can occur with minimum displacement. This will reduce stresses in the mulch layer that will be added when soil is packed around the paper edges. This packing must be accomplished with minimum soil movement parallel to the paper edges.

2.8 Estimated Lettuce Production Costs After Incorporating Phase I

The foregoing analysis has included the theoretical feasibility of phase I for reducing costs in the thinning and weeding operations. The final determining criterion on which further expenditures of time and money depend is the estimated maximum cost of using the new system based on no yield increase. The following analysis will not consider increased yield but will consider increased costs of seed resulting from seeding at the new spacings.

The purchase of new equipment will increase miscellaneous costs due to depreciation. In arriving at the cost of the seeder and mulch layer, one-unit manufacturing is assumed instead of assembly-line manufacturing. On this basis the retail value of new equipment for phase I may be estimated as follows:

Material per seeder head		$ 25.00
Labour and shop rental per seeder head		600.00
Prototype cost (7 heads)		4,375.00
Material for mulch applier		100.00
Labour and shop rental for mulch applier		600.00
	Sub-total	$ 5,075.00
20% overhead and depreciation on manufacturing and distribution		1,015.00
Royalties		1,000.00
	Sub-total	$ 7,090.00
Development costs - 10%		709.00
	RETAIL PURCHASE PRICE:	$ 7,799.00

The operating time for the machine, based on a field configuration as shown in Figure 5, is 2.86 hours/acre, assuming a machine speed of 1/2 mile/hour. The average active time for the seeder on a 40 acre farm (the average size in the study), seeded three times per year is 343.2 hrs. For a 2,000 hour machine life, this represents seeding 700 acres. The depreciation, assuming no resale value would be $11.14/acre. For a 1,000 hour life, the depreciation costs are $22.28/acre.

For calculation of the seed costs due to the new planting density, assume that the existing production of 17,592 heads per acre represents 70% of the seeds planted. From Figure 3 these cost $10.72. The seed cost for 71,328 heads would therefore be $30.42.

For calculation of the seeding labour assume 2.85 hours of planting and 2.15 hours for miscellaneous associated activities. An average labour cost of $1.57/hour, results in a labour cost of $7.85/acre. Figure 6 shows an estimated cost chart incorporating all aspects of phase I except the cost of the mulch paper. The difference in costs between Figures 3 and 6 indicate the potential savings, not including the cost of the mulch paper. The potential savings are $259.07/acre. In order to make a new technique worthwhile the producer should gain at least 50% of the increased savings. Therefore the maximum expenditure for mulch should be $129.00/acre, restricting the maximum mulch price to 0.33¢/ft^2.

Labour Breakdown - $1.57/hr	OPERATION	Material Breakdown
	1. Soil Preparations	NO CHANGE
Sub total	$ 114.17	
Weeding $ 20.00	2. Production Operations	$30.42 Seed
Seeding 7.85		15.33 Spray
Spraying 5.94		4.21 Drainage
Irrigation 9.42		Mulch costs not included
	$43.21 $49.96	
Sub total	$ 93.17	
	3. Harvesting Packaging Distribution	NO CHANGE
Sub Total	$ 598.13	
	4. Misc. Expenses Overhead	
Additional Deprecia-tion 22.28	$ 381.22	
Sub Total	$ 381.22	
TOTAL COST	$ 1,196.95	

FIGURE 6. Estimated cost to produce one acre of lettuce using Phase I techniques.

For newsprint of 0.003 inch thickness, the price per acre at the existing retail price of \$165.00/ton is \$30.70. This represents a cost of 0.10¢/ft^2. Using newsprint, the total production costs are estimated at \$1,236.65/acre. This represents an increase in the return to management from \$40.79/acre to \$259.35/acre or an increase of 635.8%.

The project appears economically and theoretically feasible warranting further investigation. The next stage in the feasibility study is to design and build test models and study their practical feasibility.

3. DESIGN OF THE PRECISION SEEDER

The precision seeder is basically three separate mechanisms that operate together to take individual seeds from a seed mass and place them in the ground. The first mechanism is a seed selection system, the second is a seed transporting system and the third is a seed planting system. A model seeder (Figure 7) which performs these functions, was designed, fabricated and tested. It is discussed in detail below.

3.1 The Seed Selection System

Basically three separate functions are performed by the seed selection system. These are: storing a mass of seeds, selecting single seeds from the mass and metering individual seeds to the seed transportation system.

The seed mass is stored in the seed hopper (Figure 8). The hopper holds seeds in a position suitable for individual seed selection. The hopper base angle is greater than the angle of repose of the seed, allowing the seed to flow toward the seed selection drum (Figure 11) when the seed level in the hopper drops. Two shafts (Figure 8-A) hold the hopper in a fixed position with respect to the seed selection drum. An adjustable feedgate is built on the hopper (Figure 9-A). Lowering the gate reduces the seed level at the seed selection drum whereas raising the gate increases the level. Once the gate is fixed at a given height the seed level at the selection unit remains constant,

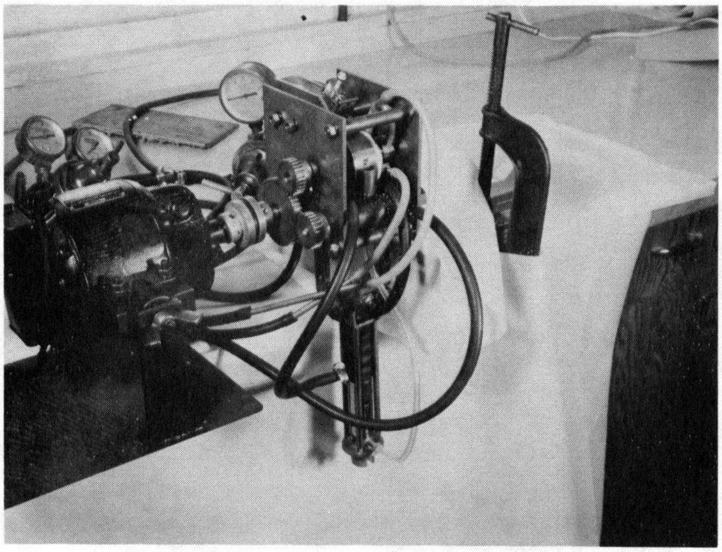


FIGURE 7 Model Precision Seeder

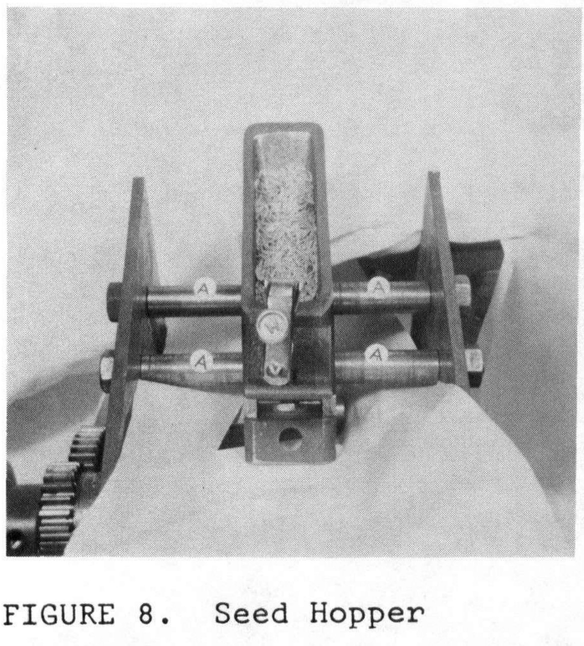


FIGURE 8. Seed Hopper

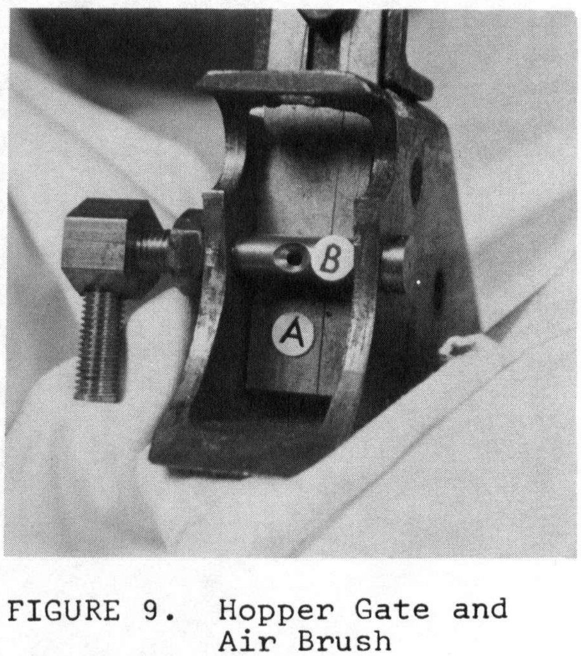


FIGURE 9. Hopper Gate and Air Brush

independent of the seed level in the hopper. This independent condition exists until the seed level in the hopper approaches the height of the bottom of the adjustable gate. An air brush is mounted on the hopper (Figure 9-B). The only adjustment available on this model is rotation, which allows the position of the centerline of the outflowing air to be adjusted. When the hopper is placed in a fixed position the clearance between it and the seed selection drum is 0.01 inches. The holes drilled in the hopper (Figure 10-A) allow the air from the airbrush to flow out. Their relative size lowers the air velocity to approximately 1/130 of the airbrush nozzle velocity preventing the airstream from carrying seeds out of the hopper area.

