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Eucalyptus in California

June 14-16, 1983, Sacramento, California



Cover: A stand of 50-month-old *Eucalyptus camaldulensis* growing in Calistoga, California. Average height of the trees is 6.7 m and average diameter-at-breast-height (d.b.h.) is 7.9 cm.

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Proceedings of a Workshop on *Eucalyptus* in California

June 14-16, 1983, Sacramento, California

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PREFACE

Although eucalypts (genus *Eucalyptus*) were introduced into California more than 125 years ago, little has been done to provide systematic programs for identifying superior planting stock. Eucalypts have long been considered landscape trees but are now in demand because of their potential for short-rotation fuel biomass production. Growers need a reliable source of rapidly growing planting stock. To provide information for that purpose, species and provenance tests have been and are being conducted.

To bring together researchers working with eucalypts to define the state of our knowledge about the genus, "A Workshop on *Eucalyptus* in California" was held June 14 to 16, 1983, in Sacramento, California. It was sponsored by the Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture, Berkeley, California, and Cooperative Extension, University of California, Berkeley, California.

Speakers from California, Florida, Hawaii, Oregon, and France presented information about advanced breeding programs and discussed how their results and methods could be applied in California. Major topics included species selection,

products, uses, and economics, growth and yield, cultural requirements, breeding programs, and propagation.

To expedite the publication of the Proceedings, we asked each author to assume full responsibility for submitting manuscripts in photoready format by the time the conference convened. The views expressed in each paper are those of the author and not necessarily those of the sponsoring organizations. Trade names are used solely for necessary information and do not imply endorsement by sponsoring organizations.

These Proceedings will serve as a useful reference for landowners, foresters, nurserymen, and horticulturists who are considering planting species of this versatile and useful genus—the *Eucalyptus*.

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Part 1. History of Eucalypts in California

***Eucalyptus* Helped Solve a Timber Problem: 1853-1880¹**

Gayle M. Groenendaal²

California was settled in an era before the full impact of the industrial revolution that was taking place in Great Britain was fully realized, a revolution that was to change the course of western culture more drastically than any previous time in history. Friedrich Engels wrote in 1845 of the industrial revolution as "a revolution which at the same time changed the whole of civil society, and the significance of which for the history of the world is only now beginning to be understood" (Tucker 1972). Society of today tends to forget the needs of the historic peoples before machinery, electricity and advanced technology changed the standards of living. It is only by reading the newspapers, including the advertisements, journals, and books of the previous era do we begin to understand the daily lives and needs of these people. It is through such research that the author has tried to piece together the eucalyptus story in California. In the following article, the impending timber crisis is described, laying the framework for the wholesale planting of eucalyptus in California. Why eucalyptus were chosen will be dealt with in the second part of the article including some of the history of the introduction of the genus to the state.

THE TIMBER PROBLEM--THE BEGINNINGS

Let us consider for a moment the impact of the immigrant population on the environments of California in the early 1850's. Both Sacramento and San Francisco had been small settlements with few inhabitants in 1848. Many of the later boomtowns were located in the foothills in regions that had for centuries been populated with Native Americans with small populations, more or less in harmony with the environment. Within a year, 80,000 gold seekers had passed through or settled in these areas (Bancroft 1890). Tent cities were established to house the new settlers. Urban infrastructures were insufficient or totally lacking--there were no sewage systems, water lines, roads, mail service, transportation facilities [sic], nor fuel supplies (Taylor 1867).

San Francisco was an area of oak woodland and grass, and Sacramento was located in the tules at

Abstract: Eucalyptus were introduced into California in 1853 as an ornamental by Capt. Robert Waterman. However, due to the destruction of the native woodlands and forests, people became concerned about future supplies of fuel and timber and began to experiment with different types of trees to plant. Eucalyptus became a favorite after 1870, because it was fast growing, was believed to be of great medicinal value, and was supposedly fireproof. By 1880, the eucalyptus were widely planted throughout the state and today many of these early plantings remain to remind Californians of the first energy crisis in California.

the confluence of the Sacramento and the American Rivers. Many of the new boomtowns were at first located in the scattered oaks and grasslands of the foothills. None were located in areas of extensive forests, and soon the oaks were gone (Taylor 1867).

As the Bay area and the valley became more and more settled, the need for timber and timber products grew. Lumber was needed for building more permanent structures, including sidewalks, fuel for heating, cooking, and steam production. Everything was built of wood: carriages, wagons, stages, sleds, farm implements, tools for mining timber for weirs and sluices for the gold recovery, and later timber for the mine shafts (Bancroft 1890; Taylor 1867). The list could go on and on.

Timber was abundant in some areas, too much so for the early settlers. Their first thought was of food production and how to clear the land cheaply and easily for crops. Fire was the great land clearer, and in the early 1850's great forests were fired to clear the land rapidly. Soon the timber receded, and the ox teams and skid roads came into being. The very size of the lumber, its location in rugged sites, and its distance from the greatest consuming centers was to bring about a destructiveness that would later motivate the movement by John Muir and others to try to enforce conservation practices (Bancroft 1890; Groenendaal 1983; Sparhawk 1949).

In California Life Illustrated, Reverend (later Bishop) William Taylor writes of the early days in San Francisco in 1849, where firewood was selling for \$40.00 a cord. He describes his neighborhood:

"The sand hills back of where I lived had been thickly covered with evergreen scrub oaks, but they had all been cut off, clean as a newly mown meadow."

The need for fuel was already felt in other parts of California by 1855, as witnessed by a notice to trespassers by John A. Sutter of Sacramento, published in the California Farmer on May 24th, warning that those who cut timber and

¹Presented at the Workshop on Eucalyptus in California, June 14-16, 1983, Sacramento, California.

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cordwood would be subject to punishment. As settlers spread out over the land, fuel became more precious and harder to obtain.

As early as 1858, colonel James L. L. Warren was running feature articles in the California Farmer on planting trees for the future needs of the people. He introduces one article as follows:

"The following excellent article we clip from the Germantown (Pa.) Telegraph. It contains many valuable hints worthy of notice, and those who look over our State, can see how many thousands of acres might be improved in the vicinity of farms, that would add to their beauty and value. The day is not far distant when firewood will be wanted, and such labor now 'will pay'".

The article that he was referring to is entitled Planting Trees and gave a description of the silviculture of European countries that were in the habit of setting out forest trees," to supply the places of those which have been consumed to supply material for fires, and artistic and mechanical purposes."

The California Culturist ran an article dated July, 1860 stating:

"Not the least in importance among the many subjects interesting to agriculturists, as also to many others of our population, is that of the question--where are we to obtain our supply of firewood in the future? Taking, for example, that portion of the country known as the Bay district, we find the supply already almost exhausted. The trees which formerly stood on the hills of contra Costa and Alameda, visible from the bay, are to be seen no more. The magnificent oak groves of Oakland and the Encinal have been so thinned and mutilated to furnish a supply of fuel, that the residents of those vicinities have awakened to the fact that in order to retain a shelter from the strong summer winds, they must abstain from destroying their trees.

Farmers cannot afford to pay the price which is demanded for coal; but as that will before long be as cheap as wood, or, as we should say, wood will be as expensive as coal, it is extremely desirable that we should 'take time by the forelock' and devise some plant for remedying the evil."

On May 4, 1860, Warren published an article in the California Farmer that had been written for the San Andreas Independent entitled, Destruction of the Forest. It read as follows:

"But two or three years ago, all the hills immediately surrounding our

mountain towns, were overgrown with magnificent oaks and ornamental manzanitas. Most of the once proud oaks have been wasted: the American with his span of mules, carried away the larger branches in cord-wood; then came the hyena pack-trains of Asia, cutting up the smallest branches, thinning the chaparral, and laying waste all that is ornamental. The huge trunks are generally left to decay where they fell. Our people have been sadly extravagant in this matter; and they may be sure that the day is not far distant, when this immense waste of timber will be unavailingly regretted. Wood is now six dollars a cord. In two years it will be eight dollars."

A paper by the Reverend Frederick Starr, in the report of the Department of Agriculture for 1865, predicted a timber famine within 30 years and advocated the immediate undertaking of carefully planned research on how to manage forest and how to establish plantations, especially of the hardwood trees. This paper was to play an important role in the nation. It became an impetus of the forest movement that would eventually see the founding of the U.S. Forest Service, it was also a prime force behind the development of the Eucalyptus Boom in California (Sparhawk 1949).

C. F. Reed, the President of the State Board of Agriculture in California, wrote in his report to the Board in 1869:

"The subject of a plentiful supply of lumber and wood, for the various purposes of life, is one that we cannot much longer neglect. Whoever takes the trouble to look this subject fully in the face, and reflects upon the future of California, must feel, as we do, that something should be done, and that immediately, looking to the substitution of new forest in the place of the old ones in our State, now so rapidly being consumed and destroyed..."

He continues in a later section, "It is now but about twenty years since the consumption of timber and lumber commenced in California, and yet we have the opinion of good judges, the best lumber dealers in the State, that at least one-third of all our accessible timber of value is already consumed and destroyed! If we were to continue the consumption and destruction at the same rate in the future as in the past, it would require only forty years, therefore, to exhaust our entire present supply..."

He goes on to say, "One of the worst features of the settlement of new countries by Americans is the useless

and criminal destruction of timber. In our State this reckless and improvident habit has been indulged in to an unprecedented extent.

Thousands upon thousands of the noblest and most valuable of our forest trees in the Sierra Nevada districts have been destroyed without scarcely an object or a purpose, certainly with no adequate benefit to the destroyer or to any one else. This practice cannot be condemned in too severe terms; it cannot be punished with too severe penalties."

