Forest Research Group

Forest Research Notes

Volume 8, Number 2

Second Quarter, 2011

How Trees Grow

Trees Do Not Grow at a Constant Rate

Foresters use words in their discussions about tree growth that may mislead investors.

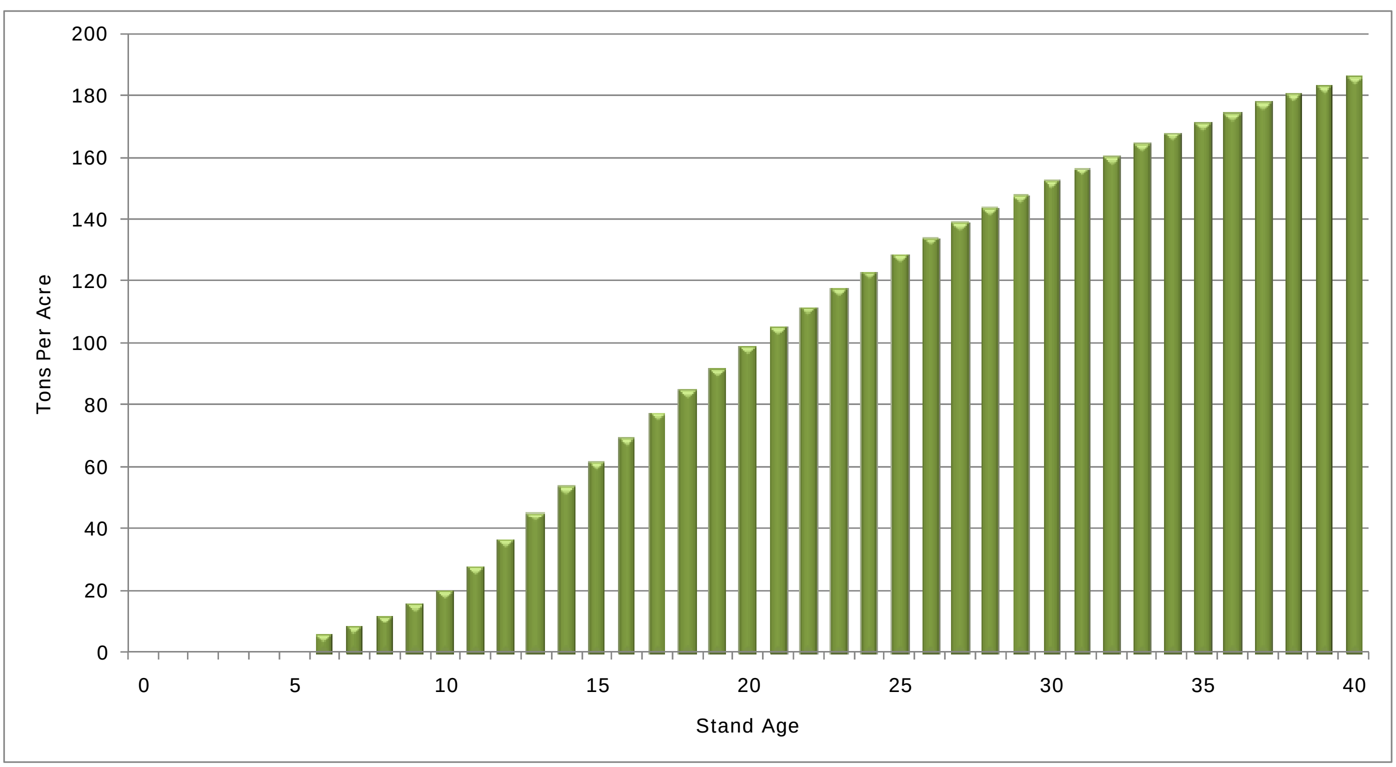
Foresters often talk about a growth rate using phrases like "*40 cubic meters per hectare per year*", or "*5 tons per acre per year*". This is usually referred to as the *mean annual increment* or MAI. This may lead people to assume that this is an annual growth rate--that a stand will add 5 tons/acre/year, year after year.

But trees don't grow that way.

Trees grow in an "s"-shaped or *sigmoid* curve. Figure 1 shows such a yield curve for merchantable volume of a southern pine stand. (This curve was developed by averaging several proprietary yield curves--note that no thinnings are applied to this stand.) The shapes and slopes of curves differ from species to species and from location to location and by site quality for a species, but they are all sigmoid curves.

