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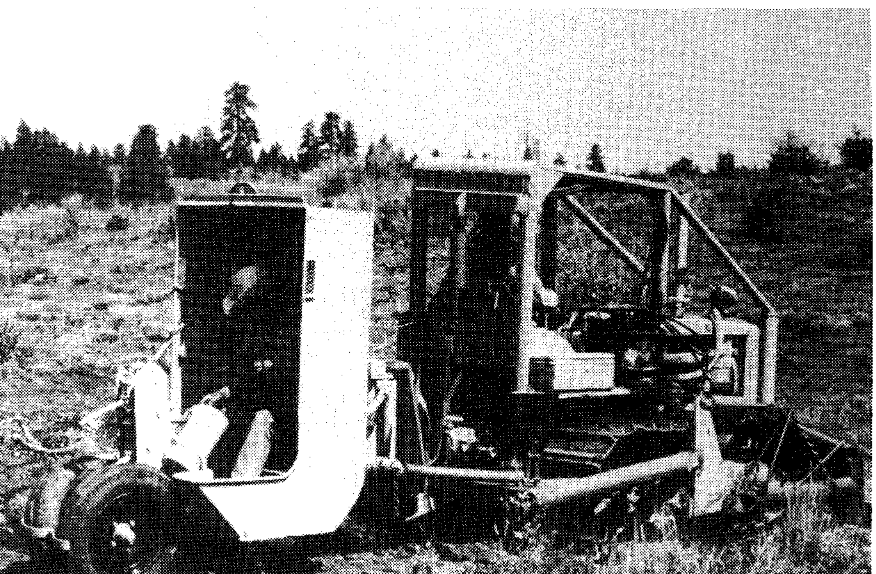
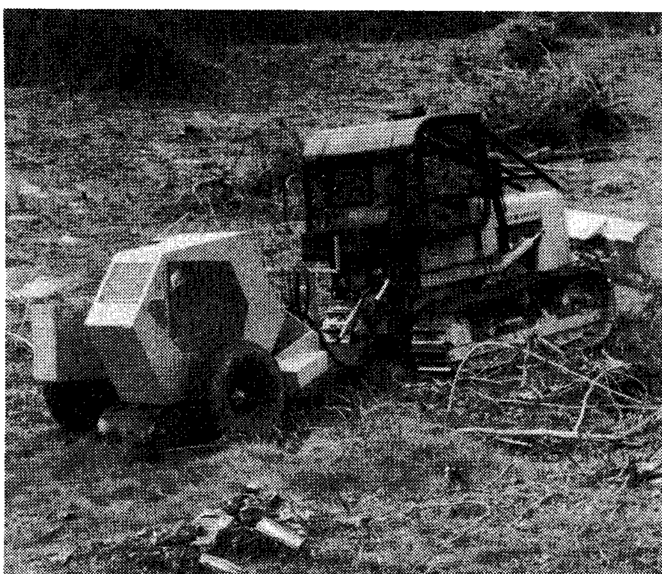
Guidelines for Evaluating Mechanical Tree Planters





Guidelines for Evaluating Mechanical Tree Planters

by

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and

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Forest Service
Equipment Development Center
San Dimas, California

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INTRODUCTION

Few debate that successful mechanical tree planting offers many advantages over hand planting. These advantages include more uniform and generally higher quality planting, less costly planting, and often reduced site preparation requirements. New machines, or new developments added to existing machines, are continually being introduced and marketed. The new machines need to be evaluated to determine their economic feasibility and to gauge their performance and planting quality.

Before an evaluation can be carried out, performance criteria for the tree planting machine must be developed and an evaluation procedure established. This report describes mechanical tree planter performance criteria that were developed by the San Dimas Equipment Development Center (SDEDC) in cooperation with the Southeastern Area State and Private Forestry, and methods for measuring and determining conformance to these criteria. Time and motion studies, planting quality, planter productivity, and other measurements are described.

THE BIG PICTURE

When evaluating mechanical tree planters, standards for tree planting machines and planting systems must be used. Quantified standards make conducting an evaluation easier, since a unit of measure is established and the introduction of personal bias is rendered more difficult. For example, economics require that mechanical planting costs must be less than the next best alternative (hand planting), and quality must be at least as good as the least acceptable hand-planted tree. More than just the initial purchase of the machine must be considered; the question "How does the total cost of machine planting compare with the total cost of hand planting, when quality is also considered?" must be answered.

Quantification of planting quality parameters is necessary. One person's qualitatively marginal planted tree is another person's no-plant. Quantifiable limits such as "No more than 25 percent of the seedlings may be planted with root collars more than 1-in deeper or shallower than root collar placement at the nursery," or "no more than 25 percent of trees may be planted at a lean of more than 30 degrees" need to be determined and placed in writing in advance of testing. Generally, contract hand-planting requirements (limits) will suffice as mechanical planter quality limits.

Operational requirements for the planting machine need to be identified. What size tractor and what kind of labor are required for operating the planter? What are the support equipment requirements? How much fuel is needed? Measuring performance also requires measuring site characteristics and silvicultural limits, conducting time and motion studies, reliability studies, and system studies.

Test personnel need to maintain records of tree planter productivity, maintenance requirements, delays, site descriptions, planting quality, mechanical damage to seedlings, fuel consumption, and planter operational safety.