The timber problem was not unique to California, it was a national problem. By 1868, the problem had become so acute as to cause a number of states to enact laws to encourage planting forest trees by offering bounties or by granting tax reductions or exemptions. Arbor Day was first declared and celebrated in Nebraska in 1872, at the instigation of J. Sterling Morton, later Secretary of Agriculture. Several railroad companies planted trees for ties and timber in the Great Plains and in California. But the biggest push towards planting forest trees came about when Congress passed The Timber Culture Act, in 1873. People who received free land for homesteading were required to plant forty acres of each 160-acre claim in trees. The forty acres were later reduced to ten (Sparhawk 1949).

On the Economic Value of Certain Australian Forest Trees and their Cultivation in California was published by the newly established California Academy of Sciences in San Francisco in 1871, and was the first of many papers to urge the planting of the Eucalyptus and Acacias as a solution to the growing timber famine.

Robert E. C. Stearns of the Academy wrote:

"When we consider the fact of the great number of farms in California that are nearly or wholly destitute of wood, and the great and continuous expense entailed by our system of fencing, the importance to the farmer of dedicating a portion of his land to the cultivation of forest trees, from which he can obtain fuel and fencing materials is too palpable to admit of debate..."

He continues, "Of the Eucalypti, E. globulus is very common in California, and easily cultivated: it is the Blue Gum of Victoria and Tasmania. This tree is of extremely rapid growth and attains a height of 400 feet, furnishing a first-class wood; shipbuilders get keels of this timber 120 feet long; besides this they use it extensively for planking and many other parts of the ship, and it is considered to be generally superior to American

Rock Elm."

Franklin B. Hough was the first to try to bring about a systematic effort to arouse public interest in the preservation and conservative use of the natural forest areas, distinct from planting of artificial forests, in his address to the American Association for the Advancement of Science in 1873. A memorial written by the Association as a result of Hough's address was sent to Congress (Sparhawk 1949). It said:

"The preservation and growth of timber is a subject of great practical importance to the people of the United States, and is becoming every year of more and more consequence, from the increasing demand for its use; and while this rapid exhaustion is taking place, there is no effectual provision against waste or for the renewal of supply..."

H. H. Bancroft tells the California timber story in his History of California published in 1890. He writes:

"The area covered by forests in California is very small in proportion to its size, 478,000 acres in total acreage of 11,400,000, according to the forestry statistics in U.S. Agriculture Report of 1875, which place it lowest among the 36 states there listed. This gives an average of only 4.0 per cent of forest land, San Diego and Alameda (counties) ranking lowest, with 0.1 and 1.2 per cent, and Nevada, Mariposa, and Santa Cruz (counties) highest, with 55.9, 53.2 and 52.8 per cent, respectively. The valuable timber belts are confined to the humid coast and mountain regions in central and northern parts, from 37° latitude to the Oregon border; and the interior valleys and the south are comparatively bare, relieved by clumps along the streams, and occasionally by a scanty vegetation on the less arid north side of the hills..."

Under all the inroads, favored by the small value of land in early days, there has been a great waste of forest resources, and in spots accessible for shipping and near settlements, as in Santa Cruz and San Mateo, and in the mining belt, there is little timber left, large districts being entirely denuded. Before the U.S. occupation, forest fires regularly devastated large sections owing to the custom, among Indians especially, of thus gathering insects and other articles of food. This is one of the evident checks to forests in the valleys. Subsequently shepherds and hunters were in the habit

of firing large tracts to promote the growth of pastures. Sheep in particular have kept down the renewal of forest by eating the shoots..."

After this description of waste, Bancroft goes on to contradict this evidence by saying,

"Yet, after all, the inroads upon timber do not affect more than one-fifth of the entire area, and most of this is renewing itself, so that the supply is practically inexhaustible. This is notably the case in the redwoods and partly in the mining belt, and it is believed that the Truckee region will also revive. Laws have been passed for the protection of forests, but with little effect...There is a further compensation in the artificial planting of trees, fostered by the state, and latterly by arbor-day festivals. This is extended not alone to roads and settlements, for shade, screen, and embellishment, but to entire groves of forest dimensions, for fuel and industrial purposes, notably for remedying the lack of hard wood sufficient to supply in due time the demand and to balance destruction elsewhere. The sycamore, willow, and cottonwood grow readily, for fences and fuel, also lombardy poplar, but the black locust and especially the eucalyptus are most widely planted, the latter promising to prove very desirable for elasticity and hardness."

Nelson Courtlandt Brown wrote as late as 1919,

"over one-half of our population live in wooden houses and two-thirds of the population use wood for fuel."

He gives the rates of consumption for 1880 as 18 billion board feet as compared to 40 billion board feet for 1919. He sums up the timber problem that was plaguing the nation in the following sentence.

"We are using our forests three times as fast as they grow."

After 1868, tree planting the United States had become a patriotic duty. Articles appeared urging the planting of trees to stave off the impending timber famine. California began to heed the call with the rest of the nation and commenced planting trees. the California State Agricultural Society offered a premium of \$50.00 to be awarded to the best timber plantings in the winter of 1870. The California Horticulturist commented on the situation in the following article in August of 1876.

"In California everything is done on

a large scale if at all. Grape vines are planted by the hundreds of thousands, and wheat fields extend to thousands of acres, and the groves of forest trees are what in the East would be called extensive forests.

Of late Californians have commenced the planting of forest trees, and this, too, upon the same extended scale which marks all their operations. The Blue Gum tree at present being a general favorite..."

Why were bluegums the present favorite? Why were they chosen over better timber trees and thousands planted over the countryside to such an extent that even today the horizon of California is dotted with the remnants of the 19th century plantings? The answer lies in the needs of the populace of the 1800's.

EUCALYPTUS--INTRODUCTION AND USAGE

Californians were not the only people who had become enchanted with the eucalyptus trees. A Frenchman, Prosper Ramel, traveled to Australia as a trader in 1854, where he visited the Botanical Gardens in Melbourne. He saw his first Tasmanian bluegum in the gardens and was so taken by the phenomenal vigour of this species of tree that he became determined to promote this tree in the old world. He saw it covering the mountains of Algeria, making marshes salubrious and chasing away fever. He was aided to this end by Ferdinand von Mueller, the most famous of all the early Australian botanists (the first to classify and systematize the genus Eucalyptus). Between 1855 and 1857, they pushed enthusiastically and perseveringly for culture of the bluegum on a forestal scale overseas (Zacharin 1978).

France was to play a very important role in the eucalyptus transfer story. (Although, they do not grow well there except along the Mediterranean coast from Cannes to Monaco and on the island of Corsica.) French botanists and gardeners were pioneers in studying the eucalyptus and it was through their efforts that France was to become the key distributing point for the secondary transfer of seeds and knowledge of the eucalyptus to southern Europe, Africa, and the United States (McClatchie 1902; Zacharin 1978).

It was due to the research done on the eucalyptus in France and the Mediterranean countries that gave rise to the fable that eucalyptus, especially Eucalyptus globulus (Labill.), could purify the air and eliminate malaria. Medicinal properties of all kinds were attributed to the oil, leaves and bark of the tree. Eucalyptus globulus became known as the fever or miracle tree (McClatchie 1902; Pacific Rural Press 1870-1880; Zacharin 1978).

Eucalyptus globulus is a fast growing hardwood tree, obtaining a growth of twenty feet per year.

The wood is dense and burns well. A plantation of globulus can be harvested every seven years for firewood without harm to the tree, as it coppices from the roots and can be harvested continuously without replanting. Globulus grows well in a variety of soils, including many poor soils, and can survive with a minimum of rainfall. One limiting factor is freezing weather, which it cannot tolerate for any length of time without killing the tree. These facts, taken together with the supposed medicinal uses, made the tree a very valuable tree. It is little wonder that the people, not only in California, but also in China, India, Portugal, Spain, South Africa and South America began to plant the tree by the thousands (Penfold and Willis 1969).

Eucalyptus were introduced into California as an ornamental by clipper ship Captain Robert H. Waterman in 1853. In a biography of Waterman, David A. Weir (1957) reports that Waterman had a dream when he retired from the sea and that dream was to plant a "heap o' trees." On retirement, Waterman set forth to accomplish that dream.

Waterman bought an undivided half interest in a twelve-mile square tract of land in Suisun Valley in 1850 with another sea captain, A. A. Ritchie, as his partner. The Captain laid out the cities of Fairfield and Cordelia, which he named for his wife, in Solano County. He hired Josiah Allison, a horticultural expert, to help him landscape his towns and his own ranch home. Waterman, accompanied by Allison and Ritchie traveled the immense Suisun Valley and surveyed the boundaries, staked out roads, and marked future tree locations (Weir 1957).

Waterman commissioned his ex-first mate, Jim Douglass, to bring him some eucalyptus seeds on his next voyage to Australia. In 1853, records Weir, Douglas brought the Captain a bag of bluegum seed, and from these seeds came the stands of eucalypts that are still growing around the Captain's home and along many of the roads of the Suisun Valley. Waterman reportedly gave seeds of the eucalyptus to the new settlers of Fairfield and to his friends in other areas (Weir 1957). This is the first record identifying the genus Eucalyptus with sailing vessels and tied them to the trade that must have brought them from the Australian continent to the California coast.

