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Evaluation of an Intermittent-Furrow Tree-Planting Machine

The Marden Manufacturing Co.'s Spot Planter, Model 100

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by

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INTRODUCTION

Tree seedlings, whether bare-root or containerized, can be planted by hand or by machines. When faced with a large reforestation effort, the use of efficient and effective tree-planting machines can be most beneficial. One commercially available intermittent-furrow mechanized planter, described in the section that follows, was evaluated on the Bienville National Forest, Strong River Ranger District, Raleigh, Miss. The field evaluation was based on a "Performance Criteria for Intermittent Tree Planter," developed by the Forest Service San Dimas Equipment Development Center (SDEDC), in cooperation with the Southeastern Area of State and Private Forestry, and approved by the Forest Regeneration Committee, which is chaired by a member of the Timber Management Staff, Washington Office.

SPOT PLANTER, MODEL 100

The Marden Manufacturing Company, Inc., P. O. Box 1157, Auburndale, FL 33823, produces the Marden Spot Planter, Model 100 (fig. 1). This intermittent-furrow mechanical planter is mounted on a two-wheel carrier that can be towed by a rubber-tired or crawler tractor. The planter weighs 5,400 lb (2400 kg) and is capable of planting both bare-root and containerized stock. The height of the planter above the ground is adjusted by means of a turnbuckle (fig. 2).

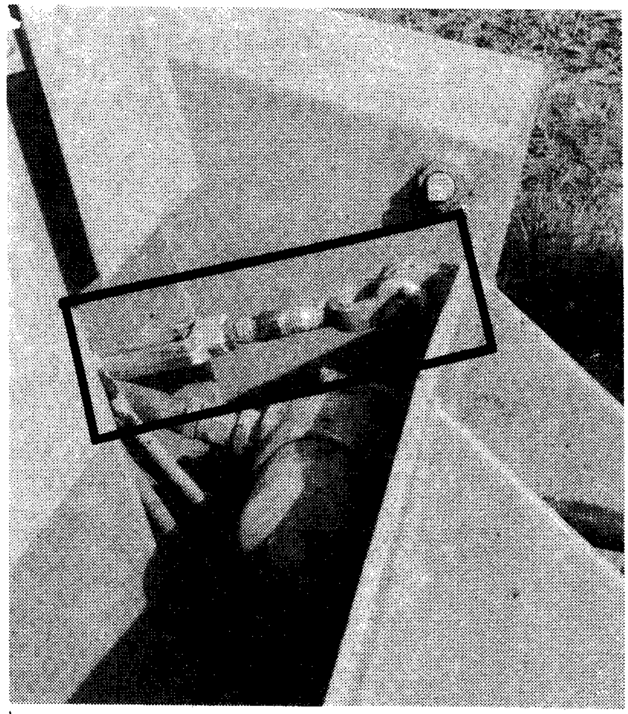

Figure 2. Initial turnbuckle.

Figure 1. Marden Spot Planter, Model 100.

