NURSERY EQUIPMENT DEVELOPMENT FOR AUTOMATIC FEEDING OF BARE ROOT SEEDLINGS

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Abstract.--The development of an unmanned tree planting machine requires automatic control, detection, sorting, and feeding of pine seedlings prior to or during the planting operation. A tree nursery spacing study indicated that seedling spacing of 2" x 3" resulted in uniform seedlings and was recommended for future adaptation.

The design and development of a precision drum seeder is discussed. Originally designed for precision seeding of loblolly pine seeds, the machine's application can be extended to a variety of forestry and agricultural applications. For the Southern pine nursery application, the seeds are placed on the prepared seedbed with 3" spacing between rows and 2" between seeds in the row. The drum is capable of metering, transporting, releasing, and packing or pressing the seeds into the soil of the prepared bed. A one-half scale prototype was field tested. There were a few missing seeds and multiple seeding was not significant.

The proposed seeded tape-sheet system utilized a combination of non-degradable tape material attached to a sheet of degradable material where single seeds are positioned in a special array for future handling of seedlings during field planting. The seeds germinate and grow in the holes or through perforations of the non-degradable tape material and the degradable sheet loses its structure and disintegrates after seed emergence. The seedlings growing in the tape will be harvested by pulling the tape after undercutting the roots and forming a seedling roll. The seedling rolls are then ready for field transplanting.

Optical and mechanical linear displacement devices for detecting and sorting of pine trees were compared in the laboratory using taped seedlings. Test variables such as operating speed, width of acceptance window or diameter range for selection, and seedling diameter were investigated for determining the performance characteristics of each device. Both systems were found suitable for future implementation on an unmanned tree planting machine with minor design modifications.

INTRODUCTION

The need for a regional forest management equipment development center to meet the increasing demand for wood was recognized by the forest industry and the School of Forest Resources. The Forestry Equipment Cooperative (FECO) program was started officially on January 1, 1976. The first project undertaken

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by FECO was the design and development of an energy-efficient unmanned tree planter capable of operating under adverse forest conditions.

Since the Cooperative was conceived, the interaction between the planting machine design criteria and other forest management inputs such as tree nursery practice and site preparation techniques was evident. Constraints imposed by these inputs were recognized in the development and design of the FECO tree planter. The system approach necessitated the expansion of the Cooperative task and objective to include the impact of existing nursery practice and to develop alternative designs at the nursery level such that bare root seedling singularization and automatic feeding of the planting machine becomes possible.

The main objectives of this paper are to discuss the results of nursery and greenhouse studies, to present new concepts in nursery practice for future tree singularization, and to describe the machine development at North Carolina State University.

TREE NURSERY PRACTICE

Today's nursery practices for growing southern pine seedlings call for surface sowing 4-ft wide beds, either broadcast or drilled (eight rows). The seeds are covered by mulching material to maintain optimum soil moisture for germination. Root pruning, weed control, and fertilization are conducted periodically during the growing season. Bed lifting takes place in November-March, depending on the region, using a single- or multi-row bed lifter. The seedlings are bagged or bundled for field planting. Seedling grading before packaging has lost favor in recent years, even though some organizations put high value on the practice. Within the kraft bag or bundle, the seedlings are tightly packed; the interlaced roots and variability in seedling size caused by a lack of grading makes separation and singularization of trees a difficult task.

Seedling Singularization for Automatic Feeding

Seedlings will need to be singularized for automatic feeding from existing bagged or bundled seedlings. Root meshing and interlacing cause great difficulty in handling and separating the seedlings. Lack of uniformity of seedlings is another factor responsible for hampering singularization of seedlings from existing nursery stock.

The following observations summarize our views pertaining to future automation:

1. Before lifting, the seedlings are secured and self-supported in the bed. Perhaps stitching or taping the seedlings in the row can be completed before or during the lifting operation.

2. During lifting, using either the single-row or the 8-row bed lifter, the seedlings are held tightly between two belts and are geometrically oriented, i.e., tops up and roots down. Again stitching or taping of the seedlings can be accomplished before they leave the belts.

3. The seedlings released from the lifter belts are loose and have lost the gripping control; however, they do maintain some geometric orientation. If they are bagged on the lifter, sorting and feeding of seedlings might be achieved at the time of planting.

4. If shed-sorting is required, the seedlings are handled again either on a belt or manually. Here the seedlings are controlled and re-oriented. Perhaps it may be possible to stitch, glue, or tape them together at that time.

There are two schools of thought regarding automation of tree planting machine systems. One approach could be achieved by revising existing nursery practices, i.e., controlling the seedlings in status 1 or 2 above by taping or stitching before or during lifting, or loading the seedlings in status 4 above on tapes as in the Whitfield, Nissula, and Brika systems (Hassan, 1980). The other approach is based on direct handling of bagged or bundled bare root seedlings in status 3 above on the unmanned tree planter by utilizing a combination of a mechanical and pressure differential system (Graham and Rohrback, 1981) or by using the hook and saddle concept (Bowen, 1981).

Results of several singularization studies conducted at North Carolina State University indicated that stitched or glued (using hot melt) seedlings did not survive after planting. However, the presence of the filament taping material on the seedlings did not affect survival or growth compared to the control untaped seedlings (Hassan, 1976, 1977). The singularization efficiency of the mechanical-pressure differential system was reported to be 76.4 percent (Graham and Rohrback, 1981).

The above literature review and previous research efforts at NCSU resulted in the need for new approaches for controlling and/or growing singularized bare root seedlings.

Nursery Bed Spacing Study

Seedling singularization might be achieved if beds were seeded such that seedlings are uniformly spaced which could be accomplished by closer rows, perhaps as many as 12 or 16 for the four-foot bed, and larger distances between seedlings in the row. A 90-ft. bed at the N. C. Forest Service nursery (Griffiths State Nursery) at Clayton was utilized for this seeding study. The seeding spacing between and within rows was accurately controlled. Seeding was completed using templates designed especially to provide the required seeding density. Ten rows spaced at 6, 4, and 3" were seeded at densities varying between 16-48 seeds/ft^2. Table 1 summarizes the treatments and results. The averages appearing in Table 1 were determined from six 2-foot plots along the bed.

It is evident that the highest percent stand was achieved for the closer rows 3 and 4 inches where the pine seeds were placed at 2 and 1.5" apart, respectively (Table 1). These are very important findings, especially when improved pine seeds are used. Undoubtedly a bed seeded at 2" x 3" will permit lateral root pruning in two directions, along and across the bed, resulting in uniform seedlings.

Table 1.--Seeding Experiment and Results - Griffiths State Nursery, Clayton, N.C. Seeded in April, 1976 and Sampled in January, 1977.

