A Highly Efficient Machine Planting System for Forestry Research Plantations—The Wright-MSU Method

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Abstract

For forestry research purposes, grid planting with uniform tree spacing is superior to planting with nonuniform spacing because it controls density across the plantation and facilitates accurate repeat measurements. The ability to cross-check tree positions in a grid-type plantation avoids problems associated with dead or missing trees and increases the efficiency and accuracy of data collection. Such features are particularly beneficial for long-term research plantations. The time and effort required to achieve an accurate grid plantation can be substantial, however, especially in large plantations. This article describes a new, efficient system for machine planting trees on a grid that is useful for a variety of forestry progeny tests—the "Wright-Michigan State University" (W-MSU) method developed by the late Dr. Jonathan Wright and others at Michigan State University. This study compared the W-MSU method with more labor-intensive and common methods of planting trees on a precise grid (direct seeding and planting into augered holes) and found the accuracy of spacing trees was statistically similar among the three methods.

Introduction

Stand density (number of stems per unit area) affects the growth rate and stem form of trees (Jagodzinski and Oleksyn 2009; Jiang and others 2007). Given the importance of stand density for growth and timber form, research designed to evaluate these characteristics should hold spacing consistent across a plantation. Stand density in a plantation is a product of two linear dimensions: row and within-row spacing, and thus, follows a logarithmic, rather than a linear curve. As a result, deviations up or down do not have equal effects on density and tighter spacing increases density more so than wider spacing decreases density (figure 1).

Consistent spacing among rows is essential if mechanized cultural practices such as mowing or band applications of herbicides are planned. Agricultural and orchard systems often specify very precise and tight tolerances for row spacing (± 0.1 in/0.25 cm) so that mechanized operations can be performed without damage to the crop and to enable multiple row operations. Multiple row spraying or cultivation is uncommon in forestry, making such tight tolerances unnecessary. For forestry plantations, typical row spacings range from 6 to 14 ft (1.8 to 4.3 m), and the tolerance can be up to ± 6 to 9 in (15 to 23 cm). Single-row cultural operations consist of strip spraying herbicides and mowing vegetation in the middle of rows with a small tractor.

Within-row spacing is the distance of plants down a row. The regularity of within-row spacing for both agriculture

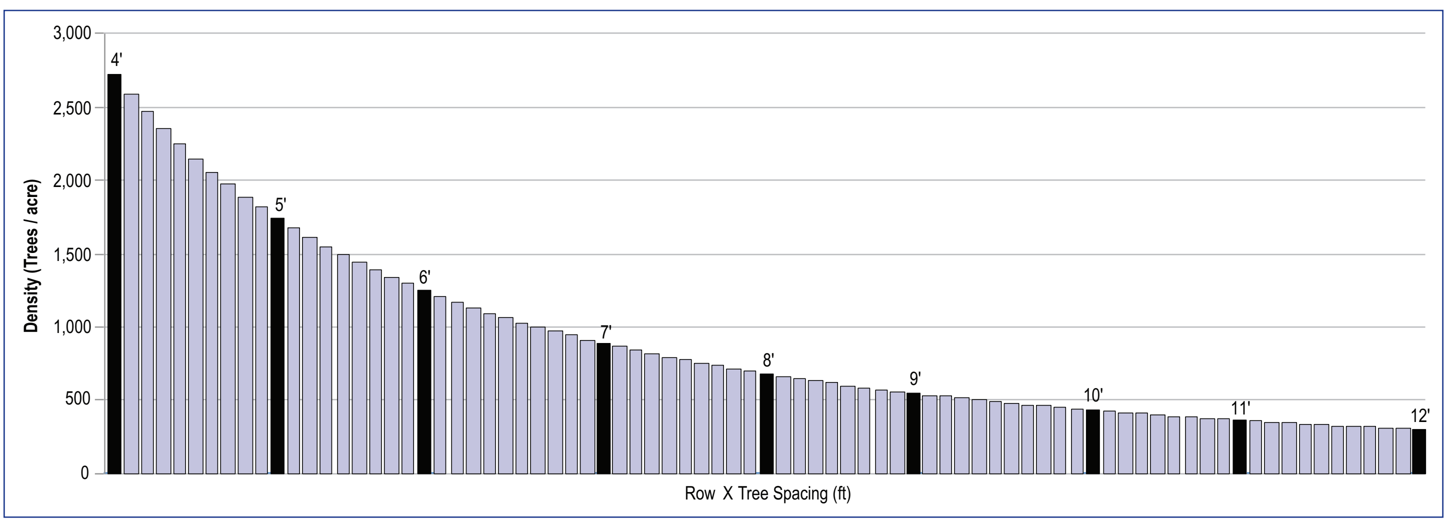

Figure 1. Calculated plantation stand density of a perfect square grid based on deviations of 0.1 ft (3 cm) on overall tree spacing.