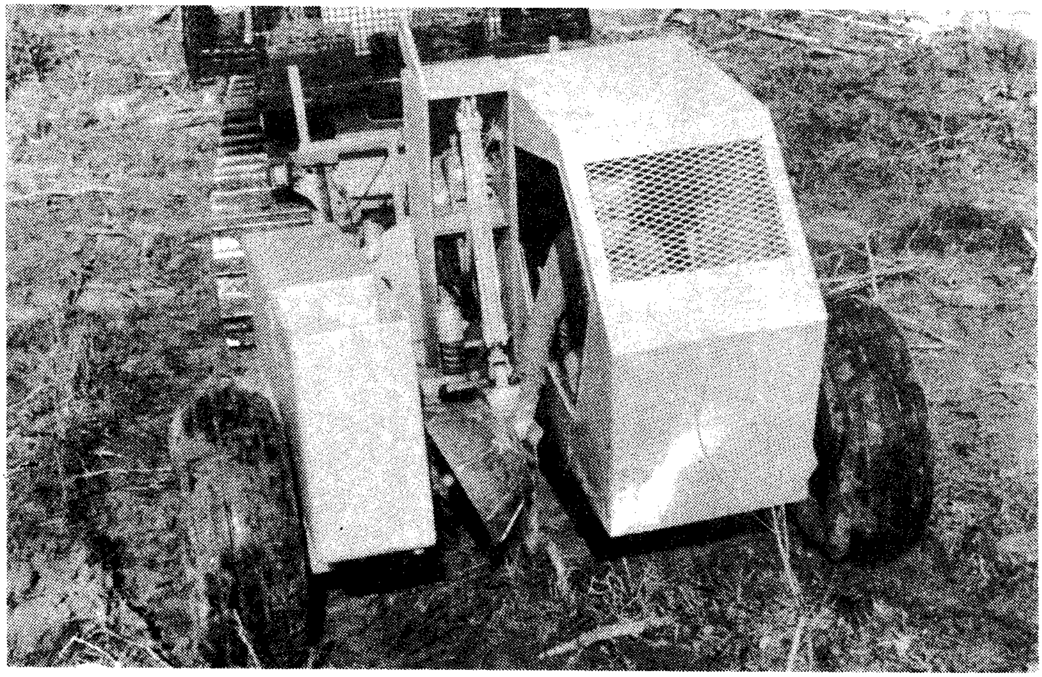

Figure 3. Rear view of Model 100.

The Model 100 has a planting mechanism that can be powered by the hydraulic pump on the towing tractor or by a power take-off (pto) pump driven by the tractor's engine. Pressure and return lines serve as the hydraulic connections between the planter and the tractor. The Marden Manufacturing Company recommends a 15 to 30 gpm (57 to 114 *l*/min) pump.

The planter's hydraulic operations are controlled by electrically operated solenoid valves that require the tractor to have a 12-V dc power supply. Or, the Spot Planter can be purchased with an on-board two-cylinder diesel engine and a battery to power and control its hydraulic system. When the planter is so equipped, the planter can be connected quickly to the towing tractor, since only a hitch is needed.

The Model 100 operator sits in the planter facing rearward (fig. 3) and manually loads seedlings. The planting sequence is initiated by depressing a foot pedal switch, which actuates the solenoid hydraulic valve and causes the planting arm to move downward. When the planter moves forward, the hollow dibble (fig. 4) forms a furrow into which a seedling is injected. The packing wheel then firmly plants the seedling. (In figure 5, the soil around the planted seedling was removed to ascertain the machine's planting effectiveness—root placement, soil compaction, etc.)

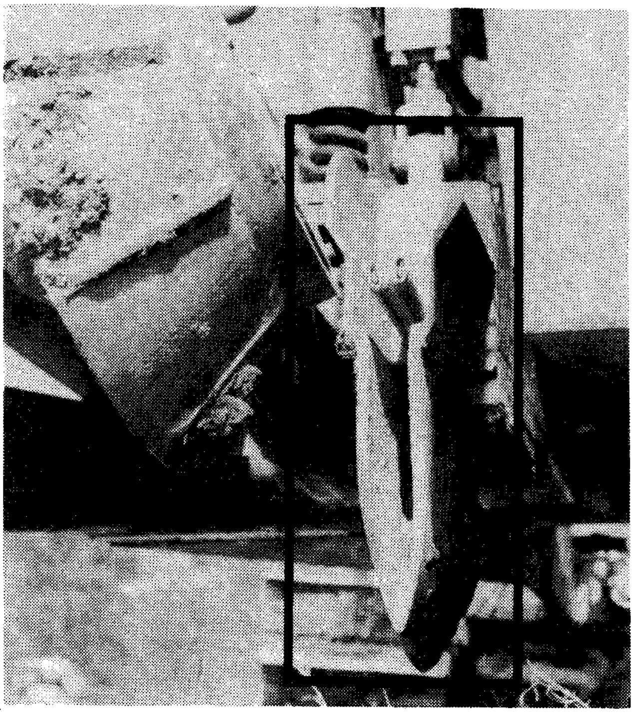

Figure 4. Dibble.

The arm returns to the reload position when the pedal switch is released. The total cycle time to load, lower the planting arm, eject and pack the seedling, and return the planting arm so it is ready again to be loaded is 3½ to 4 sec. A Marden Manufacturing Company operation and parts manual is supplied with each Model 100.