Row No. & Treatment Length	Distance Between Seeds	Distance[a] On Left of Row	Distance[a] On Right of Row	Seeding Density Per Row	Average Standing Seedlings	Stand %	Average Seedling Height
	in.	in.	in.	$Seeds/Ft^2$	$Trees/Ft^2$		in.
1/(0-90')[b]	1	3	3	24	20	83	13.0
2/(0-45')	1/2	3	3	48	35	73	11.9
2/(45-90')	1	3	3	24	18	75	12.8
3/(0-45')	3/4	3	3	32	24	75	11.9
3/(46'-90')	1	3	3	24	19	79	12.0
4/(0-90')[c]	2	3	3	24	19	79	12.8
5/(0-90')	2	1.5	3	16	14	88	11.8
6/(0-90')	2	1.5	1.5	24	22	92	12.4
7/(0-90')	2	2	1.5	21	20	95	12.3
8/(0-90')	1.5	2	2	24	22	92	12.3
9/(0-90')	1.5	2	2	24	21	88	12.5
10/(0-90')[b]	1.5	2	2	24	22	92	12.8
Broadcast Bed Seeded at the Same Time				40	22	55	11.6

[a] Half the distance to the adjacent row on either left or right of the row in question.

[b] Boundary row.

[c] Staggered two rows 1-inch apart and 2 inches between seeds.

In order to examine the uniformity of seedlings, 50 seedlings were lifted representing seeding spacings 1/2" x 6", 3/4" x 6", 1" x 6", (2-2")[2/] x 6", 2" x 3", and 1 1/2" x 4", respectively. The seventh treatment was taken from an adjacent bed which was broadcast-seeded at 40 $seeds/ft^2$. The seedlings were lifted very carefully to avoid root damage, brought to the laboratory where data on root length, total green length (from root collar to terminal bud), and stem diameter for each seedling were recorded on magnetic tape. The results of the statistical analysis are shown in Table 2. Again the closer row treatment (2" x 3") resulted in the largest diameter seedlings; however, the most uniform seedlings were from 1" x 6" treatment, keeping in mind that all treatments except for 1 and 2 had seeding density of approximately 24 $seeds/ft^2$.

Stitching trials.--Trials were conducted on the 90-foot experimental bed discussed in the above section using an industrial bag stitcher. The machine jammed with the fresh needles and injured and broke seedling stems, when tried in August before the seedlings were hardened. However, when paper tape was placed between the sewing head and the seedlings, the results were very

2/ Staggered two rows one-inch apart and two inches between seeds.

Table 2.--Effects of Spacing and Seeding Density on Uniformity of Seedlings.

VARIABLE	MEAN	MIN VALUE	MAX VALUE	STANDARD DEVIATION
	mm	mm	mm	
TREATMENT 1	SPACING 1/2" x 6"		SEEDING DENSITY - 48 SEEDS/FT^2	
Root Length (mm)	177.1	110.0	240.0	26.67
Green Length (mm)	282.4	154.0	372.0	50.67
Stem Diameter (mm)	4.6	2.5	7.1	1.03
TREATMENT 2	SPACING 3/4" x 6"		SEEDING DENSITY - 32 SEEDS/FT^2	
Root Length (mm)	203.2	144.0	264.0	25.98
Green Length (mm)	315.5	229.0	413.0	49.72
Stem Diameter (mm)	5.0	2.5	7.2	1.04
TREATMENT 3	SPACING 1" x 6"		SEEDING DENSITY - 24 SEEDS/FT^2	
Root Length (mm)	200.0	132.0	245.0	20.52
Green Length (mm)	286.5	200.0	372.0	39.38
Stem Diameter (mm)	5.0	3.4	7.9	0.8
TREATMENT 4	SPACING (2-2")* x 6"		SEEDING DENSITY - 24 SEEDS/FT^2	
Root Length (mm)	206.3	132.0	283.0	33.68
Green Length (mm)	328.9	192.0	423.0	56.93
Stem Diameter (mm)	5.6	3.5	8.3	1.09
TREATMENT 5	SPACING 2" x 3"		SEEDING DENSITY - 24 SEEDS/FT^2	
Root Length (mm)	185.4	135.0	235.0	26.22
Green Length (mm)	311.2	207.0	456.0	61.30
Stem Diameter (mm)	5.7	3.6	8.8	1.07
TREATMENT 6	SPACING 1 1/2" x 4"		SEEDING DENSITY - 24 SEEDS/FT^2	
Root Length (mm)	177.0	143.0	215.0	18.80
Green Length (mm)	294.1	196.0	396.0	46.94
Stem Diameter (mm)	5.3	2.5	7.4	1.07
TREATMENT 7	BROADCAST BED		SEEDING DENSITY - 40 SEEDS/FT^2	
Root Length (mm)	162.7	95.0	258.0	35.52
Green Length (mm)	275.7	169.0	373.0	43.16
Stem Diameter (mm)	4.6	3.1	6.9	0.74

* Staggered two rows one-inch apart.

successful. More design studies and development are required to adapt the bag stitcher to this system.

Taping trials.--Another trial to singularize and control seedlings for automatic feeding was completed through the use of filament tapes of 1/4" and 1/2" width. This method is the most promising investigated to date and can be implemented on existing bed lifters by taping the seedlings directly underneath the belt and then rolling the tape and seedlings on a roller to contain 500-1000 seedlings each. It would then be possible to spray the roots with a clay suspension and bag in the field, thus eliminating all packing shed operations.

Gluing trials.--Using paper tape and plastic glue (hot melt) to hold seedlings together was tried and might be adapted to shed operation. Plastic glue plugs with melting temperatures of 325° and 450°F were available and used to hold seedlings to paper tape. These high temperatures caused some concern as to their effects on the tree's cambium layer and seedling survival.

Greenhouse Survival Study

A greenhouse study was conducted to plant trees receiving various treatments (taping, gluing, and stitching) which might be used in tree singularization for automatic machine feeding, and to determine the effects of these treatments on seedling survival and growth rate as compared with a control. Each treatment contained 10 seedlings obtained from the nursery spacing studies distributed randomly on a bench in the greenhouse. The study started in January, 1977, and data were monitored for two months. The results of seedling survival for the different treatments are shown in Table 3. It is obvious that the taped treatments, with tape removed or not, have some merit for future application.

Table 3.--Effect of singularization treatment on seedling survival, January, 1977 - Greenhouse Study, NCSU.

Treatment	Percent Survival After			
	15 Days	30 Days	45 Days	60 Days
Taped	60	50	40	40
Tape removed	80	60	60	60
Hot melt (325°F)	70	20	0	0
Hot melt (450°F)	60	20	0	0
Stitched	20	0	0	0
Control (not treated)	80	80	70	60

PRECISION DRUM SEEDER

The results of early studies indicated that applying vacuum to the apertures of pipes embedded into, and uniformly spaced, on the circumference of a drum made the metering of singularized pine seeds possible and feasible (Hassan, 1981).