The second function, selecting single seeds, is done primarily with the seed selection drum and related components (Figure 11). The drum (Figure 11-A)rotates. At one end of the drum is the control plate, a metal-backed teflon insert (Figure 11-B) that fits into the end of the seed selection drum. The control plate is prevented from rotating by a locking rod (Figure 11-C). The rod and control plate are free to move parallel to the axis of drum rotation which allows the spring (Figure 11-D)to hold the control plate in constant contact with the seed selection drum. The seed selection orifice (Figure 11-E) is removable and screws into the drum until outside surfaces are flush. (This removable seed orifice (Figure 12) is incorporated

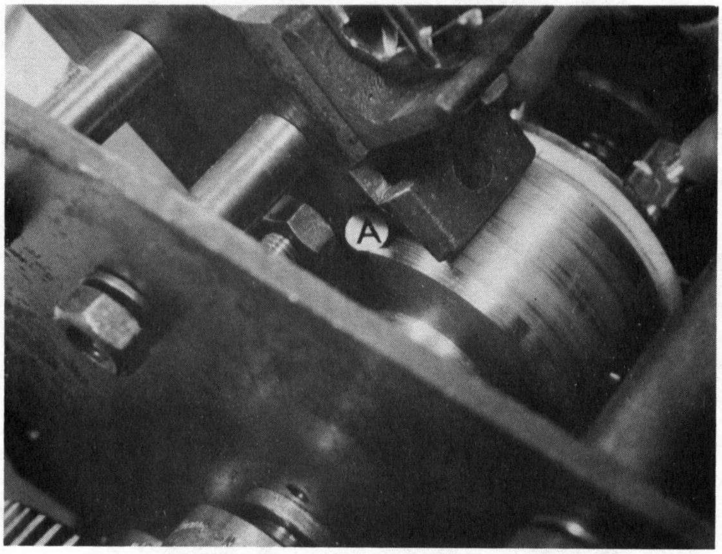


FIGURE 10. Hopper Vent Holes

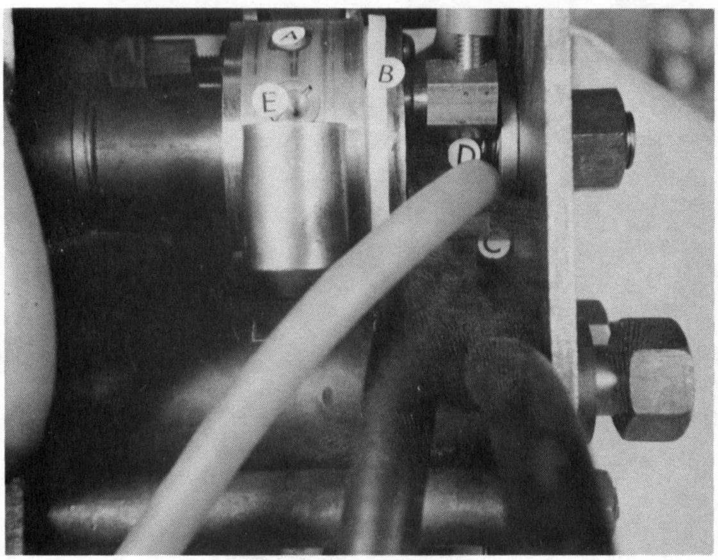


FIGURE 11. Seed Selection Drum and Related Components

into the design to make the model experimental. Should the seed selection device appear feasible, then tests could be conducted for machine-seed performance for all horticultural seeds by manufacturing and testing various seed selection orifices, and using the one more suitable for any specific seed type. The teflon control plate (Figure 13) is in contact with the seed selection drum. There are two main parts on the control mechanism. There is the vacuum groove (Figure 13-A) and the pressure hole (Figure 13-B). A partial vacuum is always maintained in this groove by connecting it to a vacuum pump. The final enclosing surface for this groove allowing the partial vacuum to be maintained is the drum contacting surface (Figure 14-A). The pressure hole contains air pressure with the same drum contact surface forming the final enclosing surface. This air pressure is maintained above atmospheric pressure with a pressure source connected to the hole. There is a hole drilled parallel to the drum centerline (Figure 14-B) that connects the contact surface with the seed orifice socket on the drum. Thus, depending on whether the hole is in contact with the vacuum groove or the pressure hole, air will flow into or out of the seed orifice.

The third function performed by the seed selection system is metering individual seeds to the seed transportation system. This is performed by the seed receiver (Figure 15-A). In addition to receiving the seed discharged from the seed

FIGURE 12. Removal Seed Orifice

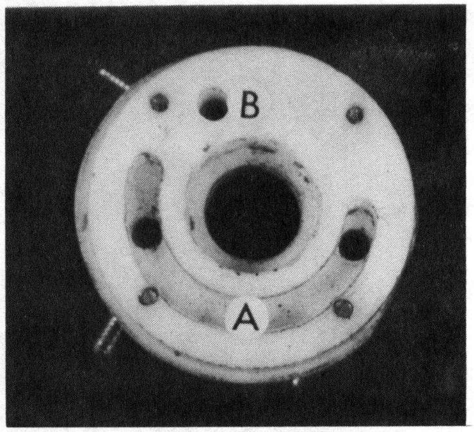


FIGURE 13. Teflon Control Plate Insert

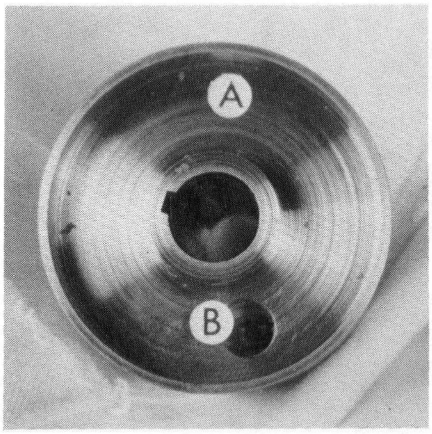


FIGURE 14. Seed Selection Drum - End View

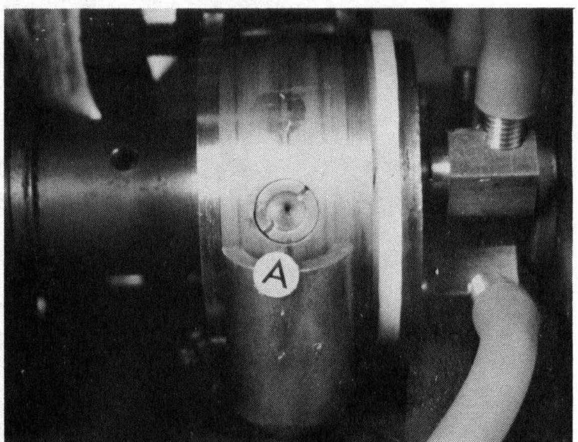


FIGURE 15. Seed Receiver

orifice, the seed receiver directs the seed into the air flow regulator (Figure 16-A).

The seed selection system works in the following manner. The drum rotates, carrying the seed orifice through the layer of seeds held in the hopper. At this point the hole in the drum contacts the vacuum groove and air flows through the seed orifice drawing seeds into the orifice. This air flow continues as the drum rotates carrying the seed orifice in position below the air brush. The position of the air flow from the air brush nozzle is adjustable and the air velocity is adjusted by increasing or decreasing the pressure. These two adjustments are varied until all but one of the seeds are blown away from the seed orifice back into the hopper. The seed orifice continues to rotate on the drum surface until it is above the receiver. The hole in the drum is now past the vacuum groove and is aligned with the pressure hole in the control plate. The air pressure differential is therefore reversed at the seed orifice and outflowing air carries the single seed away from the drum and into the receiver, completing the cycle.

3.2 The Seed Transporting System

The transporting system is composed of the air flow regulator (Figure 16-A), the distribution tube (Figure 17-A) and the probe receiver (Figure 18). The air flow regulator is a simple rotating valve composed of an outside cylinder and a rotating center shaft. The seed receiver is fastened