The prime mover for the planter was a John Deere (JD) 550 crawler tractor, usually used by the District to pull

Figure 5. Well-planted seedling.

a fire plow. To maintain this capability, the planter's hitch was extended by adding a short pullbar, which became a rigid extended drawbar. This meant that either a fire plow or the planter could be hitched to the tractor; further, the pullbar enabled the planter and tractor to turn in a shorter radius.

The JD 550 is a 72-hp (53.7-kW) tractor with a converter-driven, three-speed, power-shift transmission and a tandem center hydraulic valve system with a 15-gpm (57-*l*/min) pump. When towing the planter, the tractor is not run at full throttle. Since this pump was just at the planter manufacturer's threshold requirement when the tractor was at full throttle, a 23-gpm (87-*l*/min) pump (at full throttle) was installed as a replacement for the original pump. Also, a flow divider valve was added so that the planter and the tractor blade could be operated simultaneously.

FIELD TEST PROGRAM

The Model 100 Spot Planter and the JD 550 tractor were used on the Strong River Ranger District during winter of 1981 to reforest 136 acres (55 ha) in small scattered parcels. Loblolly pine *(pinus taeda)* was planted on 8- by 8-ft (2.4- by 2.4-m) spacings at 681 seedlings per acre or 1,683 seedlings/ha, with minimum acceptable stocking established at 300 well-distributed seedlings per acre (741 seedlings/ha). All loblolly seedlings were 1-0 bare-root stock.

In addition, a 35-acre (14-ha) sheared and windrowed site with droughty, sandy soils was planted with longleaf pine *(Pinus palustris)* on a 5- by 8-ft (1.5- by 2.4-m) spacing, giving 1,089 seedlings/acre. Minimum acceptable stocking was established at 600 well-distributed seedlings/acre (1,482 seedlings/ha). Longleaf seedlings were also 1-0 bare-root stock.

District personnel recorded the following data during the operation of the Marden planter: Elapsed planting time and number of seedlings planted; also down time and reason, plus repair time. Engineers from SDEDC recorded: Instantaneous production rates, drawbar pull, and planting quality. Data were analyzed by both District and SDEDC personnel.

EVALUATION CRITERIA

The evaluation criteria used were the "Performance Criteria for Intermittent Tree Planter:"

1. **Stock Type and Configuration**—Ability to plant bare-root and most containerized stock, one or two rows at a time. When bare-root stock is planted, a means of preventing the roots from drying out must be provided.

2. **Site Characteristics**—Capable of operating on sites where intensive site preparation has not been done; sites that are on hilly, rocky terrain that is strewn with logging debris—including those times when muddy conditions prevail.

3. **Production Factors**—Should be able to plant from 700 to 1,800 tree seedlings per hour; desired spacing between the seedlings in a planting row is a minimum of 5 ft (1.5 m).

4. **Planting Factors**—Consistently plant the seedlings 10-in (25-cm) deep, with 75 percent of the root collars between ground level and 1 in (2.5 cm) below ground. When planting bare-root stock, the seedlings should be inserted vertically (75 percent to be within 15 degrees), with "J" roots to be a maximum of 25 percent.

5. **Packing Factors**--Ability to close the planting hole with adequate packing that leaves no air pockets—without overcompacting the soil, which would restrict water infiltration and inhibit root growth.

6. **Planter Configuration**—Should attach to and be operated by a "small" prime mover—preferably a crawler tractor in the 10,000- to 15,000-lb (4540- to 6800-kg) range and require only an operator for the tractor and one for the planter. (Or, if cost effective, have an automatic feed system, thereby eliminating the planter operator.) Also, again if cost effective, the planter could be an integral, self-propelled, special-design machine.

7. **Planter Price**—The tree planter must be affordable. That is, the planter must be able to be operated on a sound economical basis under a force account or at a profit by a contractor. The purchase price that allows the planter to be affordable is very dependent on the production rate.

8. **Planter Performance**—Have high system reliability, with a minimum mean-cycles-between-failure (MCBF) of 12,000—approximately 11 to 17 acres (4.5 to 7 ha)—and a minimum inherent availability of 85 percent, which requires a high degree of maintainability.