Two turn-of-the-century writers, Alfred J. McClatchie and C. H. Sellers, identified William C. Walker as introducing 14 species of eucalyptus in 1856. Abbott Kinney, another writer on eucalyptus credits C. L. Reimer as introducing 14 species in January of 1856. Other writers have claimed Bishop William Taylor introduced the genus. Based on the surviving records, Waterman introduced eucalyptus, while R. W. Washburn, owner of the Shell Mound Nursery of Alameda, was the first tradesman to list the genus for sale in his one page catalog for 1856 (Brown 1982). The late Charles Shinn, whose father, James Shinn, owned

the Shinn Nursery in Niles, California, and whose uncle, Charles Shinn, was the editor of The California Horticulturist, wrote to the Oakland Tribune in 1936 that Colonel James L. L. Warren, editor and owner of the California Farmer, "widely advertised and distributed seeds, especially E. globulus as early as 1856."

Very little is known of Washburn, and what is known has been gleaned from the California Farmer between the years 1858-1860. According to the Farmer, "R. W. Washburn of the Shell Mound, made a handsome display of fruit," at the State Horticultural Society meeting in 1858. Washburn's ad of March 23, 1860 stated that Shell Mound had been awarded the First Premium for the best nursery by the Alameda County Agricultural Society; that twelve Premiums were awarded by the California Horticultural Society in 1859; and that two diplomas by the Sonoma and Contra Costa Agricultural Societies had been awarded them. However, in the February 8, 1861 advertisement for Shell Mound, Mr. L. A. Gould, was listed as the proprietor. Neither the nursery nor Washburn is mentioned in later years in the California Horticulturist nor in the Pacific Rural Press (Groenendaal 1983).

William C. Walker, owner of the Golden Gate Nursery in San Francisco from 1849-1865, has been given the credit for the introduction of eucalyptus by most authorities. While he may not have introduced the genus, he was the first to list the different species that he had in stock in his nursery catalog dated 1858-59 (Brown 1982; Butterfield 1938; Butterfield and Eastwood Letters). Col. Warren of the California Farmer considered the Golden Gate Nursery in 1856 to have, "the largest and most choice collection of plants in the state... [and was] very liberal in introducing in the country many new and rare plants of great value." He first introduced the term Eucalyptus into his advertisements June 26, 1857, but no species were listed, only the genus name. He continued to advertise the nursery in the Farmer until the early 1860s.

Stephen Nolan, owner of the Bellevue Nursery established in 1860 in Oakland, was an active promoter of eucalyptus and had the most extensive offerings of different species. Nolan had imported seed from Australia in 1860 and planted them in 1861. By 1871, his nursery catalog listed 34 different species (Brown 1982; Butterfield 1935). His nursery was described in the January 23, 1875 issue of the Pacific Rural Press. The article describes many of the trees that were found in the nursery at that time, but of particular interest was the following passage:

"We were especially pleased with the great variety and fine specimens of Australian gums, and with one among them just suited for the crests of those apparently barren hills away in the distance. The eyes of our friend

lighted with enthusiasm of Nature's poet as he pictured the day when that landscape would be relieved and the whole country fertilized by these magnificent trees..."

Southward, near Alameda, another importer was busy. This was Annie Taylor, wife of Bishop William Taylor. Bishop Taylor left San Francisco in May of 1862 to do missionary work in Australia. In his autobiography, The Story of My Life, Taylor wrote:

"There were no Eucalyptus in California in 1849. I sent seed from Australia to my wife in California in 1863. Her seed sowing made such a marvelous growth that a horticulturist neighbor of ours wrote me to send him a pound of seed--the smallest of all seeds, and the nurseries, thus seeded, dotted the whole country with great forests of evergreens, the most prominent land marks [sic] of the Pacific Coast."

Many people have taken Bishop Taylor's statement in his autobiography to mean that he introduced the eucalyptus to California, but this was explained in a brochure that was written by his son, William, and distributed at the Bishop's funeral. According to the brochure, the eucalyptus trees were widespread in California when Bishop Taylor left for Australia, and it was their popularity that led him to send the seed to his wife (Oakland Tribune 1936).

Annie Taylor gave many of the seeds to James T. Stratton, the Surveyor-General of California. Stratton planted and propagated the bluegums to such an extent that by 1870, he had the largest commercial eucalyptus planting in the state (Transactions of the California State Agricultural Society 1870-71).

Up until this date the eucalyptus had been used mainly as ornamentals and, as such, many of the early pioneers of California had planted them to a limited extent. Only a few of these early plantings will be noted here. Captain Joseph A. Aram planted good sized groves of Eucalyptus globulus and Eucalyptus camaldulensis in the early 1860s. The first supply of seed to reach southern California was sent in 1863 by "an Australian missionary" (Reverend Taylor?), the seeds were divided among the large land holders of the area: Verdugo, Workman, Banning, Sanchez, and Wolf skill (Padilla 1961). General Henry M. Naglee planted about sixty acres of mixed eucalyptus trees in 1866, that were reported to be eighty feet tall with diameters of eighteen inches in 1876. There are records of more plantings during this period that are covered more extensively by Groenendaal (1983).

To promote commercial planting of forest trees, the California State Agricultural Society in 1870

offered a premium of \$50.00 for the largest quantity of useful trees to be planted during the year. James T. Stratton won the premium by demonstrating that he had planted fifty-three and one-half acres of Eucalyptus globulus and three thousand Eucalyptus camaldulensis (Dehnh.) trees (Transactions of the California State Agricultural Society 1870-71). This was the birth of a new era for the eucalyptus trees in California, from this date forward the trees would be planted mainly as a commercial venture instead of as an ornamental.

Throughout the pages of The California Horticulturist and The Pacific Rural Press, Stratton's premium winning forest can be followed over the years. The California Horticulturist carries this article in 1874.

"...When Gen. Stratton was setting out the trees, the neighboring farmers laughed at him and advised him to desist and attend to his surveying, as he would be dead long before the timber would amount to anything; but the laugh is now on the other side. Five years hence the available timber will be immensely valuable for manufacturing and for firewood ... No doubt General Stratton's foresight in planting these extensive and beautiful groves will produce not only cords of wood but cords of money; for, if cut down and sold now, at the age of only four years, the young forest would bring many thousands of dollars."

In the first volume of the California Horticulturist (1870), Professor Henry Nicholas Bolander of the California Academy of Sciences published a lengthy article on the eucalyptus, explaining that such a paper has become a necessity because eucalyptus are so extensively planted in California. He quoted Ferdinand von Mueller's work in which von Mueller envisions,

"Even the rugged escarpments of the desolate ranges of Tunis, Algiers and Morocco, might become wooded; even the Sahara itself, if it could not be conquered and rendered habitable, might have the extent of its oases vastly augmented. Fertility might be secured again to the Holy Land, and rain to the Asiatic plateau or the desert of Atacama, or timber and fuel be furnished to Natal and La Plata. An experiment instituted on a bare ridge near Melbourne demonstrates what may be done."

In 1870, a man settled in Santa Barbara who would do more to publicize the eucalyptus than any man of this era. This was the Honorable Ellwood Cooper, a wealthy gentleman who was retiring from diplomatic service. In 1872, he purchased a pocket ranch (2,000 acres) twelve miles west of Santa Barbara and named it Dos Pueblos Ranch,

where he began to experiment with eucalyptus. Cooper wrote to James McClatchie in 1900 about his interest in eucalyptus:

"There were Blue Gum trees growing in the state during my first visit in 1868. I saw a few specimens in private gardens from ten to twenty feet high; was attracted to their beauty; so that when I located in Santa Barbara in 1870, I at once conceived the idea of forest planting (McClatchie 1902)."

The ranch was a desolate spot when he bought it, covered with scrub and a few oaks, but within a few years, it became a show place, featuring many species of eucalyptus. Taking advantage of a previous acquaintance with Thomas Adamson, Jr., the United States Consul General at Melbourne, Australia, Cooper wrote to him asking for seeds of different species and asked for books or information on the eucalyptus. Adamson sent him seeds and informed Cooper that Ferdinand von Mueller, the government botanist, had delivered some lectures on the subject. The lectures had been printed, but all had been sent to London. However, von Mueller would send one of his originals, provided Cooper would have it printed in America and return to him fifty copies. Cooper, using von Mueller's propagation and culture notes, planted the seeds that Adamson had sent him (Warren 1962).

In 1876, Cooper was asked to give a lecture to the college of Santa Barbara, of which he was the president. He combined his interest in eucalyptus and the need to promote forestry in his lecture. The lecture was so well received that he was asked to publish it. This led to his book on the subject, Forest Culture and Eucalyptus Trees. Cooper's book makes an emotional appeal to forest the slopes of California with eucalyptus trees to counterbalance the destruction of the hardwood forests on the eastern seaboard. His speech was published along with Ferdinand von Mueller's lectures, keeping his promise to have the material published in America. In the book, Cooper writes of his own plantation:

"At my home I have growing about 50,000 trees. The oldest were transplanted three years ago. A tree three years and two months from the seed, transplanted two years and ten months ago is nine and one-half inches in diameter and forty feet and six inches high (Cooper 1876)."

The rapid growth of the eucalyptus trees began to excite farmers. It seemed practical after all to plant forest trees, that would mature in one's lifetime, and could be harvested in only seven years for firewood. Soon the Rural Press, The California Horticulturist and The California Culturist ran articles in nearly every edition describing the new plantings. One such article

published in the Pacific Rural Press in 1874 describes the growth:

"The rapid growth of the eucalyptus is wonderful. Anson Goodspeed has on his lot in north Healdsburg some trees which have grown 40 feet in two years, and others 22 feet in 18 months..."