and forestry plantings determines overall stand density. The tolerance of within-row spacing in forestry systems is often less critical, however, because cultural operations are rarely conducted between plants. For forestry plantations, consistent within-row spacing is useful to keep competition from neighboring trees constant, and to simplify data collection. Precise grids permit accurate crosschecking of each tree's position with others in neighboring rows and, thereby, reduce errors that may occur when trees die or volunteer seedlings have grown up in rows. Consistent within-row spacing also enables workers to cross mow vegetation if desired.

Site conditions, weather, planting method, and plantation goals determine how tree positions are marked. Uneven terrain and the absence of straight reference lines from which to orient require modest surveying techniques to mark a plantation. Various planting methods exist, each with its own virtue for different stock types, field conditions, and scales. For afforestation research in particular, a robust planting method capable of executing various experimental designs across many site types is needed. The W-MSU machine planting method is described and deviations in intended row and within-row spacing are compared with two common methods used to achieve a precisely spaced grid plantation: direct seeding and planting into augered holes.

Methods

Plantations and Plant Material

Nine progeny test plantations established by the Forest Service Northern Research Station, Hardwood Tree Improvement and Regeneration Center, Purdue University, were used for this study (n = three plantations per planting method). Plantations were located in Indiana and Michigan. Each planting is comprised of half-sib progeny from numerous families. For each of the nine plantations, the experimental design of the progeny test is either a randomized complete block design with 6 to 18 blocks or a randomized incomplete block design with 20 to 30 blocks. Each experimental block is composed of 36 to 64 trees arranged as square as possible, for example 6 rows by 6 trees, 6 rows by 8 trees, etc. Each planting has a 95-percent or better stocking rate, achieved by replanting in the second or third year if needed. Black cherry (*Prunus serotina*), black walnut (*Juglans nigra*), butternut (*J. cinerea*), and northern red oak (*Quercus rubra*) seeds were collected from clone banks or seed orchards at Purdue University or the Indiana Division of Forestry Nursery (INDoF), Vallonia, IN. For trees planted in augered holes and machine-planted trees (W-MSU method), seeds were fall sown at the INDoF. Seedlings (1-0) were lifted while they were dormant with 10 to 12 in (25 to 30 cm) of root and 2 to 5 ft (0.6 to 1.5 m) tall stems. For direct seeding, seed was stratified at Purdue and sprouted before planting in the spring.

Direct Seeding

Two black walnut progeny tests at 8 by 8 ft (2.4 by 2.4 m) and one butternut progeny test at 12 by 6 ft (3.6 by 1.8 m) were direct seeded. Plantation grids were delineated by defining a front and back baseline and marking rows with 18-in (45-cm) wire flag stakes. Within-row tree positions were marked with plastic drinking straws. To protect seed from squirrel predation, 6- by 4-in-diameter (15- by 10-cm-diameter) plastic tubes were buried around each seed. The seed was then planted 2-in (5-cm) deep inside the tube and covered with a 12-in (30.5-cm) square of poultry wire that was secured with two "U" shaped metal rods. Seedlings were allowed to grow through the wire for the first season after which the wire was removed. Weeds were controlled by a combination of hand cultivation and herbicide applications to achieve a 3-ft (0.9-m), weed-free strip down each row. Vegetation in the middle of rows was mowed several times during the season and at the end of the season. A 7.5-ft (2.3-m) plastic mesh fence surrounded the plantings to prevent browse from white tail deer (*Odocoileus virginianus*).