Figures 1 and 2 illustrate the design details of a field prototype. One revolution of this drum would sow 400 seeds in 16 rows. The left side ends of the 25 pipes of the drum seeder are sealed, while the right side ends are connected to a vacuum chamber by means of flexible rubber hoses, which are clamped to a cam follower circular disk by means of a flexible strip. The vacuum chamber is rigidly connected to the drum's hollow shaft. Vacuum is applied to the chamber through a swivel portion of the shaft which is within the vacuum chamber to permit evacuation of the chamber and pipes.

Seeder Operational Functions

The drum rolls in a hopper filled with seeds and rigidly bolted to the frame. The air jet, located above the drum surface, is applied to blow excess seeds off the drum holes leaving single seeds. As the drum rolls further, it brings the seeds to the seedbed. At that time, the vacuum on the particular pipe in contact with the seedbed surface is cut off by means of a cam squeezing the flexible rubber hose which connects the vacuum to the pipe, fig. 2. As the vacuum to that particular pipe is cut off, the seeds attached to it are released and packed into the ground by weight of the rolling drum. The vacuum to that particular pipe is disconnected until the pipe gets back into the hopper, and the cycle is then repeated.

The four basic operational functions of the seeding system - metering single seeds, conveying, releasing, and pressing the seeds into the prepared seed bed - are accomplished by use of the vacuum assist cylindrical drum and cam arrangement. The seeds are held by vacuum and released only when they are in contact with the ground, thus, seed impact and scattering is eliminated. The seeding density is independent of the tractor ground speed since the drum rolls freely with minimum or no slippage. The complete drum seeder assembly is simple and compact; however, the system requires a vacuum pump, an air compressor, and a power source, fig. 1.

Field Testing Unit and Results

In order to evaluate this drum seeding concept, a one-half scale field testing unit, similar to the one shown in fig. 1, to sow 8 rows with seeding spacing of 2" x 3" was designed and constructed.

The field unit was tested on beds at the Griffiths State Nursery, Clayton, NC, in August, 1977, and at the Weyerhaeuser Nursery, Washington, NC, in April, 1978. The tractor operational speed was approximately 0.3 mph.

All components of the drum seeder - the vacuum pump, the air compressor, and the generators - performed properly. The loblolly pine seeds were sown precisely at 2" x 3" spacing and packed by action of the rolling drum seeder.

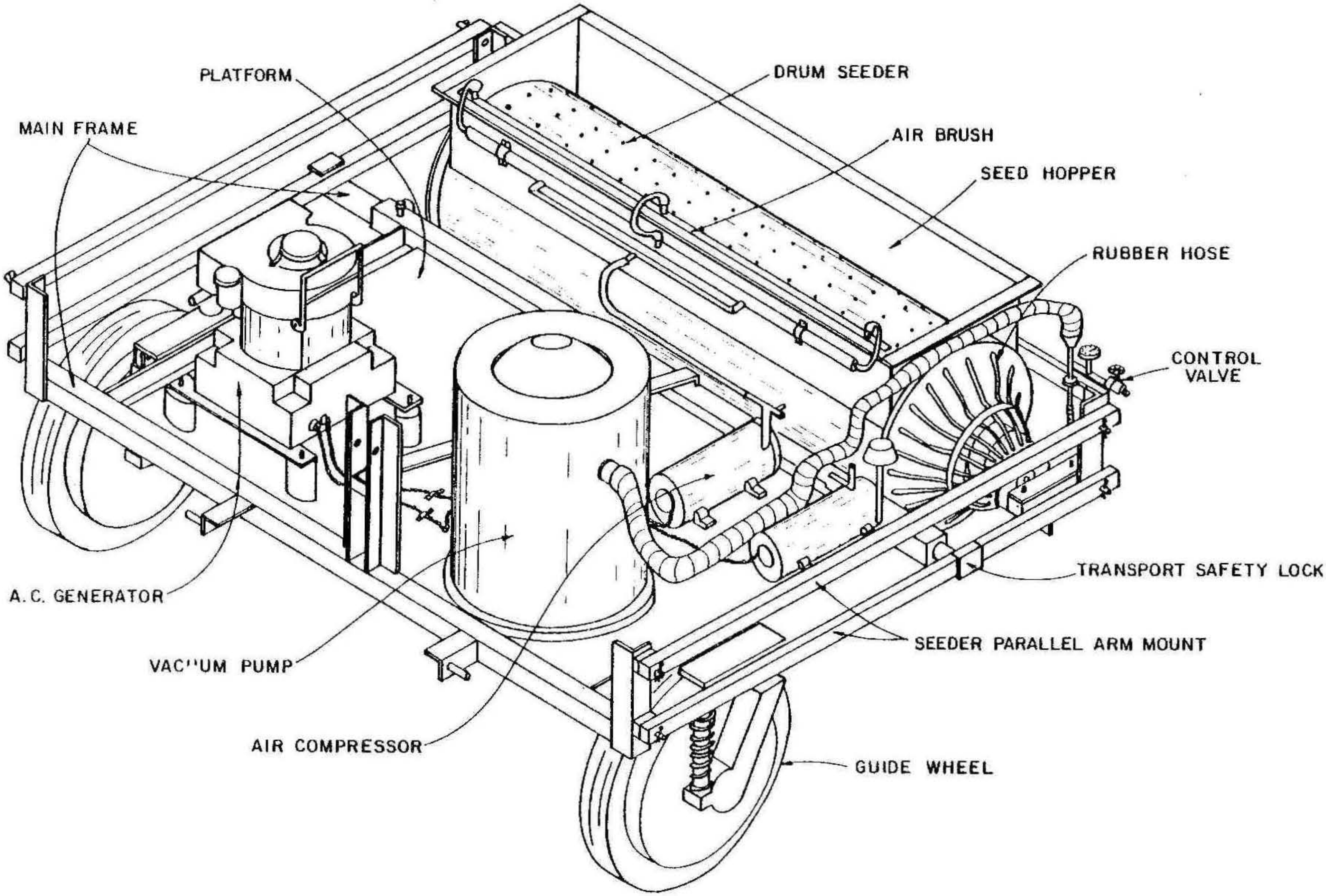

Figure 1.--Schematic drawing of the precision drum seeder and the housing assembly complete with a three point hitch attachment.