However, it was not just the rapid growth of the trees that convinced the farmers to plant eucalyptus trees. Reports of the medicinal uses of eucalyptus trees were also reported in the press. Claims were made for the eucalyptus as an anti-malarial antidote; bronchial and pulmonary complaints could be cured by smoking the leaves; drinking eucalyptus tea would clean the system; and cholera epidemics were stemmed by planting eucalyptus around living quarters. The Pacific Rural Press ran several articles over the years on the subject, the most extensive one published on April 5, 1879.

The eucalyptus were also reported to be fireproof. On October 20, 1877, an article was published in the Pacific Rural Press called attention to a tree standing on the grounds of the old German hospital on Brannan street that had passed through the fire of August 1876 seemingly unharmed. This was reported at a meeting held at the Academy of Sciences. In that same meeting, Dr. Gibbon proposed that the planting of eucalyptus trees along public streets would be an important means of checking a conflagration, while Dr. Albert Kellogg stated that eucalyptus shingles were used on houses in Australia and added that it was impossible to fire a roof made of this material; he further suggested that Californians would be wise in following the Australian's example.

The attributes of the eucalyptus filled the pages of the early press reaching its zenith when the Central and Southern Pacific Railroads made public its intentions in January of 1877 to plant eucalyptus along the entire line of both roads. The railroad companies saw great advantages in these plantings: they would have a constant supply of timber suitable for repairing the roads; the fall of rain would be increased by the trees and the climate modified; and they would absorb malarial poisons along the lines (Pacific Rural Press 1877).

By the mid-1870s the planting of eucalyptus was so evident in California that visitors to the state remarked on their prominence. Mary Cone mentions in her book, Two Years in California, published in 1876 that the eucalyptus were a great favorite and were "much" cultivated. Ludwig Salvatore wrote in his book, Los Angeles in the Sunny Seventies: A Flower from the Golden Land,

"The largest forest is on the Anaheim branch of the Southern Pacific at a point where it crosses the San Gabriel

River, about twelve miles from Los Angeles, where 190,000 trees have been set out. This forest belongs to the Forest Grove Association of which Judge [R. M.] Widney is president. In December [1874] ten pounds of seed were brought down from San Francisco, and the seeds planted in a nursery. When two months old, the shoots were transplanted into a lot box and set two inches apart. By April [1875], the young plants had a height of 9 or 10 inches, and at that time they were set out in the ground ten feet apart. Within a year they were from 9 to 12 feet high (Padilla 1961)."

By 1880 over fifty groves had been planted in eucalyptus (mainly *E. globulus*) amounting to several thousand acres (Groenendaal 1983). The first Eucalyptus Boom was beginning to take place (the second boom would occur in the early 1900s). Farmers heeding the cry to plant fuelwood and timber could see the advantages (the disadvantages not being known at this time) in planting eucalyptus trees. Eucalyptus would give them fuel and timber, cure their ills, prevent conflagrations, and turn a profit in a very short time. It truly was considered the miracle tree.

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Part 2. Species Selection

Adaptability of Some *Eucalyptus* Species in Southwest Oregon¹

Lee O. Hunt²

One of my forestry professors in the late twenties expressed the view that by midcentury all the commercial timber in western Oregon would be cut. His definition of commercial timber was strictly old-growth Douglas-fir within easy reach of the major waterways. He was substantially correct since logging trucks, cats, mobile skidders, and loaders, etc., had yet to appear on the scene.

As late as the early seventies no less an authority than Dr. Roy Silen, Principal Geneticist of the Pacific Northwest Forest and Range Experiment Station expressed the view that there was no place in the Northwest for exotic forest tree species. On the basis of his studies at the Wind River Experimental Forest in central Washington, he indicated that no exotic species of forest trees could successfully compete or produce the volume and quality of timber that Douglas-fir and associated conifers can.

Only about a year ago the Oregon State Department of Forestry agreed to recognize any hardwood species as acceptable to meet the reforestation requirements of the State's Forest Practices Act. Further, in their standards for qualifying under the Western Oregon Small Tract (Forest) Optional Tax program they set a rotation of 60 years for Site Classes I and II, Douglas-fir, and 90 years for Site Classes III through V. Forest land taxes in Oregon are substantially higher than those for Washington. Over 93 percent of forest land in southwest Oregon is Site III or below; over two-thirds of this is in the two lower Site Classes, IV and V.

Several cost and return workshops on growing Douglas-fir forest crops have shown that using a discount rate of 8 to 10 percent and a 60-year rotation will inevitably fail to yield the grower a reasonable return on his investment.

With that background of professional and official policies and attitudes, there were virtually no incentives for the non-industrial forest

Abstract: Professional and official attitudes and reports discourage the use of exotics in the Northwest. Not only will the small woodland owner fail to make a reasonable return on his investment in growing native trees, he may not live long enough to harvest a crop. Short rotation alternatives are sought by using certain species of Eucalypts. Adaptability of such species is sought by out-planting plots in Douglas County. Considerable data has been accumulated on cold tolerance, survival, juvenile growth and deer damage to the species planted. Certain species appear to be adapted in southwest Oregon.

land owners to grow crops of trees which they would have little likelihood of harvesting in their lifetimes. The screening of trials of Eucalyptus species were a part of a personal program to try to find some alternatives to the 60- to 90-year rotations considered necessary to grow a crop of merchantable trees.

One can wonder why anyone in their right mind would consider spending money to grow Eucalyptus in southwestern Oregon with the professional and official attitudes plus the lack of specific knowledge on the silviculture of growing Eucalypts and an unknown market. Other disincentives include the lack of a nearby pulp market, lack of nursery stock sources, and the general antipathy toward trying untested and largely unknown species. There is a common attitude that there are no cold tolerant Eucalypts and thus they won't grow in Oregon. Even if they would survive, the wood is thought to be useful only for a low grade of firewood. This attitude is the more surprising when one sees, as I did last fall, vast areas of native Maritime pine, (*Pinus pinaster* Ait.) in Spain being converted to Eucalyptus and Monterey pine (*Pinus radiata* D. Don). Some 60 percent of the output of rayon, paper pulp and hardboard in Spain is from Eucalyptus. The expansion of Eucalyptus plantations is exploding throughout the world's milder climatic areas.

Several timber supply surveys and programs, such as Beuter, McClean, and Forestry Program for Oregon, predict as much as a 22 percent decline in timber supplies in Oregon by the end of this century. Can Eucalyptus and other short rotation tree crops fill the hiatus between the end of the old-growth native forests and the second crop? Just two years ago only about 1,000 cords of firewood were shipped from Douglas County, Oregon to California. This past season some 20,000 cords were shipped south, mostly to the San Francisco Bay Area, and almost entirely consisting of oak and madrone.

There has been a phenomenal increase in the harvesting of hardwoods, chiefly oak and madrone, in southwest Oregon in the past couple of years. Government agencies have sharply increased charges for firewood cutting permits from federal and state lands. The high cost of fossil fuels and electricity has brought on a wave of interest in wood as a fuel source. Thirty-two small woodland owners have purchased Eucalyptus seedlings this

¹Presented at the Workshop on Eucalyptus in California, June 14-16, 1983, Sacramento, California.

²Private Consulting Forester and Tree Farmer

past season from my small backyard nursery for the express purpose of growing firewood. As I make each sale and suggest some site and cultural requirements I shudder a bit because of the lack of specific data on species requirements, growth, yield, wood properties, and, of course, their cold and drought tolerances. However, I can take some consolation in the fact that at my age I probably won't be around to face the consequences of those recommendations.

Please forgive the lengthy introduction. I do believe we must recognize that we are entering a new field, one in which few professional foresters are interested or will accept. Now let us take a look at the chain of events that has brought us the limited amount of information on the adaptability of Eucalypts in southwest Oregon. Correspondence with CSIRO (Commonwealth Scientific and Industrial Research Organization), the research group in Australia, brought 14 packets of Eucalyptus seed to us in 1971. These species are included in table 1.

Table 1--List of Eucalyptus Species in Original Field Trials

<u>E. amygdalina</u>	<u>E. grandis</u>
<u>E. dalrympleana</u>	<u>E. nitens</u>
<u>E. delaquatensis</u>	<u>E. obliqua</u>
<u>E. fastigata</u>	<u>E. ovata</u>
<u>E. fraxinoides</u>	<u>E. regnans</u>
<u>E. flaucescens</u>	<u>E. subcrenulata</u>
<u>E. globulus</u>	<u>E. viminalis</u>

These species were recommended as being the better timber species with some cold tolerance. They were grown in Spencer-LeMaire Tinus Root-trainer containers for one growing season. They were out-planted in the early winter of 1972-73 in replicated plots at elevations of about 500 to 2,500 feet. Perhaps fortunately, the midwinter following these out-planting recorded the lowest temperatures in about two decades. Lows at 0°F and below occurred in all plot locations. All species were killed outright or frozen back to the ground. Only a few specimen of Eucalyptus dalrympleana, delaquatensis, glaucescens and nitens survived at all. These four species were replanted in new plots during the 1974 through 1977 seasons. Temperatures during these four years were moderate with minimums of 12° to 15°F. Only minor frost damage was noted and growth was generally good.

Early season rains occurred in late August and early September of 1978. This was followed by warm sunny weather for the next six weeks. The trees continued to grow vigorously during this early fall period. During the second week in November temperatures dropped 40° to 50°F over night to lows of 5° to 10°F. Almost all trees of all species were wiped out. Some few larger trees

from earlier plots were killed, others badly damaged. All of these plots were in the interior valleys and foothills of Douglas County. One plot located near Bridge, along Highway 42 on the west slope of the Coast Range, showed only minor frost damage to a few trees of any of the species at a minimum temperature of about 140°F. These trees have shown remarkable growth even with considerable native hardwood competition. Insofar as the interior valleys and foothills of southwest Oregon were concerned we were again back at square one.