9. **Energy Requirements**—The tree planter shall be energy efficient and perform its functions with less energy input than a continuous-row tree planter having a comparable output.

10. **Planter Safety**—The tree planter must be safe to operate. If no automatic feed, a safe and comfortable operator station and rollover protection must be provided.

EVALUATION RESULTS AND DISCUSSION

The evaluation results gave quantitative and qualitative insight into the Marden Spot Planter's performance. Results are reported in the order of the established criteria:

Stock Type and Configuration

Only bare-root stock was planted; the planter plants one row at a time. The manufacturer claims that containerized stock may also be planted. The planter is equipped with a reservoir capable of holding approximately one bundle of seedlings in which water or ice can be placed to keep seedlings cool and to prevent them from drying out. However, root dryout protection is accomplished by covering the planting stock with burlap or other suitable materials and is dependent on planter operator conscientiousness.

Site Characteristics

The planting sites were prepared late the previous summer by either shearing and windrowing or roller-drum chopping. Site topography was variable, ranging from rolling with moderate slopes to relatively flat. Soil types were also variable and consisted of clay loams, sandy loams, or prairie clays.

Production Factors

The average instantaneous production rate measure was 952 seedlings/hr with a standard deviation of 70. When this instantaneous rate is reduced by a field efficiency of 80 percent, the planting rate becomes 762 seedlings/hr. The instantaneous production rate is the rate of planting with no interruptions, delays, or inefficiencies (i.e., the theoretical maximum production).

Field efficiency is the ratio between the productivity of a machine under field conditions and the theoretical maximum productivity (instantaneous production rate). Field efficiency accounts for the failure to utilize the theoretical operating width of the machine; time lost because of operator capability, habits, and operating policy; and field characteristics.

The planter packing wheel is mounted on the planting arm (fig. 6). This requires that the planting arm and foot remain down until the packing wheel has passed beyond the newly planted seedling. The average spacing between seedlings was 7.3 ft (2.2 m) with a data sample standard deviation of 0.7 ft (0.2 m). This is about the closest spacing that the Model 100 can achieve.

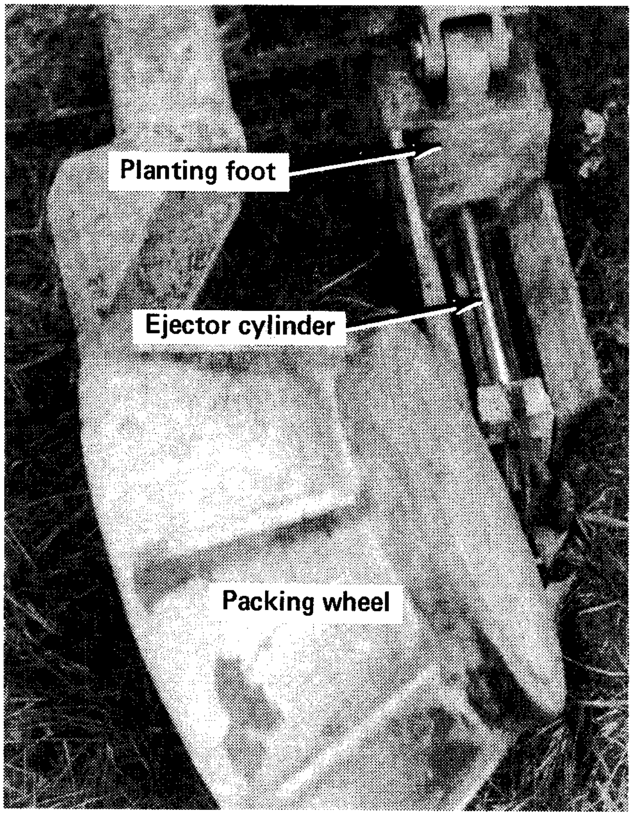

Figure 6. Planting arm components.

During planting, the dibble stayed in the ground an average of 54.5 in (138 cm). This is approximately 24.5 in (62 cm) longer than necessary to place the seedlings in the ground. Using the average spacing of 7.3 ft (2.2 m) and the average length the dibble was in the ground, the dibble was out of the ground for an average length of 33 in (84 cm). During this time, the arm must come up, be reloaded, and returned to the ground.