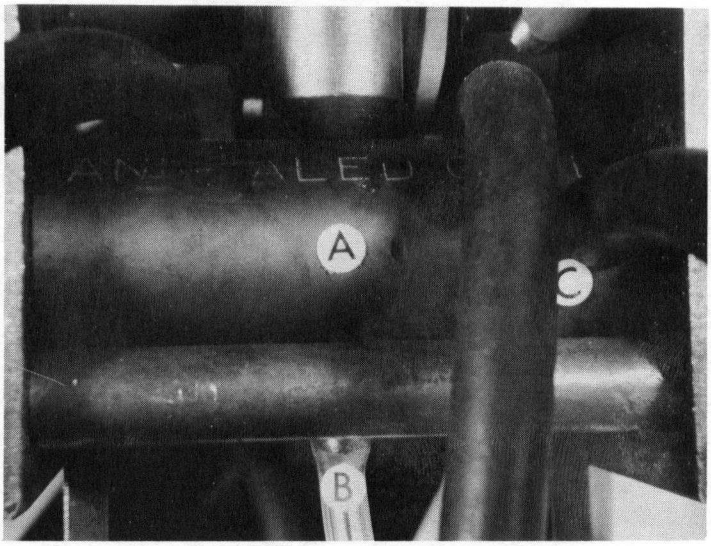


FIGURE 16. Air Flow Regulator

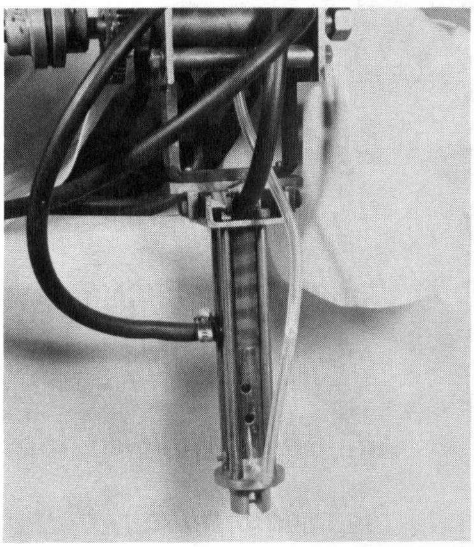


FIGURE 17. Distribution Tube

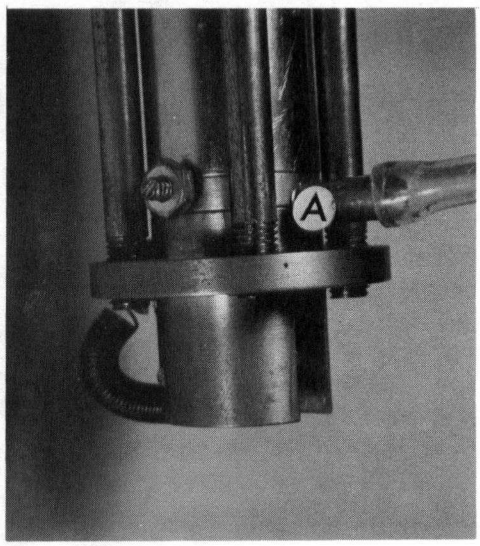


FIGURE 18. Probe Receiver

to the top center of the outside cylinder, while the distribution tube connector (Figure 16-B) is fastened to the bottom center. The centerlines of the connector and the receiver coincide forming a hole through the outside cylinder of the air flow regulator. This centerline bisects the cylinder axis at 90°. Another connector (Figure 16-C) connects a pressure supply to and through the wall of the cylinder. The outside cylinder is fixed in position. The inside shaft (Figure 19) rotates, driven by a gear timed with the seed selection drum, rotating at the same velocity. There are two holes in the shaft that are at 90° to and bisecting the longitudinal centerline of the shaft. One hole (Figure 19-A) passes through the shaft while the other is at 90° to the through hole connecting it with the shaft surface (Figure 19-B). There is a slot (Figure 19-C) milled in the rod parallel to the shaft centerline, that connects the pressure source (Figure 16-C) with the distribution tube (Figure 17-A). Every cycle, when the slot contacts the pressure source, air flows through the slot, into the through hole and into the distribution tube. The distribution tube is tygon tubing that conducts the seed from the air flow regulator to the probe receiver.

The probe receiver (Figure 18) is where the seed is held until it is driven into the ground. There is a connector (Figure 18-A) attaching the probe receiver to the distribution tube. The probe receiver is composed of two sections,

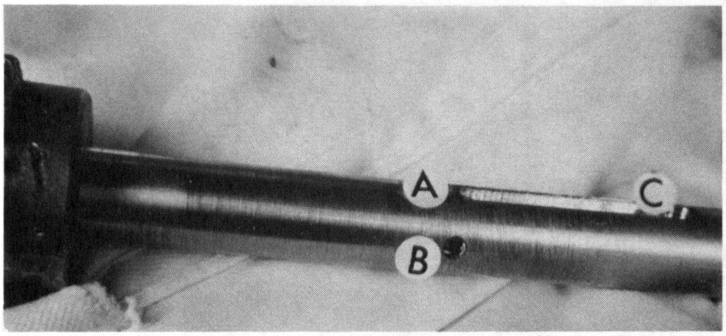


FIGURE 19. Inside Shaft Air Flow Regulator

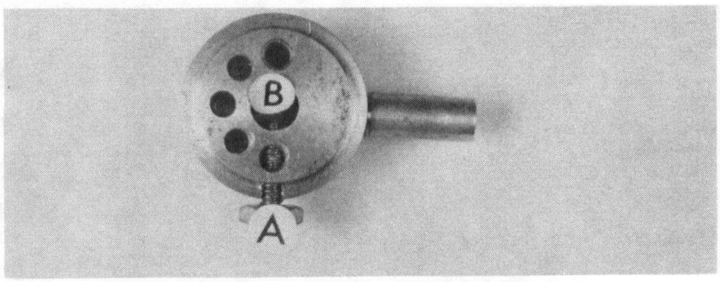


FIGURE 20. Probe Receiver - Top Portion

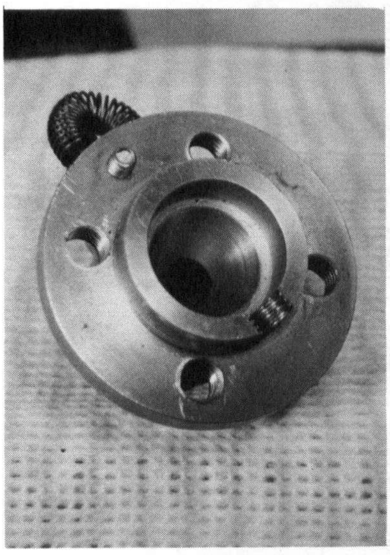


FIGURE 21. Probe Receiver - Bottom Portion

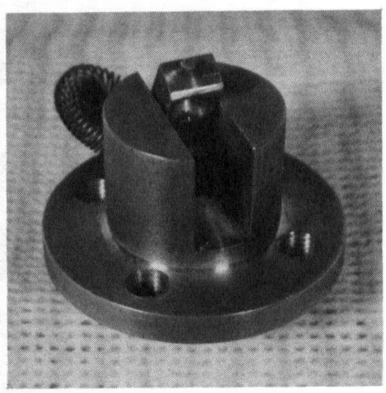


FIGURE 22. Spring Loaded Valve

a top portion (Figure 20) and a bottom portion (Figure 21). The top portion has a center hole acting as a probe guide (Figure 20-B) and several vents. These vents allow the air carrying the seed to exhaust, preventing a build up of pressure in the transporting system. This portion also contains a threaded screw (Figure 20-A) that fits into a slot on a probe and prevents the probe from rotating about its own axis. The bottom portion has a large inside diameter with sloping walls. The air stream goes out through the vent dropping the seed into this sloping receiver. The seed slides down the side into another center hole at the base that serves as a second guide hole for the probe. There is a spring loaded valve covering this second guide hole (Figure 22). In this valve, at the center of the second hole, is a countersink where the seed is stored until the probe carries it into the ground.

The transporting system functions as follows. The seed drops into the receiver from the drum and gravity carries it down through the outer cylinder of the air flow regulator. It rests on the rotating center shaft. As the shaft rotates, the through hole lines up with the centerline of the distribution tube and the seed falls through the airflow regulator. The center shaft continues to rotate until the slot lines up with the air pressure source. At this time air begins to flow through the airflow valve and distribution tube, into the probe receiver. This airstream carries the seed into the probe receiver where the airflow and seed separate. The air flows at decreased velocity out of the air vent and gravity carries the seed to the bottom of the probe receiver, through the second guide hole into the countersink on the spring loaded valve. The seed has now been transported to a storage location in the planting system.

3.3 <u>The Planting System</u>

The planting system is divided into three main mechanisms, the planting air flow regulator (Figure 23), the piston and cylinder section (Figure 24), and the probe (Figure 25). The complete planting system (Figure 26) (excluding the planting air flow regulator) may be adjusted vertically to vary the depth the probe goes into the soil (Figure 26-A). The cylinder and probe receiver are connected by a venting spacer (Figure 26-B). This venting spacer is necessary to keep the cylinder and probe receiver aligned and the venting prevents piston and cylinder air leaks from interfering with seed position in the receiver. Four long bolts (Figure 26-C) hold these three units together and connects them to a pivot point. The pivot point (Figure 26-D) is necessary because the seeder must move with respect to the soil surface and the pivot allows the probe tip to remain at one position in the soil as the seeder moves. This allows the probe to enter the mulch and pivot to relieve the forces caused by relative motion that could tear it. It should be noted that when a force is applied to the probe (i.e. force of entry into the soil) the moment caused by