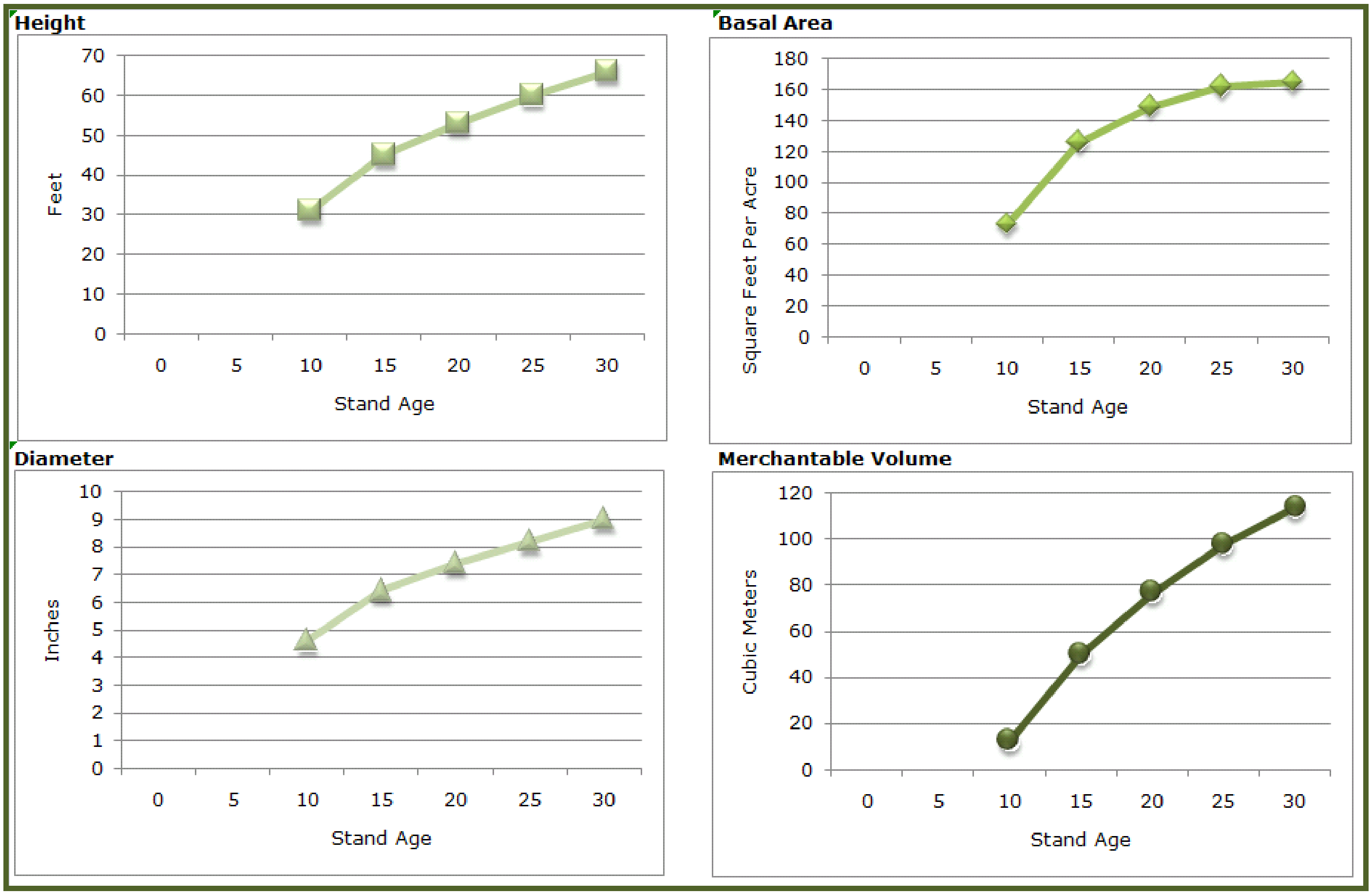
There is no constant growth rate here in Figure 1 (e.g., 5 tons per acre per year), nor is there a constant percentage growth (e.g., 8 percent per year).

Figure 1. Merchantable Volume (Yield) Curve for Loblolly Pine, Hypothetical Stand



Source: Forest Research Group

Figure 2. Height, Basal Area, Diameter and Merchantable Volume Curves for Loblolly Pine, West Gulf Region



Source: Wenger, 1984

Curves for diameter, height, basal area[1] and volume (both total and merchantable volumes) are all sigmoid curves. Figure 2 shows four curves for loblolly pine from unthinned plantations on previously harvested sites in the West Gulf Region of the US South. All four curves show part of a typical sigmoid shape. (The left-hand sides of the curves are missing because the data were collected for trees 5 inches DBH[2] and larger--data was simply not collected for smaller trees.)

For some species, it takes years of data to see the curves. For example, Wenger (1984) includes data for ponderosa pine that shows the diameter MAI still increasing after 200 years.

Calculating the MAI

The MAI is calculated by dividing the total volume (or height or other characteristic being measured) by the age of the stand.

Table 1 shows the annual volume growth or a*nnual increment* and the MAI for the stand in Figure 1. The annual increment is simply the growth in each year. Note that the annual increment varies with age, which means the MAI will also vary with age.