Another plot was established in the spring of 1978 on the Schofield Creek drainage near Reedsport, Oregon, some 10 miles from the coast. This was Site Class II land owned by Douglas County and had been previously planted to Douglas-fir nursery stock. Table 2 indicates the survival and average growth of the species at the age of 5 years, along with the seed source elevations in feet.

Table 2--Survival and Average Growth of Species, Age 5 years

Tree Species Tree Species Name	Source Elev. Seed	Averages for trees		
		Survival Percent	Ht. Ft.	DBH Inch
<u>E. dalrympleana</u>	3800	79	27.6	5.4
<u>E. delegatensis</u>	4500	67	35.6	6.0
<u>E. gunnii</u>	3200	71	22.6	2.9
<u>E. johnstoni</u>	1800	67	29.5	3.3
<u>E. nitens</u>	4000	75	30.8	5.8
<u>E. urnigera</u>	3000	71	24.3	2.9

In the coastal areas of southwest Oregon, these three Eucalyptus species appear to be out-growing Red Alder by almost 2 to 1, as shown in figure 1. The widespread use of Eucalyptus species throughout the world would make one suspect that they are superior to red alder for chip production, both in volume and quality.

Additional plots were established in late summer and early fall of 1979 on our tree farm near Winston, Oregon. Species planted again included E. dalrympleana, delaquatensis, gunnii, and nitens. New species were added, including archeri, pauciflora, and urnigera. The following winter saw temperatures drop to 2°F at the planting sites. Table 3 shows an evaluation of the frost damage that was sustained by these species.

The winters of 1981 and 82 were very mild and no additional frost damage was observed at minimums above 15°F. These results would indicate that only E. archeri, gunnii, glaucescens, and urnigera can be considered suitable at this time for the interior valleys of southwest Oregon.

Several other species have been out-planted for cold tolerant screening the past two years, but

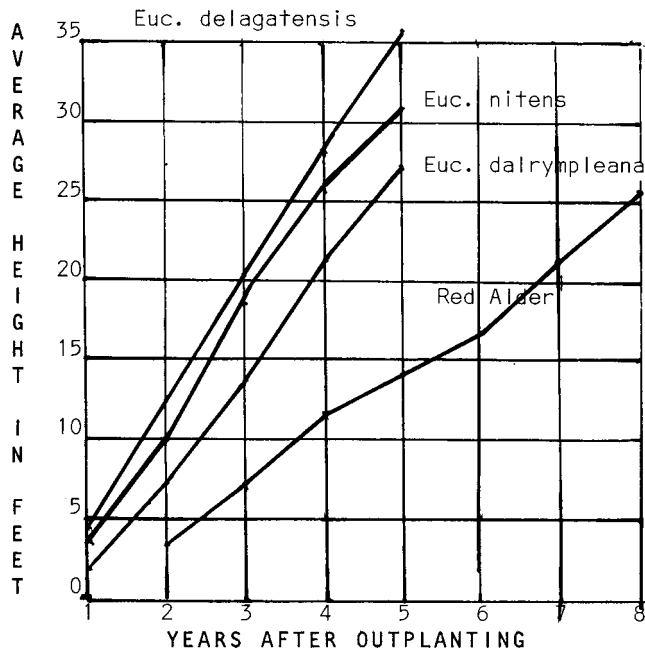


Figure 1--Comparison of early growth for three of the Eucalyptus species and that of Red Alder (*Alnus rubra* Bong).¹

¹Data from: DeBell, Dean S. and Wilson, Boyd C. Natural Variation in Red Alder. Utilization and Management of Alder (Symposium Proceedings) 1978. Published by PNW Forest and Range Experiment Station, Portland, Oregon.

they have not gone through even a moderately severe winter. Thus, they have not had a sufficient test to evaluate them. Included in these last out-plantings are *Eucalyptus camphora*, *cinerea*, *divaricata*, *globulus* (Barnback seed source), *irbyi*,

Table 3--Evaluation of Frost Damage

Species Name	Damage in Percent by Class ¹				
	0	1	2	3	X
<i>E. archeri</i>	81	16	3	0	0
<i>E. dalrympleana</i>	6	22	19	12	41
<i>E. delagatensis</i>	5	19	21	31	24
<i>E. glaucescens</i>	23	10	7	19	31
<i>E. gunnii</i>	96	4	0	0	0
<i>E. nitens</i>	2	14	34	34	16
<i>E. pauciflora</i>	0	0	8	79	13
<i>E. urnigera</i>	98	2	0	0	0

¹Damage classes are: 0 - no damage observed; 1 - slight damage shown by tender tips frosted; 2 - tender tips frosted and up to 50 percent of the leaves frozen; 3 - severe, total tree frozen and killed back to the ground, but subsequently resprouted; X - tree killed and failed to resprout.

nova-anglica, *stellulata*, *subcrenulata*, and *viminalis*. Only *Eucalyptus globulus* sustained frost damage at the 16°F temperature of two years ago and the 21°F of this past winter.

R.L. Tichnor of the North Willamette Experiment Station, Oregon State University, has recorded more specific data on a greater number of Eucalyptus species than any other worker with whom I'm familiar. Even most of the hardier species he tested, such as *Eucalyptus gunnii*, *pauciflora*, and *urnigera* he found were killed by temperatures of 5° to 8°F.

Another serious problem is deer damage, both from browsing and horning of the stems of young trees. There is a wide variation to susceptibility from deer damage as indicated by table 4, compiled from a survey made in may of this year.

Table 4--Deer Damage to Certain Eucalyptus Species

Species Name	Age Yrs.	Surv Pct.	Damage Class			
			0	1	2	3
<i>E. archeri</i>	5	45	0.0	12.8	41.0	46.2
<i>E. archeri</i>	3	55	0.0	0.0	0.0	100.0
<i>E. dalrympleana</i>	3	50	66.7	13.3	13.4	6.6
<i>E. divaricata</i>	2	65	0.0	0.0	0.0	100.0
<i>E. glaucescens</i>	3	43	68.8	13.7	11.7	5.8
<i>E. globulus</i>	2	45	100.0	0.0	0.0	0.0
<i>E. gunnii</i>	3	33	0.0	0.0	15.4	84.6
<i>E. irbyi</i>	2	93	0.0	23.0	20.5	56.5
<i>E. nitens</i>	3	69	95.0	0.0	5.0	0.0
<i>E. nova-anglica</i>	2	74	100.0	0.0	0.0	0.0
<i>E. subcrenulata</i>	2	70	100.0	0.0	0.0	0.0
<i>E. urnigera</i>	3	33	7.8	23.0	30.7	38.5

Deer Damage classes are: 0 - no damage observed; 1 - light damage showing less than 40 percent of side branch tips browsed with no visible reduction in height growth, 2 - 41 to 75 percent of twigs including the leader browsed, some stunting of growth visible; 3 - severe damage with virtually all twigs including leader and most of leaves eaten, almost no height growth since planting, occasionally horned trees were girdled and killed.

A few additional species were grown this past year (1982) from seed furnished by Dr. Stanley Gessel of the University of Washington on his return from a visit to CSIRO in Australia. Dr. Gessel is carrying on some testing of Eucalypts in the Seattle area. The species included *Eucalyptus cinerea*, *coccifera*, *camphora*, *dalrympleana*, *delagatensis*, *stellulata*, and *viminalis*. All but two were out-planted in three separate areas in central Douglas County this late winter of 1983. They have been subjected to no less than 28°F to date and have had no substantial deer pressure.

Dr. Nicholas Malajscuk, Mycologist with CSIRO at Perth, Australia, spent a year working with Dr. James Trappe, Principal Mycologist with the Pacific Northwest Forest and Range Experiment

Station at the Forest Science Laboratory in Corvallis, Oregon, on mycorrhizae of *Eucalyptus*. *Eucalyptus archeri*, *glaucescens*, *gunnii*, and *urnigera* were inoculated with three species of mycorrhiza, *Hynangium carneum*, *Scleroderma albidum* and *Hymenogaster albellus*. Besides laboratory tests, inoculated seedlings were out-planted on our Willis Creek Tree Farm. Preliminary findings indicate that in the laboratory only *Hynangium carneum* produced abundant mycorrhiza and it did so on all four of the *Eucalyptus* species. Field surveys will be made this year and findings will be published probably next year.

So where are we in this scramble for information on growing *Eucalyptus* in southwest Oregon? From observations to date, our screening tests indicate that in the interior valleys and foothills only *Eucalyptus archeri*, *glaucescens*, *gunnii* and *urnigera* have consistently shown sufficient cold tolerance to withstand our more severe winter temperatures. Of the four, *Eucalyptus urnigera* appears to be the fastest growing and is adapted to a wider range of sites. In four years of growth *Eucalyptus dalrympleana*, *delagatensis* and *nitens* show greater diameter growth than does *Eucalyptus urnigera* but not as much height growth. At this point my major production, if you can call some 5000 to 7000 seedlings per year a major production, is concentrated on *Eucalyptus urnigera* and to a lesser extent on *glaucescens*. Both are inherently larger trees than the other two, are about equally cold tolerant and much less susceptible to deer damage. I do find considerable frost tolerance variation among trees in the same species and even within the same seed lot.