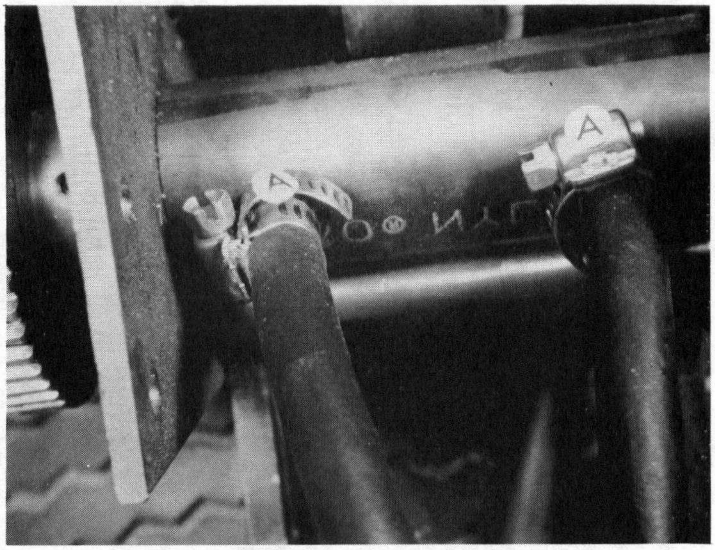


FIGURE 23. Planting Air Flow Regulator

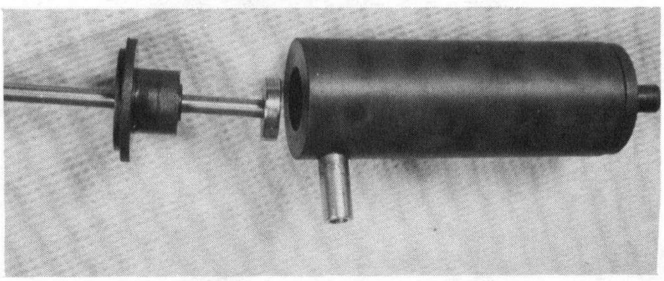


FIGURE 24. Piston and Cylinder

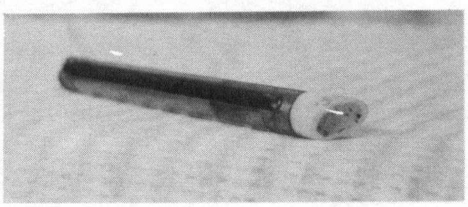


FIGURE 25. The Probe

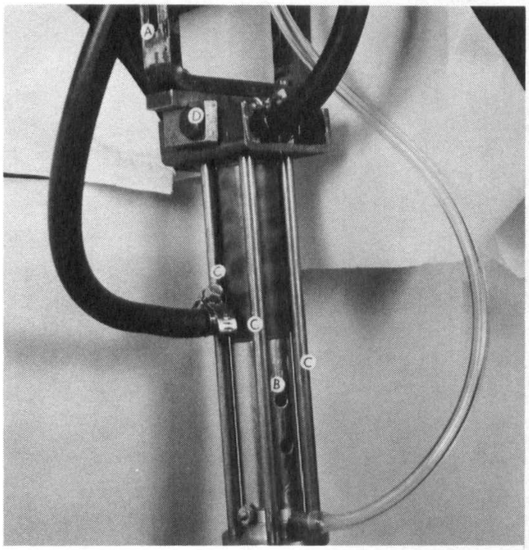


FIGURE 26. Planting System Assembled

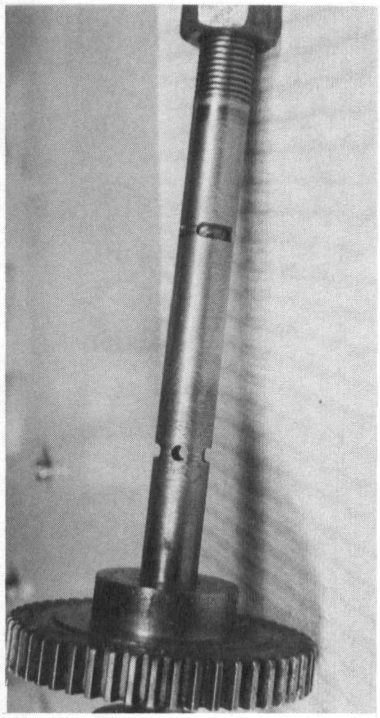


FIGURE 27. Inside Shaft

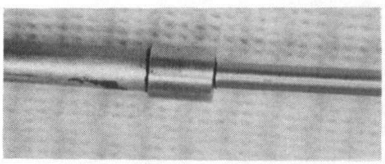


FIGURE 28. Probe-Piston Coupling

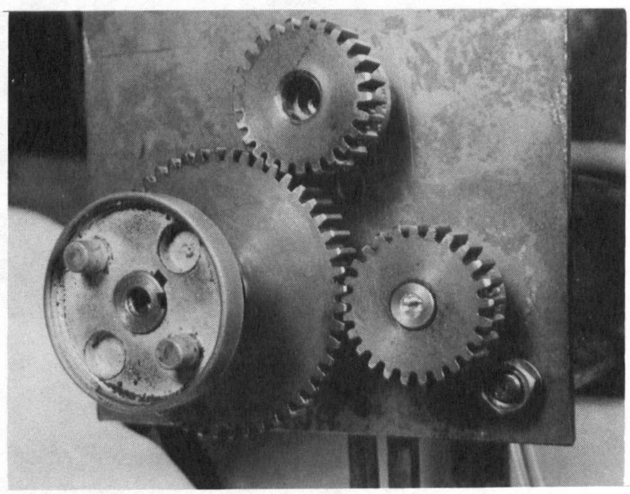


FIGURE 29. Timing Gears

the resulting force about the pivot points tend to hold the planter vertical. This prevents the seed planter from pivoting when the probe first enters the soil and the resulting force is applied.

The limiting factor for the probe is that it must accelerate faster than 1g regardless of the acceleration direction. This is necessary to allow the seed to stay within the seed cup on the probe tip as the probe travels from the probe receiver to the soil surface. One complete probe cycle is as follows: the probe extends, with acceleration greater than 1g, through the probe receiver, capturing one seed with the probe cup. Extension with acceleration continues until the probe tip has penetrated through the mulch layer and into the soil to the desired depth. The probe now withdraws back into the probe receiver, leaving the seed in the soil. The probe is held in the receiver for a suitable length of time to obtain the desired seed spacing in the soil. Ideally, considering the time for a complete machine cycle to be unity, the time in the withdrawal position should approach unity while the probe extended time should approach zero. As ideal conditions are approached the speed of forward travel can be increased with the speed then limited by the transport system or peripheral drum speed limitations. The easiest apparent way to get a rapidly extending and withdrawing probe appeared to be an air activated piston, with flow controls designed to minimize the probe travelling time and maximize the extended probe acceleration. This leaves the probe withdrawn for most of the cycle. Furthermore an air activated piston limits the force on the probe allowing an obstruction to stop the probe rather than cause mechanical damage that would occur if a fixed displacement system were used.

The first operating mechanism for the planting system is the timing control. This control, called the planting air flow regulator, is a simple rotary valve. The rotary valve has an outside cylinder (Figure 23) held in a fixed position with an inside rotating shaft on which a gear is fastened (Figure 27). The outside cylinder has two through holes (Figure 23-A) complete with connectors. One hole forms a connector between an air pressure source and the piston top; the other is a connector between an air pressure source and the piston bottom. There is another set of holes, with one hole in the plane of each through hole, that connects outside atmosphere with the inside of the outside cylinder. This set of two holes act as exhaust ports, one for the top of the piston and the other for the bottom. The gear on the rotating shaft supplies the force to rotate the shaft and keeps the valve timed with the rest of the machine. There are two through holes on the rotating shaft which align with the through holes in the outside cylinder. There are also four slots in the same rotary plane of the shaft as the through holes. These slots connect the top and bottom of the piston with their respective exhaust ports. These sets of slots and holes are so positioned that when pressure is applied to the top of the cylinder the exhaust port for the bottom of the piston is open. Similarly, if the pressure is on the bottom of the piston the top exhaust port is open.

The piston and connecting rod are fabricated from one part to ensure that their centers were on the same axis to prevent binding, as both have small clearances to act as an air seal at the bottom as well as the top of the piston. The piston travel and connecting rod length are determined by the maximum desired probe penetration. The probe and connecting rod are connected by a coupling (Figure 28) that allows the piston and connecting rod to rotate with respect to the probe whose rotary position is fixed. Relative longitudinal motion is prevented by this coupling. The probe (Figure 25) has a slot milled down one side and the set screw in the top part of the probe receiver fits in this slot to prevent the probe from rotating. A teflon tip on the probe is used to minimize dirt and moisture adhesion. The teflon tip is angled to gradually cut the mulch around the probe periphery as the probe passes through. The center of the teflon tip is hollow to create a cup to hold the seed during soil entry to minimize seed crushing. The lead edge of the teflon tip strikes the spring loaded valve giving it an acceleration greater than 1g which, in effect, leaves the seed suspended in the centerline of the probe. This allows the seed to enter the cup in the teflon tip of the probe as the probe is accelerating faster than 1g. Relatively, the seed falls into the cup.

This mechanism operates in the following manner. After the seed has landed in the countersink of the spring loaded valve, the planting air flow regulator allows air to enter above the piston and exhaust air below the piston. The piston, connecting rod and probe accelerate downward under the air pressure load. The probe strikes the valve and catches the seed in the teflon tip. The probe containing the seed then enters the soil and reaches the full travel. At this point the planting air flow regulator introduces air below the piston while exhausting air above. This decelerates and then accelerates the probe, withdrawing it and leaving the seed behind. When the probe has withdrawn sufficiently, the spring loaded valve closes, completing one full cycle of the seeder. In the meantime another seed has been selected and is being transported to the probe receiver as part of the next cycle.

3.4 General Information

This experimental model has many variables including vacuum pressure, air brush pressure, seed discharge pressure, seed transport pressure and piston pressure. The seed orifice is also variable and the depth of probe with the resulting seed penetration in the soil is adjustable. The air brush position is also adjustable.