The annual increment rises much more quickly than the MAI. The relationship between the two is more clearly shown in Figure 3. Note that the annual increment peaks early in the life of the stand.

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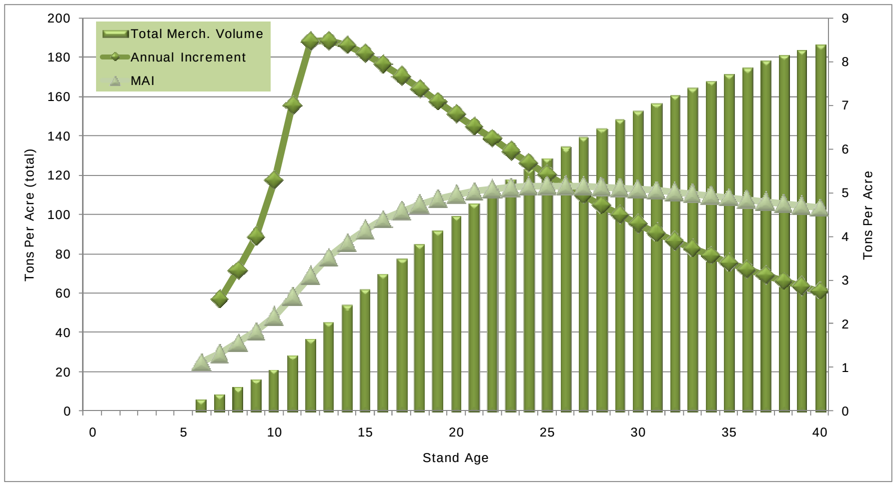
[1] Basal area is a means of expressing the density of a stand.
[2] DBH is diameter at breast height--4.5 feet or 1.37 meters above the ground.

Table 1. Annual Increment Calculations

Age	Total Merch. Volume	Annual Increment	MAI
0	0		
1	0		
2	0		
3	0		
4	0		
5	0		
6	7		1.11
7	9	2.55	1.32
8	12	3.22	1.56
9	16	4.00	1.83
10	22	5.28	2.17
11	29	7.00	2.61
12	37	8.46	3.10
13	46	8.48	3.51
14	54	8.37	3.86
15	62	8.18	4.15
16	70	7.94	4.38
17	78	7.67	4.58
18	85	7.38	4.73
19	92	7.09	4.86
20	99	6.80	4.95
21	106	6.51	5.03
22	112	6.23	5.08
23	118	5.95	5.12
24	123	5.68	5.14
25	129	5.43	5.16
26	134	5.18	5.16
27	139	4.94	5.15
28	144	4.71	5.13
29	148	4.49	5.11
30	153	4.29	5.08
31	157	4.09	5.05
32	161	3.90	5.02
33	164	3.73	4.98
34	168	3.56	4.93
35	171	3.40	4.89
36	174	3.25	4.85
37	178	3.11	4.80
38	181	2.98	4.75
39	183	2.85	4.70
40	186	2.74	4.65

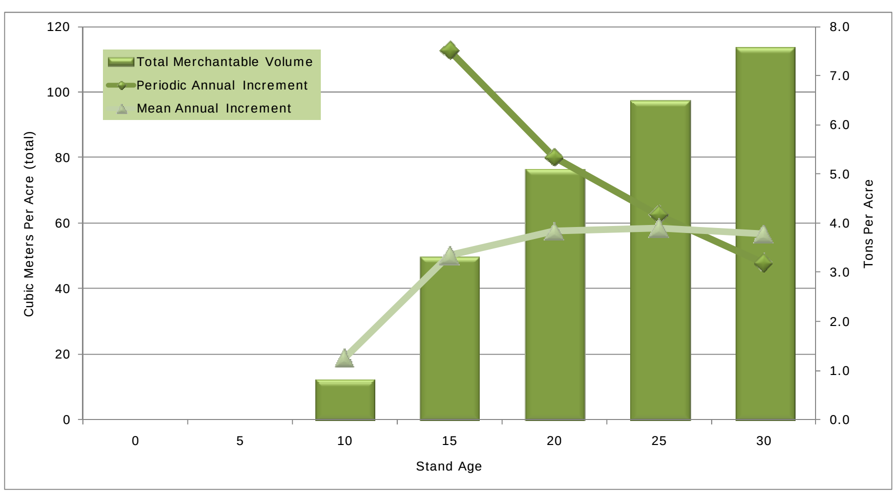
Figure 3. Loblolly Pine, Hypothetical Stand



The annual increment and MAI eventually cross, in this case at age 26, and the MAI begins to decline after this age. Foresters call this the *biological rotation age* because this is the age at which the stand would be harvested if the objective is to maximize long-term wood production. This is *not necessarily* the age at which the stand would be harvested if the objective is to maximize financial returns--*that* age depends on the mix of products produced (e.g., sawtimber vs. pulpwood) and the market prices for those products.

