Professor Roy Sachs is one of the leading UC researchers on biomass.

Maximum biomass yields on prime agricultural land

Roy M. Sachs ❑ Jerry Ripperda ❑ Glen Forister ❑ George Miller ❑ Poonipope Kasemsap
Maureen Murphy ❑ John Beyl

To compete with tree and row crops on California's prime agricultural lands, biomass yields may have to exceed 20 dry tons per acre per year at a market price of $30 per dry ton. The results we report here for a selected clone of *Eucalyptus camaldulensis* (river red gum), grown in an intensively managed plantation at 2,719 trees per acre, suggest that the required yield can be exceeded by the third year after planting. A clone of *E. grandis* (rose gum) would probably give similar yields.

With low nitrogen fertilization (130 to 150 pounds per acre per year), however, neither *E. grandis* nor *E. camaldulensis* clones achieved yields above 13 to 14 tons per acre per year. Although this is much greater than the yield in less intensively managed plantations, it is still below that required for all but pulpwood markets.

Yield study

Five plantations of clones and seedlings were established from 1981 through 1985 at several planting densities. Various fertilization and irrigation programs were followed. At Davis, the plantation was irrigated to satisfy transpiration need; tensiometers controlled a solenoid valve that controlled the irrigation system. We estimate that the plantations at full canopy cover received 75 percent of pan evaporation for 1986-87. At the Orange County plantations (South Coast Field Station, Irvine) drip irrigation was scheduled once or twice weekly to replace pan evapotranspiration. For both irrigation systems, there was one emitter per tree located in the rows, half way between the trees. At the Dixon location, sprinkler and furrow irrigation was used at weekly intervals to replace pan evapotranspiration. Double border rows surrounded the yield blocks; that is, biomass yields were computed from the interior trees only.

In several plantations, trees have been harvested at different times after planting to determine the relationship between diameter (or area) at breast height and fresh weight of trees representing a range of size classes. The function for biomass vs. trunk area at breast height (ABH) produced a nearly direct relationship from which biomass estimates have been made for all yield blocks. Samples of wood chips were oven-dried at 190°F for 3 days to determine percent dry weight. This number was used to estimate dry biomass production. The average dry weight was 39% for 2-, 3-, and 4-year-old plantations of *E. camaldulensis* C-2 clone and *E. grandis* G-1, and this figure was used to compute biomass accumulations.

Three-year-old trees are largely or totally sapwood, which may have a higher and more variable moisture content than that of older trees. Wood from the 7-year-old *E. camaldulensis* and *E. dalrympleana* (mountain gum) in the study by Donaldson and co-workers had 47% to 49% dry weight, with little variation among samples. Significant error can thus be introduced into preharvest biomass estimates without a precise determination of the dry weight percentage.

Yields

The highest estimated yields of *E. camaldulensis* have been for a small, 4-year-old plantation of the C-2 clone, with 2,719 trees per acre, receiving an average

TABLE 1. Cumulative biomass and computed annual growth rate for *E. camaldulensis* C-2 clone, 4.5-year-old plantation, planted June 1983, 2,719 trees per acre, Dixon

	Months after planting						
Measurement	13	25	30	32	36	49	56
DBH (in)	1.93	2.98	3.35	3.44	3.69	4.35	4.55
Height (ft)	15.3	22.0	—	33.5	36.5	50	—
Dry weight*:							
Per tree (lb)	16.1	38.3	48.4	51.0	58.7	81.6	89.2
Tons/ac	21.8	52.0	65.8	69.3	79.8	110.9	121.3
Tons/ac/yr	18.1	25.0	26.3	26.0	26.6	27.2	26.0
Marketable chips†					21.3	21.8	20.8
Volume, harvested trees:							
Cu ft/ac			3133				
Cu ft/ac/yr			1301				
Cords/ac			36.7				
Cords/ac/yr			14.6				
N content, trees	**N (lb) removed per acre**						
0.4% N	175	416	526	555	638	887	970
0.6% N	263	624	789	833	957	1330	1456
0.8% N	350	832	1052	1110	1276	1774	1940

NOTE: Fertilized with an average of 400 lb/ac/yr nitrogen.
* Dry weight values calculated assuming 39% dry weight.
† Total biomass × 80%.

TABLE 2. Production of C-2 clone planted May 1985, 1,210 trees per acre, UC Davis

	Months after planting				
Measurement	12	15	18	21	26
DBH (in)	1.53	2.45	2.92	3.07	3.60
Dry wt/ tree (lb)	9.05	23.22	32.98	36.45	50.13
Tons/ac	5.5	14	20	22.1	30.4
Tons/ac/yr	5.5	11.22	13.28	12.58	13.97

NOTE: Nitrogen was applied in irrigation water at the rate of 135 pounds per acre per year.