One adjustment that is not available on this model is the probe cycle time. The time in the cycle when the probe begins to extend and withdraw are constant. If the pressures introduced are large, then the probe extends rapidly to the fully extended position and will not begin to withdraw until the planter air flow regulator reaches a predetermined position. This could leave the probe in the fully extended position for too long. This is a design fault that should be corrected before actual field tests are initiated. The activator to withdraw the probe must be a function of the probe position only, while the probe extension that initiates the planting cycle must continue to be timed relative to the rest of the precision seeder. Three gears (Figure 30) keep the machine parts synchronized.

3.5 Test Results - Precision Seeder

A preliminary testing experiment was conducted in the laboratory to test the precision seeder. The objective of the test was to determine the feasibility of the existing machine, evaluate its performance and observe the general machine behaviour. The machine performance is a function of the individual parts or systems. In order to determine where the problems exist it is necessary to isolate the systems and test their individual performances. This was done by testing the performance of the seed selection system first and then testing the performance of the combined transporting and planting system. The combined systems were then evaluated separately by observations made during the experiments.

The test for the seed selection system was conducted by adjusting the air brush pressure, the vacuum pressure and the seed removal pressure to give the most dependable visual results. The objective was to maximize the number of single seeds selected. No record of the resulting adjustments was attempted because in the low operating ranges used, the high pressure regulator gauge readings on the laboratory air supply system were not dependable.

The seed selection unit was operated for 1,000 cycles and the number of zero, double and triple pickups were counted. The gauges were re-adjusted visually and a second test was conducted similar to the first but with slightly different pressure and vacuum settings. Results of these tests are given in Table I.

TABLE I TEST RESULTS OF SEED SELECTION UNIT

Frequency of Seeds Picked	Test #1	Test #2	Average
Single seed/cycle	66.1%	66.8%	66.4%
Double seeds/cycle	20.9%	15.7%	18.3%
Triple seeds/cycle	1.2%	.09%	.1%
Total no seeds	1,115	1,009	2,124
Average no seeds/cycle	1.12	1.01	1.06

The average total seeding rate of 1.06 seeds/cycle is satisfactory but the distribution about the mean is too great. The minimum acceptable performance of this machine should be 95% singles, 3% doubles and 2% misses. An observation made during the testing indicated a high of 15 consecutive singles prior to a double or miss. This indicates a possible 94% single seeding rate and if this can be accomplished inconsistently it should be able to be duplicated regularly. Other observations include that singles, doubles and misses occur in sets with as many as 10 misses and 6 doubles occurring consecutively. This implied that the pressure setting on the air brush nozzle was fluctuating. This was not detectable on the high pressure regulator gauge in the laboratory air supply system, indicating the need for a pressure regulator that will deliver a consistent airflow accurately in the 0 to 2 psig range.

Another difficulty was due to the air brush design. The air brush should have been similar to that used for the conifer precision seeder (2) as uniformity of the airflow seems important. The momentum imparted on the seeds by the air brush airstream was sufficient to bounce the seeds out of the hopper. This problem prevented increasing the air brush flow and therefore restricted the range of vacuum settings that could be used. A higher vacuum setting and air brush pressure combined with an air brush design change should improve the seed selection tool performance. In order to give the air brush and corresponding vacuum settings more range a new hopper design should be considered. One concept would be a hopper that is completely enclosed at the seed drum surface but includes a vertical vent large enough to expel the air from the air brush and separate the seeds from the airstream in the process.

As expected the conical shaped seed orifice performed satisfactorily, confirming that relative seed symmetry is almost as acceptable as perfect seed symmetry. The design could be improved, for instance, by restricting the large diameter of the seed orifice cone to seed length plus 10%. This will allow the air brush to be placed closer to the position where the seeds are held which should help in seed removal. Some consideration should be given to the conical angles for relatively symmetrical seeds. For seeds relatively symmetrical about one axis the cone angle should be larger and the orifice size smaller than the corresponding cone angle and orifice for truly symmetrical seeds. One important factor that determines machine performance is seed cleanliness. It is imperative that the seed be clean before any assessment of maximum performance can be made. The seed used in this test was commercially prepared for non-precision seeding use. Properly cleaned seed could undoubtedly reduce the number of misses by 50%. A miss (experienced with the conifer precision seeder) usually contained a small particle of seed coat in the orifice blocking the vacuum and undoubtedly the same situation occurred with the lettuce seed.

The expected 95%, 3% and 2% distribution should be well within the capabilities of this seed selection system. The following modifications should prove this:

(a) Clean seed

(b) Pressure regulators accurate under 2 psig

(c) An improved air brush with more range of adjustment

(d) A new hopper complete with vent

(e) New shape detail on the cone and seed orifice size.

A series of tests after each modification should show a continual improvement of the seed selection system. After modification (d), each type of seed tested should have an independently designed seed orifice.

Some sticking due to limited allowable seed discharge pressure was evident in this design. To compensate for this, a design modification on the seed receiver is required, or a scavange cycle similar to that used in the conifer precision seeder should be incorporated in the control plate. A seed receiver design modification would allow increasing the discharge pressure without the possibility of blowing the seed out of the receiver.

Two independent tests were conducted on the combined planting and transporting systems. Each was similar to the seed selection system test. Pressure and vacuum conditions were adjusted to give what appeared to be the best consistent operating conditions. The number of seeds delivered by the probe cup was recorded for each cycle. Results of these tests are given in Table II.

TABLE II. TESTS RESULTS OF SEED DELIVERED BY PROBE

Number of Cycles	Number of cycles having --			
	Zero seeds	One seed	Two seeds	Three seeds
1,000	265	596	126	13
1,000	320	590	84	6
Totals 2,000	585	1,186	210	19

The total percentage of seed delivered by the probe should be 100% of those delivered into the seed receiver. From Table I it is seen that the total number of cycles expected to deliver seeds to the receiver is 1716 while from Table II it is seen that only 1415 probe cycles delivered seed. In other words, only 82% of the seed selected by the seed drum was delivered by the seed probe. It was difficult to determine where these seed losses occurred. Observations indicated that most of the losses occurred in the seed transportation system although some losses also occurred in the planting system.

Seeds were often blown out of the seed receiver rather than dropped through the air flow regulator. There were two factors contributing to this. A high discharge pressure was required to remove the seed. This caused turbulence in the receiver and often supplied sufficient air flow to carry the seed out of the receiver. This problem will be eliminated by the proposed receiver design change. The second factor was air leakage between the airflow regulator shaft and its enclosing outside cylinder. This leakage air flows out through the receiver often preventing the seed from falling to the shaft. When this occurred the seed was not in the proper position to fall through the shaft hole at the intended time and remained in the receiver. This problem can be overcome by changing the valving arrangement and this change is discussed in the general recommendation portion of this report.

Another location where seed losses were noticed was in the vent portion of the probe receiver and this could be due to two factors. The transport system might have too much air moving through it resulting in a large enough vent velocity to carry the seeds out of the probe receiver. The second problem could be too much turbulence in the probe receiver, causing the seed to bounce near the venting portion on the top. The new valving arrangement should solve the air volume problem while the second problem could be alleviated by increasing the dimensions of the probe receiver.

Seed damage appeared minimal with a maximum estimate of 2%. There are two areas where this damage could occur.

The first is between the probe and the bottom probe guide where there is a possibility of jamming. The new valving arrangement and/or the change in dimensions of the probe receiver could correct this. The second area is between the probe tip and the spring loaded valve where there is a possibility of crushing seeds. This can be avoided by making the countersink deeper than the seed length and modifying the spring loaded valve so it is 90° to the probe centerline when it is closed.

The recommended modification sequence to improve the transport and planting systems is:

(a) Implement a new air flow valving arrangement

(b) Increase the dimensions of the probe receiver

(c) Build a spring loaded valve seated at 90° to the probe.

The piston arrangement worked satisfactorily although leaks occurred around the air flow control valve. Furthermore the long lead lines offered enough resistance to the flow that increasing the air flow rate in and out at the piston is possible. The biggest problem is the fixed firing time of the piston due to the specific distribution of cycles on the valve shaft. These problems can be overcome by changing the valve arrangement. These changes are discussed in the general recommendations.

The results of the total combined system are predicted using the independent tests. Since the machine operates as a series unit the following is assumed: (Reliability of Seed Selection) X (Reliability of Transport and Planting) = Reliability of the machine. From Tables I and II it is seen that of a total of 2124 seeds selected by the seed drum only 1663 were delivered to the probe. On this basis, assuming the planting system is independent of whether the seeds are singles, doubles or triples, the reliability of the combined system is 0.784.

The total machine reliability for seed placement then is:

Singles = .664 X .784 = .521

Doubles = .183 X .784 = .144

Triples = .01 X .784 = .00784

For 2000 cycles, using the machine reliability the estimated results are:

Singles =	2000 X .521	= 1,042 seeds
Doubles =	2000 X .144 X 2	= 576 seeds
Triples =	2000 X .00784 X 3	= 47 seeds
	Total	= 1,665 seeds

From Table II the actual number of seeds delivered in 2000 cycles were:

Singles	= 1,186 seeds
Doubles	= 420 seeds
Triples	= 57 seeds
Total	= 1,663 seeds

This above method of measuring machine performance can be used as a technique to determine the approximate effect of individual modifications on the performance of the total machine. The machine will be practical if the total machine reliability for single seeds exceeds 0.9.

