ECONOMIC COMPARISONS OF CLUSTER AND GRID PLANTING METHODS

William H. Emmingham and James A. Entry

INTRODUCTION

Rapid, successful reforestation is the first essential step in a forest management program. Increasing environmental awareness by the public places greater emphasis on successful reforestation practices (Lavender 1979). The accepted method of regeneration in even-aged management has been to clearcut and plant seedlings in a regular grid pattern. Excess seedlings are often planted to prevent spacing gaps of merchantable trees at harvest age. Excess planted trees that survive must be removed so that they do not compete with crop trees for moisture, nutrients and light. Trees that are removed in precommercial and commercial thinning operations either cost money or produce very little financial return. Commercial thinning operations often reduce future profits through mechanical damage of crop trees from felling and yarding operations. Further profit losses may result from insect or disease invasion of crop trees, especially if thinnings are not carried out in a timely manner.

In this paper we explore the concept of cluster planting and develop a system for calculating cluster planting density. Planting seedlings in a loose cluster pattern at crop tree spacing could help assure that the future stand would have as many crop trees as possible while reducing the need for and/or the cost of thinning. We developed this strategy because of the fact that final harvest produces by far the greatest financial return of all forestry operations. Planting trees in cluster patterns could afford more control over management of competing vegetation and keep thinning costs to a minimum. Preliminary data suggest that planting trees in cluster patterns improves tree growth and form, decreases browsing intensity, and substantially reduces planting and thinning costs compared to planting in the conventional grid pattern (Emmingham unpublished data).

Planting seedlings in a cluster pattern would in some cases reduce planting costs by reducing the number of seedlings planted per unit area. Table 1 presents a comparison of the number of trees planted per acre of ground with a grid planting pattern and a cluster planting pattern. An attractive final tree spacing at harvest for coastal Douglas-fir is 17' x 17' (5.2 m x 5.2 m) or about 150 trees/acre (T/A). If a site has a low rate of seedling survival, one could plant three seedlings/cluster (3 x 150 = 450 T/A or use the conventional grid planting scheme of 8' x 8' (2.5 m x 2.5 m) or (680 T/A). A primary benefit would be a higher probability of having a crop tree at proper crop tree spacing. Savings would include the cost of collecting seed, growing and planting 230 seedlings/acre, i.e., 68-450. On a site with excellent seedling survival (e.g., 95%), common practice is to plant using a 12' x 12' grid pattern or 300 trees/acre. Following the focus on crop tree spacing, we would plant only one tree at a 17' x 17' spacing, thereby saving half of the seedlings.

The decision between choosing cluster and grid planting methods hinges on the severity of the site and hence the probability of seedling survival. The less favorable the site, the more advantage there is to cluster planting. It also depends on the intensity of management planned for the area; a topic covered later in the discussion. Wood quality arguments will also be discussed.

Table 1.—Comparison of the number of seedlings/acre planted at various grid spacings and at 17 x 17 ft. cluster spacing.

PLANTING METHOD			
Grid		Clusters (at 17 x 17 feet)	
Spacing	Seedlings/ acre	Trees/ Cluster	Seedlings/ acre
8 x 8	680	1	150
12 x 12	300	2	300
14 x 14	200	3	450
17 x 17	150	4	600

PROBABILITY ANALYSIS

The chance of retaining a crop tree from trees planted in a cluster arrangement can be determined by knowing 1) the probability of survival of any one seedling on a particular site and 2) the number of seedlings planted in each cluster. Crop tree retention is most heavily influenced by seedling survival, because the mortality rate after establishment is generally low. We can calculate the probability of having a crop tree at any given crop tree space (CTS). Transformed to a per/hectare basis, the probability calculated for a specific CTS translates to percent of the crop tree space that will have crop trees at final harvest. For example, if three trees were planted in each cluster on an area known to have a 60% survival rate the probability of all trees surviving equals the probability of tree A surviving (P_{a_S}) x the probability of tree B surviving (P_{b_S}) x the probability of tree C surviving (P_{c_S}).