Augered Holes

Two black walnut and one black cherry progeny tests, each at 8 by 8 ft (2.4 by 2.4 m) spacing, were planted using augers. Plantation grids were marked as described above for direct seeding. Planting holes were drilled 16-in (40.6-cm) deep with a 12-in-wide (30.5-cm-wide) auger mounted on the front of a skid steer. Straws, or 6.0 by 0.5 in (15 by 1 cm) wooden stakes if the soil was hard, were used to mark the center point of each tree down each row, and both were painted orange to facilitate the skid steer operator's view. The operator targeted the straws or stakes to drill each hole. Planters typically centered trees in each hole, but occasionally tree positions were adjusted by visually sighting down each row and perpendicular to the row for holes drilled off center. Weeds were controlled by herbicide applications to achieve a 3-ft (0.9-m), weed-free strip down each row. Vegetation in the middle of rows was mowed once or twice during the growing season and at the end of the season. Plantations were fenced to prevent deer browse.

Machine Planting—The W-MSU Method

The W-MSU method requires three people to execute: a tractor operator, a planter, and a tree handler. A fourth person is helpful to check the within-row spacing of trees and replant trees planted too high, too low, or too far from the intended spacing. A Whitfield Model '88-2N' machine planter was used and was pulled by a John Deere 6410 front wheel assist, 100 horsepower tractor. The machine planter has a 26-in (66-cm) coulter wheel followed by a 2-in (5-cm) trencher foot that opens a slit in the ground as the tractor drives forward and two packing wheels behind the unit closes the slit to set the trees.

All three machine-planted (W-MSU method) plantations were planted at 8 by 8 ft (2.4 by 2.4 m) spacing and each was a different species: black cherry, black walnut, and northern red oak. On the baseline of the edge of each planting, each 8-ft-row position was marked with an 18-in wire flag stake (figure 2). Odd rows were marked with pink-colored flags and even rows were marked with white-colored flag stakes. This pattern of alternating colors was maintained across each plantation to aid in navigation. At 160-ft to 200-ft intervals (multiples of 8 ft), a parallel line of flag stakes was repeated. At a minimum, three such lines were marked out so that the tractor operator could use three or more flag stakes to sight on (figure 2).

A secondary method of keeping the tractor straight was to mount a 16-ft (4.8-m) bar on the front of the tractor and hang chains on both sides 8 ft (2.4 m) from center to run along the last planted row of trees. Thus, when the tractor operator and others were sighting the tractor path using the flag stakes, they could also crosscheck the position of the tractor by checking where the chains fell on the previously planted row. The tractor travels at the lowest gear possible at a throttle speed between 1,400 and 1,600 revolutions per minute.

At the time of marking baselines with flag stakes, a third colored flag stake (yellow) was inserted exactly in between tree rows, matching the pattern diagrammed in figure 2. A 200- or 300-ft (60- to 90-m) rope with marks at 8-ft (2.4-m) intervals was strung tight between the yellow flags so that orange painted wooden stakes could be quickly inserted on the center of each mark, with the broad side of each stake parallel to the marking rope. This step was repeated for each line of yellow flags. To save time, three rows of orange stakes were marked and then five rows are skipped before another three rows are marked with orange painted stakes. When completed, the rows of orange stakes provide a straight line-of-sight corresponding to the proper within-row spacing. Because the orange stakes are placed in the middle of the tree rows, they are