3.6 Precision Seeder Recommendations

The simple rotating valves used in the test model can be machined to overcome leakage between the inner rotating shafts and outer cylinders. They have an inherent weakness however that cannot be overcome. This is because the "on" or "off" time on these valves is fixed by the mechanical distribution of holes and grooves on the shafts making the valve position independent of the position of the device it is controlling. It is therefore recommended that the mechanical valves be replaced with microswitch activated air solenoids. The probe airflow regulator should be replaced by a timing cam that operates a microswitch which in turn activates two air solenoids. One solenoid allows air into the top portion of the piston while the other simultaneously opens the exhaust below the piston. A second microswitch is required to activate an air solenoid to allow air into the bottom of the piston and to activate a second solenoid to open the exhaust at the top end of the piston. This microswitch must be activated by the piston position and must also override the initial microswitch closing the bottom exhaust and the top inlet. Including this type of control has two advantages. It eliminates leakage and minimizes the cycle time for the probe in the extended position. A timer safety device would have to be included. In this way, if an obstacle prevented the probe from extending to where it can activate the second microswitch, the timer would return the probe automatically. The solenoids should be located close to the piston and cylinder and should use large air lines to minimize friction losses.

The air flow regulator for the transport mechanism should also be another cam operated microswitch to control an air solenoid. The microswitch should be adjustable to control the air solenoid "on" and "off" time. This will enable the system to use a high pressure air surge to carry the seed to the probe receiver then cease further air flow, stopping turbulence and therefore allowing the seed sufficient time to drop into position before the probe firing cycle begins.

Some measurements should be taken to determine the size range of horticultural seeds in order to design the transport and planting mechanisms to operate with the entire range of seeds. If the size range is too large then there may have to be two or three different optional sized systems that are purchased to meet a grower's specific need.

The final concept of the precision seeder is to operate it in conjunction with the mulch layer applier. The seeder is eventually to be timed with the mulch paper applying rate and by varying the drive ratio between the applier and the seeder the spacing of the seeds in the direction of travel can be adjusted. Side spacing will be adjusted by changing the distance between multiple precision seeders.

Cost and feasibility studies should be done comparing the use of carburetor vacuum or a vacuum pump and a similar comparative study between installing a compressor on tractors or using compressed air cylinders.

4. DESIGN OF THE MULCH LAYER APPLIER

A machine which will apply a mulch layer to the soil surface must perform two functions. The machine must be capable of preparing the soil for the mulch layer and must also be capable of applying the mulch layer on the prepared soil surface. Two important unknowns have to be considered for soil preparation. The soil reaction to an applied load has to be determined in order to design a machine to perform a given series of operations, while the limiting forces to be used in applying the mulch layer also have to be determined.

A test was undertaken to determine the reaction of a soil to an applied load and the resulting forces due to this reaction. A scale roller was fabricated and used as a penetrometer on an Instron apparatus. A confined soil sample was placed on a compression cell and the roller pushed into the soil at a constant penetration rate. The forces and sinkages were recorded at regular intervals and the results were plotted using the Bernstein equation. The curve was a good fit but due to a lack of understanding of the exact soil reaction a second set of data were obtained using the same conditions and a round penetrometer probe. A similar curve was plotted, but the two curves had different constants. A detailed attempt was made to derive a soil reaction pattern that would explain the different curves. It was assumed that the manner in which the soil would react to a load would be the same in both cases but that shape of the applied load would vary the distribution of the soil reaction, resulting in different total results. Several computer programs were run assuming different soil reactions in an effort to correlate the two resulting curves. Assumed reactions could, in no way, account for the differences, so it was assumed that any further attempt to use any of these results for predicting soil reactions for a full scale load would be completely erroneous. One interesting observation is the accuracy of the Bernstein equation derived for each shape. Apparently, regardless of the distribution of the soil reaction, within one shape, the exponential relationship between pressure and sinkage is valid. Considering that one obvious reaction is density change under an applied load, an assumption was made that the soil density change is exponential with an applied load and an effort was made to solve the problem in this manner. The result of this effort is the beginning of a theoretical approach to correlating soil reactions resulting from density changes (3) to applied loads. However, no easy way was determined to evaluate the constants so the approach was not helpful for this particular problem.

As a result of this inability to measure the soil forces and determine the soil reactions, the design of the ground preparation unit became more of an estimating procedure than a design problem.

The design limitations for the mulch applying section of the machine were calculated from testing newsprint at a constant strain rate of 0.5 cm per minute. Observations made during testing of newsprint strips indicate that room dry newsprint is elastic in the lower stress and strain regions. The elastic limit is approximately 25% of the rupture point. Table III presents the force required to rupture various samples of room dry newsprint. The lowest recorded rupture force was 0.977 lb/in width while the elastic limit was reached at an average load of 0.244 lb/in width. From these values, it appears that the maximum tension used in removing newsprint from a roll should be limited to 0.16 lb/in width (2/3 of the elastic limit). For strips 68 inches wide, the maximum allowable force will be 11 lbs. Limiting the force during paper application to 11 lbs should prevent any permanent deformation or residual internal stresses in the mulch layer.

Table IV lists the forces required to rupture water-saturated newsprint. Saturated newsprint did not have an elastic region and was time dependent. When considering wet newsprint (such as a mulch layer that has been placed on the soil and wetted by irrigation) it is safe to assume that the paper is plastic in nature and that if a force is applied to the paper it will continue to creep until the stresses reach zero or the paper yields. Comparing the results in Table IV with those in Table III shows that the rupture strength of dry newsprint is approximately four times the strength of wet newsprint.

Table V shows the maximum elongation at rupture of

TABLE III RESULTS OF TENSION TESTS ON NEWSPRINT USING THE INSTRON APPARATUS

Each sample is 1.865 inches long X 1 inch wide X .0025 inches thick. The newsprint is room dry.

Sample No.	Failure Force (lbs)
1	.977
2	.926
3	1.023
4	1.102
5	1.146
6	1.072
7	1.159
8	1.164
9	1.195
10	1.182
11	1.202
12	1.078
13	1.058
14	1.102
Mean	1.099

TABLE IV RESULTS OF TENSION TESTS ON NEWSPRINT USING THE INSTRON APPARATUS

Each sample is 1.865 inches X 1.0 inch X .0025 inch. The center portion of each specimen was immersed in water for approximately one minute until a one inch length was saturated.

Sample No.	Failure Force (lbs)
1	.256
2	.242
3	.229
4	.249
5	.210
6	.257
7	.290
8	.282
9	.285
10	.260
11	.280
12	.254
13	.284
14	.273
15	.249
16	.262
17	.273
Mean	.261

TABLE V RESULTS OF STRAIN TESTING NEWSPRINT SAMPLES IN THE INSTRON APPARATUS

The change in length recorded is the maximum occurring when the sample fails in tension. The samples are 1.865 inches X 1.0 inch X .0025 inch. The newsprint is room dry. Maximum strain is change in length/final length.

Sample No.	Maximum Elongation (inches)	Maximum Strain $(\frac{inches}{inches})$
1	.0557	.0290
2	.0539	.0281
3	.0594	.0309
4	.0569	.0296
5	.0591	.0307
6	.0547	.0285
7	.0547	.0285
8	.0571	.0297
9	.0492	.0257
	Mean	.0290

TABLE VI RESULTS OF STRAIN TESTING NEWSPRINT SAMPLES IN THE INSTRON APPARATUS

Maximum elongation occurs at the time when the sample fails in tension. Maximum strain is the change in length/final length. The samples are saturated over a volume of 1 inch X 1 inch X .0025 inch after immersion in water for approximately one minute.

Sample No.	Maximum Elongation (inches)	Maximum Strain $(\frac{inches}{inches})$
1	.0284	.0276
2	.0314	.0304
3	.0286	.2078
4	.0259	.0252
5	.330	.0319
6	.0320	.0310
7	.0235	.0235
8	.0460	.0440
9	.0397	.0382
	Mean	.0310

room dry newsprint. The average strain is .029 in/in. Table VI gives the same results for newsprint which has been immersed in water for approximately one minute. Under the latter conditions the average strain is .031 in/in. Comparing the two tables indicates that the difference between the average maximum strains for wet and dry newsprint is only 7%. From these results it appears that the main design criterion will be limiting the stresses in the paper layer such that creep relief of these stresses will not exceed the maximum allowable strain. Using a design strain of 50% of the average strain at rupture, the allowable strain is .015 in/in. Assuming that one half of this strain occurs when the newsprint is placed on the ground with fixed ends, and that the other half occurs due to creep relief of the accompanying stresses, the maximum allowable strain to which the newsprint may be exposed during application is .008 in/in.