Season-long time and motion studies are required to measure planter productivity; reliability, availability, and maintainability; and to assess planter/prime mover configurations. Individual, randomly selected seedlings must be inspected, dug up, and variously measured to determine planter adherence to planting and packing quality criteria. Planting site characteristics need to be quantified (as much as possible), and their effect on the planters determined for each stand. Planter/prime mover energy requirements and planter safety incidences must be monitored throughout the evaluation. Equipment necessary for conducting a thorough planter evaluation is outlined in table 1.

Table 1. Instrumentation and equipment

- **Digital watch**
- **Stopwatch**
- **Data sheets & pencils**
- **100-ft long cloth measuring tape**
- **Thermometer**
- **Abney**
- **Clinometer**
- **Counter (mounted on planter)**
- **Operating time recorder (optional)**
- **Chaining pins**
- **Hydraulic load cell, 10,000 lb or a hitch pin equipped with a strain gauge**
- **Heavy chain**
- **Caliper**
- **Clamps**
- **Full scale (10 to 20 lb)**
- **Push scale (durometer) (20 lb)**
- **Durometer plugs**

GAUGING PERFORMANCE

Measuring conformance to performance criteria requires conducting tests directed at each criterion. A discussion of general time and motion study requirements follows. Later, each performance criterion used in previous evaluations conducted by SDEDC is stated and is followed by guidelines for measuring and determining conformance to the criterion.

Time Study

Time study data form the basis for much of the machine performance analysis. Planting rates; reliability, availability, maintainability (RAM); and operational requirements may be calculated from good time study data.

Time study data are best collected using the continuous timing method on a site-by-site basis. The Planter Time Study Data form, in the appendix, is helpful when collecting the data. Continuous timing requires that a clock be started at the beginning of the day and run throughout the day. A digital watch is adequate as a clock and local time may be used as clock time.

The time study should consist of recording the time at which a particular event starts or occurs. Recording time to the nearest minute in a tree planter evaluation is quite satisfactory. Events may be coded prior to carrying out the study. This facilitates data recording, as then only the start time and event code need be recorded. A sample of codes found useful is shown in the Planter Time Study Event Codes form in the appendix. Not all events can be anticipated in advance. Events that reoccur frequently in the field can be assigned their own code during the time study.

All the data must be evaluated later. Observations and comments made during planting operations on the time study data form are often very helpful in the data analysis. Repetitive failure items, delays, troublesome ground conditions, etc. all warrant mention in the comments section.

Most planters are equipped with counters. Production cannot be measured on a number of trees planted basis without a counter. Planters not equipped with a counter may be outfitted with mechanical or electrical counters for less than $60. Any Regional or Forest Equipment Specialist will be able to help specify and install adequate counting equipment.

A detailed procedure for the time study portion of an evaluation is shown in table 2. An example of what the data collected might look like is shown in figure 1.

Table 2. Detailed test procedure for time study data collection

1. Prepare a Planter Time Study sheet noting stand, compartment, planter, and date.

2. Clock time (local time) on the digital watch should be kept to the nearest minute.

3. When an event begins, the clock time should be noted and recorded. The corresponding event code shall also be noted, and the reading on the tree counter noted and recorded.

4. When an adequate event code does not exist, the data collector shall create a new event code.

5. The first event of the day should be recorded no later than the scheduled starting time. For example: If work is to begin at 8:00 am, and the planter is still being transported to the planting site at 8:00 am, event code 76 would be recorded at 8:00 am.

6. Subsequent events shall be recorded by coding their starting time and code.

7. Work that begins early should be recorded, and the early start shall be noted under comments.

8. Total number of trees planted each day should be recorded. It is suggested that the counter be reset each day.

9. Comments are most helpful and are required to explain, in more detail, the various event codes. For example: A repeat failure of a particular hose or bolt may be noted in the comments section. Please describe what failed.

10. Any corrective maintenance item (repair) requiring less than 10 min is an "adjustment" item.

11. Number the data sheet pages.

PLANTER TIME STUDY DATA

Date: 3/1/85
Prepared by: M. Record

Stand: 11A Compartment: 27 Planter: XYZ - 2 row

Clock time	Event	Counter reading	Comments/observations
8:00 AM	71		
8:03 "	11	000	Joe is planting
8:07 "	12		Turn into next row
8:07 "	11		
8:11 "	13		Go around mud hole
8:12 "			
8:29 "	72	506	
8:35 "	11	506	
9:11 "	11	1,126	Turn into next row
9:30 "	51	1,183	Quality appears good
9:46 "	72		
9:50 "	11	1,183	Mark is planting
10:07 "	35	1,421	Lots of mud in dibble
10:11 "	11	1,421	

Figure 1. Sample tree planter time study data sheet.

A preliminary data reduction may be carried out at the end of each day. The data collector may tabulate cumulative time each day spent under each event code (e.g., total the time spent planting), as well as total the number of times and total elapsed time spent in each event code. Having the data collector perform this preliminary data reduction also gives the collector an appreciation for how this information will be used and may open the collector's eyes to routines or events that may be corrected or modified in the field the next day to enhance/improve/speed-up the planting operations.