If you add the reloading length of 33 in (84 cm) and the length of 30 in (76 cm) required to place the seedlings, the total is 5 ft-3 in (1.6 m), which is very close to the desired minimum spacing of 5 ft (1.5 m). But, because the planting arm must stay in the ground longer so the packing wheel, which is attached to the planting arm, can pack the seedlings, the minimum spacing that can be achieved is 7.3 ft (2.2 m).

The planter planted well while turning and is able to plant up and down slopes without creating furrows that would be washed out during an intense rainfall.

Planting Factors

The planter plants seedlings 10-in (25-cm) deep. On a sheared and raked site, 60 percent of the seedlings measured were planted with their root collars between ground level and 1-in (2.5-cm) below ground level. (The shearing was accomplished with a Rome Plow Company K/G clearing blade.) On a double-drum roller chopped site, 74 percent of the seedlings were planted within the established criteria. Thirty-five percent of measured seedlings were "J" rooted and 84 percent of the seedlings sampled were within 15 degrees of vertical.

The planter fully meets the seedling inclination requirement and almost meets seedling placement (74 percent) on the double-drum roller chopped site. Seedlings were "J" rooted more frequently than desired.

Packing Factors

The planter meets the packing criterion. The seedling pull tests (fig. 7) indicate that packing was adequate when compared to the four-needle pull test. The four-needle pull test is used by foresters to determine adequate packing. Four needles of a seedling are pulled on; if the needles pull off, leaving the seedling in the ground, the seedling is deemed to be adequately packed. If the seedling is pulled out of the ground by the four-needle test, the seedling is deemed to not be adequately packed. The four-needle test is a pull of about 2 to 3 lb (0.9 to 1.4 kg). On most pull tests, 4 to 6 lb (1.8 to 2.7 kg) was required to pull the seedling out of the ground.

On a double-drum roller chopped site, pull tests were conducted to measure differences in packing resulting from the packing wheel pushing uphill or downhill. The force required to pull up seedlings planted with the packing wheel pushing uphill is more than that for downhill. Regardless of packing wheel orientation, packing is deemed adequate.

Measurements made with a durometer, an instrument that determines soil compaction, indicate that packing wheel induced soil compaction increases with depth. These durometer measurements are intended to give an indication of soil packing and are to be used for comparison with past and future studies. No voids (air pockets) were found while making these measurements.

The packing wheel throws a considerable volume of soil ahead and to the side of the seedling (fig. 8—direction of Model 100 travel is towards top of figure). The soil is

Figure 7. Seedling pull test.

removed adjacent to the seedlings, leaving a large depression in the ground alongside the seedling. Marden claims the depression acts as a catch basin for rainwater. The utility of this basin is dubious at best. Less soil remains holding the seedling in place and providing moisture.

Thus, a problem may exist in that the remaining soil could dry out, erode, or fall away. In reviewing the planted areas, the District silviculturist has not found this to be a problem with loblolly pine and associated soils, but somewhat of a problem with longleaf pine and associated coarser sandy soils because this type of soil dries out faster.

Planter Configuration

The planter was pulled, without difficulty, with a 15,500-lb (7030-kg) JD 550 crawler tractor. Drawbar pull measurements were made. The maximum pull, with the dibble in the ground, was 4,500 lb (20.2 kN), with a mean pull of 3,000 lb (13.3 kN). This would be just in the range of a 10,000-lb (4536-kg) prime mover, if the terrain were not too difficult.

Planter Price

The affordable purchase price of a mechanical tree-planting machine is very dependent on machine production rates and hand planting costs in the area the machine is to be used. SDEDC personnel developed equations, based on an economic analysis of both towed and self-propelled planters, which predict when a mechanized approach is more economical than hand labor for tree planting. (See Project Record 8124 1203, June 1981, available from SDEDC.)

The empirical equation for the affordability of towed planters, such as the Model 100, is: X = -$67,500 + 1,203 (HPC) (MPR), where X = maximum affordable tree planter purchase price, HPC = hand planting cost ($/seedling), and MPR = machine production rate (seedlings/hr). Hand planting costs on the District have run from $55 to $65/acre ($135 to $160/ha) for stocking 681 seedlings/acre (1,683 seedlings/ha), or 8¢ to 9.5¢/seedling. Therefore, the maximum affordable tree planter purchase price would be:

X = -$67,500 + 1,203 ($0.095/seedling) (762 seedling/hr)

= $67,500 + $87,085 = $19,585.