$$P_{S3} = P_{a_S} \times P_{b_S} \times P_{c_S}$$
$$P_{S3} = 0.6 \times 0.6 \times 0.6$$
$$P_{S3} = 0.216$$

The probability that trees a and b survive and tree c dies is

$$P_{S2} = P_{a_S} \times P_{b_S} \times P_{c_d}$$
$$P_S = 0.6 \times 0.6 \times 0.4$$
$$P_S = 0.144$$

Published in proceedings of "Interior Douglas-Fir: The Species and Its Management" held February 27 – March 1, 1990 in Spokane, WA, USA.
Compiled and edited by D.M. Baumgartner and J.E. Lotan, Washington State University Extension, Pullman, WA.
(Bulletin Office, WSU, PO Box 645912, Pullman, WA 99164-5912.) MISC0230. 301 pp.

In like manner, the probability that trees a and c survive and tree b dies

$$P_{s2} = P_{a_s} \times P_{b_d} \times P_{c_s}$$

$$P_{s2} = 0.6 \times 0.4 \times 0.6$$

$$P_{s2} = 0.144$$

The probability that trees b and c survive and tree a dies would also be 0.144.

The probability of any two trees surviving is

$$P_{s2} = P_{a+b_s} + P_{a+c_s} + P_{b+c_s}$$

$$P_{s2} = 0.144 + 0.144 + 0.144$$

$$P_{s2} = 0.432$$

The probability of having two or more trees at a crop tree site is

(0.216 + 0.432 = 0.648) 64.8%

The probability that any one tree survives per cluster is computed using the same process.

The probability that only tree a survives is

$$P_{s1} = P_{a_s} + P_{b_d} \times P_{c_d}$$

$$P_{s1} = 0.6 \times 0.4 \times 0.4$$

$$P_{s1} = 0.096$$

The probability that only tree b or c survives is also 0.096.

The probability of only one tree surviving is

$$P_{s1} = P_{s a_s + b_s - c_d} + P_{a_s + c_s - b_d} + P_{b_s + c_s - a_d}$$

$$P_{s1} = .096 + .096 + .096$$

$$P_{s1} = 0.288$$

The probability of all three seedlings dying is

$$P_{D_d} = P_{a_d} \times P_{b_d} \times P_{c_d}$$

$$P_D = 0.4 \times 0.4 \times 0.4$$

$$P_D = 0.064$$

Thus, the probability that all three seedlings will die and a gap will develop in a canopy is 6.4%.

Similarly, the probability that at least one seedling will survive is 93.6%

$$P_{s3} = P_{s2} + P_{s1} + P_s$$

$$P_s = 0.216 + 0.432 + 0.288$$

$$P_s = 0.936$$

Note that the probability of at least one tree surviving can also be computed by subtraction; i.e., one minus the probability that all three seedlings die.

$$P_s = 1 - P_d$$

OR

$$1 - 0.064 = .936$$

This offers a short cut way of computing the most important probability; the probability of having a crop tree at any specific CTS. The probability that at least one tree survives with a 90, 60 or 30% survival rate with 1-5 trees planted in each cluster is given in Table 2.

Table 2.—Probability that at least one tree survives per cluster given a 90, 60, or 30% survival rate and 1-5 trees/crop tree space.

Survival Rate	Trees/cluster 1	2	3	4	5
90	90.00	99.60	99.90	99.99	99.99
60	60.00	84.00	93.00	97.50	99.00
30	30.00	64.00	78.00	87.00	92.20

GAP ANALYSIS

Our management objective is to maximize the number of final crop trees while minimizing the number of trees planted without developing gaps in crop tree spacing. Often the probability of survival varies over a site. This makes the concept of cluster planting more valid because the lower the probability of survival, the greater the difference between the probability of one tree surviving in a cluster as opposed to a grid pattern (Table 3). The benefit of planting trees in clusters is that as surviving trees mature, they are much more likely to be evenly spaced, reducing competition for light, water and nutrients.