Performance Criteria

Each of nine performance criterion used by SDEDC in past planter evaluations is presented and is followed by a discussion of measurement (data collection) required to gauge adherence to that criterion and analysis of collected data.

1. **Stock type and configuration**—Ability to plant both bare root and most containerized stock, one or two rows at a time. When bare root stock is planted, protection from roots drying out must be provided.

Sales and promotional literature will often state whether the planter is designed to plant bare root or containerized stock or both. Determining suitability for each type of stock requires carrying out the tests described in this report with each type of stock. A machine that sucessfully plants containerized stock will not necessarily work satisfactorily with bare root stock or vice versa.

Determining whether enough protection from drying of roots is provided may be done by direct observation. Protection similar to that provided for hand-planting is adequate provided that seedling storage is not near machine parts that get excessively warm (e.g., exhaust pipes, hydraulic fluid reservoirs). Protection from drying out of tree roots is generally dependent on the care and concern of the tree planter operator. Also, some containerized stock are shipped without the container and the roots must also be protected from drying out.

2. **Production and site factors**—Capable of planting from 700 to 1,800 seedlings per hour in hilly, rocky terrain that is strewn with logging debris, where intensive site preparation has not been done. In addition, the planter must be able to operate in muddy conditions. Also, seedling spacing as close as 5 ft is desired.

Production information—planting rate may be discussed in terms of two time bases. Average production rate is measured by totaling the number of trees planted during the evaluation (or time study) and dividing by the amount of time elapsed in planting, turning, dealing with field conditions, etc. Breakdowns are not included in operating time, but are included under corrective maintenance time. Using the event codes called out on the Planter Time Study Event Codes data sheet, average production rate would be calculated by dividing the number of trees planted during an evaluation by the number of hours spent in "operating time" event codes.

The instantaneous production rate is the rate of planting with no interruptions, delays, or inefficiencies; i.e., it is the theoretical maximum production rate. The ratio of the average production rate divided by the instantaneous planting rate, expressed as a percentage, is known as the field efficiency. Field efficiency accounts for the failure to utilize the total theoretical operating capability of a machine. (Examples of not utilizing full capability of machine include: Time lost because of operator capability, habits and operating policy, and field characteristics.) Field efficiencies of 65 to 80 percent are reasonably expected with mechanical tree planters. Computation of field efficiencies which yield low ratios may point out that some operating characteristics, habits, or policy may be excessively holding back production.

Instantaneous planting rate (IPR) measurements should be made at least three times per planting site (or soil type). The measurements should be made at randomly selected times. A model Instantaneous Planing Rate Measurements data sheet is in the appendix.

Ascertaining instantaneous planting rates require measuring sample row slope and length, time required to plant the row, number of seedlings planted, and tractor gear and engine speed (rpm). Time measurements are best made with a stopwatch. Collect instantaneous planting rate data on the IPR measurements data form as follows:

a. Select a time (coordinated with the planting crew) to make the measurements. Long, relatively straight rows are required for these measurements.

b. With the planter moving forward at planting speed, start the stopwatch. With a chaining arrow, mark where the rear of the planter was when the stopwatch was started.

c. Let the planter plant 40 to 90 trees (the more, the better). Stop the stopwatch and mark where the rear of the planter was when the watch was stopped.

d. Record the planting time.

e. Measure and record the distance traveled by the planter.

f. Count and record the number of trees in the sample row.

g. Measure the slope of the row with an abney or clinometer.

h. Record the prime mover gear and engine rpm.

i. At least three of these measurements must be made at each site type.

j. Divide the number of trees planted by the time elapsed during the IPR test to determine the IPR. If the time collected was in minutes, multiply by 60 to express instantaneous planting rate in tree/hour. For example:

Trees planted = 69

Time = 2 min 22 sec = 2.367 min

$$\frac{69 \text{ trees}}{2.367 \text{ min}} \times \frac{60 \text{ min}}{\text{hr}} = \frac{1749 \text{ trees}}{\text{hr}}$$

Dividing the length of sample row by the time required to plant the sample row will give planter/prime mover speed. For example, if the sample row above was 414 ft long:

$$414 \text{ ft} \times \frac{1 \text{ mi}}{5280 \text{ ft}} \times 2.367 \text{ min} \times \frac{60 \text{ min}}{\text{hr}} = \frac{1.99 \text{ mi}}{\text{hr}}$$

Travel speeds and production rate data may be used to help plan and schedule future planting jobs.

Site Information—Planting site information (including site history, soils, topography, harvest method, site preparation method, and residual slash load) should be collected. This will help form a data base for the subject tree planter so that others may be helped in determining whether a particular planter will work on their site. Site information may be collected on the Planting Site data form (two pages) seen in the appendix. The data should be collected for each stand and compartment. When collecting data for the site data sheet:

a. Note stand, compartment, date, and area of site.

b. Attach a map of the site or sketch one on the back of the data sheet. On the map, include any outstanding features such as mud holes, rock outcroppings, extremely steep pitches, brush fields, etc.; include contour lines.

c. Site history. Collect the site history data as indicated on the data sheet. This may best be done by consulting the District Silviculturist. Stand composition information requested includes species, age, and size distributions. Harvest prescription, method, and equipment are of interest. Note the site preparation prescription and equipment used. Also note the elapsed time between site preparation and planting operations.