The purchase price of the Marden Spot Planter was $9,995—well within the maximum affordable tree planter purchase price.

Planter Performance

Season-long records of planter production, operating time, breakdowns (failures), and repair time were kept to determine reliability (R), availability (A), and maintainability (M):

R (reliability) is generally defined as the probability that an item will perform its job without failure for the period of time intended under operating conditions intended, and is generally expressed in terms of frequency of failure (e.g., mean-cycles-between-failure, or R = MCBF).

- **A (availability)** is generally defined as the time a component is doing its job compared to the total time it is expected to be doing its job. Availability is generally expressed in percent.

  —**Inherent availability (A_i)** is defined as the total operating time (OT) during a given time interval *divided* by OT *plus* the total active corrective maintenance time (TCM):

$$A_i = \frac{OT}{OT + TCM}$$

  —**Operational availability (A_0)** is defined as OT during a given interval *plus* standby time (ST), *divided* by the OT, *plus* the ST, *plus* down time (DT), where DT equals total active corrective maintenance time (TCM), *plus* total active preventive maintenance time (TPM), *plus* total administrative and logistics time (ALDT)—or total up time *divided* by the total time.

$$A_o = \frac{OT + ST}{OT + ST + TCM + TPM + ALDT} = \frac{\text{Total up time}}{\text{Total time}}$$

- **M (maintainability)** is generally defined as the characteristic of design and installation expressed as a probability that a component, a piece of equipment, or a system can be repaired in a given time using prescribed procedures, and with defined resources available. M should be (when possible) expressed both in quantitative and qualitative terms. The quantitative term generally used is mean-time-to-repair (MTTR), or M = MTTR. The qualitative terms are the prescribed procedures and defined resources. Prescribed procedures would be, but not be limited to, equipment publications that provide the necessary information on the operation and maintenance of the equipment—such as operators', repair, and parts manuals. Defined resources would be, but not be limited to, repairmen, repairmens' training, tools and repair equipment, repair facilities, and available repair parts.

More specific definitions of performance terms, from Military Standard 721B, 10 March 1970, are as follows:

- **Reliability:** The probability that an item will perform its intended function for a specified interval under stated conditions.

- **Availability:** A measure of the degree to which an item is in the operable and commitable state at the start of the mission, when the mission is called for at an unknown (random) point in time.

- **Maintainability:** A characteristic of design and installation expressed as the probability that an item will be retained in, or restored to, a specified condition within a given period of time, when the maintenance is performed in accordance with prescribed procedures and resources.

The relationship between the three concepts is:

$$\text{Availability} = \frac{\text{Reliability}}{\text{Reliability} + \text{Maintainability}} = \frac{R}{R+M}$$

$$= \frac{\text{MTBF}}{\text{MTBF} + \text{MTTR}}$$

The following are the R, A, and M, using the total season-long operating and failure data (table 1) gathered during the 136-acre (55-ha) District field test effort, for the Marden Spot Planter Model 100, only (without the JD 550 prime mover data):

Reliability

R = MCBF = No. of seedlings planted ÷ No. of Model 100 failures = 92,800/23 = 4,035 cycles/failure.

Availabilities

A_i = 124.7 hr (OT) ÷ 124.7 hr (OT) + 53.8 hr (maint.) = 124.7/178.50 = 0.70 = 70 percent.

A_o = 124.7 hr (OT) + 4.5 hr (ST) ÷ 124.7 hr (OT) + 4.5 hr (ST) + 63.8 hr (DT) = 129.2/193.00 = 0.67 = 67 percent.

Maintainability

M = MTTR = 53.8 hr (corrective maint.) ÷ 23 failures = 53.8/23 = 2.34 hr/failure.

The following are the R, A, and M, again using the total season-long operating and failure data—this time for both the planter and the prime mover combined:

Reliability

R = MCBF = 92,800 seedlings ÷ 27 failures = 92,800/27 = 3,437 cycles/failure.