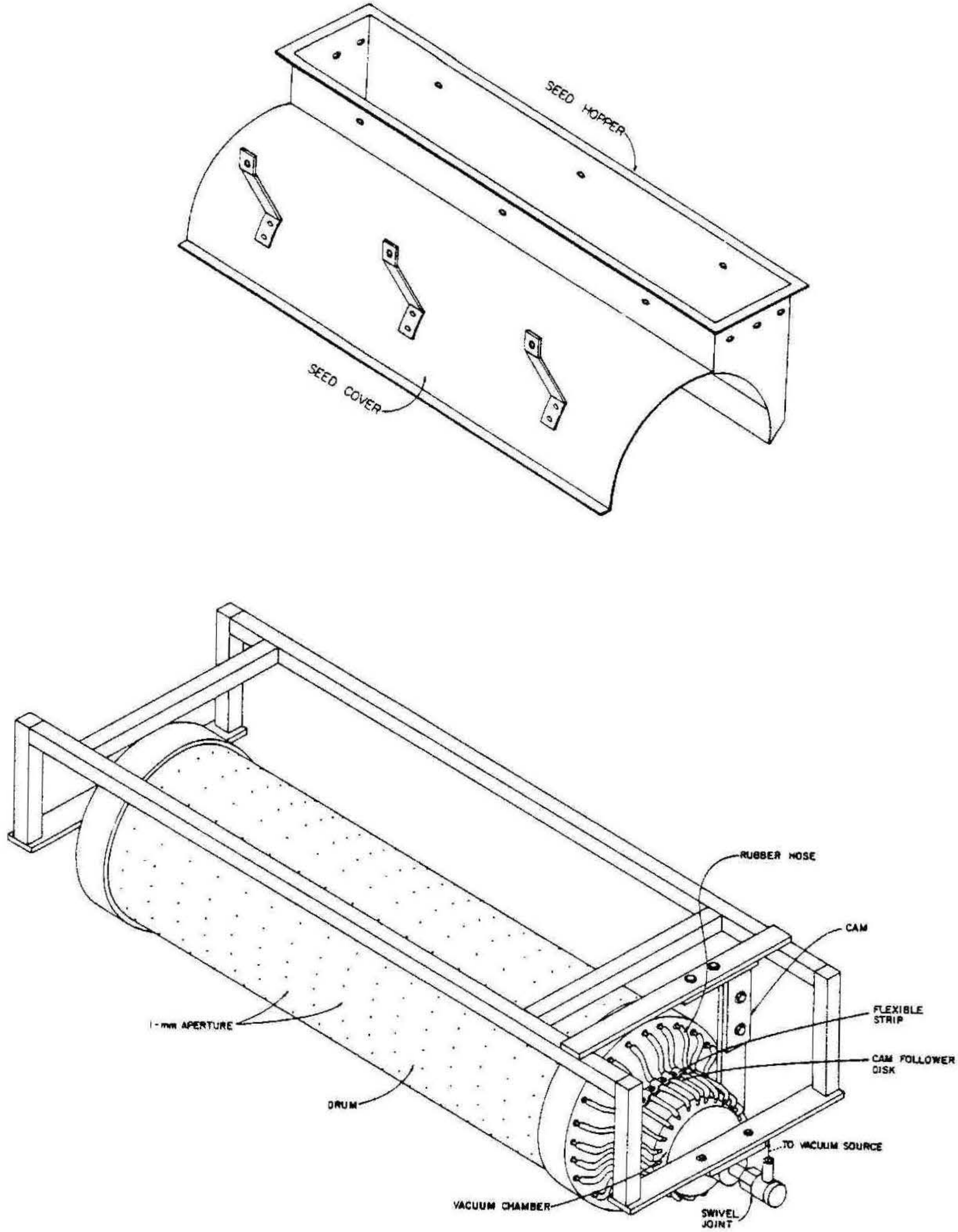

Figure 2.--Three dimensional view of the vacuum drum seeder showing detailed design of the seed hopper (top) and vacuum chamber, cam mounting, rubber hose attachment, and drum seeder.

The unit was found to be speed sensitive; the higher the ground speed the greater the number of seed misses, which could be due to the lack of seed contact with the apertures at high speed. It was felt that this problem might be eliminated if the seeds were agitated, which might bring the seeds closer to the apertures and minimize the seed pick up height.

Mechanical agitation of seeds was tried using a spring-loaded roller powered by means of friction on the portion of the drum surface within the seed hopper. This design turned out to be very successful in minimizing the percentage of misses and allowing operation at higher speeds. Design modifications and improvements are needed to optimize the shape of the mechanical agitator.

Excessive vibration transmitted from the power unit to the drum seeder resulted in increases in the percentage of misses. The vibration problem might be eliminated if the engine driven portable AC generator was isolated or powered differently. Also, it was noted that the seeds tend to accumulate to one side in the hopper especially if the nursery bed was not level. This problem can be avoided if dividers or partitions are included in the hopper design.

Conclusions

The following comments summarize the experience gained from the field testing of the precision drum seeder over two seasons and offer alternatives for future modifications.

1. The drum surface should be cleaned of dirt and debris before entering the hopper. A stiff wire brush rubbing on the drum should clean soil and debris from the drum surface and help to reduce hole clogging.

2. Metal fittings should be used between the seeder pipes and the rubber hoses to prevent the hoses from touching the ground and protect them from breakage and cuts.

3. The bed surface has to be level to prevent seed accumulation in one side of the hopper causing seed spilling. Partitions in the hopper might minimize problems resulting from the seed movement.

4. Multi-unit seeders to sow three beds or more could be utilized to increase the machinery productivity. However, it should be emphasized that the width of the nursery bed is 4 ft hence, mounting the three widths or more might represent some frame structural problems.

5. The results of the field tests indicated that the vacuum drum seeder had sown the loblolly pine seeds precisely. This result is of great importance since the available mechanical bed seeders drill the seeds in the rows, and as the seeds drop through the drop tubes, they scatter on impact with the ground.

6. Precision seeding might facilitate seedling lifting and enhance automation of tree planting.

SEEDED TAPE-SHEET ROLL SYSTEM

The proposed seeded tape-sheet system utilizes a combination of non-degradable adhesive tape material attached to a sheet of degradable material where single seeds are positioned in a special array, for future handling of seedlings during planting. The original seeded tape-sheet roll concept was based on the removal of the hole material from the adhesive non-degradable tape and employing external glue to secure the seeds to the degradable blanket material (Hassan, 1982). The main functions of this wide sheet are to hold the seeds, to be spread upon a prepared seed bed, and to disintegrate after the seeds germinate and sprout.

A schematic of the proposed system is shown in fig. 3. The non-degradable rolls are positioned at a particular space that is recommended by the nursery practice for the crop under consideration. The tapes are then perforated at equal intervals by a tape puncher. This operation might be eliminated if the tapes could be furnished with the proper perforations (flaps). A precision seeder similar to the one discussed in the previous section will deposit single seeds within the perforations on the tape adhesive side. The seeded tapes are then assembled to the wide sheet or blanket made of degradable material. A spring loaded take-up reel will wind the seeded tape-sheet in rolls of desired length to suit the length of the nursery beds. A positive power drive is implemented throughout the system (fig. 3). Details of the drive mechanism, controls, tape guides, and accessories are not shown in fig. 3.