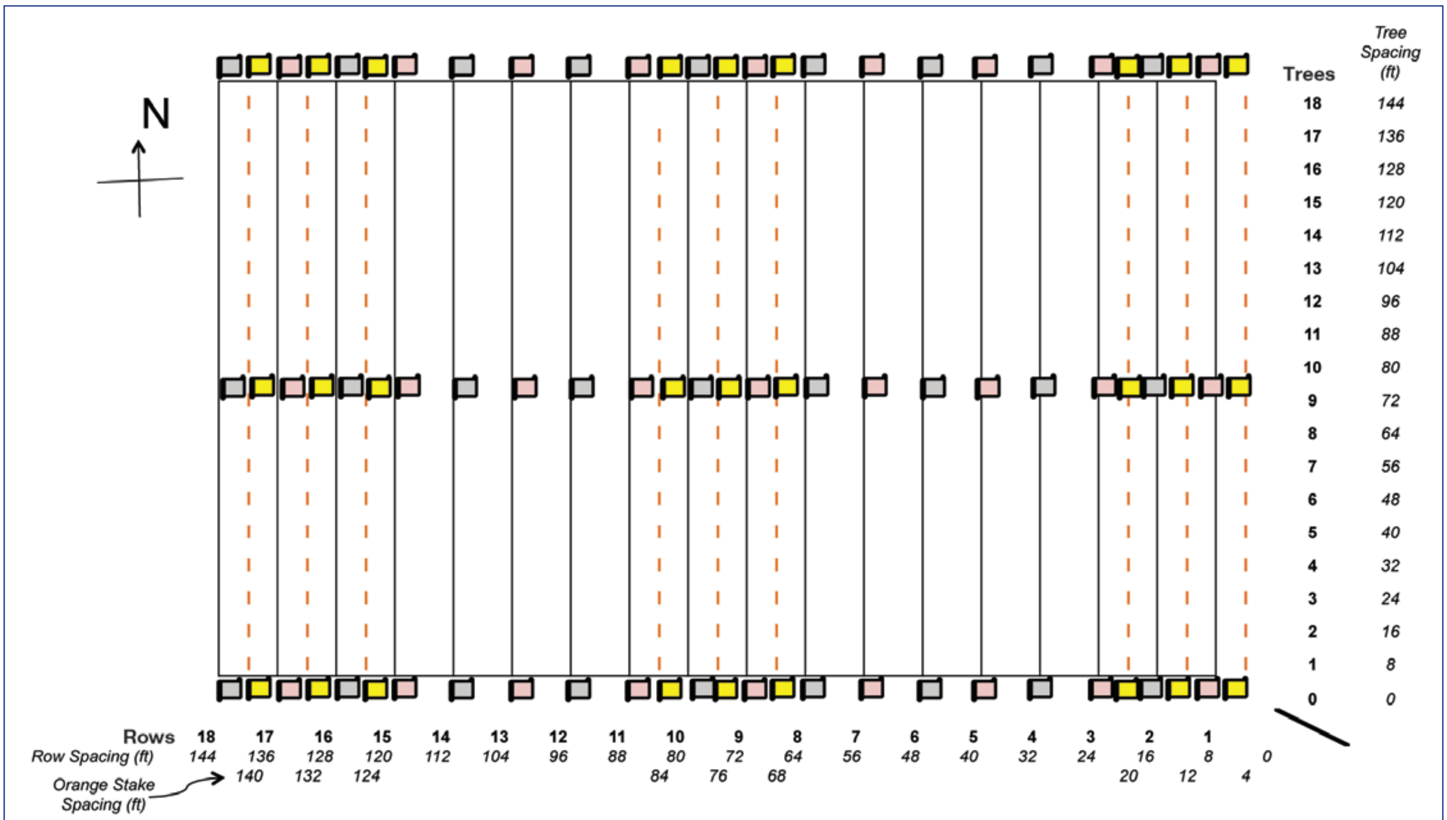

Figure 2. Diagram of the Wright-Michigan State University (W-MSU) method for an 8- by 8-ft plantation containing 324 trees. Three lines of flag stakes on the ends and in the middle of the plantation are baselines the tractor operator will sight on; interior baselines are set at multiples of 8 ft to facilitate marking the orange painted stakes. The orange stakes are positioned in the middle of three rows as indicated; in this example, four rows are skipped and another set of three rows of orange stakes are installed. A string or tape measure is run between the yellow flags on the baseline to mark every 8 ft where the orange stakes are placed.

not run over by the tractor. As the tree planter physically sets trees, they set each one at the point where the orange-painted stakes visually appear as a straight line (figure 3) and all of the lines of orange painted stakes provide a consistent visual reference across the entire plantation. This key aspect of the W-MSU method enables good control of within-row spacing.

The tree handler hands groups of trees to the planter in their proper order according to the experimental design as the tractor travels down the row. Depending on the specific design and personal preferences, the tree handler can ride on the tree planter itself, or walk along on the ground. In all cases, blocks of trees were presorted ahead of planting to contain a prescribed number of families and set number of trees per block. Each replicate block was randomized and bundled so that it was ready to load onto the planter at the time of planting (figure 4).

Figure 3. Orange wooden stakes in alignment for the planter to sight on to set trees at the correct point down the rows (top) and a field after being planted (bottom) (Photo source for both: Forest Service, Northern Research Station).