Along the coastal strip there are greater opportunities for using other species that may yield higher volumes and perhaps better wood quality. If chips for paper pulp or hardboard is the objective of the plantations, then it would appear that *Eucalyptus dalrympleana* and *johnstoni* would be preferable since *Eucalyptus nitens* and *delagatensis* are non-sprouters. If a truly cold tolerant provenance of *Eucalyptus globulus* could be found it would, no doubt, produce greater volume than almost any other species. There appears to be little chance that the highly prized species, *Eucalyptus grandis* or *regnans* can be grown in the Northwest, although I still have three of the latter alive after four years. The one surviving *Eucalyptus grandis* has frozen back to the ground every year but this past winter. With the number of species in the genus there may be others that will prove to be valuable and adapted to this area.

I have avoided being specific about site conditions at our out-planting sites. This is due to a lack of detailed soil surveys and rainfall records in the immediate vicinity of the plantations. Generally, rainfall in the interior valleys and foothills varies from about 28 to 40 inches per year at elevations under 2000 feet. Snow is usually light and remains on the ground only a few days during the few times that snow does occur.

At the Bridge site the rainfall approaches 70 inches and in the Reedsport area from 80 to 90 inches; both areas rarely receive any snowfall.

Coastal soils tend to be deeper, more fertile and better drained than those in the interior. Soils in the interior valleys and foothills vary widely, but largely are moderate to heavy clays and clay loams, often shallow on the hills. Of special interest is the apparent ability of *Eucalyptus urnigera* to tolerate dense clay soils with impeded drainage. In low areas water may stand around the trees, even when young, for several days at a time without ill effects.

So far as I have been able to learn, only one timber company has initialized trials of *Eucalyptus*, along with cottonwood, for biomass fiber production. International Paper Company is investigating the possibility of growing *Eucalyptus* species on its coastal lands near their pulp mill at Gardiner. There is no firewood market for *Eucalyptus* in the Northwest since there are no established stands of a size to harvest. While it is premature to draw specific conclusions from the limited research I have carried on, there is a developing interest and demand, and people can be expected to plant *Eucalyptus* trees.

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Southern California Trial Plantings of *Eucalyptus*¹

Paul W. Moore²

Following the Arab oil embargo of the 1970's, new interest was generated in renewable energy resources. Among the forest species that had potential for rapid production of biomass was *Eucalyptus*.

Three species had shown wide adaptation to California soils and microclimates. *Eucalyptus globulus* was widely planted as windbreaks and woodlots in the milder coastal and intermediate valleys from the Mexican border on the south to the Oregon border on the north. *E. camaldulensis* and its closely allied species *E. teretecornis* dominated the interior and desert valley plantings.

Observations and comparisons of these *Eucalyptus* species with other genera such as *Acacia*, *Grevillea*, *Pinus*, *Platanus*, *Populus*, *Prosopis*, and *Taxodium* strongly supported the assumption that certain *Eucalyptus* species would be the best selections for biomass production in climatically suited sites in California.

In order to obtain better data on the comparative performance of *Eucalyptus* in an interior valley of southern California, a trial planting was made in the spring of 1979 at the Moreno Ranch field station of the University of California near Sunnymead, California (117°11' W longitude, 33° 54' N latitude).

¹Presented at the Workshop on *Eucalyptus* in California, June 14-16, 1983, Sacramento, California.

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Abstract: A trial planting to compare the biomass production of 9 tree species was established in May 1979. Species compared were *Acacia melanoxylon*, *Casuarina cunninghamiana*, *Casuarina equisetifolia*, *Eucalyptus camaldulensis*, *E. dalrympleana*, *E. regnans*, *Populus* hybrid, and *Taxodium distichum*. *E. globulus* was substituted for *E. regnans* when the latter failed to survive.

E. camaldulensis and *E. dalrympleana* were superior to all other species.

Other commercial plantings have been established in the intermediate and interior valleys of Riverside and San Diego Counties. *Eucalyptus* species included in such plantings are *E. bicostata*, *E. camaldulensis*, *E. camphora*, *E. deanei*, *E. globulus*, *E. grandis*, *E. rudis*, *E. saligna*, *E. tereticornis*, *E. trauti*, and *E. viminalis*.

Observations are being made on the comparative performance of the different species and their response to varying stocking rates and cultural practices.

Eight species were planted on May 22, 1979. These were:

Casuarina cunninghamiana, *Casuarina equisetifolia*, *Eucalyptus camaldulensis*, *Eucalyptus dalrympleana*, *Eucalyptus globulus*, *Eucalyptus regnans*, *Populus* hybrid, *Taxodium distichum*.

The *eucalyptus* species were obtained from the California State Department of Forestry nursery at Davis, California.

The *Casuarina*, *Populus* hybrid, and *Taxodium* seedlings were obtained from the Florida State Dept. of Forestry nursery. The *Populus* hybrid was planted as unrooted hardwood cuttings. All other trees were small seedlings. *Acacia melanoxylon* were grown from seed purchased from Carter Seed Co., Vista, California.

Each species was replicated 10 times with 9 trees planted 3 X 3. Spacing was 10' X 10'.

Soil

San Emigdio Loam. One percent slope.

Temperature

Extreme annual range between -12.8°C to 43.3°C. In most years the lowest minimum is close to -7°C. The highest maximum is in the range of 40°C to 42°C.

Wind

Prevailing daily winds during the growing season are from the west and southwest with velocities of 9 to 12.9 km per hour. During the

winter months strong easterly Santa Ana winds with velocities of 30 mph and gusts as high as 60 mph occur annually.

Rainfall

The 100-year annual average rainfall is 10.85". Total annual precipitation ranged from 2.95" to 22.45". Rainfall patterns show several occurrences of 2 to 6 consecutive dry years with monthly rainfall patterns that would be unfavorable for establishing and maintaining non-irrigated plantings. Seventy-one percent of the total annual rainfall occurs during the 4 months December through February. Monthly rainfall during April to October is insignificant and would not contribute enough soil moisture to sustain growth.

Irrigation Water

Irrigation water is supplied from wells. Total dissolved solids fluctuated around 550 ppm. Boron content is 0.77 ppm. During the first year irrigation was given weekly for the first month then extended to 3-week intervals during the summer months. Three-week intervals have been maintained during the second, third, and fourth growing seasons.

Fertilizer

No fertilizer has been applied throughout the life of the planting.

Weed Control

Weed control has been practiced to maintain a weed free condition. The worst weed on the site is bind weed (Convolvus arvensis). Mechanical cultivation by disk plus Roundup spray as required is the program.

Survival

Survival rates were taken on July 24, 1979 -- 9 weeks after planting.

Eucalyptus regnans had very poor survival rate: 58 percent were dead by July 24, 1979; 25 percent were weak and only 17 percent were considered normal. Because of the poor survival all plots of E. regnans were eliminated and planted with Acacia melanoxylon. The Acacias were grown on the site in 1-gallon cans from seed purchased from Carter Seed Co., Vista, California. Transplanting was done during the 1st week in August 1979.

Survival counts were made on July 24, 1979. Eucalyptus globulus had a survival rate of 66 percent; E. camaldulensis 99 percent; E. dalrympleana 78 percent; Populus hybrid 92 percent; Casuarina cunninghamiana 78 percent; C. equisetifolia 67 percent; Taxodium distichum 99 percent.

Cold Tolerance

Minimum temperatures of -7.2°C occurred on the night of November 14, 1979 and -7.8°C on the night of November 21, 1979. Freeze injury was evaluated on December 10, 1979.

Severe injury was sustained by E. globulus, C. cunninghamiana and Acacia melanoxylon. Most trees of these species were killed to the ground. A few resprouted from the basal buds in the spring of 1980.

Moderate injury occurred on C. equisetifolia.

Slight to moderate injury occurred on E. camaldulensis.

Slight tip burn was sustained by E. dalrympleana.

No injury was experienced by the Populus hybrid or Taxodium distichum.

Insect Damage

The only insect damage observed was an invasion of Poplar borers. The trunks were so weakened by borer activities that several trees broke near ground level. The infestation occurred on all of the Poplar trees in the planting. This was considered to be a serious drawback for the species and it was eliminated from further studies and all trees were removed at the end of the 1981 growing season.

Eliminations and Selections

At the end of the 1981 growing season an evaluation was made to select the species with the best potential for wood fuel production.

The following species were eliminated from further study due to their poor performance as indicated below:

Acacia melanoxylon due to susceptibility to cold damage and slow growth compared to the 2 remaining Eucalyptus species.

The 2 Casuarina species due to cold tenderness and comparatively slow growth.

The Populus hybrid because of susceptibility to severe damage by the Poplar borer.

Taxodium distichum due to extremely slow growth and injury by boron in the irrigation water.

The 2 Eucalyptus species, E. camaldulensis and E. dalrympleana performed so much better than the other species that they were saved for further observation and future selections for seed trees.

E. camaldulensis is superior to E. dalrympleana for total biomass produced to date. However, in cold locations E. dalrympleana would be more

likely to survive sub-freezing temperatures during the early life of a planting.. E. dalrympleana is cited as being resistant to temperatures as low as, -12°C whereas E. camaldulensis is cited to resist minimum temperatures of -6°C.

Observations of established E. camaldulensis in the interior valleys around Perris, Hemet and Winchester verify that this species is resistant to -10° in these locations.

Variability

Great variability exists in the population of E. camaldulensis in this trial. Volume calculations on a tree-to-tree basis made on December 8, 1982 showed a range in volume of 0.12 cubic feet to 5.30 cubic feet per tree. Fifty percent had a calculated volume of 2.00 cubic feet or larger.