Table 1. Field test failure data summary

Marden Spot Planter, Model 100 subsystem		No. of failures	Repair time (hr)
Hydraulics (planter related)		7	16.0
Hydraulics (planter and tractor related, ½ to each)*		2	11.5
Ejector mechanism		10	19.3
Turnbuckle		2	2.0
Other		2	5.0
	TOTALS	23	53.8

John Deere 550 prime mover subsystem		No. of failures	Repair time (hr)
Hydraulics (tractor related)		2	2.0
Hydraulics (planter and tractor related, ½ to each)*		2	11.5
	TOTALS	4	13.5
	GRAND TOTALS	27	67.3

*There were four hydraulic failures related both to the tractor and the planter, so one half was charged to the tractor and one half to the planter.

Table 2. Effect of subsystem improvements.

Criteria	Desired attainment	Actual attainment	Subsystem that is assumed to have no failure: Hydraulics	Ejector cylinder	Turnbuckle	All three
Reliability, MCBF	12,000	4,035	6,629	7,138	4,419	46,400
Availabilities						
Inherent	85%	70%	83%	78%	71%	96%
Operational	–	67%	80%	74%	69%	96%
Maintainability, MTTR						
Actual	–	2.34	1.88	2.65	2.46	2.50
Desired	2.78	2.34	1.88	2.65	2.46	2.50

Availabilities

A_i = 124.7 hr (OT) ÷ 124.7 hr (OT) + 66.8 hr (maint.) = 124.7/191.5 = 0.65 = 65 percent.

A_o = 124.7 hr (OT) + 4.5 hr (ST) ÷ 124.7 hr (OT) + 4.5 hr (ST) + 78.8 hr (DT) = 129.2/208.0 = 0.62 = 62 percent.

Maintainability

M = MTTR = 68.8 hr (corrective maint.) ÷ 27 failures = 68.8/27 = 2.55 hr/failure.

A comparison of desired performance criteria for R, A, and M (see table 2) with the season-long actual results shows that the Model 100 did not meet the performance criteria in reliability and availability, but did in maintainability.

Reliability Growth

From reliability data, reliability problem areas can be identified and necessary corrective action taken in these areas to improve reliability. This is referred to as reliability growth.

Inspection of table 1 indicates that if problems with the Model 100 hydraulics, ejector mechanism, and/or turnbuckle were corrected, both R and A would be greatly improved. (The size of the turnbuckle was increased from 1 to 1½ in [2.5 to 3.8 cm] during the evaluation, after which there were no more failures of the turnbuckle.) An analysis of the effect of hypothetically correcting the three subsystem problems can be seen in table 2. A solution to each subsystem's failure is assumed, each in turn and then as a group, with the resulting improvements in R, A, and M listed.

As to M, the MTTR is not directly stated in the criteria. Nevertheless, knowing the production rate, the MCBF, and the desired inherent availability, the desired M can be calculated using the concept of mean-time-between-failure (MTBF), where:

MTBF = MCBF ÷ production rate = 12,000 ÷ 762 trees/hr = 15.75 hr.

Now, since A = R ÷ (R + M), A = MTBF ÷ (MTBF + MTTR), or MTTR = (MTBF/A) -MTBF; thus, MTTR = (15.75 hr/ 0.85) - 15.75 hr = 2.78 hr. The season-long MTTR was 2.34 for the planter only, and 2.55 when the prime mover is included; both are below the desired 2.78 hr.

Energy Requirements

The Model 100 design, with the packing wheel attached to the planting arm (fig. 6), causes the dibble (fig. 4) to stay in the ground much longer (in fact, 45 percent longer) than is necessary to just plant a seedling (fig. 8)—see discussion presented under Production Factors. Seedlings are planted by the Marden machine within the first 17.4 in (44 cm), with a standard deviation of 3.7 in (9 cm), implying that the dibble needs to be in the ground for only 30 in (76 cm) instead of the 54.5 in (138 cm).

As stated under Planter Configuration, the mean drawbar pull of the planter with the dibble in the ground was 3,000 lb (13.3 kN); when out of the ground the pull was only 500 lb (2.2 kN). Thus, a 13 percent reduction in fuel use could be achieved if the dibble did not remain in the ground any longer than necessary to place a seedling.