Data are often reported in 10-year intervals rather than annually, especially for long-lived species. In these cases, the change from one period to the next is called the *periodic annual increment* or PAI. The PAI is the average growth rate over the age-class interval. Figure 4 shows the PAI and MAI curves for the merchantable volume curve in Figure 2. Here the biological rotation age is somewhere between 25 and 30 years but the 10-year data do not allow us to be more precise than that.

Figure 4. Loblolly Pine, West Gulf Region

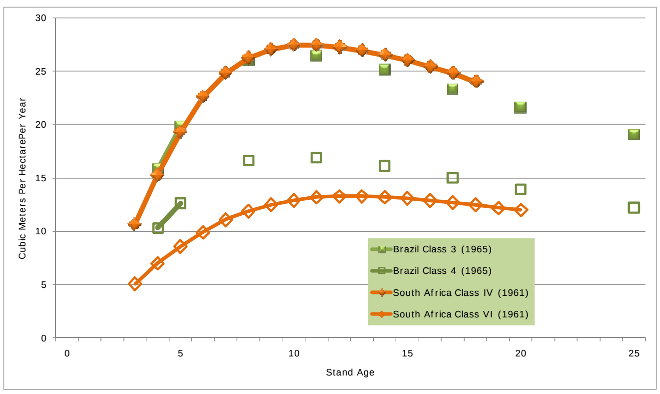


In the case of the hypothetical stand (Figure 1), the MAI at Age 26 is just over 5 tons/acre/year. Harvesting the stand at that age would yield 5.16 tons/acre/year X 26 years = 134 tons/acre. Harvesting the stand at Age 15 would *not* yield 77 tons/acre (5.16 tons/acre/year X 15 years), because the MAI at Age 15 is only 4.15 tons/acre/year.[3]

Other Regions

Figure 5 shows volume MAI curves for eucalyptus in Brazil and South Africa. The site classes shown were reported as the most common site classes in the study regions.

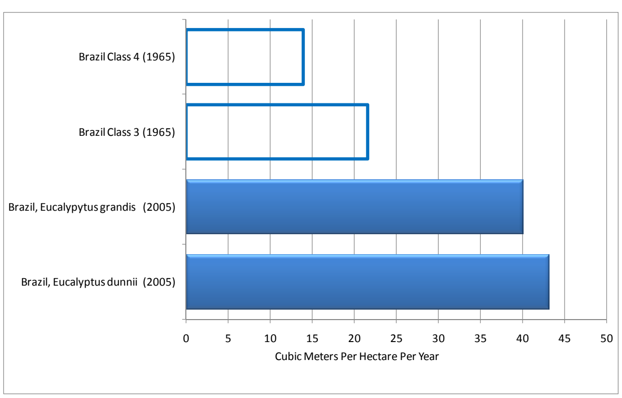
Figure 5. 1960s Eucalyptus MAIs



Source: UN FAO (1981)

Not only do MAIs change over the life of the stand, they also change over time as new rotations are established. Figure 6 compares the UN FAO (1981) MAIs for Brazil in 1965 with those reported by Cubbage et al (2005).

Figure 6. Eucalyptus MAI Comparison



Sources: UN FAO (1981) and Cubbage et al (2005)

While the data are not exactly comparable (the FAO data are for a mix of seven different eucalyptus species and there is no breakdown by site class for the Cubbage, et al data) the chart indicates that MAIs for eucalyptus in Brazil have about doubled in the past 40 years. This has been achieved in by genetic improvement and a move to cloning successful strains.

Summary

Foresters often use MAI to discuss tree growth, but that number is an average over the life of the stand and there is an assumed rotation age in the discussion. If stands are harvested before or after that assumed rotation age, yields will be different.

MAIs can also change from one rotation to the next as improved seedlings and silvicultural practices are utilized.

We have not discussed thinning, which can add to the complexity of the analysis. A stand may be growing at a rate of 5 tons/acre/year, but the final harvest will not reflect that rate if significant volumes are removed in thinning operations.

References

- Cubbage, Frederick W., et al, 2005, *Timber Investment Returns for Plantations and Native Forests in South America and the Southern United States*, SOFEW, Forestry: Economics and Environment Proceedings of the Southern Forest Economics Workshop 2005 April 18-20, 2005 Baton Rouge, LA
- UN FAO, 1981, *Eucalypts for Planting*, FAO Forestry Series No. 11, UN FAO, Rome
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Forest Research Notes, Vol. 8, No. 2

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[3] It is likely that the per-ton value of the timber at Age 15 would be less than the per-ton value of the timber at Age 26.