The degradable sheet should be 12" to 16" wider than the seed bed to cover the edges with soil to prevent wind damage to the sheet. The seed-side of the sheet should be faced down to place the seeds in contact with the soil particles to assure the seed-mineral contact needed for germination. After the seeds germinate, the seedlings grow through the openings of the nondegradable tapes. The degradable sheet loses its structure and disintegrates after seed emergence.

The proposed system assumes that the nondegradable tape will retain its strength during a growing season of 8 months or longer. At harvest, the seedlings growing in the tape will be lifted using existing bed lifters modified with a take-up reel to roll the tape with the seedlings. The seedling roll is ready for handling and transport to planting sites, where it will be mounted on an unmanned automatic planting machine.

1981-1982 Greenhouse Study

A single-row portable hand-operated perforation unit made of two rollers and positively driven was constructed to perforate the 1" filament tape (non-degradable material) at a distance of 2 inches. Single seeds were then placed on the 1/2" flap prior to adhering the tape to the cheesecloth (degradable material). Several greenhouse studies were conducted to test the validity of this concept. The results of the early 1980-1981 study indicated that laying the seeded tape-sheet roll with the sheet material facing the soil particles resulted in a better stand than with the tape side facing the soil surface.

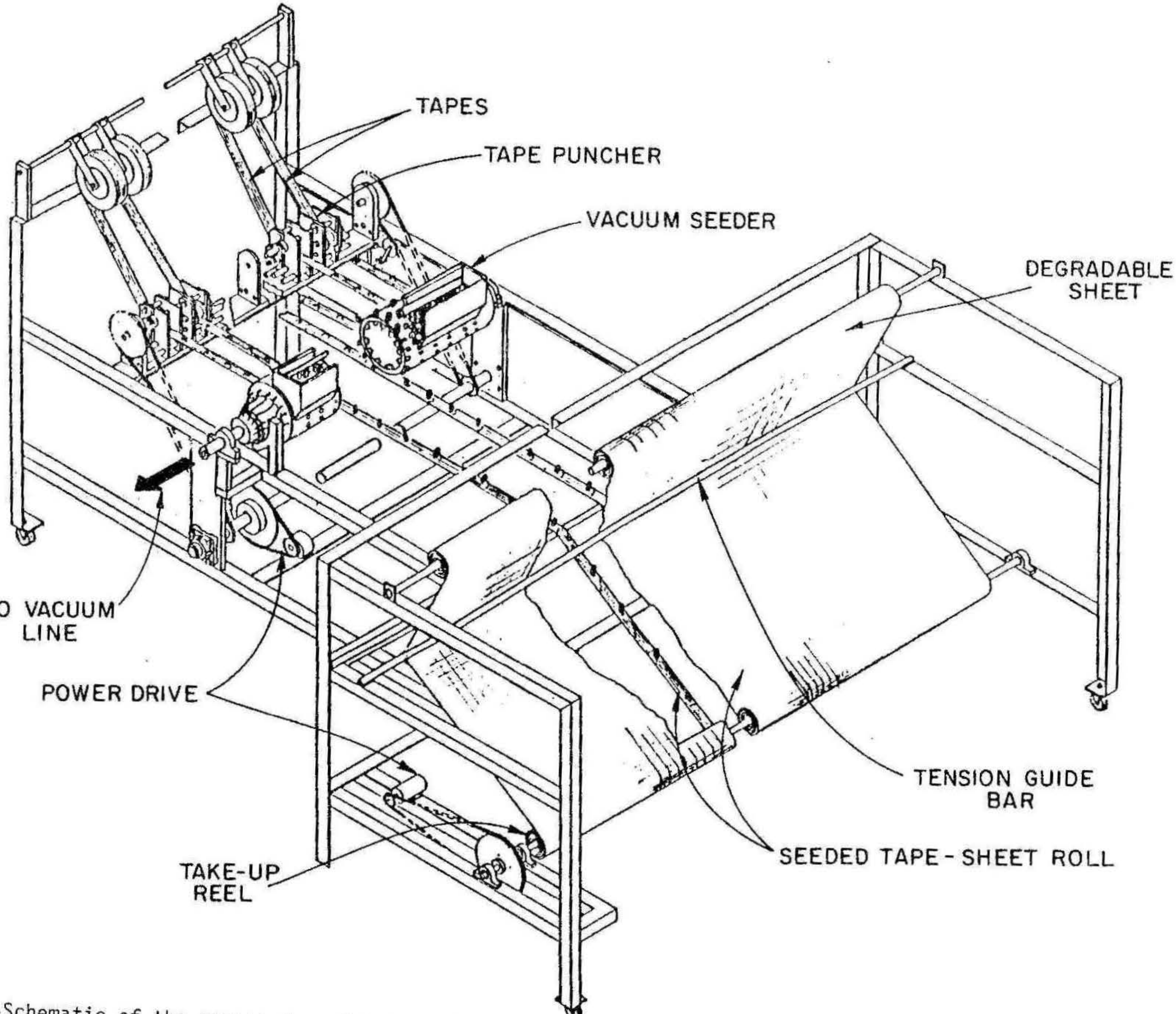

Figure 3.--Schematic of the proposed seeded tape-sheet system for growing bare root seedlings for future automation of the tree planting machine system.

A four-replication greenhouse study was initiated in March, 1981, to test the germination and stand establishment of seeded tape with different treatments. The perforations were semi-circular with direction either along the tape fiber (0°) or 45° as shown in Table 4, to test the effect of angle of perforation on the strength property of the tape material. The perforated flaps were cut in the middle to reduce the impact of the tape material on the seed germination (treatment #3, Table 4). Seeds were placed on the untreated tape of treatment #5 at 50 mm and glued to the cheesecloth material within the tape holes in treatment #4 representing the original concept. The seeds were placed directly on the soil in the control treatment. Each treatment consisted of 30 seeds with four replications randomly placed in trays on a greenhouse bench equipped with a controlled mist irrigation system. The seedlings were allowed to grow for 13 months until harvest in April, 1982.

Table 4.--Greenhouse study comparing the tape perforations with punched holes and other treatments (March 81-April 82).

Treatment	No. of Seedlings/Treatment Grown in Tape	Total	Seedling Stand per Treatment %	Tape Strength lbs
1. 0°-perforation	41	44	34.2	35
2. 45°-perforation	30	33	25.0	34
3. 0°-perforation with slit	67	71	55.8	32
4. Punched holes	71	72	59.2	31
5. Untreated tape	0	10	0	52
6. Control - no tape	86	86	71.7	--
7. Unused control tape with 1/2" hole	--	--	--	125

Results of the Greenhouse Study

The results of this study are summarized in Table 4 which shows that the angle of perforation has no effect on the strength properties of the tape material and that, in general, the perforated tape exhibited higher strength than the punched tape. The presence of the tape flap and glue affected the seed germination and resulted in a less dense stand than the control. Perhaps two seeds should be placed at each perforation to increase the germination percentage in future applications. Only 10 seedlings out of the 120 seeds placed on the untreated tape germinated with root systems extending on the tape surface. The tap root and shoots were unable to penetrate the filament tape material; thus tape punching or perforation cannot be eliminated.