Consider a lettuce bed with a top width of 54 inches as shown in Figure 4. Assume that a 68 inch wide layer of newsprint is used to cover the bed. A seven inch width of the newsprint is placed beneath the soil surface, on either side of the bed, to hold the mulch layer in place. The 14 inch width of newsprint below the soil surface must absorb the total force placed on the newsprint by the paper tension control mechanism in the mulch applying machine. Assuming also that the 14 inch width becomes saturated immediately upon contact with the soil and that the stress-strain relationship in the paper is linear, the average allowable force that may be applied to the paper per inch of width is:

$$\frac{\text{(failure force for saturated paper) X (allowable strain)}}{\text{(strain at failure for saturated paper)}}$$

Using the previously presented data for newsprint, the maximum allowable force required to actuate a paper tension control mechanism is:

$$\frac{(.261)(.008)(14)}{.031} = 0.943 \text{ lbs.}$$

4.1 Soil Preparation Unit

The soil preparation unit must accomplish three objectives. The first objective is to smooth out all soil surfaces that will contact the mulch layer. This is to prevent stress concentrations in the mulch layer during application. The second objective is to compact the soil surface sufficiently so that soil settling will be insufficient to create stresses large enough to tear the mulch layer. The third objective is to place the edges of the mulch layer beneath the soil surface with sufficient soil compaction to prevent the mulch from moving.

The first two objectives can be accomplished by a combination of soil tools. The first tool is a roller (Figure 30). The roller simultaneously smooths and compresses the soil surface, and minimizes the bulldozing effect in front of the mulch applier. In conjunction with the roller, two side plates (Figure 30-A) smooth and compact the soil at their inside edges. The cutting edges of the vertical side plates

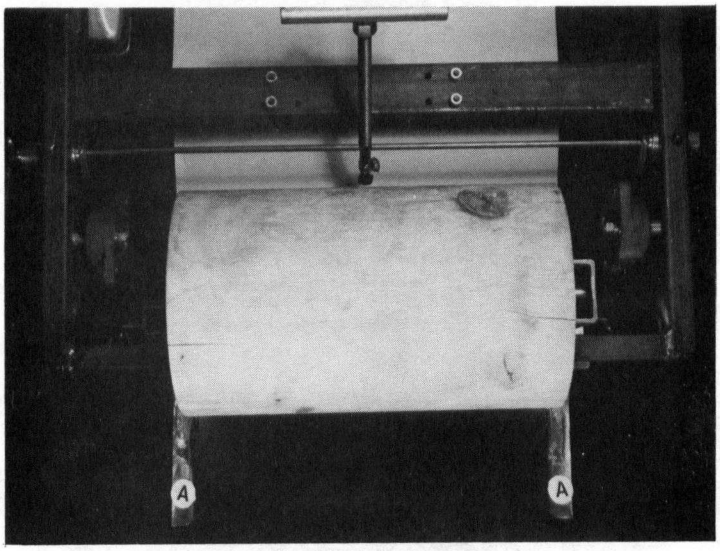


FIGURE 30. Roller and Side Plates

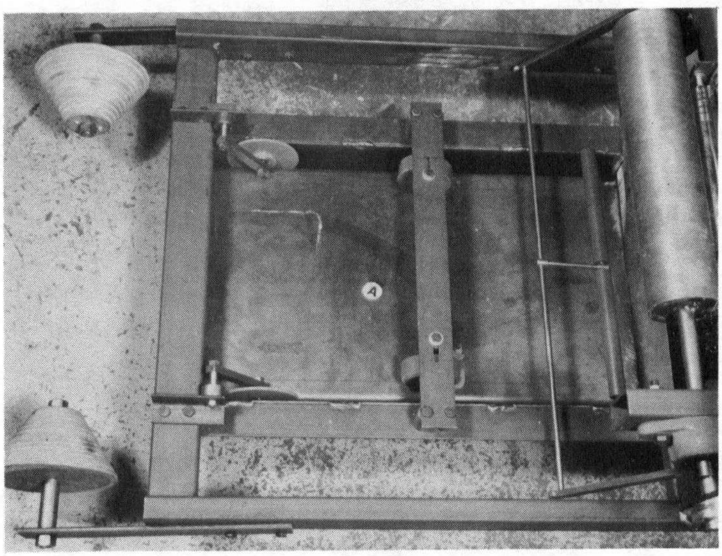


FIGURE 31. Slider

are angled at 45° to move the soil from in front of the side plates to their inside edges. Some bulldozing will undoubtedly occur but the effect at the inside edges should be reduced by the roller.

In displacing the soil from the lead edge, the side plates create a groove in the soil at the sides of the mulch layer that will eventually serve to hold the mulch layer in position. The inside edges of the side plates are part of the slider (Figure 31-A), bent at 90° to the slider while the outside edges are separate steel plates bolted to the inside edges at the bottom, and to the main machine frame at the top. This results in a hollow groove between the inside and outside edges to act as a guide for placing the mulch edges within the soil. The slider and side plates act as a transition surface for the mulch. The slider serves to align the mulch parallel to the soil surface while the hollow side plates serve as a transition for placing the mulch layer edges beneath the soil surface (Figure 32). The material thickness of the inside side plates and slider serves as an additional safety factor for limiting mulch layer stresses as follows. The peripheral distance over the top edge of the slider and side plates on which the paper is guided is greater than peripheral distance over the bottom surfaces that contact the soil. This distance difference should be sufficient to allow the compressed soil to expand, when the compressive forces of the soil preparation unit are removed, without adding additional

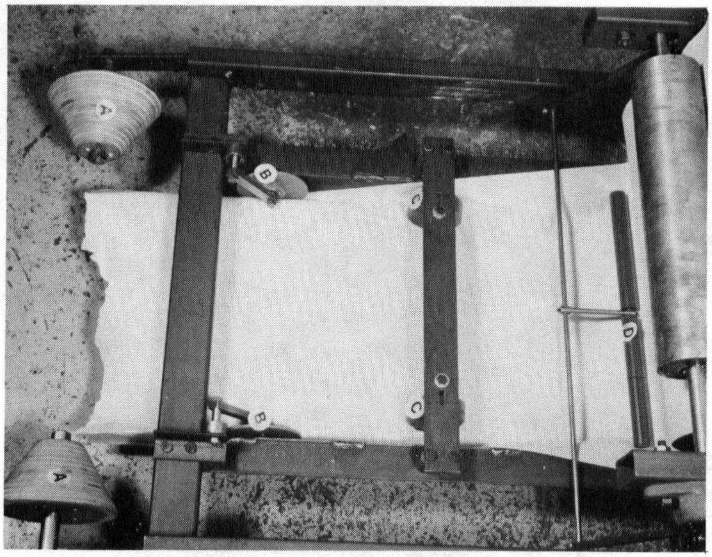


FIGURE 32. Slider and Orientation Controls

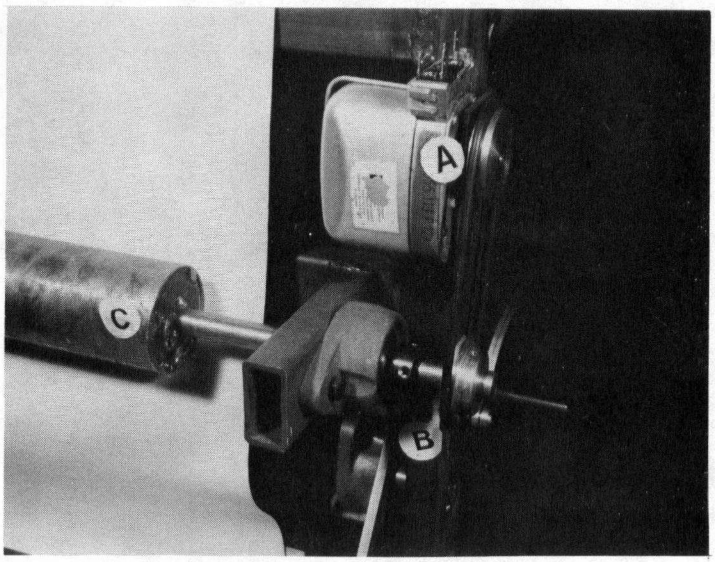


FIGURE 33. Drive System

stresses to the mulch layer. It is therefore expected that the prepared soil surfaces will uniformally expand to fit the mulch layer dimensions set by the machine.

The final requirement of the soil preparation unit is to fill the soil grooves formed by the side plates. The grooves must be filled with sufficient soil so that friction between the mulch and the compacted soil will prevent mulch movement. The limiting factor for compaction is the degree of soil packing on the inside mulch edges. If soil compaction during filling exceeds compaction of the soil inside the mulch edges, a displacement of the mulch will occur that could increase the mulch stresses. A further restriction is that no movement of the filling soil should occur parallel to the mulch edges. Such displacement could pull the mulch edges, introducing further stresses. In an effort to keep the back-filling motion perpendicular to the mulch edges a set of rotating cones (Figure 32-A) are used. A study by Kim (4) using cone penetrometers indicated that displacement of the soil to this type of applied load was quite uniform in directions perpendicular to the applied force. To obtain the desired uniform displacement rotating cones are used, each approximately a continuously operating penetrometer.

The total requirement of the soil preparation unit is to produce a smooth continuous three sided soil block, and to cover the block with paper mulch without disturbing the prepared block.