d. Soil. The desired information may be collected by consulting the District Soil Scientist. Soil types and textures, and the site's composition of each of these types and textures are to be recorded. It is often better to collect a soil sample on site for analysis rather than use Soil Conservation Service maps or soil resource inventories. This is due to local variations.

e. Topography. Topography measurements should be made with a cloth tape, a clinometer, or an abney. The cloth tape will give the needed accuracy and is easy to use. The average path slope and side slope measurements should be made where site slopes are observed to be fairly typical. Maximum path slope measurements should be made where the terrain is observed to be the steepest. Maximum path slope measurements should be referenced to planter direction by noting a "+" slope if the planter was pulled up the slope, or a "–" slope if the planter was pulled down the slope. Lengths of slope measurements should be made with a cloth tape, beginning and ending at discernable breaks in the slope.

f. Residuals and brush. Brushiness and level of residual should be measured by the standard method used by the District.

g. Spacing. Determining minimum tree spacing simply requires measuring the distance between the trees when planting as rapidly as possible. On some machines, hydraulic system requirements, chains, gears or other planting system drive components will determine minimum tree spacing. Where timed hydraulic circuitry determines tree planting cycle time, forward speed (in ft/min times cycle time) will determine theoretically minimum tree spacing. A forward speed of 1.99 mph and a minimum planting cycle time of 3 sec yields a minimum spacing of:

$$1.99 \text{ mph} \times \frac{5280 \text{ ft}}{\text{mi}} \times \frac{1 \text{ hr}}{3600 \text{ sec}} \times \frac{3 \text{ sec}}{\text{tree}} = \frac{8.756 \text{ ft}}{\text{tree}}$$

Slowing the tractor down may allow closer spacing.

3. **Planting quality**—Consistently plant the seedling 10-in deep such that 75 percent of the seedlings have root collars between ground level and 1-in below the ground; when planting bare root stock, the seedling should be inserted vertically (not more than a 30-degree lean, 75 percent of the time) with no "L" or "U" roots 75 percent or more. There should not be more than 20 percent skips or no-plant. Overall successful planting should be 75 percent or greater. On some species the cotyledon scar is easier to identify than the root collar and, therefore, should be used as the guide. When using the cotyledon scar, set the seeding at the cotyledon scar or 1 in below.

The planter success is not measured by productivity alone—more importantly, planting quality must be assessed. Planting quality measurements shall be made for each planter on each planting site and recorded on the Planting Quality data form, found in the appendix.

Planting quality measurements need to be made on enough randomly selected seedlings to determine with reasonable certainty how well the planter is performing. Measurements should be made the same day as planting. Generally, at least 100 randomly selected seedlings per 20-acre site must be examined. Of these 100, alternate seedlings will undergo pull force tests. The other seedlings, if they pass the four-needle pull test, will have the root system configuration examined.

Any randomization scheme is sufficient for determining which seedlings will be examined. One method is to choose a row, then using single digit random number tables, go up the indicated random number of trees and make measurements. The next four random numbers are used as follows:

a. If the number is even, go left; if it is odd, go right.

b. The next number dictates the number of rows to go left or right determined from above.

c. If the next number is even, go left in the row; if it is odd, go right in the row.

d. This number will tell you the number of trees to go up or down in that row.

Specific planting quality measurements are made as follows:

a. Prepare a Planting Quality data sheet.

b. Note whether the tree is a "no-plant." If it is, give the reason (e.g., not in ground, upside down) in the comment section.

c. Measure the seedling lean with a protractor and plumb line. Hold the protractor base plumb with the plumb line. Align the plumb line with the seedling base. Read the protractor where the seedling stem crosses it (within 5 degrees). A "+" will indicate the tree lean is in the direction of planter travel, a "–" will indicate lean opposite the direction of planter travel.

d. Note the root collar placement where it is relative to the ground. Also measure root collar diameter.

e. Four-needle pull test. Grab four needles of the seedling (one needle each from four different fascicles) and firmly pull upward. If the needles break off before the tree is pulled from the ground, note that the tree passed the four-needle pull test. On some species the four-needle pull test cannot be performed; when this is the case, use the pull test.

f. Every other tree will undergo a pull test. If not undergoing a pull test, the seedling root system configuration will be examined, if the seedling passes the four-needle pull test.

g. Pull test. Attach the clamp to the tree just above ground level. Set the pull scale indicator to zero. Attach the pull scale to the clamp and pull firmly and steadily upward until the tree is pulled from the ground. Note and record the required maximum pull force as indicated by the scale indicator. Go to step "i."

h. Root configuration measurement. Carefully dig the soil away from one side of the seedling. Note the configuration of the tap and lateral roots. Are there any L, U, or angles? If yes, how long are the L, U, or angle portions? Make a small sketch showing approximately the angle of distortion.

i. Measure and record tap root and shoot length.

j. Measure, with a caliper, root collar diameter.

k. Note any change to bark and root endodermis.

l. If seedling lean is less than 30 degrees, tap root is not "L" or "U" rooted, lateral roots are not swept up, root collar is within 1 in of ground level or below, or the cotyledon scar is at ground level or 1 in above ground level and everything else is okay, note that the seedling is adequately planted.

m. Comments are most helpful when analyzing data. Note trends, common irregularities, or other points of interest.