Conclusions

The filament tape and cheesecloth are suitable materials for future applications of the seeded tape-sheet roll system. Tape perforation concept offers a much simpler system than the hole punching concept. The seedlings grown in the tape are singularized and controlled and lend themselves to future application of the unmanned tree transplanter for planting bare root seedlings.

SEEDLING DETECTION DEVICES

The detection device for feeding and sorting of bare root seedlings should satisfy the following design criteria in order to be compatible with FECO's development goals for the unmanned tree planter:

1. Seedlings grown in tapes or taped (Maw, 1980) should be spaced at random intervals which vary between 1 and 8 inches.

2. Only seedlings with root collar diameter in the specified range will be selected.

3. Suitable seedlings must be available for each planting cycle, i.e., every 2.75 seconds for a planting rate of 1300 seedlings/hour.

Two spools of 30 taped seedlings each were prepared and used for testing the two detection systems described below. Pine seedlings of various diameters were taped at an average distance of 2.5 in. The seedling diameter range was 0.08 to 0.51 in. The average seedling diameters for Tape-I and Tape-II were 0.27 and 0.12 in., respectively.

Optical Detection System

Figure 4 shows the major components of the optical detection device. The taped seedlings are wound on an aluminum spool mounted on two conical supports. Friction between the supports and the spool is adjusted by means of a spring-loaded bolt system for controlling the seedlings' tape tension.

The taped seedlings are guided and fed between two feeding rollers, which are rotating in opposite directions. These rollers are made of plastic tubing, 4-in. in diameter, covered with a thick rubber foam to avoid seedling damage and to introduce enough friction to pull the tape through. The lower roller is powered by a magnetic clutch/brake, and the top roller free rolls by means of the friction between the two rollers.

When an acceptable seedling is detected, a generated signal stops the feeding rollers, bringing the seedling tape to a halt, positioning the seedling on a cutter guide platform. The tape on either side of the positioned seedling is cut by a blade mechanism. A holding finger is lowered to hold the tape during the cutting process. The cutter blade mechanism is a rotating eccentric knife which rotates with the same speed as the tree insertion mechanism. Therefore, when the cutter blades complete one revolution, one seedling is available for automatic feeding.

The seedling-holding fingers device is made of three rubber fingers connected to an arm which is activated by a cam/follower mechanism. The cam is synchronized with the cutter blade motion such that the fingers are holding the seedling during the cutting action. The same cam activates a microswitch to reset the total system after each successful tape cutting action. The complete circuit block diagram can be found in Sasan and Hassan, 1982, and Hassan, 1977.

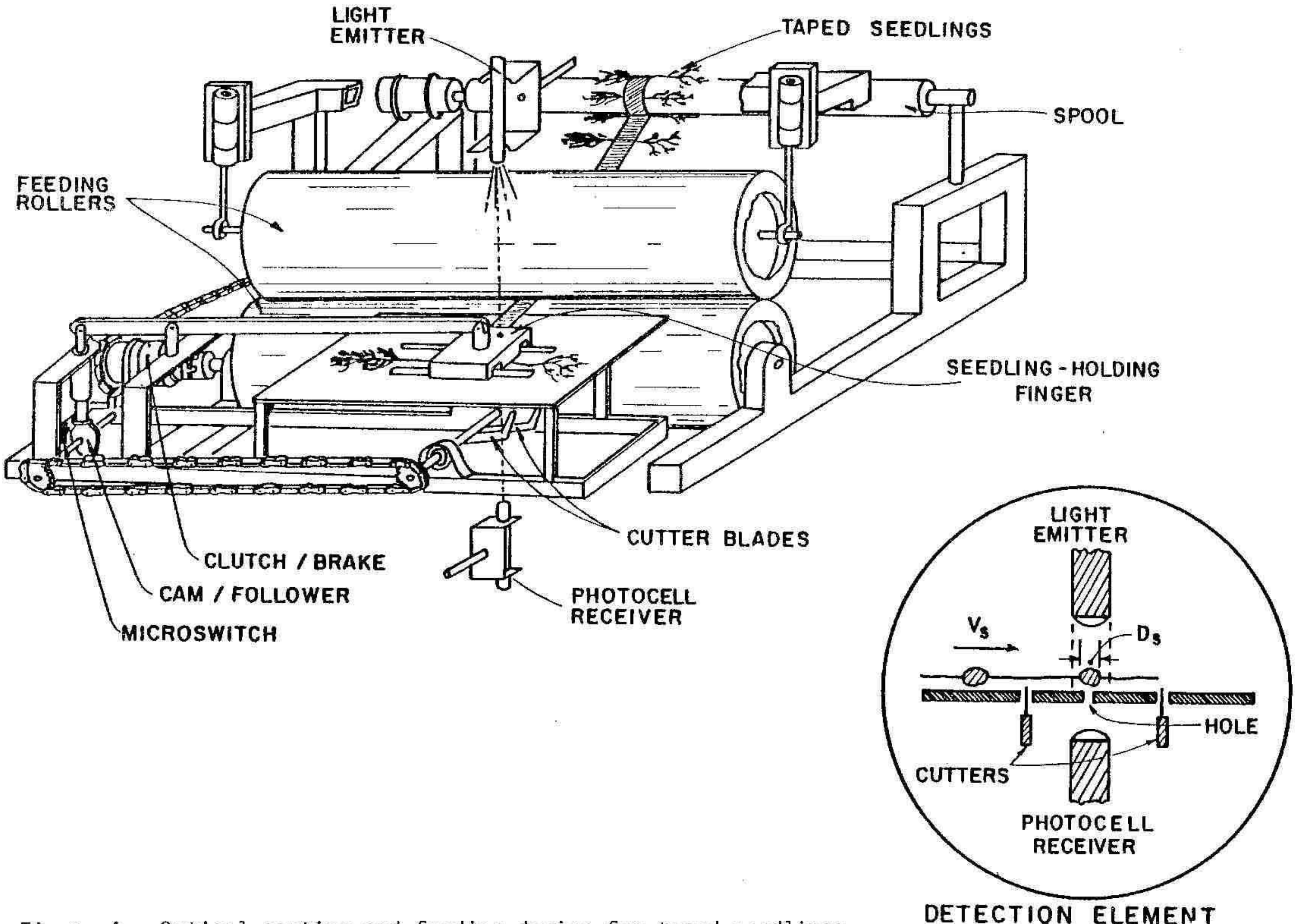

Figure 4.--Optical sorting and feeding device for taped seedlings.

