

## Wide-Space Planting: How to Make it Work

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Abstract: My preceding report "Density Trajectory For The Fastest Growth" shows how to maximize financial returns from the most valuable final harvest of forest plantations: keep the number of trees constant throughout rotation. Given the diminishing demand for small-size timber produced by what used to be called commercial thinning, final harvest is often the only source of income. Controlling stand density by initial spacing alone means wide distance between rows of planted trees—up to 12 m. Along with many advantages, such distances create formidable problems for growing trees: establishment mortality, inability to select better trees, competition from undesirable vegetation, and poor wood quality. To overcome these problems, it is proposed to plant trees in clusters, use the alleys between tree rows for agriculture, and prune the trees. Clusters allow us to select better trees, eliminate (or at least drastically reduce) the disruption of stand structure caused by mortality and assure the needed number of crop trees. Instead of struggling with the competing vegetation, we put to agricultural use the portion of land unutilized by pines until they close their crowns. Thus, the minimum number-maximum yield strategy leads naturally to diversified land use: agroforestry. The space between pine rows can be used to grow forage or any crop (wheat, oats, soybeans) that does not compete with trees for light. When trees reach the cow-resistant height (3-4 m), grazing can be permitted. Combining the two most common kinds of land management, forestry and agriculture, is attractive for a variety of ecological, economic, and personal reasons. Traditionally, foresters improved wood quality by keeping high stand density. Unfortunately, such density kills many trees and slows the growth of the rest. Pruning is a better way to improve stem form and wood quality than choking trees with density. Pruning improves wood quality physically by cutting off branches, and physiologically by removing of the apical meristem of branches (which stimulates the production of juvenile wood) and forcing trees to grow taller, which moves the crown apical meristems further from the lower bole. Pruning also makes the pruned portion less tapered, though it increases the size of knots above the pruned area. Two prunings are recommended. The first clears 50 percent of the bole when trees reach the height of about 5.5 m. The second pruning, done when trees are 8.6 m high, clears 60 percent of the bole (one sawlog of 5.2 m). The described system not only increases financial returns but maximizes them. On good sites (site index >20, base age 25 years) the system doubles sustainable returns as compared with regular forestry or agriculture practiced separately.

Keywords: agroforestry, financial returns, initial spacing, pruning, stand density control, thinning, wood quality.

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## GROWING TREES WITHOUT THINNING

There are many ways to design a management system utilizing the minimax strategy and compensating for its shortcomings. Whereas the growth and management reasoning behind minimax is applicable everywhere, its implementation is conditioned by specific environmental and economic realities. Reported below is such a management system tailored to the most successful species in the southeastern United States, loblolly pine. For this species and this area, it is proposed to plant trees in clusters, grow them in single widely-spaced rows, use the alleys between the rows for agriculture, and prune the trees.

### Agroforestry

Growing only the trees we intend to harvest (250-450 per hectare) means that at the beginning only a small portion of the land is occupied by trees. If the rest is allowed to overgrow with competing vegetation, we will not get much yield. But controlling competition (especially with chemicals) is expensive and not always environmentally friendly. Instead of struggling with the competing vegetation we can put to agricultural use the portion of land unutilized by pines until they close their crowns. Thus, the minimum number-maximum yield strategy leads to diversified land use: agroforestry (Zeide 1998, 2003). It is a natural extension of forestry; optimal forestry is agroforestry.

The space between pine rows can be used to grow forage or any crop (wheat, oats, soybeans, for example) that does not compete with trees for light. When trees reach the cow-resistant height (3-4 m), grazing can be permitted. As trees become larger, agricultural activities are phased out and no income is expected from stands with density index higher than 300 (basal area > 14 m<sup>2</sup>/ha). Combining the two most common kinds of land management, forestry and agriculture, is attractive for a variety of ecological, economic, and personal reasons. Root systems of established trees are deeper than those of agricultural species. This fact minimizes competition for soil nutrients and moisture, and allows for fuller land utilization (Clason 1999). The following benefits of agroforestry are compatible; indeed, they complement each other.

For trees. Minimal cost of establishment; control of undesirable vegetation; natural and artificial fertilization, which come as byproducts of agricultural use; stand density that maximizes growth of trees (low at the beginning and high at the end); accessibility for pruning and harvesting; reduced damage from ice, root rot, and wildfire.

For agricultural crops and cattle. Land for cultivation or grazing; shade for animals; wind shelter for cattle and crops. The microclimate of agroforests is favorable to both plants and animals. It is characterized by higher soil moisture, humidity and night-time carbon dioxide levels, and lower evaporation that result in reduced respiration rates.