Analysis of these data may begin immediately after the data are collected. The number of trees determined to be no-plants, divided by the total number of trees planted will yield the skip or no-plant percentage.

The number of trees planted adequately (i.e., not L-rooted), root collar depth within established limits, lean less than 30 degrees, divided by the total number of trees sampled, times 100, yields the overall successful planting percentage.

A rapid survey if possible by a certified silviculturist, or if not possible at least by an experienced regeneration forester, covering a large number of trees classifying them into sucessfully planted and unsucessfully planted—and, if unsucessfully planted, the reason for not successfully planted will be found helpful to the designer in identifying and rectifying machine shortcomings. (See table 3 for an example of an actual survey made by a certified silviculturist.)

Table 3. Example of results from tree planting quality survey by a certified silviculturist

Attempts	433
Successful	268
Percent successful	60
Unsuccessful	175
Percent unsuccessful	40

Cause(s),or contributing cause(s), of unsuccessful attempts:

Cause	Percent of total attempts with this cause 1/	Percent of unsuccessful attempts with this cause 1/
Inadequate packing	21	51
Lean	9	21
Depth	11	27
Skip (no tree planted)	13	31
Mud	11	27
Light slash	7	18
Medium slash	5	13
Heavy slash	2	5

1/ A seedling may have more than cause.

Pull force measurements are used to develop a data base for packing comparisons in different soil types or from District to District.

Tracking seedling characteristics is helpful if further analysis, analysis beyond planting adequacy, is conducted. For example, one may wish to conduct a failure analysis later and search for reasons or causes of planting failures. In the past we have found by failure analysis that a planter may work well with trees whose tap roots are less than X inches long or whose collar diameter was less than Y inches. Failure analysis may result in more success in future plantings (during the evaluation) and also provide further criteria for machine designers. Failure analysis should be based on observations on specific seedlings. Also, while survival is a key success factor, seedling growth is also critical and is correlated with good roots and large seedling caliper.

4. **Packing quality**—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.

Four-needle pull tests and the pull tests described above are not, of themselves, sufficient measures of packing quality. Seedling roots must be in intimate contact with soil to prevent drying out. For those seedlings selected for root configuration examination, packing shall also be measured and recorded on the Packing Quality data sheet, found in the appendix. Any air pockets encountered while digging soil away from the roots shall be noted.

Degree of packing is best measured by using the standard compaction test method of measuring soil bulk density. However, this method's requisite collection of samples, drying, and weighing is a slow, laborious process.

Overpacking may be measured, quasi-quantitatively, using a soil hardness durometer made up of a plug of known diameter and a push scale. A complete durometer kit will include plugs of many sizes providing capability to measure a wide variety of hardnesses.

The soil in front of or behind the seedling will be measured for resistance to horizontal penetration with the durometer. At 2-in increments of depth, the durometer plug shall be forced into the soil to a depth of 1 in. Soil hardness determines plug size. The maximum force required to force the plug in at each increment shall be recorded. At least 20 measurements per (20-acre) site should be made. The exact number of tests is best determined by the level of statistical significance desired in the test.

Soil packing/hardness control measurements should also be made on hand-planted seedling holes and on unplanted, natural, undisturbed soil—also 20 per site, so that a basis for comparing the tree planter packing is established. The location and size of air pockets should be observed. The number of trees found with air pockets near more than 10 percent of the root mass should be tallied as failed plantings.

Compute average packing at each depth for the machine-planted trees and for the control (hand-planted trees and undisturbed site measurements). Divide the pounds required to push the plug into the ground by the area of the plug face. This will yield psi or packing pressure. How much packing pressure deviation between control measurements and machine planted trees is allowable is a subjective matter; limits may be set by the District Silviculturist.

Ambitious evaluators may wish to conduct correlation studies between bulk density and durometer measurements.

5. **Planter/prime mover configuration**—Should attach to and be operated by a "small" prime mover—preferably a crawler tractor in the 10,000 to 15,000 lb range and require only two operators (one on the tractor and one on the planter)—or, if cost effective, have an automatic feed system so the planter operator is not needed. Also, if cost effective, the unit could be an integral, self-propelled, special-design machine. If the tree planting machine plants two rows at a time (which may be desirable for increased production), the tree planter may require two tree planter operators.

Initial estimation of required tractor size is best made by an experienced operator. Tractor weights are available in manufacturer's sales literature and user manuals. Tractor weight is an important parameter because tractors cannot generally pull more than 30 percent of their own weight.

Drawbar pull measurements help determine pull requirements (and thus tractor size) for a tree planting machine. Drawbar pull measurements need to be made at least once per planter evaluation. Making these measurements requires installing a hydraulic load cell or using a hitch pin equipped with a strain gauge between the tractor and the planting machine. To make drawbar pull measurements, use the Drawbar Pull Measurements data sheet in the appendix and proceed as follows:

a. Choose a long, straight row.

b. Place the hydraulic load cell or strain gauge equipped hitch pin between the planter and prime mover. Using a hydraulic load cell may be a problem because of the added linkage. This added linkage problem can be overcome by obtaining an 8- to 12-in diameter log approximately 15 to 20 ft long. Place one end of this log on the tractor (cab) and one end on the tree planter cab. Support the tongue of the tree planter by a vertical chain as shown in figure 2. With this arrangement, the chain only supports vertical loads and all horizontal loads (drawbar pull) pass through the hydraulic load cell.