4.2 The Mulch Layer Control System

The actual mulch layer control system is similar to that previously proposed. The force limitations derived earlier apply to the control system. It is assumed that the largestforce involved in mulch application is the force required to pull the mulch paper from its roll. The forces required to bend the paper edges are considered negligible as well as the forces required to keep the mulch in a centered position on the paper feeding plates. For the above reason, the powered roller (Figure 33-C) is located close to the paper roll (Figure 34). The mulch tension must continuously be monitored between the soil and the drive roller, if the mulch stress is to be kept below design limits. The mulch changes direction by 90° (Figure 34) as it passes onto the slider (Figurer 31-A). A tension roller (Figure 32-D) is located at the apex of the triangle the mulch makes between the fixed position roller, the tension roller and the fixed position control rollers (Figure 32-C). The tension roller is free to rotate about a fixed axis (Figure 35-A) and when the tension in the mulch reaches a certain level the force moves the tension roller. The only tension on the mulch is that due to the tension roller resistance at the triangle apex. The control rollers are used to form a portion of the sensing triangle and to keep the mulch centered smoothly on the slider. They are designed to utilize the friction between them and the mulch as a driving force and their angles

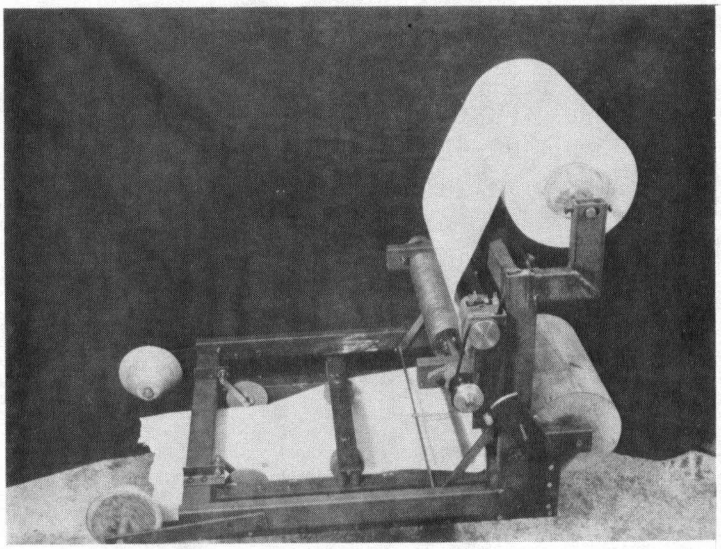


FIGURE 34. The Complete Mulch Layer Applier

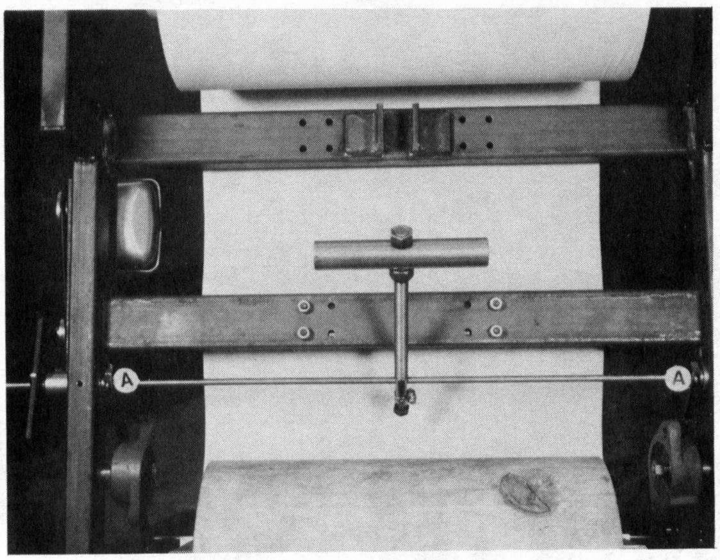


FIGURE 35. Rotation Axis for Tension Roller

are to be adjusted to convert some of this force to a slide pull to center and hold the mulch firmly on the slider. The mulch is bent 90° at the edges and held in position for packing underground by a set of bending rollers (Figure 32-B). At this point the mulch will leave the machine as a pre-formed covering for the prepared smooth three sided continuous soil block the soil preparation unit has produced. The only external force applied as resistance to pulling the paper from the machine is due to the weight and rotational resistance of the tension sensing roller assembly. The roller rotates about fixed points (Figure 35-A) and this rotation is used to vary the resistance of a variable resistor (Figure 33-B). The variable resistor is connected in series with a 12 volt battery operated D.C. motor (Figure 33-A), which is connected by belt to the powered roller used to remove mulch from the roll.

All these units together form a feedback system. The position of the tension sensing roller is proportional to the mulch tension, controlling the variable resistor setting, and determining the feed roller speed which alters the mulch tension appropriately. As the tension sensing roller supplies the most tension during mulch removal, there is an adjustable counterbalance to minimize this force (Figure 36-A). When adjusted properly the only force required to reposition the tension roller is the force required to overcome the mechanical friction of the variable resistor. This force should be well

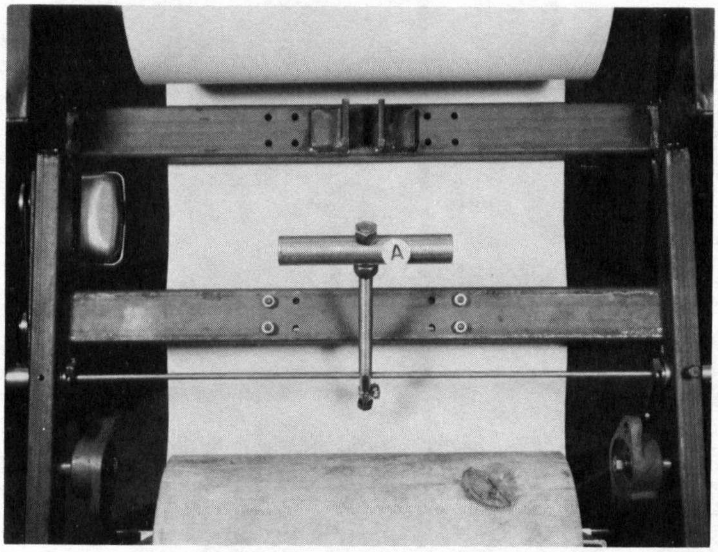


FIGURE 36. Tension Roller Counterbalance

within the limitations of the mulch strength.

4.3 Machine Operation

The machine is designed to operate in the following manner. The machine is placed on the soil and moved its full length, leaving two grooves in the soil between the rotating cones and the side plates. The mulch is pulled by hand from the end of the slider until it reaches the point where the cones have backfilled the groove. Initially, an external force is used to fix the mulch end. The machine is now moved ahead until the cones have packed the mulch edges within the soil so that the resulting friction is sufficient to pull the mulch from the machine. As the machine moves ahead the mulch tension increases, lifting the tension roller, adjusting the feed roller speed, and increasing the mulch removal rate. If the mulch is removed too rapidly, the tension reduces, allowing the tension roller to drop, slowing the rate of mulch removal. Thus the mulch will be placed on the soil under tension within the limitations of the paper strength. The tension stress will oscillate between acceptable limits.

A field test is necessary to determine if the machine works suitably. The field test should initially be a test of the soil preparation unit, followed by a test of the entire process.

4.4 Anticipated Problems

The difference in friction factor between the control rollers and mulch and between the mulch and slider is not as large as intended. Any attempt to develop enough friction force between the mulch and control rollers, to get the full benefit of the rollers, results in an unacceptable friction drag between the mulch and the slider. There may not be any need for centering the paper if the rotating cones apply equal force on both sides of the mulch. In this case, the mulch will remain smooth and centered over the slider without the control rollers. However, if testing indicates a centering control is necessary, it may be necessary to attach teflon strips under the paper to reduce slider friction.

The existing system uses a simple, variable resistor in series with the paper drive motor. This may reduce the motor torque at lower speeds to a level below the required drive roller torque. Should this occur a more complicated circuit is available that will reduce the motor speed without significantly reducing its torque.

Should the bending and control rollers both present a problem the rollers should be replaced with a steel guide sheath. This should extend from the control roller position to the rear of the machine. The sheath should have an inside clearance equal to the mulch thickness plus 20 percent and the inside width should be equal to the mulch width plus 1/16 inch. The sheath center will be parallel to the slider from the control roller position to the rear of the machine. The sheath outer edges will be parallel to the sheath center at the control roller position but will bend gradually so that at the rear of the machine they will be perpendicular to the center. The paper will enter the sheath at the control roller position and will gradually be bent by the sheath contours so it will leave the sheath with the edges below the soil surface forming a complete covering for the soil block.

5. GENERAL CONCLUSIONS

1. Initial results of the precision seeder tests indicated the practical feasibility of the approach and justifies a program to modify the existing machine and initiate a series of tests to establish its performance.
2. The precision seeder can be developed and used independently of the mulch layer applier.
3. Test results on seed damage are needed but are not practical until all mechanical problems of the seeder are solved.
4. The mulch layer applier must be field tested and modified before a conclusion regarding its practial feasibility can be reached.
5. Detailed studies will be required to determine the effect of compacting the soil and the effect of mulch accumulation on plant growth.
6. Using a sheath for controlling the mulch is much more suitable than using rollers. However, the present model should test the general concept.
7. The combined projects appear to have enough potential to warrent further development, testing and modifications. The costs to completely determine the feasibility of the machines are estimated as follows:

Precision seeder modifications and testing	$15,000
Mulch layer testing and modifications	15,000
Combined testing and modifications	10,000
Suggested associated studies	15,000
Overhead	11,000
Total Costs	$66,000

The necessary sales required to cover the development costs are estimated at 100 units, based on the previously estimated retail price.

This has not been discussed in the main report but is included as a guide for future recommended investigations.

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