assessed by placing open petri dishes containing cockroach egg cases in cupboards and other out-of-the-way locations. After two weeks' exposure, the egg cases were placed in shell vials for emergence. Parasite emergence and reports of parasites from locations in addition to those where releases had been made indicated that the wasps had become established.

Parasite populations have not resulted in a contaminant problem in research laboratories, and many employees responded positively to the use of "good bugs" versus "bad bugs." In general, employees also seemed to be less offended by cockroaches after the parasites were introduced. However, resources were not available to assess psychological attitudes adequately.

Preliminary indications from nocturnal flashlight surveys for brownbanded cockroaches and a decrease in cockroach reports have indicated the potential effectiveness of *C. merceti* releases for controlling *S. longipalpa* in large buildings. Although others have reported that the parasite was not effective, because they found "flourishing" populations of the natural enemy and host together, we have found the host abundance has almost always been temporary. As is the case in other parasite-host interactions, however, additional parasite releases over a number of months may be required to effectively suppress cockroaches. A critical difference between our program and the observations of others has been the use of augmentative parasite releases.

Summary

In spite of the economic impact of cockroach populations, virtually no serious consideration had been given to the use of natural enemies to control them in an operational structural pest management program.

Since January 1978, *Comperia merceti*, an encyrtid parasite of cockroach eggs, has been reared and released as the principal measure employed for suppressing brownbanded cockroaches, *Supella longipalpa*, in research facilities at the University of California, Berkeley. This natural enemy of brownbanded cockroaches shows promise as the most effective and efficient approach for controlling this pest in large buildings.

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Short-rotation eucalyptus as a biomass fuel

Roy M. Sachs □ David W. Gilpin □ Tom Mock

Eucalyptus species are prime candidates for woody biomass plantations, because they grow rapidly, reputedly accumulating as much as 40 metric tons dry matter per hectare per year on a wide range of sites in tropical locations. Planted at 17,790 trees per hectare in southern California and harvested twice annually at 3- to 4-month and 8- to 9-month intervals, *Eucalyptus grandis* yielded 22 oven-dried metric tons per hectare per year (10 tons per acre per year). The material harvested is largely herbaceous with only 24 to 33 percent dry weight. Indications are that the trees are relatively deeply rooted and mine water and nutrients below depths reached by most herbaceous perennial crops.

Evergreen, coppicing (resprouting) eucalyptus species are particularly well suited to a forage crop type of management, because they may be harvested frequently with sufficient foliage left to support rapid regrowth of axillary buds. These characteristics provide for maximum annual solar energy interception, reduce the need to replant after harvest, and, owing to the continuous high foliar density, decrease weed competition. The small plot designs used do not completely eliminate border effects but they do permit comparative studies of dry matter accumulations among species grown in similar conditions.

Like many forage crops, some eucalyptus species have nonresting naked buds, which develop rapidly to form a complete leaf canopy. Rapid leaf canopy development and proliferation of small-diameter shoots permit harvesting with hay cutters (essentially a mowing operation). This management system may also maximize energy content of the harvested biomass, because the highest concentrations of oils and protein occur in small shoots and leaves.

Disease and insect problems have not been of paramount importance in eucalyptus species grown outside their native environments. For this reason, their yields may exceed those recorded in their natural habitats. As a result, large-scale plantings of eucalyptus have been introduced into suitable areas of Africa, North and South America, and India.

The purpose of this study was, first, to determine the maximum dry matter of *Eucalyptus grandis* grown in small plots on very close spacing and harvested twice a year. We eliminated, as far as possible, external plant stresses, such as drought, nutrient deficiency, disease, and insect problems. In the next phase of the program, yield of a few species will be evaluated under dryland and low fertility conditions. A second goal, to measure the total energy content of the vegetative tissue and evaluate its suitability for gasification, awaits further study using a downdraft gasifier at the University of California, Davis (see *California Agriculture,* May 1980).

Plant materials and culture

Eucalyptus grandis was selected for the studies at Santa Ana, because it was the fastest growing of more than 20 species evaluated in an earlier study. It is also rated worldwide as one of the fastest growing species in warmer, frost-free regions.

In May 1977, uniform plants grown from seed were transplanted into four experimental field plots oriented north-south, each 300 square feet (28 square meters). Plants were spaced on 75-centimeter (cm) centers in four rows, each 75 cm apart. Each plot had 48 plants, 28 plants comprising the border; yield data were computed only for the 20 interior plants. The plants were large enough to cover the plot; light interception was greater than 50 percent.