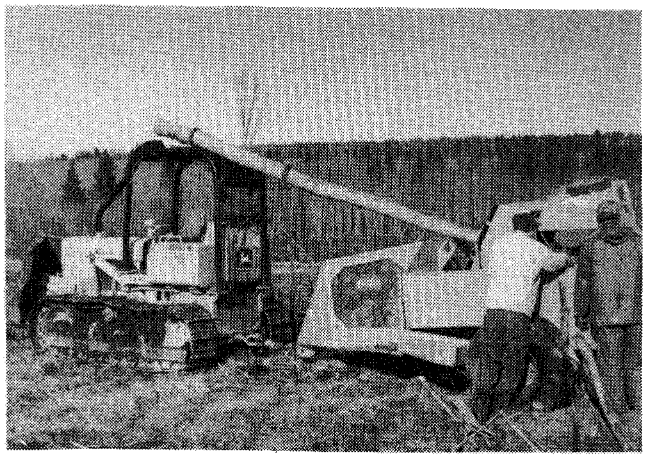

Figure 2. Method of supporting tree planter tongue when making drawbar pull measurements.

c. Prepare a Drawbar Pull Measurements data sheet.

d. Put the prime mover into gear and move forward at planting speed.

e. Record the force (pounds) required to pull the planter as indicated by the hydraulic load cell or strain gauge.

f. Initiate a plant cycle. Measure and record the pull force indicated on the dial. Make 10 to 15 of these measurements.

g. Repeat these measurements with two dibbles in the ground (if applicable).

h. Make "no dibble in" measurements again.

i. Measure and record the planting path slope with an abney or clinometer.

j. Measure the planter path side slope.

Measurements on slopes are made because drawbar pull requirements are generally greater on slopes than on flat ground.

Filling out the Planter/Prime Mover Configuration data sheet in the appendix is also worthwhile. This information could be used later when evaluation results from one area are compared with results from another area.

6. **Planter price (affordability)**— The tree planter must be affordable, i.e., the planter must be able to be operated on a sound, economical basis when operated by force account, and at a profit when operated by a contractor. The purchase price that will allow the planter to be affordable is very much dependent on production rate.

From the methodology developed in an economic analysis (reference 1) the maximum purchase price you can afford to pay for a tree planting machine can be found by the following equation:

$$X = -\$67{,}500 + \$1{,}203\ (HPC)\ (MPR)$$

where:

X = Maximum economical purchase price of a tree planter

HPC = Hand-planting cost per seedling in dollars

MPR = Machine production rate in seedlings per hour.

Either reviewing reference 1 or contacting SDEDC is advisable before applying this equation. The equation assumes particular tractor and labor costs. These may change when labor and tractor rates for a different District are considered. If actual purchase price is less than the purchase price given by the affordability equation, the machine is affordable—provided that it meets reliability, availability, maintainability, and tree planting quality criteria.

7. **Planter mechanical performance**—Have high system reliability, with a minimum mean-cycles-between-failures (MCBF) of 12,000, and a minimum inherent availability of 85 percent, which will require a high degree of maintainability.

Season-long planting records of planter production, operating time, breakdowns, corrective and preventative maintenance time—collected by time study—are used to determine reliability (R), availability (A), and maintainability (M), together RAM:

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 frequence 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_o) is defined as OT during a given interval plus standby time (ST), divided by the OT, plus the ST, plus downtime (DT); where DT equals total active corrective maintenance time (TCM) plus total active preventative maintenance time (TPM), plus total administrative and logistics downtime (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 include (but not limited to) equipment publications that provide the necessary information on the operation and maintenance of the equipment—such as operator's instructions and repair manuals and parts manuals. Defined resources would include (but not be limited to) repair workers, repair workers' training, tools and repair equipment, repair facilities, and available repair parts.

Time Categories—Events on the Planter Time Study Event Codes sheet in the appendix are divided into the time groups mentioned above. Briefly, each time group may be defined as follows:

OT (Operating Time) is the time during which the machine is actually planting. Adjustments, corrective maintenance action or repairs of less than 10 min duration fit into this time category.

ST (Standby Time) is the time during which the machine is capable of planting, but for some reason—other than TCM, TP, or ALDT—such as personnel delays, is not planting. (This includes prime mover downtime, if this is not subtracted out of time study total time.)

TCM (Total Active Corrective Maintenance Time) is the time the planting machine spends in repair or transport to a repair site.

TPM (Total Active Preventative Maintenance Time) is time spent conducting preventative maintenance—such as lubing, checking bolt torques, and oil changes.

ALDT (Total Administrative and Logistics Downtime) is time spent in activities such as planning, moving from site to site, fueling, safety meetings, etc.