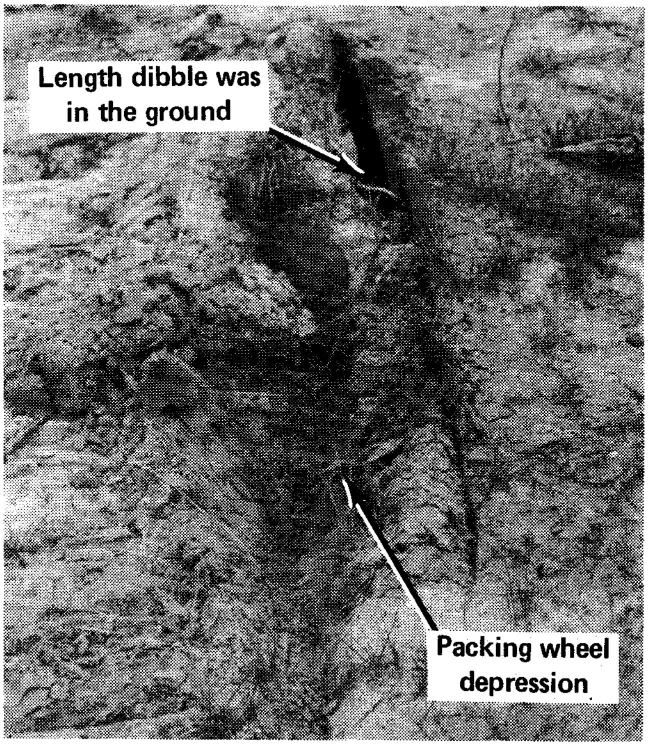

Figure 8. Seedling and marks left in ground.

In addition, the hydraulic system oil temperature was 180° F (82° C), which is higher than one would expect—indicating inefficiency. Perhaps the high heat resulted from using the flow divider in the hydraulic system.

Planter Safety

No significant safety problems with the Model 100 were observed or reported during the season-long field tests on the District. The Marden Spot Planter has a rollover-protected operator's station that is judged to be both more comfortable and safer than those usually found in conventional continuous-furrow tree-planting machines. In the Model 100, the operator enters from the left side, over the planting arm, and can sit erect,since there is no need to place the seedlings directly into the ground. The planter operator has a horn which he can use to communicate with the tractor operator.

CONCLUSIONS AND RECOMMENDATIONS

Based on the results of the field test program, the following are concluded and recommended:

The Marden Spot Planter, Model 100 meets many of the established evaluation criteria:

- Plants bare-root stock
- Has a planting rate of 762 tree seedlings per hour
- Plants the seedlings 10-in (25-cm) deep
- Can be operated by a small prime mover—15,500 lb (7031 kg)
- Is "affordable"
- Is safe to operate
- Is highly maintainable.

It did not meet some of the established criteria:

- Seedlings were "J" rooted more frequently than desired
- Reliability and availability were lower than desired, since desired R = 12,000 MCBF and the actual was 4,035; desired A = 85 percent and the actual was 70
- Had higher energy requirements than desired due to (1) dibble staying in the ground longer than necessary, (2) higher hydraulic oil temperature than desired, and (3) packing wheel removed soil from vicinity of planted seedlings
- Minimum spacing between seedlings in rows was greater than desired, since desired was 5 ft (1.5 m) and the actual was 7.3 ft (2.2 m).

(**Note:** The planter was not tested for containerized stock or under muddy conditions.)

To improve the Model 100's reliability and availability and lower its energy use, SDEDC should analyze the hydraulic system design and its operation and make improvements wherever possible to the District's Spot Planter. Also, the seedling ejector mechanism should be examined to determine failure causes and appropriate corrective action. Further, SDEDC should provide Marden with information to help them:

- Improve the Model 100's reliability and availability
- Reduce the distance that the dibble is in the ground and bring seedling spacing within rows to the desired 5 ft (1.5 m)
- Eliminate soil removal by the packing wheel from around the seedlings.

If significant progress is made in carrying out these recommendations, then the District's Model 100 should be re-evaluated in 1982.