It has been decided that the best 25 percent of the trees should be saved as a seed source block for future plantings and all others will be removed. This decision is based on the possibilities of genetic improvement demonstrated by Franklin and Meskimen in Florida.

E. dalrympleana produced less wood than E. camaldulensis. The calculated volume of the smallest tree was 0.19 cubic feet and the largest 3.17 cubic feet; 10.5 percent was larger than 2.00 cubic feet and 18.4 percent was larger than 1.5 cubic feet. The largest 50 percent averaged 1.2 cubic feet per tree.

One is tempted to speculate from data collected to date and estimate yields under another set of conditions.

The spacing on this trial is wide, 10' X 10', and the planting density is low, 435 trees per acre.

Increasing stocking density to 680 trees per acre (8' X 8') would be expected to increase yield in a short-term harvest cycle. Observations of the present planting suggest that an 8' X 8' spacing would increase the number of stems by 56 percent without decreasing stem sizes during the first 4 growth seasons.

In addition, genetic improvement could improve yield. In this trial planting there is a great variability between trees.

If we could improve our seed sources to eliminate genetically weak seedlings from the population it appears reasonable to increase yield per acre by 50 percent. In fact, Franklin and Meskimen, working in Florida, achieved a 68 percent increase in volume after one generation of selection in Eucalyptus robusta. Comparisons were made at 4-1/2 years of age.

Using two concepts of a denser planting and genetically improved seed sources, it appears that we could have achieved a theoretical increase in yield of approximately 55 percent.

The yield per acre of E. camaldulensis for all trees at the 10' x 10' spacing was 8.99 cords per acre at the end of the third growing season (90 cubic feet of solid wood equal 1 cord). A closer spacing of 8' x 8' would have resulted in a yield of 13.6 cords per acre.

If a genetically improved strain could have been used which would have performed as well as the largest 50 percent of the trees in the existing planting, production would have been 14.4 cords per acre at the 10' X 10' spacing and 22.5 cords per acre for the 8' X 8' spacing.

The dalrympleana yield at the 10' X 10' spacing was 6.42 cords per acre at the end of the third growing season. An 8' X 8' spacing would have yielded 10.0 cords per acre.

A genetically improved strain yielding the equivalent of the largest 50 percent of the existing trees would have produced a theoretical yield of 8.7 cords per acre in the 10' X 10' spacing and 13.6 cords per acre at the 8' X 8' planting.

Measurements on an irrigated 34-month-old commercial planting of E. x trabutii with a very close spacing of 3' X 5' (2904 trees per acre) gave an estimated yield of 3.24 cords per acre. The high density of this planting contributed to extremely light competition and small stem diameters averaging 1.9" DBH. Mortality, or weak trees which would most likely be unharvestable, was estimated at 25 to 30 percent of the stand. At this point in time it appears that very dense plantings will not develop good marketable cord wood sizes during a short harvest cycle of 4 to 5 years. Marketing of such plantings may be in the form of chips or densified pellets.

Other Plantings

A number of plantings have been made in San Diego, Riverside, and Imperial Counties. Those that I have observed were planted in 1980 and 1981 and 1982. Among Eucalyptus the species that have been included in commercial plantings are: biocostata, camaldulensis, camphora, dalrympleana, deanei, globulus, grandis, gunni, nova anglica, rudis, saligna, tereticornis, trabutii, urnigera, and viminialis. Clonal lines from E. grandis, E. camaldulensis, and E. x trabutii selections are being compared to seedling populations for uniformity.

It is too early to make recommendations based on the limited time that such plantings have been growing. However, some interesting observations might be cited.

E. grandis has been the most rapid grower but is also frost sensitive: 7-month-old trees exposed to -7.7°C sustained the most damage compared to 13 other species in the same planting. Saligna was the next most sensitive.

Three selections of E. globulus from cold

provenances of Tasmania were only slightly injured whereas E. globulus from a California seed source were killed to the ground by the same temperature in 1979. These provenances may be cold tolerant candidates for future plantings in the interior valleys of southern California. E. globulus appears to be equivalent to E. grandis in growth rate.

E. x trabutii, alleged to be a hybrid of E. botryoides x E. camaldulensis, is growing more rapidly than E. camaldulensis. Cold tolerance is equivalent to camaldulensis.

E. dalrympleana may be a satisfactory selection for cold sites. It appears to be growing more rapidly than E. gunnii.

E. camaldulensis and E. tereticornis occur on old non-irrigated stands throughout the interior valleys of Riverside County. They have survived drought, high temperatures, and sub-freezing temperatures. E. camaldulensis appears to be the most universally adapted species for the interior valleys and Imperial Valley of southern California. When in doubt regarding species selection in these localities, E. camaldulensis would be the safest choice.

The best seed source is the Lake Albacutya provenance of Australia and is available from Australian seed companies.

It is doubtful if any planting can be established without irrigation at least during the first two years of life.

Availability of low-cost water is an important consideration in site selection.

Although Eucalyptus has grown in California for well over a century, it has been only since the Arab oil embargo that interest in its culture as a renewable energy source has been renewed. Until recently, no research has been conducted in California on species performance, cultural requirements under intensive care, and the economics of production and marketing wood for fuel.

Some research is now under way to find answers to these questions. Significant information should be available since 1979. The first harvest of these plantings may be made as early as 1984 assuming a 50-year harvest cycle for the better plantings.

Following the first harvest the California industry will have better recommendations for future management of wood energy farms.

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Soil Conservation Service Tests of *Eucalyptus* Species for Windbreaks¹

Gary L. Young²

The Soil Conservation Service (SCS) is an agency of the U. S. Department of Agriculture. Our national plant testing program includes many grass and tree species and its goal is selecting adapted cultivars for soil erosion control. The SCS operates 23 Plant Materials Centers (PMC) nationwide, and 2 of the Centers located at Tucson, Arizona and Lockeford, California are involved in testing trees for windbreaks in the southwest. We are looking for widely adapted cultivars of several *Eucalyptus* species for use as windbreaks throughout the Mediterranean climate area of California and the adjoining warm winter area of Arizona. Our program will consist of initial testing, evaluation, and advanced testing. We expect to be involved with growing and evaluating *Eucalypts* for the next 20 years.

TEST CONDITIONS

Climate

The climatic means and extremes at Lockeford and Tucson are similar. The minimum temperature reached on an average of once each year is -8° to -7°C (18° to 20°F) and lasts less than 6 hours. The highest temperatures expected in the summer are 42° to 44°C (108° to 112°F), slightly lower in Tucson. For Lockeford, the long term average annual rainfall is about 430mm (17 inches), nearly all falling in the 6 months of winter.³ Tucson is dryer, with an average of 280mm (11 inches), but the rain is more evenly distributed over the year (Briggs 1982).

Soils

The soils at Tucson are Grabe loam and Comoro

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Abstract: The Soil Conservation Service is in the early stages of testing many species of *Eucalyptus* for windbreaks. Over 260 different species have been collected. The pre-planting selection criteria and process is described as well as the test conditions and procedures. Some sources of information on the use of the *Eucalypts* may be misleading through overgeneralization. Early results support the need for greater communication and testing of a wide variety of species and provenances in California.

fine sandy loam more than 1.5m (60 inches) deep. They are moderately alkaline and somewhat calcareous (Richardson 1979). The soils at Lockeford are deep Honcut loam and Columbia fine sandy loam. They are neither alkaline nor calcareous.⁴

Management Practices

The management practices at Tucson and Lockeford are also similar. Because we are testing these trees for use as part of a 2 or 3 species windbreak, we will manage them as we would expect the landowner to manage them. The *Eucalyptus* are planted in the spring and given deep irrigations as needed during the first summer. Supplemental irrigations in following years will be applied as necessary. We feel the increased survival and vigor of the trees justifies the investment of water and time to provide irrigation for many years.

Weed control is essential and is performed chemically and mechanically as long as needed. The trees are usually able to shade out weeds and/or withstand the competition from them after 2 years.

The management program for the nursery also includes removing broken limbs and downed or severely damaged trees. Any pattern that may be found in the breakage of limbs and trees is valuable data to record and can eliminate from further testing any species that are excessively prone to wind-throw and damage.

Design and Evaluation

At Lockeford, the plantings (nurseries) are made in blocks, not oriented or designed as windbreaks. This is primarily to save space and to facilitate management within our normal field divisions. The nurseries contain 36 accessions of *Eucalypts* (in addition to many accessions of other genera) planted in 1979, 1980, and 1981.

At Tucson, in order to include the largest possible number of different species in the tests,

⁴Soil survey records on file, Lockeford Plant Materials Center, Lockeford, Calif.

a decision was made to include those accessions where there were only 1, 2, or 3 specimens available after propagation. This causes problems in measuring the significance of observations based on so few individuals. The normal full complement at Tucson is 4 and at Lockeford is 6. At Lockeford, no accessions were included which had fewer than 6 specimens at planting time.

The trees are planted in rows of 5 accessions, each represented by 6 specimens. The spacing between the trees is 3m (10 feet); the spacing between rows is 6m (20 feet). This spacing represents a compromise between proper spacing for windbreaks and wider spacing to allow the natural shape and size to be expressed. The different accessions are evaluated throughout the year. The trees are measured for height and width (canopy cover) at the end of each growing season. The accessions are also rated for stem abundance and distribution and foliage abundance and distribution in comparison to a known standard. The standard we are using for our Eucalypts is Dwarf blue gum, (*Eucalyptus globulus* var. *compacta* Labill.), which has been in the California landscape trade for many years. As a common landscape tree, it has been planted widely, and its performance is well known. The trees are also rated for their resistance to disease, insects, cold, heat, and drought. A rating is made twice a year of the accession's vigor and of its suitability. Both of these ratings are somewhat subjective, but both are closely related to the standard of comparison. As a measure of vigor, Tucson has used the height of each year's growth expressed as a percentage of the mature height expected. All of these measurements and ratings (and many more facts) are done on standard forms. The data is then entered into the nationwide data bank SCS maintains for plant material evaluations.