For the land. When tree rows are planted along the contour, erosion is minimized. Cattle manure increases soil fertility.

For landowners. Increased utilization of the land potential and the mutualistic nature of the agricultural and forest uses mean higher income as compared with growing trees and agricultural

crops separately. Risk is spread over a number of crops and cash flow is more stable. While the returns from the forestry component will materialize at the end of rotation, the agricultural components will provide most of their returns during the initial period. These returns may more than compensate for the vanishing income from thinning. Agroforestry also fits the human life cycle. As individuals become older, they prefer less strenuous activities such as timber management. If a farmer switches to agroforestry in his middle years, then this transition will occur gradually.

### Row and cluster planting

In traditional plantations, trees are located at equal distance from each other. When stands are thinned, again we try to provide equal opportunity for each tree by maintaining regular spacing. To make coexistence of trees with annual plants productive calls for more diverse spatial patterns than simple uniformity. To share light and other resources with crops, facilitate agricultural operations, and accelerate height growth of trees, trees are planted in single rows, 10-12 m apart. Equal exposure from both sides makes tree crowns bilaterally symmetrical, which minimizes ice damage, a common problem in the loblolly pine region. The distance between trees within a row is 2-3 m.

Another difference with traditional homogeneity is planting trees in clusters. The clusters tested on the agroforestry study established in 1997-1998 by our School near Hope, Arkansas, consist of 4 loblolly pine seedlings planted at the corners of a square with sides of 30 cm. All but one tree per cluster are thinned by age 5. Clusters allow us to select better trees, eliminate (or at least drastically reduce) the disruption of stand structure caused by mortality, promote initial height growth, improve stem form with minimal reduction of final harvest, and assure the needed number of crop trees. If the imprinting of low initial density will result in undesirable consequences for tree form and growth, various cluster designs could be tested to mitigate this hypothetical effect.

### Pruning

Usually, wood quality is improved by keeping high stand density. Unfortunately, such density kills many trees and slows the growth of the rest. Traditional forestry resolved the conflict between the quantity and quality of volume growth by maintaining a stationary medium level of density. To utilize the minimax strategy, instead of choking trees with density, it is proposed to prune them. Pruning improves wood quality physically (by cutting off branches) and physiologically (by removing of the apical meristem of branches responsible for the production of juvenile wood). As a result, trees are forced to grow taller, which moves the crown apical meristems further from the lower bole, thus preventing the formation of juvenile wood. Pruning also makes the sawlog portion less tapered, though it increases the size of knots above the pruned area. Two prunings are recommended. The first clears 50 percent of the bole when trees reach the height of about 5.5 m. The second pruning, done when trees are 8.6 m high, clears 60 percent of the bole (one sawlog of 5.2 m).

### Rectangularity

It is sufficient to look at the edge of any forest stand to realize that the danger of rectangularity (within row distance to between row distance) emphasized by West (2006) is imaginary. Even when surrounded from three sides, edge trees are substantially larger than trees in middle of a stand. Tree crowns and roots are very flexible and tend to utilize most of the available land. In the stands of Scots pine (*Pinus sylvestris* L.) in Finland studied by Salminen and Varmola (1993) rectangularity varied from 1:1 to 1:6.3. These authors found no effect of rectangularity on mean height, diameter, basal area, or volume per unit area. Similar results were published by Gerrand and Neilsen (2000) for *Eucalyptus nitens* and Sharma, Burkhart, and Amateis (2002) for loblolly pine. Rectangularity usually affects the size of branches facing adjacent rows (Niemisto 1995) but not stem growth. Sequeira and Gholz (1991) indeed found growth reduction but much smaller than follows from West's (2006) generalization. They reported that in slash pine (*Pinus elliottii*) stands rectangularity of 1:6 reduced volume per hectare from 220 to 184 m<sup>3</sup>, average diameter from 18.3 to 16.6 cm. Average height slightly increased from 13.9 to 14.6 m. On the whole, it appears that rectangularity up to 1:6 has little effect on tree and stand growth. Still, to be on the conservative side, the estimates of volume growth were reduced by 10% to account for various negative factors, including the effect of rectangularity.