In every plantation, each block was as square as possible. For instance, in cases where blocks contained 48 trees, they were planted as 6 rows with 8 trees in each row. If 56 trees could fit down each row, 7 blocks could then be planted across 6 rows. Boxes on the planter are numbered 1 through 7. To begin planting, the tree handler grabs 8 trees from box 1 and hands those to the planter and then begins pulling 8 trees from box 2. As the planter plants the 8th tree of block 1, the handler hands the planter the next 8 trees for block 2 and so on. The pattern continues down the row until the 8 trees of block 7 are planted. After the row is complete, the tractor turns around and the handler now reverses the order; i.e., grabbing 8 trees from block 7, then block 6, then block 5, etc. To avoid planting trees from the wrong block, the handler places a single unique flag stake in the box with the correct block to plant and after the 8 trees of that block are pulled, counted, and ready to hand off to the planter—and only then—the flag is moved to the next box to repeat the process. In addition, unique colored flag stakes are placed ahead of planting across the plantation to define block lines; e.g., after every 8 tree and down every 6 rows, so that all members of the crew are able to check block lines and avoid miscounting. After planting, each plantation was fenced to exclude deer, and vegetation was managed as described for augered-hole plantations.

Measuring Deviations

Nine plantations, three planted by each method, were sampled in the winters of 2010 and 2011 for deviations from the intended row and within-row spacing. Trees ranged from 2 to 7 years of age at the time of measurement. An area approximately 4,350 ft^2 (400 m^2) was randomly selected within each plantation and the row and within-row spacing of 44 to 64 trees

Figure 4. Whitfield two-seat planter and black cherry trees sorted out by replicate and genotype ready to load into the boxes on the planter representing the different experimental blocks (Photo source: Forest Service, Northern Research Station).

were measured. A taut string was run down a row approximately 1 ft (0.3 m) from the center of the stems to reference the spacing of adjacent rows and a second string was run perpendicular to reference the within-row spacing of trees down the row. Measuring the ground-line caliper of stems and subtracting one-half of the result determined the center point of each tree. Missing or replanted trees were omitted. These positional data were compared with a geometric model of the intended spacing pattern; the absolute value of deviations for each tree for row spacing, within-row spacing, and overall spacing (i.e., nondirectional) was averaged by plantation. To compare planting methods, deviations were analyzed by one-way analysis of variance using Excel® (Microsoft Corp., 2007) with each plantation as a replicate.

Results and Discussion

No statistical difference in deviation from the intended spacing occurred among any planting method or between rows versus within-rows spacing (figure 5). Instead, variance in spacing for all planting methods was greater between sites, suggesting inconsistent implementation rather than variance in the accuracy of the methods themselves (table 1). The three planting methods analyzed were chosen for their practicality and accuracy to achieve a precise grid. The expectation was that direct seeding (with sprouted seed) would lead to the most precise grid, planting into augured holes would follow, and machine planting by the W-MSU method would be least accurate. Both direct seeding and machine planting were expected to lead to straighter rows compared with augered holes, and visually they do, because the center of the stem can vary in all directions when planting seedlings into a 12-in-diameter (30.5-cm-diameter) hole. The average deviations from intended spacing were similar among planting methods, however, and thus all three planting methods achieve the same plantation density.

The same work crew was not used for each plantation included in this study, nor was a precise record of labor hours kept; thus, only estimates are used to compare the relative efficiencies of each method. Although the time to plant a tree is one measure of efficiency, the amount of energy to plant is a further consideration. Less tangible, but important too, is the planning and site preparation each method requires and any additional post-planting management needs. Progeny tests, by definition, consist of seedlots of known parentage that need to be replicated throughout a plantation. As such, they are inherently time consuming to plant due to the need to keep track of the genetic identity of each tree.

To minimize physical labor, easily establish a precise grid, clearly keep track of genotypes, and minimize variation in initial stock-plant size and condition, direct seeding was assumed to be a good method for progeny testing. In general, three people could plant about 500 sprouted seeds (walnuts or butternuts) per day. The overall reliability and robustness of direct seeding, however, was unpredictable and poor. Walnut