Testing procedure.--Testing of the optical detection device was achieved by feeding taped pine seedlings (Tape-I and Tape-II) and recording the acceptance or rejection of each seedling. The test device was powered by a hydraulic motor which controlled the feeding speed. A minimum of four repetitions for each test condition was conducted.

Linear Displacement System

The linear displacement detection device was a simple, manually operated set-up that included a linear vertical potentiometer. As the tape loaded with seedlings was pulled through the apparatus, the seedling forced up the roller which was fastened to the linear potentiometer lever (fig. 5). A voltage proportional to the seedling diameter was obtained regardless of feeding speeds. This voltage was compared with the preset ranges adjusted by circuit potentiometers.

Testing procedure.--The two tapes, Tape-I and Tape-II, were used for this study. The tape was manually wound while the seedling was passing under the wheel (fig. 5). The vertical displacement potentiometer output and a marker indicating the circuit rejection or acceptance were recorded on an 8-channel strip chart recorder, Hewlett-Packard, Model 7758A. The tests were conducted at high and low speeds (8.9 and 1.5 in./s).

Results of Laboratory Testing

Optical detection device.--The taped seedlings (Tape-I) were fed through the device four times at a constant speed of 5.7 in./s. The device was set such that the maximum and minimum acceptable seedling diameters were 0.291 and 0.236 in., respectively, which defined a very narrow acceptable window. The acceptance and rejection of a seedling was recorded. Optimum performance of the optical device requires a pass percentage of 100 in the acceptance window and zero percent elsewhere. If the seedling diameter was very close to the boundary, the pass percent was reduced. Other reasons for obtaining a pass percent between 1 and 100 might be nonuniformity of seedling stem diameters, presence of fusiform rust, nonuniform cross-sectional diameter, shadowing effect of bark, bumps on the stem, and mechanical problems associated with this device such as tape misalignment, speed fluctuation due to varied friction between feeding rollers, friction at ends of seedling spool, . . ., etc.

The circuit timers were set based on both seedling diameter range and feeding speed. Hence, the optical detection method is sensitive to speed variations. During the course of evaluation of this device, it was noted that the feeding speed was dependent on the friction between the taped seedlings and the feeding rollers which increased with the presence of the seedling between the rollers and resulted in speed fluctuations. Hence, this fluctuation is dependent on seedling spacings. The feeding speed was also affected by the friction between the taped seedling spool and its axis of rotation which varied with the loading scheme. In order to eliminate the problem of feeding speed fluctuation, a linear positive drive system is recommended.

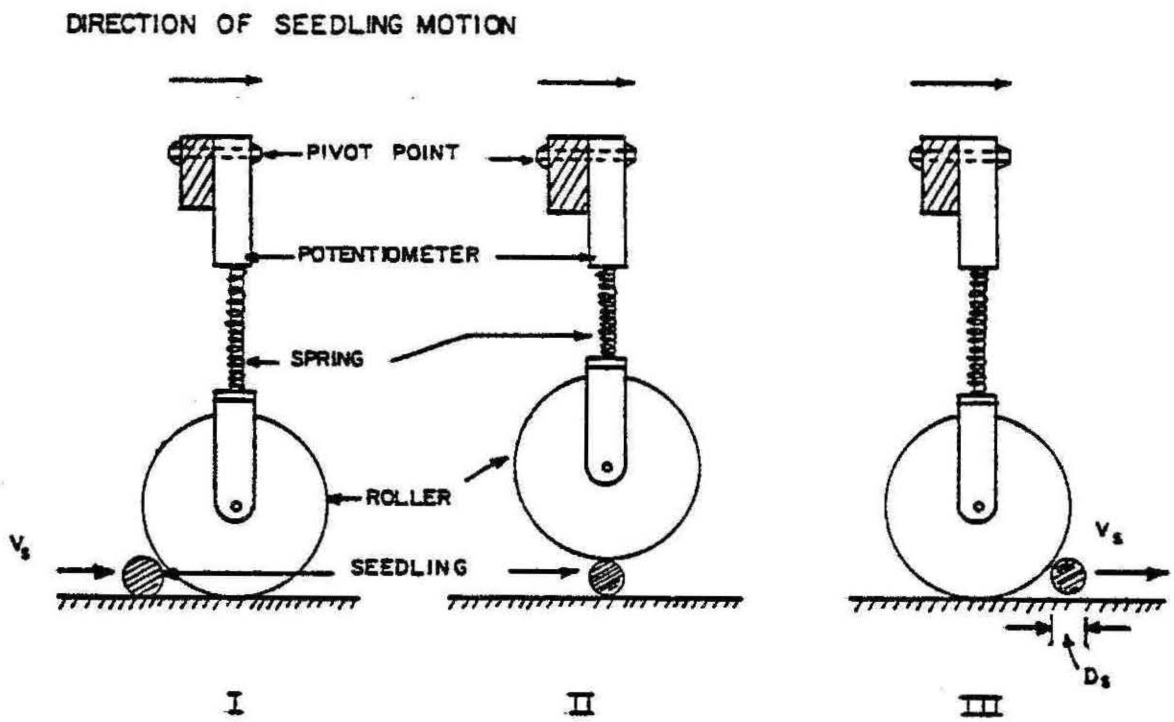

Figure 5.--Spring-loaded potentiometer for detecting and sorting seedlings.

Tape-II was used to study the effect of feeding speed and window on the seedling pass percentage. For the same window, (0.035"), a better performance of the device was achieved at high speed (10.4 in/s) where rejection of the seedlings outside the window was greatly pronounced. Similarly, increasing the acceptance window width for the same feeding speed resulted in a better performance of the optical detection device.

Linear displacement system.--The device evaluation was conducted using Tape-I with average seedling diameter of 0.27 in. Figure 6 illustrates one of the test runs recorded on the Hewlett-Packard strip chart recorder. In this test run (fig. 6), the acceptance window was set at $0.181" < D_s < 0.343"$. The device performance was good as shown in the plot where seedlings within the acceptance window were selected and those outside the range were rejected (fig. 6). This device was not as sensitive to speed as the optical system and in general, its performance improved with the increase in the window width independent of the operating speeds.

Systems Comparison and Conclusions

The acceptance and rejection performance of the optical and linear displacement detection methods are shown graphically in fig. 7. The two seedlings "k" within the acceptance window were rejected by the optical system and accepted by the linear displacement system (fig. 7). These results should be interpreted carefully, however, as to the superiority of the linear displacement system over the optical system. Table 5 summarizes the performance of the optical and linear displacement detection systems. Future recommendations are also included in the table. It should be mentioned that the linear displacement device was simple and did not include seedling removal. However, all features of the optical system including time delay and tape cutting can be implemented in the linear displacement system.