Plots received regular irrigations and were fertilized with nitrogen and phosphorus. A preemergence herbicide was applied at planting time but may have been unnecessary because of the high planting density and foliar cover. In the two years since planting we have followed no general weed control practices, but the interior yield areas have remained essentially weed-free.

Individual plants were hand-harvested and fresh-weighed in the field. Several samples were oven-dried and reweighed for computation of dry weight percentage. Harvest dates were determined by growth rate. To facilitate cutting we had decided to harvest when stem diameters were about 2 cm; this stage was attained at approximately six-month intervals.

Because coppicing was of major importance, cutting height was varied to determine whether this influenced regrowth. Plants were cut initially at 25, 50, 75, or 100 cm. Regrowth was excellent from all plants, but since the 50-cm height (or less) was easiest to manage, all plants were subsequently cut to this height.

High-density, short-rotation plantings often suffer from an initially high mortality rate of 40 percent or more. Our experience was somewhat different. Overall mortality was low, about 8 percent, but was very high in two of the four plots, mainly in the border plantings. We believe the overall low mortality resulted from the very short rotation in our studies (six months compared with three years in another study) permitting adequate photosynthesis in each plant for root system development, but we cannot account for the unusually high mortality of the border plants in the two plots.

The June and September 1979 harvests from three of four plots yielded more than 20 oven-dry tonnes (ODT) per hectare per year. During the previous harvest, all plots either approached or exceeded 17 ODT. Yields of individual plots are increasing, indicating that the plots are not yet fully established. The final harvest data should be considered the best estimate of yield, because they do not include either the initial growth achieved before field planting or a foreshortened growth period (November to June).

Uniform harvest cycles were based on stem diameter; apparently diameter growth is greater in the June to September than in the September to June interval, indicating that the form of the canopy may differ considerably during the different harvest intervals. This change in canopy form and wood accumulation is of concern, because the dry weight percentage is a direct function of the relative proportions of leaf and stem tissue in the harvested material (the greater the proportion of stem tissue the greater the dry weight percentage).

Our estimate of dry weight of the harvested biomass is a regression of dry weight to fresh weight of selected plants, not of the total plot dry weight. The regression reveals that the heavier plants have an increasing dry weight percentage, indicating greater wood formation. Moisture content of mature eucalyptus wood varies from 45 to 65 percent, depending on the relative amount of heartwood in the sample, but it is unlikely that, at the short rotations we used, any of our plots will ever have such low moisture content.

Individual plant fresh weights varied considerably in each plot. Taking the mean fresh weight yield for the plot and then computing individual plant yield as a percentage of the mean, we found that at some harvests some plants contribute almost 0 percent and others 240 percent of the mean. The annual range is considerably less — that is, a low growth rate in one harvest interval is often followed by a higher growth rate in the next. We find that in taking 10 plant samples from each plot of 20 we obtain an equally good estimate of

Yield from *Eucalyptus grandis* Plots at Santa Ana, California*

Plot	Oven-dry tonnes per hectare (ODT/ha) at harvest dates:					Annual harvest (ODT/ha)		
#	11/77	6/78	9/78	6/79	9/79	11/77† to 9/78	6/78 to 6/79	9/78 to 9/79
1	16.9	5.6	6.5	15.4	9.6	12.1	21.9	25.0
2	10.2	11.4	5.6	11.4	7.1	17.0	17.0	18.5
3	8.6	12.3	6.2	13.4	8.0	18.5	19.6	22.2
4	7.4	4.8	2.9	13.0	7.8	7.7	15.9	20.8

*Yields computed from fresh weight times dry-weight percentage.
†10-month harvest.

PLOT DESIGN

20	19	18	17	16	15	14	13	12	11
1	2	3	4	5	6	7	8	9	10

FRESH WEIGHT YIELDS (June to September 1979)

2,995	0	430	230	1,890	28	0	2,650	1,030	3,150
1,930	2,390	1,925	5,190	3,150	2,340	1,830	2,765	255	1,860

FRESH WEIGHT YIELDS (October 1978 to September 1979)

8,570	1,495	3,095	230	2,390	2,478	2,680	4,760	1,040	4,835
3,035	4,395	6,380	11,385	4,380	8,890	5,995	5,980	7,030	4,110

Plot design for *Eucalyptus grandis*. Numbered squares represent the 20 interior plants in the plot from which yield data were recorded. Fresh-weight yields are in grams.