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 specific 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 specific 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:

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

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

Calculations of RAM characteristics are a straight forward procedure. Using the hypothetical data in table 4, the characteristics may be calculated as follows:

$$A_i = \frac{135.7}{135.7 + 52.1} = 0.72 = 72 \text{ percent}$$

$$A_o = \frac{135.7 + 4.5}{135.7 + 4.5\ 52.1 + 5.0 + 2.8} = 0.70 = 70 \text{ percent}$$

$$M = \text{MTTR} = \frac{52.1 \text{ hr}}{21 \text{ failures}} = 2.48 \text{ hr/failure}$$

$$R = \text{MCBF} = \frac{95{,}217 \text{ seedlings}}{21 \text{ failures}} = \frac{4{,}534 \text{ cycles}}{\text{failure}}$$

Table 4. Sample RAM data

Time category	Hr
OT	135.7
TCM	52.1
ST	4.5
TPM	5.0
ALDT	2.8

21 failures
95,217 seedlings planted

A mechanical failure summary is often very helpful to machine manufacturers as machine weaknesses are brought to light. Machine improvements may begin around these failures. Table 5 shows a sample field test failure data summary.

Table 5. Field test failure data summary

Planter subsystem	No. of failures	Repair time (hr)
Hydraulic system	8	15.2
Packing spring support	6	15.1
Ejector mechanism	4	12.8
Cycle initiation switch	2	6.7
Wheel bearing	1	2.3
Totals	21	52.1

8. **Energy requirements**—The tree planter shall be energy-efficient. Fuel consumption records may be kept for the prime mover/planter combination during planting on the Fuel Consumption Data sheet in the appendix. Setting the limits for excessive fuel use is a judgmental matter. Keeping

track of fuel consumption during the evaluation helps in planning refueling stops during future planting jobs.

Monitoring hydraulic fluid temperatures (on the Planter/Prime Mover Configuration data sheet) helps identify systems that are particularly inefficient. Systems that have oil reservoir temperatures in excess of 180° F indicate an inefficient use of power.

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

Common sense and direct observations are necessary to ascertain planter safety. Some items to watch for include: Is there a possibility of operator appendages being caught in a planting mechanism; can residual trees be bent over and snap back and hit the operator; will the operator smack his head on the cab if a bump is hit; can the operator be thrown from the planter; are emergency escapes necessary and available? Also, during tree planter testing, the following safety procedures must be adhered to:

SAFETY DURING TEST

All standard and local safety procedures and regulations should be observed throughout the test and evaluation. In addition, the following items of safety must be observed:

A. For no reason will any person place themselves, or any portion of themselves, under the planting beam, planting dibble, or packing wheel of any planting machine.

B. No corrective or preventative maintenance work will be performed on any planter unless all power to the planter is off.

C. Data collectors will not place themselves downslope of any planter or prime mover.

D. Data collectors walking alongside or behind a planter will maintain a minimum distance of 25 ft between themselves and the planter.

E. Planting and packing quality, site, and other data measurements will be made only when the planter/prime mover are shut down or operating more than 50 ft from the measurement point.

F. Planter operators will wear seat belts during planting operations.

PRESENTATION OF FINDINGS

Evaluation results are best presented in report form. References 2, 3, and 4 provide excellent examples of tree planter evaluation reports.

LITERATURE CITED

1. McKenzie, Dan W.; Hatfield, David; Dykeman, Kenneth K. Tree planting machine—How much can you afford to pay for one? Proj Rcd 8124 1203. San Dimas, CA: Equipment Development Center, Forest Service, U.S. Department of Agriculture; 1981 June. 8 p.

2. McKenzie, Dan W.; Alsobrook, Alan; Merala, Raymond. Evaluation of an intermittent furrow tree planting machine. Proj Rcd 8224 1201. San Dimas, CA: Equipment Development Center, Forest Service, U.S. Department of Agriculture; 1982 July. 9 p.

3. McKenzie, Dan W.; Peterson, Don; Stearns, Howard. Evaluation of the Marden model 200 spot planter. Proj Rcd 8424 1205. San Dimas, CA: Equipment Development Center, Forest Service, U.S. Department of Agriculture; 1984 July. 8 p.

4. McKenzie, Dan W.; Alsobrook, Alan. Evaluation of the two-row Timberland Hodag tree planting machine. Proj Rcd 8424 1206. San Dimas, CA: Equipment Development Center, Forest Service, U.S. Department of Agriculture; 1984 June. 7 p.

APPENDIX
DATA SHEETS AND FORMS

PLANTER TIME STUDY DATA

Date: ____________

Prepared by: ____________

Stand: ____________ Compartment: ____________ Planter: ____________

Clock time	Event	Counter reading	Comments/observations

PLANTER TIME STUDY EVENT CODES

10—Operating Time
- 11—Planting
- 12—Turning
- 13—Maneuvering
- 14—__________
- 15—__________

20—Preventative Maintenance
- 21—Check motor oil
- 22—Check hydraulic oil
- 23—Lube
- 24—Refuel
- 25—__________
- 26—__________
- 27—__________

30, 40—Corrective Maintenance

Repairs:
- 31—Fingers
- 32—Trigger-plate or switch
- 33—Hydraulic leaks
- 34—Hydraulic hose
- 35—Clean dibble
- 36—Electrical trouble
- 37—Foot switch
- 38—Planting beam
- 39—Packing wheel
- 40—Ejection cylinder
- 41—Planting cylinder
- 42—Packing cylinder
- 43—__________
- 44—__________
- 45—__________