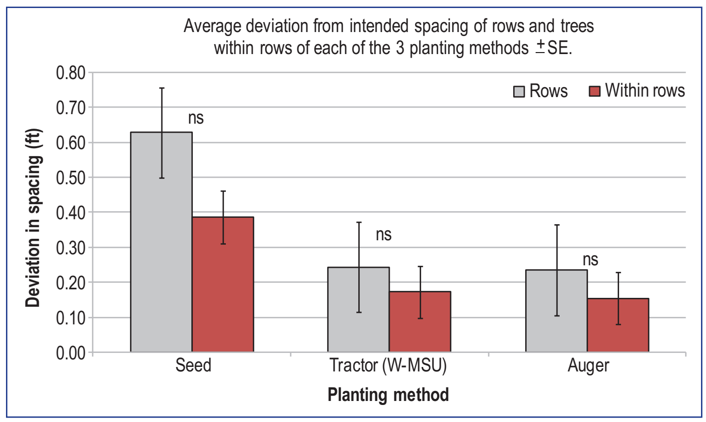

Figure 5. Comparison of the deviations from intended spacing of both row and within-row spacing for each planting method. Values are mean absolute values + standard errors of the mean. No significant differences among planting methods or for row versus within-row spacing were detected by Analysis of Variance (ANOVA).

Table 1. Summary of nine plantations sampled to compare three different planting methods with the deviation in spacing of rows and trees within rows from the intended spacing.

Planting method	Species	Year planted	Plantation location	Number of trees/ plantation	Intended spacing (ft)	Number of trees measured	Rep	Average deviation from intended spacing (ft)	
								Row	Within row
Tractor (W-MSU)	N. red oak	2007	W. Lafayette, IN	1,700	8' x 8'	58	1	0.34	0.33
Tractor (W-MSU)	Black walnut	2008	Grand Rapids, MI	1,450	8' x 8'	64	2	0.17	0.02
Tractor (W-MSU)	Black cherry	2009	Grand Rapids, MI	550	8' x 8'	64	3	0.22	0.16
Seed	Black walnut	2004	Buttlerville, IN	1,200	8' x 8'	60	1	0.45	0.31
Seed	Butternut	2003	W. Lafayette, IN	370	12' x 6'	44	2	1.38	0.76
Seed	Black walnut	2004	Lafayette, IN	450	8' x 8'	60	3	0.05	0.08
Auger	Black walnut	2005	Lafayette-H, IN	1,600	8' x 8'	64	1	0.08	0.14
Auger	Black cherry	2005	Buttlerville, IN	1,200	8' x 8'	60	2	0.19	0.28
Auger	Black walnut	2004	Lafayette-28, IN	1,200	8' x 8'	63	3	0.43	0.05
Total				9,720		537		0.37	0.24

and butternut need to be presprouted because germination rates vary. Sprouting, storing, and transporting sprouted seeds are much more cumbersome than handling dormant 1-0 seedlings to plant. Additional management tasks included planting seed inside "squirrel guards" to limit predation (which could amount to 100 percent if not checked), hand weeding around young seedlings, and additional replanting due to variable success rates (40 to 95 percent), all of which adds additional labor to the method.

Planting into augered holes is a method comparable to planting sprouted seed but, because a dormant 1-0 seedling has already germinated and survived for 1 year in the nursery, seedlings planted into augered holes prove to be more robust and predictable than sprouted seed. The larger problem with planting into augured holes is the physical challenge. Heavy clay soils, compaction, and very wet conditions make it difficult for planters to cover the roots. Workers become tired and trees can be planted poorly. For the three plantations in this study, approximately 12 people were needed to plant between 1,200 and 1,600 trees per day, not counting the skid-steer oper.ator who began drilling holes ahead of the planting crew—sometimes before dawn.

Planting seedlings with a tractor-mounted machine planter is certainly the quickest and physically easiest method for planting 1-0 bareroot dormant trees. The W-MSU method overcomes two principal problems with using tractor-driven tree planters for research plantations: establishing complex experimental designs and achieving consistent within-row spacing to achieve a precise grid. Because of the relative speed with which trees are planted, experimental replicates must be well organized. The Hardwood Tree Improvement and Regeneration Center has used the W-MSU method to establish numerous other progeny tests and silvicultural research plantations with spacings from 8 by 4 ft to 12 by 6 ft consisting of experimental designs with single-tree plots, four- or five-tree row plots, and alternating multiple species. The W-MSU method has proven to be a robust planting method across a wide variety of field sites with different vegetation types, terrain, slopes, and soil types and under various weather conditions. Using the W-MSU method, four workers were able to mark and plant 1,400 to 1,700 trees in 1 day with relative physical ease, making the method the most efficient by far for establishing high-quality plantations accurately and safely.

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