## ECONOMIC ANALYSIS

Having the ability to predict stand growth and the knowledge of operations that increase the growth, we are in position to "grow" the virtual stand from year to year and find the number of trees and age, at which profit reaches maximum. The growth-density model allows us to predict diameter increment of an average tree and accumulate diameter itself. Average height and volume can be produced in the same manner. These variables can also be found from their allometric relationships with diameter. Multiplying the returns by a number of trees and subtracting costs, all compounded to the initial age, we obtain the net present value (*NPV*) as the sum of field and stand costs and revenues by a certain age. To compare the agroforestry returns with those from annual crops, it is convenient to calculate the equal annual income, which combines all costs and returns into a single annual sum:

$$EAI = NPV \frac{i(1+i)^t}{(1+i)^t - 1}$$

where *i* is the interest rate and *t* is age. Repeating these calculations for various numbers of trees and ages, we can find the number and rotation age corresponding to the maximum of *EAI*.

### Assumptions

Economic analysis of the proposed system is based on the following assumptions typical for the loblolly pine region:

1. Agroforests are established in existing pastures, which belong to the landowners and no land rent is paid.
2. The initial annual net returns from the portion of land used by agriculture are \$124 per hectare (Husak and Grado 2002). Intensively managed forests of loblolly pine provide similar returns. Below this level, agroforestry becomes unprofitable.

3. The subsequent returns from for agriculture decrease as trees become larger. When stand density reaches 300 (basal area is about  $14 \text{ m}^2/\text{ha}$ ) agricultural use stops completely.
4. The cost of planting per seedling, including seedling cost, is \$0.12.
5. The costs of first and second prunings are \$0.40 and \$0.60 per tree, respectively. Pruning increases the price for the first log by 20%.
6. Other costs include ground preparation (ripping-discing-spraying), weed control during the first two years, and cluster thinning.
7. All costs and returns are discounted to age = 0 with 6% interest rate ( $i = 0.06$ ).
8. Although fertilization applied to the agricultural portion of the land is likely to boost tree growth, this effect is not taken into account because its magnitude is unknown.
9. Stumpage price for sawlogs (with diameter > 19.3 cm inside bark at the end of the first log) is \$36 per ton; for pulpwood (small end diameter >9.1 cm) is \$8 per ton.
10. Annual revenue from hunting lease is \$12.4 per hectare (because hunting is not compatible with grazing, this income is applied in 50% of all cases).
11. Annual property tax is \$7.4 per hectare .
12. Post-establishment mortality, rectangularity, and hazards reduce income by 10%.

### Biological and financial yield of optimal agroforests

The results of the growth and economic analysis can be summarized in the yield and income tables for optimal agroforests (Table 1). For many years, yield tables have been a major tool of forestry. They present information on the biological side of forestry (average height and diameter of trees, number of trees, stand volume and growth) by site class and sometimes by thinning level. As traditional forestry in general, yield tables ignore the financial side of management. The developed tables contain information on tree growth, stand density, costs, and returns for forestry and agricultural components.

### Minimax and thinning

Thinning has been an integral part of forest management since its origin and the loss of income from thinning could be a serious shortcoming of minimax if it is not compensated by the income from final harvest and agricultural use. Any deviation from minimax (such as intermediate thinning) decrease returns. When a model incorporating the growth equations and economic assumptions described above was run for various thinning regimes, site indices, and planted number of trees, it was found that for site index 20.4 (base age is 25 years), maximum returns of \$237 (expressed as the equal annual income per hectare) can be obtained by planting 400 trees and harvesting them at age 24. If at the age of 15, half of these trees are thinned and sold as pulpwood while the remaining trees are grown for sawlogs, maximum returns (at age 25) drop to \$170. The diameter jump caused by the removal of smaller trees during thinning was incorporated into these calculations. With thinning, the optimal planting number is 700. When half of these trees are thinned for pulpwood and the rest is kept until 26 years, the income reaches the maximum of \$177, which is 25% smaller than the minimax returns of \$237. Even when intermediate harvest can be sold, this test supports the minimax strategy: grow only the trees intended for final harvest.

Table 1. Yield and income table for optimal agroforests with site index 20.4 (base age is 25 years) and number of trees 400. Values at the optimal rotation age are underlined.