Similar work has been done (Maw et al., 1980) in which the singularization and sorting was based on seedling length. The results indicated the difficulty involved in obtaining correct length measurements of seedlings for the purpose of detection. For example, using 8.98" long cards in place of seedlings, a standard deviation of 0.146" was achieved. However, when plants of the same length were used, a standard deviation of 1.673" was obtained which clearly shows the effect of plant variation and structure on device performance.

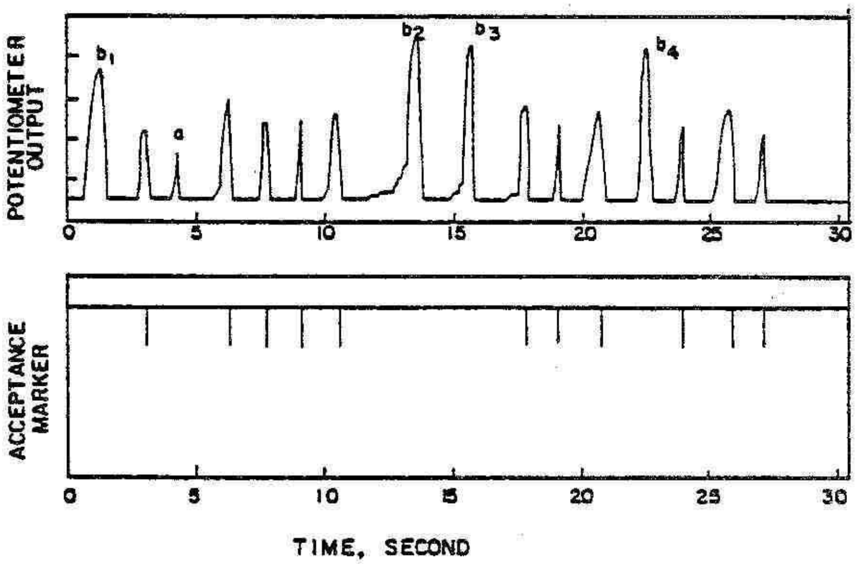

Figure 6.--Strip chart recorder output from the displacement detection device showing the acceptance markers for 16 seedlings fed at a speed of V_S= 1.5 in/s with D_{min} = 0.181 in. and D_{max} = 0.343 in. Diameter of the seedling "a" shown above was 0.138 in < D_{min} while diameters of seedlings b_1 to b_4 were greater than D_{max}.

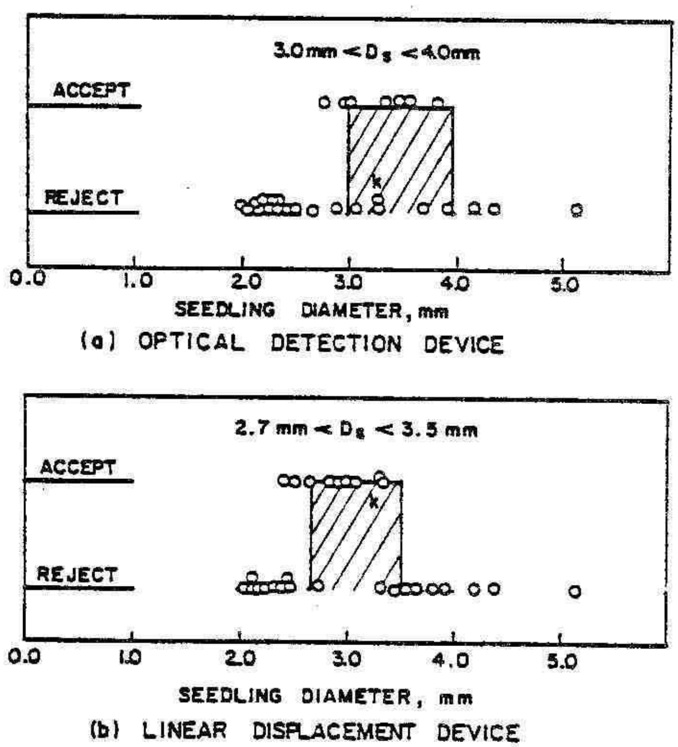

Figure 7.--Comparison between the optical detection and linear displacement methods using the same taped seedlings (Tape-II) and approximately the same acceptance window widths.

Table 5.--Comparison between the optical and linear displacement detection methods.

Parameter	Optical System	Linear Displacement System
1. Operational Speeds	Constant speed must be maintained throughout	Independent of speeds
2. Speed Sensitivity	Excellent performance at high speeds	Overshoot of potentiometer lever at high speeds
3. Sensing Method	No contact with seedlings	Direct contact with seedling
4. Life Expectancy of Sensing Device	Unlimited	Wear of displacement potentiometer after prolonged use
5. Seedling Effect	Shadowing effect of seedling bark	Sensitive to bends or curvature of the seedling stem
6. Seedling Damage	None	Might cause compression of cambium layer
7. Acceptance Window	Average performance	Better than average
8. Design recommendations	Positive drive to eliminate speed variations	Use of wheeled caliper for diameter detection
9. Future Adaptation on Tree Planters	Not affected by daylight, infrared modulated light used. Required frequent cleaning and dust removal.	System should be isolated from vibration transmittance. Not sensitive to dust contamination.

LITERATURE CITED

Ardalan, S., Hassan, A. E. 1982. Automatic feeding and sorting of bare root seedlings. Transactions of the ASAE 25(2):266-270.

Bowen, H. D. 1981. Useful concept for automatic tree planters. Proceedings of the Symposium on Engineering Systems for Forest Regeneration, ASAE Publication 10-81:162-170, American Society of Agric. Engineers, St. Joseph, MI.

Graham, L. F., Rohrbach, R. P. 1981. Mechanical singularization of bare root pine seedlings. Proceedings of the Symposium on Engineering Systems for Forest Regeneration, ASAE Publication 10-81:186-193, American Society of Agricultural Engineers, St. Joseph, MI.

Hassan, A. E. 1976. FECO First Annual Report, Unpublished, 57 p., School of Forest Resources, North Carolina State University, Raleigh, NC.

Hassan, A. E. 1977. FECO Second Annual Report, Unpublished, 93 p., School of Forest Resources, North Carolina State University, Raleigh, NC.

Hassan, A. E. 1981. Precision drum seeder for uniform spacing. Transactions of the ASAE 24(4):879-883.

Hassan, A. E. 1982. A new concept for growing bare root singularized seedlings. ASAE Paper No. 82-1073, American Society of Agricultural Engineers, St. Joseph, MI. 24 p.

Maw, B. W., and Suggs, C. W. 1981. Loading bare root plants onto a reel. ASAE Paper No. 81-9083, American Society of Agricultural Engineers, St. Joseph, MI. 10 p.

Maw, B. W., Suggs, C. W., and Harris, D. 1980. Progress in the mechanical singularization and sorting of seedlings. ASAE Paper No. 80-1055, American Society of Agricultural Engineers, St. Joseph, MI. 16 p.