Experimental *Eucalyptus grandis* plot at U. C. South Coast Field Station, Santa Ana, harvested twice a year produced fuel at a rate of up to 22 metric tons per hectare.

variance; thus, future plot sizes for species screening will be reduced with considerable savings in maintenance.

Clearly there is intense competition within the plots that accounts for the major portion of the plant-to-plant variance observed at individual harvest. Moreover, plants on the eastern side of the plots produce considerably more growth, which suggests that less water stress and, hence, more photosynthesis occurs before noon than after noon. This is common in regions where afternoon temperatures and atmospheric water demands are higher than in the morning. The implications of the east-west yield variance with respect to plot design are important. The border plantings may not be sufficiently dense to create uniform conditions within the yield area and hence the absolute yield values reported may differ from those obtained in larger scale plantings.

Undoubtedly, there is seedling variance, known to be high in eucalyptus species, but it has not yet been identified sufficiently to warrant further studies on vegetative propagation of high yielding individuals.

Improved management, particularly leaving more foliage on the plants at each harvest, may increase yields. This may require more frequent harvesting, perhaps three times annually, timed with a light interception index. Ideally we should like to harvest at 100 percent incident light interception and cut plants so that the remaining vegetation still intercepts 50 percent of the incident light.

So far we have failed to obtain response to fertilization, perhaps because of underground runoff from other experiments some distance from our plots. Similarly, varying irrigation regimes has not successfully altered growth rates; the plants may be deeply enough rooted in the sandy loam soil to tap aquifers or runoff from other experimental plots. Future research on short-rotation perennial crops will be done in more isolated areas where drainage from neighboring fields can be controlled. The greater than 20 ODT per hectare per year is typical of yields from annual agricultural crops, such as corn, sorghum, and sugar beets, grown with high nitrogen and water. One would expect yield to decline with reduced fertilization and irrigation in isolated, frequently cropped eucalyptus plantings as in other high-yielding crops.

It should be emphasized that, since plot establishment, there have been no further costs for pest or weed control or land preparation. We have partially achieved our initial objective, namely, to produce biomass at lower cost than is possible with most annual crops. A corn crop grown for grain on a neighboring plot with similar fertilization and irrigation, but greater weed control problems, produced half the biomass of *E. grandis*. Silage corn, planted at higher densities, would have yielded significantly more biomass than did our 60,000 corn plants per hectare, but overall annual yields would have been lower, because *E. grandis* has a much longer growth period.

We have been sufficiently encouraged by these studies to extend them to several other perennial species, including *Acacia melanoxylon, Ailanthus altissima, Eucalyptus camaldulensis, E. camaldulensis* × *rudis, E. globulus* 'Compacta', *E. oleosus, Pinus radiata, Populus* hybrids, *Robinia pseudoacacia, Sequoia sempervirens, Salix* spp., and *Tamarix*.

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Geologic nitrogen may pose hazard

Several studies by University of California researchers have suggested that high, potentially hazardous levels of geologic nitrate occur naturally in alluvial soils along the western San Joaquin Valley. Nitrate concentrations are uniform to great depth in unirrigated profiles of these soils and range up to 2,000 milligrams per liter in the soil solution. The major focus of our research was to examine the relationship of this nitrogen to the soil system and to identify the sources of the naturally occurring nitrate in the alluvial soils.

Two index drainage basins were selected for investigation. Cantua Creek Basin is immediately to the west of alluvial soils previously reported to contain high levels of indigenous nitrate. It also has a representative suite of the geologic sediments that occur in the Coast Ranges. The Ortigalita Creek Basin, on the other hand, was studied because it is not near soils with high levels of naturally occurring nitrate and because it contains an incomplete suite of the Coast Ranges' geologic sediments (represented by the Panoche and Tulare Formations). These two basins have physiographical characteristics similar to those of the numerous basins throughout the eastern flank of the Coast Ranges that drain into the San Joaquin Valley.

Results

Total nitrogen concentrations in the Cantua Creek Basin geologic sediments, determined by standard methods, ranged from a few micrograms per gram (μg/g, dry weight basis) to nearly 4,800μg/g. Organic nitrogen was the major nitrogen species in older shale sediments, reaching a maximum concentration of nearly 1,200 μg/g in the Panoche and Moreno Formations. These dark, organic-rich shales are typically interbedded with light-colored sandstones.

Nitrate concentrations were always less than 100 μg/g in the older sediments and did not contribute significantly to the total nitrogen concentrations. However, nitrate was the dominant species in the younger sediments and played a significant role in their total nitrogen concentrations. The most recent sedimentary formation (Tulare) had a maximum total nitrogen concentra-