Per acre density of seedlings planted in cluster patterns can be lower than in a grid pattern. The within-clump density is greater, however. We found no literature dealing with clump density and tree competition. Plantations of grid planted trees may suffer periods of competition wherein growth of all trees slows, and self-thinning of the stand is not sufficient for optimum plant growth (Oliver *et al.* 1986; Oliver and Larsen 1990). This might be described as stagnation or "temporary" stagnation before the stand experiences a wave of mortality and survivors slowly recover, building crown and eventually growth rates.

We hypothesize that the competition and self thinning process for trees planted in clumps starts much sooner. Since they begin competition with neighbors when they are smaller,

Published in proceedings of "Interior Douglas-Fir: The Species and Its Management" held February 27 – March 1, 1990 in Spokane, WA, USA.
Compiled and edited by D.M. Baumgartner and J.E. Lotan, Washington State University Extension, Pullman, WA.
(Bulletin Office, WSU, PO Box 645912, Pullman, WA 99164-5912.) MISC0230. 301 pp.

dominance within a clump becomes established earlier, and self-thinning proceeds earlier in the life of the stand. As dominance is established earlier, the land manager can select a crop tree in each cluster where excess trees have survived. Dominant trees established through natural selection or thinning should have less competition until harvest. This is a testable hypothesis. Should the above hypothesis be proven, solution of the best crop tree from each cluster would be simplified.

Timing of precommercial thinning will depend on how close the trees are planted within clusters. Cluster spacing should allow the seedling to grow rapidly until it overtops the most serious competing plants. This suggests that trees planted in a grassy environment could be planted at a close within-cluster spacing, while trees planted in a brushy environment should be planted at a greater within-cluster spacing and precommercially thinned at a later time.

Table 3.—The change in probability (P2-P1) that at least one tree survives in each cluster with 30, 60 and 90% survival rates.

Survival Rate	PROBABILITY P1 1 Tree	P2 2 Trees	P2-P1 Difference
90	90	99	9
60	60	84	24
30	30	64	34

Foresters and, more importantly, planters must be aware of why a seedling survives. There are often important microsite differences between planting sites. So called micro-sites can have more competition from grass or brush, a frost pocket or shading by slash. Cluster planting will not solve all these problems, but it may help. Cluster planting may not be practical when soils are extremely rocky (skeletal) and suitable planting sites are limited. Planters can significantly increase plantation success by identifying favorable planting sites.

Soils containing a high percentage of rock fragments limit the area of root growth and increase root competition for moisture and nutrients (Bloomberg and Reynolds 1982). Grasses draw heavily on soil moisture in the spring and early summer, leaving little moisture for trees in late summer when the grasses go dormant. Trees, however, shade the grass, and reduce its cover, particularly when trees are in a cluster. In essence, a tree may have a better chance of surviving when it is competing with other trees, especially the same or similar species, than it does in competing against grass. Ungulates may browse trees in either grid or cluster plantings. Carlson (1984) reported that trees planted in clusters were browsed less, and less severely than trees planted in a grid pattern.

In other areas where a specific disease is prevalent or insect and/or diseases exist, cluster planting may aid in improving seedling survival. White pine (*Pinus Monticola* Dougl. ex Don) is often the choice for regenerating areas infested with *Armillaria* spp. (Fr ex Fr.) or *Phellinus weirii* (Murr.) Gilb. since it is resistant to both. However, white pine blister rust, *Cronactium ribicola* (Fish.) may be a major consideration in the decision to regenerate with this species. Hungerford *et al.* (1982) reported that thinning increases the incidence and severity of infection by blister rust due to the increased airflow and thus teliospores flowing through the stand. If white pine were planted in a cluster pattern, a likely result would be that airflow and the number of teliospores and thus the incidence of *C. ribicola* would be reduced. Research on this hypothesis has not been performed. However, testing of this and similar ideas, such as planting different species of trees in a cluster pattern in root disease areas, may be warranted.