Adjustments:
- 46—Adjust hydraulic pressure
- 47—__________
- 48—__________
- 49—__________

50—Standby Time
- 51—Break time
- 52—Terrain conditions
- 53—Walk between sites
- 54—Personnel delay
- 55—__________
- 56—__________
- 57—__________

60—Administrative Time
- 61—Strategy meeting
- 62—Planting review
- 63—Safety meeting
- 64—__________
- 65—__________
- 66—__________

70—Logistics Down Time
- 71—Load seedlings into storage bin
- 72—Transfer seedlings from bin to operator
- 73—Change operator
- 74—Wait for mechanic
- 75—Wait for parts
- 76—Transport to and from planting site
- 77—Transport to and from preventative maintenance
- 78—Transport to and from repair
- 79—__________

80—Prime Mover Time
- 81—Corrective maintenance
- 82—Preventative maintenance
- 83—Warm-up
- 84—__________
- 85—__________
- 86—__________

90—Other
- 91—Lunch
- 92—Weather delay
- 93—Fire delay
- 94—Time study delay
- 95—Miscellaneous delay
- 96—Stock
- 97—__________
- 98—__________
- 99—__________

INSTANTANEOUS PLANTING RATE MEASUREMENTS

Date: ____________________

Prepared by: ____________________

Stand: ____________________ Compartment: ____________________ Planter: ____________________

Sample row no.	Sample row slope (%)	Length of sample row (ft)	Time to plant (min/sec)	No. trees planted	Tractor gear (rpm)

PLANTING SITE DATA

Date: ______________________

Prepared by: ______________________

Stand: ______________________ Compartment: ______________ Page ____ of ________

Area (acres): ______________________ (map attached or on reverse) ______________________

HISTORY

Stand composition before harvest ____

____

____

____

Harvest: Prescription/method ____

____

____

Site preparation methods and equipment ____

____

Time elapsed since site preparation ______________________

SOIL

Soil type(s)/% of each type ____

____

____

Soil texture(s)/% of each texture ____

____

____

Relative soil moisture (% field capacity) ____

TOPOGRAPHY

Average slope along planting path (%) ____

Maximum slope along planting path (%) ____

Length of maximum slope (ft) ____

Average side slope (%) ____

Maximum side slope (%) ____

—continued—

PLANTING SITE DATA (Continued)

Stand: ______________________________ Date: ____________________

Compartment: ________________________ By: ____________________

Page ________ of ________

	Plot 1				*Plot 2*				*Plot 3*			
	3″	3.1″–6.0″	6.1″–10″	10″	3″	3.1″–6.0″	6.1″–10″	10″	3″	3.1″–6.0″	6.1″–10″	10″
Residuals No. stems by dbh												
Brush No. stems by diamter at ground level												
Slash Piece length by diameter class												
Rocks No. by average diameter												

Narrative site description ____

PLANTING QUALITY DATA

Stand: ____________ Species/type/age: ____________ Date: ____________

Compartment: Prepared by: ____________

Page ______ of ______

Planter: ____________ Prime mover: ____________ Blade: ____________ Date planted: ____________

Sample No.	No. plants	Lean angle (°)	Pass 4-needle pull tests	Measured pull force (lb)	Shoot length (in)	Root length (in)	Root collar depth caliper	Bark scraped or damaged?	*Tap root*			*Lateral root*			Comments
									L-root? (in)	U-root? (in)	Angle root? (in)	L-root? (in)	U-root? (in)	Angle root? (in)	

PACKING QUALITY

Date: ______________________________

Prepared by: ______________________________

Stand: ____________________ Compartment: ______________ Planter: ________________

Tree sample no.	Durometer plug (size)			Packing (lb)				Air pockets?
		2"	4"	6"	8"	10"	12"	

Comments: ____

DRAWBAR PULL MEASUREMENTS

Date: ____________________

Prepared by: ____________________

Stand: ____________________ Compartment: ____________________ Planter: ____________________

Row	Slope (%)	Side slope (%)	Pull (lb) 1–dibble (in)	Pull (lb) 2–dibbles (in)	Pull (lb) No.–dibble (in)

PLANTER/PRIME MOVER CONFIGURATION

Date:

Stand: ____________ Compartment: ____________ Prepared by: ____________

PLANTER

Make: ____________ Model: ____________

Operator(s) experience (hr): ____________

PRIME MOVER

Make: ____________ Model: ____________

Year: ____________ Service hours: ____________

Weight: ____________ Operator(s) experience (hr): ____________

Operating gear: ____________ Engine rpm: ____________

Hitch description: ____________

Comments: ____________

Turning radius: ________ ft ____________

BLADE

Make: ____________ Model: ____________ Year: ____________

HYDRAULIC SYSTEM

Hydraulic or PTO connection to tractor ________ gpm ________ ________ psi

On board hydraulics: Pump ________ gpm ________ ________ psi

Hydraulic oil temperature (° F) ________ Where measured? ________

Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Date															
Morning break															
Lunch															
Afternoon break															
End of day															

FUEL CONSUMPTION DATA

Date: ______________________________

Prepared by: ____________________________

Machine planter or prime mover	Date	Fuel added (gal)	% operating time since last fill-up or tree planting