Age	D	H	Weight		Basal area	SDI	Total cost	Returns		NPV	EAI
			total	sawlog				field	stand		
5	5.1	5.2	2.3	0.0	1	33	276	560	0	321	68.5
6	7.0	6.3	5.2	0.0	2	53	394	626	0	273	50.0
7	8.9	7.5	9.9	0.0	2	78	399	686	46	379	61.1
8	10.8	8.6	16.8	0.0	4	106	554	736	78	309	44.8
9	12.8	9.6	26.2	0.0	5	138	558	776	118	389	51.4
10	14.8	10.6	38.3	0.0	7	172	563	806	166	465	56.9
11	16.6	11.5	52.7	0.0	9	206	566	827	217	537	61.3
12	18.3	12.4	69.1	0.0	11	240	570	840	270	602	64.7
13	19.9	13.2	87.0	0.0	12	273	574	847	322	661	67.2
14	21.3	14.1	106.3	0.1	14	304	577	848	373	712	68.9
15	22.6	14.8	126.7	7.8	16	334	580	848	521	860	79.7
16	23.9	15.5	147.8	28.6	18	363	583	848	817	1155	102.9
17	25.0	16.2	169.5	61.9	20	391	586	848	1226	1564	134.3
18	26.1	16.8	191.5	103.9	21	417	588	848	1683	2020	167.9
19	27.1	17.4	213.8	143.9	23	441	591	848	2065	2402	193.7
20	28.0	18.0	236.2	181.0	25	465	593	848	2369	2706	212.3
21	28.8	18.5	258.5	214.9	26	487	595	848	2603	2939	224.9
22	29.6	19.1	280.8	245.9	28	508	597	848	2777	3112	232.6
23	30.4	19.5	302.9	273.9	29	528	599	848	2897	3233	236.5
24	31.1	20.0	324.7	299.1	30	547	601	848	2974	3309	237.3
25	31.7	20.4	346.2	321.8	32	565	603	848	3013	3347	235.7
26	32.3	20.9	367.5	343.0	33	583	604	848	3027	3361	232.7
27	32.9	21.3	388.3	363.9	34	599	606	848	3027	3361	229.0
28	33.5	21.6	408.8	384.4	35	615	607	848	3014	3348	224.8
29	34.0	22.0	428.9	404.5	36	629	609	848	2990	3324	220.1
30	34.5	22.3	448.6	424.2	37	643	610	848	2957	3290	215.1
31	34.9	22.7	467.8	443.4	38	657	611	848	2915	3248	209.9
32	35.4	23.0	486.7	462.2	39	670	612	848	2865	3198	204.4
33	35.8	23.3	505.1	480.6	40	682	613	848	2810	3143	198.8
34	36.2	23.6	523.0	498.6	41	694	614	848	2749	3081	193.0
35	36.6	23.9	540.6	516.1	42	705	615	848	2683	3016	187.2

- N – number of trees per hectare
- D – average tree diameter, centimeters
- H – average tree height, meters
- Weight total – sum of sawtimber, pulpwood, and topwood weights, ton/ha
- Weight sawlog – weight of sawtimber, ton/ha
- Basal area – m<sup>2</sup>/ha
- SDI – stand density index
- Total cost – sum of costs for forestry operations, including tax, \$/ha
- Returns: field – accumulated net returns from agricultural use, \$/ha
- Returns: stand – current net returns from pulpwood, sawtimber, and hunting lease, \$/ha
- NPV – net present value, \$/ha
- EAI – equivalent annual income, \$/ha.

### The bottom line

The constructed yield and income tables allow us to find the optimal number of harvested trees and rotation age by site index (Table 2). Profit increases with site quality; whereas on poor sites (with site index less than 17) agroforestry is unprofitable ( $EAI < \$124$ ), it may more than double the average income of \$124 on good sites as compared with regular forestry or agriculture practiced separately. Optimal number of trees also increases with site quality but diameter at the age of optimal rotation remains nearly constant (30 cm). At this diameter all trees reach

merchantable size. By the time of harvest, density (547, Table 1) is only half as high as the maximum of 1112 (Reineke 1933).

The described system not only increases financial returns but maximizes them by:

1. Optimization of stand density throughout the rotation.
2. Optimization of rotation period.
3. Diversification of land use by compatible species.
4. Improving quality of merchantable wood by cluster planting and pruning.
5. Reduction of expenses on planting and thinning.
6. Minimization of root rot, insect infestation, and other risks associated with high density, which would be maintained only during a relatively short period before harvest.
7. Growing sturdy well-spaced trees with symmetrical crowns which reduces ice damage and other hazards.

Table 2. Optimal rotation and number of trees by site index (meters at 25 years).

Site index	Age	N	D	Returns			Equal annual income		
				pulp	sawlog	total	field	stand	total
15	33	173	29.5	119	3610	3731	87	19	106
17	29	247	30.5	135	6121	6254	78	55	132
18	27	346	30.5	184	9318	9503	66	104	170
20	25	420	30.5	233	11671	11903	60	158	218
21	23	445	30.7	228	13106	13334	58	214	272

Variables and units are the same as in Table 1.

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