Planting trees in a cluster pattern may be particularly beneficial on sites where poor survival rates are expected due to drought, brush or wildlife browsing. Several situations where cluster planting would be the method of choice are 1) on steep slopes where intermediate entries are difficult or overly expensive, 2) in areas where access with equipment is low, 3) in situations where planting stock is limited, and 4) in large remote areas where management intensity is expected to be low.

When seedlings are planted in a cluster pattern, vegetation management can be restricted to a smaller area. Herbicides may be applied from a backpack sprayer instead of aerially. Herbicide could be applied directly to a particular plant, reducing risk of runoff and stream contamination. Planting seedlings in a cluster arrangement may make mechanical vegetation control practical. Forest workers would have a better chance of locating clusters in dense brush and avoiding high damage rates experienced in grid planting.

Planting trees in a cluster pattern also could reduce thinning cost. Terlesk and McConchie (1988) found a substantial savings in time and supplies used in thinning and pruning operations when trees were planted in clusters than when they were planted in grid patterns. Trees would be closer together, affording less movement by the thinner. Commercial thinnings could be less costly due to reduced felling and yarding costs owing to added space between trees. The residual stand would most likely experience less mechanical damage than trees planted in a grid pattern. Since the trees are clumped, there is space to fall trees without hitting crop trees. Since clumps are easily identified, thinning instructions or contract specifications can merely specify removal of the poorest tree from each clump. Since planted clump trees will be easier to identify in a stand, in growth of natural regeneration may also be more easily identified and removed if necessary.

When planting trees in cluster patterns, competition among trees will begin much earlier in the life of the stand. Foresters must be aware of when competition among trees becomes detrimental and thinnings should be initiated. In many cases planting trees in patterns may not reduce losses due to insects or diseases. In cases where insect populations or disease are in epidemic stages trees planted in cluster patterns may suffer as much growth loss or mortality as trees planted in grid patterns.

WOOD QUALITY

A primary deterrent to planting in clusters has been that trees may develop poor form and suffer a reduction in wood quality. In some management systems such as pulp wood production, wood quality is not very important. In extensive forestry operations the cost of producing high quality wood may not be

Published in proceedings of "Interior Douglas-Fir: The Species and Its Management" held February 27 – March 1, 1990 in Spokane, WA, USA.
Compiled and edited by D.M. Baumgartner and J.E. Lotan, Washington State University Extension, Pullman, WA.
(Bulletin Office, WSU, PO Box 645912, Pullman, WA 99164-5912.) MISC0230. 301 pp.

justified. Some have argued that foresters should simply grow the cheapest wood possible and let tree breeding or wood technology solve the wood quality issue (Nankoong *et al.* 1969).

There is no doubt that trees in clumps will develop large limbs on the exterior of the clump. Limb size on the interior of the clump will, however, be smaller, partially offsetting the loss of quality on the exterior side. Trees planted in a three-tree clump will probably develop large branches of only a quarter of their circumference. Future studies should focus on crown recession and knot size comparisons in cluster and grid plantations. The use of pruning can reduce the importance of knot size as a wood quality factor. Terlesk and McConchie (1988) tested the idea of planting one tree in the middle of a cluster and do not recommend the practice.

We have evidence that cluster planted coastal variety Douglas-fir do not develop crooked boles (i.e., from leaning) when grown in three-tree clusters up to 30 feet (10 m) in height (Emmingham unpublished data 1990). Stiell (1982) found that when *Pinus resinosa* was thinned to 4 trees/cluster and clusters were 1.68 m apart, the trees developed a lean which could affect wood quality. The strong apical dominance exhibited by most conifers argues against leaning as a serious drawback for cluster planting. Most hardwoods, however, have weak apical dominance and would be unsuited to cluster planting (Zimmerman and Brown 1974). Bormann (1985) found that *Alnus rubra* (Bong.) thinned in a clumpy manner developed severe lean and crooked boles.