TABLE 3. Production of C-2 clone planted October 1984, 1,210 trees per acre, South Coast Field Station

	Months after planting	
Measurement	32	38
DBH (in)	3.75	4.33
Dry wt/tree (lb)	54.39	72.51
Tons/ac	32.9	43.9
Tons/ac/yr	12.72	13.83

NOTE: Nitrogen was applied in irrigation water at 150 pounds per acre per year.

of 400 pounds nitrogen per acre per year, mainly as ammonium sulfate but with additions of ammonium phosphate and urea. The estimated biomass growth rate was 25 to 27 tons per acre per year for the third and fourth year after planting (table 1). The growth rate did not increase after the third year, suggesting that competition for light at this tree density limited further increases in yield. Harvesting of this plantation would probably begin between the third and fourth year, if the most rapid rotation cycle were desired.

Yields of other C-2 plantations at 1,210 trees per acre at Davis and Irvine supplied with much lower nitrogen fertilization peaked at 14 tons per acre per year (tables 2 and 3). Although the lower yields at these plantations were probably due to inadequate nitrogen fertilization and not to the lower planting density or to irrigation method, this supposition must be tested with further experiments where nitrogen or irrigation system only is varied and planting density is held constant. Since canopy closure was achieved 12 months after planting at 1,210 trees per acre, we expect growth rates for both the 2,719- and 1,210-tree plantations to be roughly equivalent after this period.

One *E. grandis* clone, G-1, grown in short-rotation intensively cultured plantations at the South Coast Field Station and Davis at 1,210 trees per acre, has attained growth rates somewhat greater than those of a seedling plantation with 1,750 trees per acre. At 2 years, the average biomass yield was about 12 tons per acre per year for both the seedling and clonal plantations. The growth rate of the higher density seedling plantation had begun to decline by the end of the second year, but was still increasing in the clonal plantations. The projected annual growth rate for the Davis clonal plantations is about 13 tons per acre by the end of the third year. Both plantations were probably growing under a nitrogen deficiency for maximum growth, which would tend to lessen potential maximum yield differences between the two plantations.

Nitrogen nutrition

Whole-plant nitrogen analyses for the C-2 clone ranged from a low of 0.4% to more than 0.7% nitrogen per unit biomass. These values were obtained for plantations that received 135 to 400 pounds nitrogen per acre per year. There was no correlation observed between nitrogen applied and nitrogen content of the wood. Foliar nitrogen levels did not differ significantly between C-2 plantations receiving 135 and 400 pounds nitrogen per acre per year. In both cases, nitrogen levels were 1.8% to 1.9% (dry weight basis).

The nitrogen required for maximum yield has not yet been determined. We do know, however, that yields were highest (more than 25 tons per acre per year) when nitrogen fertilizer was supplied at 400 pounds per acre per year in the C-2 plantations at Dixon. Assuming 0.4% to 0.6% nitrogen for the total biomass, we estimated that the trees removed approximately 300 pounds per acre per year (table 1). Thus, to achieve maximum yields it may be necessary to add at least this amount of nitrogen annually.

A sharp decline in the C-2 growth rate at Davis 18 months after planting suggests that nitrogen may have become yield-limiting at that time. These plantations received only 135 pounds nitrogen per acre per year. Since they had probably removed 160 to 240 pounds by the 18th month (table 2), they should have depleted nitrogen reserves in the soil so that the nutrient, not light or moisture, became the growth-limiting factor. Soil analyses at the end of the growing season indicate residual nitrogen of 5 pounds per acre-foot. This is below the nitrogen reserves of approximately 70 pounds per acre in these soils before planting.

Tissue analyses suggest that the G-1 clone may remove somewhat less nitrogen per unit biomass than does C-2. Nevertheless, even G-1 plantations are capable of removing more than the 135 to 150 pounds supplied.

Marketable yields

Eucalyptus camaldulensis C-2 clones at Davis were over 35 feet tall at 28 months and 45 to 50 feet after 48 months. About 80% of C-2's total biomass should be available for chipping or cordwood, since the ratio of trunk:branch biomass was close to 5:1 in the third year after planting. Thus, more than 20 dry tons per acre per year would be marketable as pulp-quality wood chips in a C-2 plantation receiving adequate nitrogen. At 20 tons per acre per year and prices of $20 to $30 a ton, the return to the land would be $43 to $243 per acre per year, based on cost estimates by Klonsky et al.

Roy M. Sachs is Professor, Jerry Ripperda is Graduate Research Assistant, Glen W. Forister is Staff Research Associate, and Poonipope Kasemsap is Graduate Research Assistant, Department of Environmental Horticulture, University of California, Davis; George E. Miller is Extension Agricultural Engineer, Department of Agricultural Engineering, UC Davis; Maureen Murphy is Staff Research Associate, and John Beyl is Superintendent of Cultivations, UC South Coast Field Station,