SUMMARY POINTS

1. Foresters are usually aware of seedling survival on most sites. If one can estimate seedling survival rates, the number of trees desired in each cluster can be estimated using the methods described in this paper.
2. Planting trees in a loose cluster pattern can lead to a reduction in the number of seedlings to be planted on a site and a reduction in planting costs.
3. Cluster planting offers a way to hedge against gaps in crop tree spacing as the probability of individual tree survival decreases.
4. Planting seedlings in a loose cluster pattern can reduce the cost of thinnings and herbicide or mechanical vegetation control, further reducing the cost of stand management.
5. Cluster planting may offer a way to assure crop tree survival and dominance where planting stock is limited, sites are droughty or brushy, mechanical vegetation control is necessary, and natural regeneration is prolific.

Probability of seedling survival may be quite different than long-term survival of forest trees. Foresters must assure crop tree survival and dominance. Although there has been little research on the efficacy of planting trees in cluster patterns, the possible ecological and economic benefits certainly justify further research.

ACKNOWLEDGEMENTS

The authors would like to thank Dr. Jim Mital, Forest Resources Department, University of Idaho, Moscow, Idaho; Monica Spicker, Spokane Community College, Spokane, Washington and other participants in the symposium, Douglas-fir: The Species and Its Management, for their valuable suggestions and comments.

LITERATURE CITED

Bloomberg, W. J. and G. Reynolds. 1982. Factors affecting the transfer and spread of *Phellinus weirii mycelium* in roots of second growth Douglas-fir. Can. J. For. Res. 12:424-427.

Bormann, B. T. 1985. Early wide spacing in red alder (*Alnus rubra* Bong.): Effects on stem form and stem growth. USDA Forest Service Research Note PNW-423. 7 pp.

Carlson, D. H. 1987. Effects of grazing management and tree planting pattern in a young Douglas-fir agroforest. M.S. Thesis. Oregon State Univ. 168 pp.

Hungerford, R. D., R. E. Williams, and M. A. Marsden. 1982. Thinning pruning western white pine: a potential for reducing mortality due to blister rust. Research Note INT-322. Ogden, UT: USDA Forest Service, Intermountain Forest and Range Exp. Sta.

Lavender, D. P. 1982. Seeds, cone collection, processing and storage. *In:* Cleary, B. D., R. D. Greaves, and R. K. Herman, eds. Regenerating Oregon's forests: a guide for the regeneration forester. 283 pp.

Nankoong, G., A. C. Barefoot, and R. G. Hitchings. 1969. Evaluating control of wood quality through breeding. Tappi 52(10):1935-1938.

Oliver, C. D. and B. C. Larsen. 1990. Forest Stand Dynamics. McGraw Hill. New York. In press.

Oliver, C. D., K. L. O'Hara, G. McFadden, and I. Nagame. 1986. Concepts of thinning regimes. *In:* C. D. Oliver, D. P. Hanley, and J. A. Johnson, eds. Douglas-fir: Stand management for the future. Univ. of Washington, College of Forest Resources, Institute of Forest Resources. Contribution #55, p. 246-257.

Stiell, W. W. 1982. Growth of clumped vs. equally spaced trees. For. Chron. 58(2):23-25.

Terlesk, C. J. and M. McConchie. 1988. Stand reorganization: Results from the trials at Hautu Forest, New Zealand. New Zealand J. For. Sci. 18(3):329-344.

Zimmermann, M. H. and C. L. Brown. 1974. Trees: Structure and Function. Springer-Verlag. New York. 336 pp.

Authors

William Emmingham
Forest Science Department
Oregon State University
Corvallis, OR 97331

James Entry
Forest Science Department
Oregon State University
Corvallis, OR 97331

Published in proceedings of "Interior Douglas-Fir: The Species and Its Management" held February 27 – March 1, 1990 in Spokane, WA, USA.
Compiled and edited by D.M. Baumgartner and J.E. Lotan, Washington State University Extension, Pullman, WA.
(Bulletin Office, WSU, PO Box 645912, Pullman, WA 99164-5912.) MISC0230. 301 pp.