SPECIES SELECTION

When we assemble a collection, it is for a particular need; in this case, windbreaks. The selection process used by the SCS is to explore existing information sources to select the 2 or 3 most promising species. We then conduct ecotype testing within that species. Unfortunately, there are many species of *Eucalyptus* and a small number of references and information sources for their adaptations. Because of this, we decided to test a large number of *Eucalyptus* species for general characteristics. From these, we would select a few species on which to conduct provenance or ecotype testing.

Collection

The group of species from which we can make our selection has been strongly affected by our source of seed. We requested packets of seed from Australia through our National Plant Materials Center at Beltsville, Maryland. The Australians sent us many small packets from the National

Botanic Garden in Canberra. Most of the packets are marked with some collection location data. The amount of seed in a packet (usually less than 1 gram) is seldom enough for more than a single test. The Australians have compensated for this by sending a large number of species. We have received over 300 accessions from Australia and about 50 from domestic sources. Many of these 50 were probably also collected in Australia. These 350 accessions represent 263 species. We will select from these to compile the list of species and accessions for our future plantings. The next nursery will be propagated soon and will be planted in the early spring of 1984. It will consist of approximately 200 accessions.

To guide us in our selection, we are using information from the first small nurseries we planted in 1979, 1980 and 1981 combined with information from the Tucson PMC. Several reference books we have located contain information on adaptations, requirements, and physical properties for a large number of species (Jacobs 1981). These books also cover a wide range of conditions. Some data are on important or restrictive conditions that we cannot test at Lockeford, such as shallow soils and saline or calcareous soil.

Selection Criteria

Species that are adapted to a wide range of soils and climatic conditions are most appropriate to our needs. More importantly, when we make a selection, it is primarily based on those characteristics that we feel are most relevant to windbreaks in California: growth habit, mature size, drought tolerance and frost tolerance.

Growth Habit

The preferred growth habit is a tree with a columnar form and one to several trunks. The foliage and small limbs should be persistent and relatively dense near the ground for several years. These two basic requirements can cause conflicts with other management systems. The multiple trunks and the persistent foliage near the ground would be negative factors in a woodlot management system. The low foliage would also contribute to the fire hazard that is a concern with the Eucalypts.

Deciduous bark, leaves and branches can create a problem when *Eucalyptus* are planted near row crops. Selection of a species for agricultural windbreaks is limited by these characters not because they affect windbreak efficiency, but because they affect the acceptance of a species by users.

Mature Size

For our needs and our tests, the mature size should be between 15m (50 feet) and 40m (130 feet). This large size is preferred for two reasons.

First, the large trees have a very rapid growth rate when young, (expressed as a percent of mature height achieved each year) and will thus achieve a suitable height for windbreaks (8-12m 1.26-40 feet) in a relatively few years. Second, the major application for these trees is the protection of agricultural land and operations. The economics of farm management dictate that windbreak rows be tall and widely separated to minimize the land consumed and maximize the size of the fields between windbreaks.

Drought and Frost

Drought tolerance and frost tolerance are the two most important factors used by Eucalyptus growers in species selection.⁵ Both are somewhat subjective and are affected by local conditions. The data the growers are relying on could be misleading.

Their information may be based on a vigorous local planting. A species' sensitivity may be masked by an unknown irrigation source or a more sheltered position during frost periods. To obtain accurate frost sensitivity or tolerance data, we maintain a recording weather station approximately 300m (1000 feet) from our plantings.

We are trying to select species that are drought tolerant, but we are not subjecting our plants to drought at this time for two reasons. First, we propose and presume that windbreaks will generally be irrigated. Second, we are unable to subject the plants to a true drought due to a fairly shallow moisture level from the nearby Mokelumne river.

In the future, advanced testing will involve several different sites in the various climatic areas of California where more extreme conditions will be encountered.

Selection Complications

Another source of errors in suitability information is the misidentification of species that survive or fail. Only training, care, and good reference authorities can solve this problem.

It is also very difficult to interpret the existing climatic data from foreign sources. There are always questions of which data most accurately describe the critical factors. Are they mean maximums and minimums of temperature or are they the extremes?; is it the amount or the distribution of rainfall for the year?

Other questions remain if the information is incomplete or misleading through generalization. Does the dry season coincide with the hot season? Are the frost periods of long duration or of only a few hours? One example of such misleading data comes from a European publication. In describing the climate of California relative to the needs of (E. globulus Labill.), San Francisco is used as the reference climatic station for the state (Jacobs 1981).

RESULTS

One result of our test to date is the observation of two conditions or patterns that exist in some of the Eucalypts.

The first is a variation in the limb attachment morphology between species. The process of shedding small branches in the Eucalypts has been praised by timber and landscape users for producing clear trunks. The process we observed affects the major limbs or secondary trunks in some species, e.g. (E. grandis W. Hill ex Maiden). As a limb puts on its second years' growth, a crescent-shaped area of bark is formed just above where the limb meets the trunk. This crescent extends into the joint area, filling it and forming a plane of weakness directly across the area where tension forces supporting the limb are greatest. The wood in this area also seems to be weak, separating along a conical surface, with very little shattering or breaking. In those species not showing this limb characteristic, e.g. (E. globulus Labill.), the joint area is filled by trunk and limb wood instead of bark.

The second pattern is similar. In some species, e.g. (E. smithii R. T. Bak.; E. macarthurii H. Deane & Maiden), the trunk will separate from the roots. After a tree falls during a strong wind, we see it has broken cleanly near or slightly below ground level. The broken end of the trunk is a convex surface. This surface consists of several planar areas each representing the attachment point for a root. The wood in these areas is not shattered and broken. It appears to be compressed and fibrous. The plane the fibers are in is perpendicular to the centerline of the trunk and roots. A similar surface is on the ends of the roots. There is very little broken wood and virtually no disturbance of the ground where roots have started to pull loose. The area involved appears to be at or near the point where "root" tissue meets "stem" tissue. This physiological point may be a contributing factor in the location of the failure point.

Further observation of these and other species is needed to see if a predictable pattern exists.

Some other preliminary results are variations and correlations between our test plants and the literature.

⁵Personal communication with Sherman Finch, State Forester, Soil Conservation Service, Davis, Calif.

Manna gum, (*E. viminalis* Labill.), has exhibited enough differences between our two accessions that a provenance trial should be conducted under California conditions. There are many provenances recognized in Australia (Jacobs 1981). Both accessions have reached 10m (32 ft.) in 4 years.

Maiden's gum, (*E. maidenii* F. J. Muell.), is now called (*E. globulus* Labill. ssp. *maidenii* Kirkp.). This is our outstanding performer. Starting from seed, it has reached a height of 12m (40 ft.) in 4 years. In Australia, the crown widens as the tree matures (Forestry Commission 1980). This may require a rotation management system to maintain the proper shape.

Sugar gum, (*E. cladocalyx* F. J. Muell.), shows good vigor and growth rate, but it has a bare trunk and an open crown. Sugar gum has been widely used for windbreaks in Australia (Jacobs 1981). Multiple row windbreaks are planted, and every few years one row is cut for wood or poles. The coppice shoots from the stumps fill in the openings between the remaining trunks.

Karri gum, (*E. diversicolor* F. J. Muell.), is described as a tall, single trunk tree that is excellent for timber (Jacobs 1981). Our accession has suffered very minor visible frost damage, but as a result, has become a very irregular shrub.

Camden wollybutt, (*E. macarthurii* H. Deane & Maiden), is considered a good shelterbelt tree because of its form and lack of windthrow. In our accession, 5 of the 6 specimens have broken at the base in moderate winds.

Dwarf blue gum, (*E. globulus* var. *compacta* Labill.), has demonstrated excellent potential for windbreaks. Ours have grown to 5 m (16 ft.) tall in 4 years and are very dense. It may be too dense for the first 3 years, letting very little air filter through. Approximately 5 percent of the

plants revert spontaneously to the tall form. This leaves gaps in the row. This variety may make an excellent 2-row windbreak with one of the taller, more open species.

CONCLUSIONS

It is too early in our testing program for us to have a recommended variety or even a species of *Eucalyptus* for growers and researchers. There are some things we do have. We have seed samples of a large number of species for our future work. As a government agency, we can work through foreign research groups to get more seeds and test results. We also have the facilities of the Plant Materials Center, our testing and evaluation system, and our nationwide data base, to help us develop and distribute information on *Eucalyptus*.

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Eucalyptus as a Landscape Tree¹

W. Douglas Hamilton²

There have been 5 distinctly different studies by Cooperative Extension from the Hayward Office in the last 15 years involving the genus *eucalyptus* and are briefly discussed.

1. Landscape Tree Evaluations: two studies

a) Known as the LTE project, this study, initiated in 1971, involved Extension advisors in 15 counties under the leadership of Extension Specialist, W. B. Davis. We evaluated a range of *Eucalyptus*, most of which were not in the trade. We also evaluated problems related to the site. Forty-three species were selected which were known to have a broad range of adaptability. Seed was obtained from a commercial company in New Zealand and container-grown at University of California, Davis. While growth measurements were made yearly and problems noted, a final rating was made as to the acceptability of the species for the site, from outstanding to unacceptable. In order for a candidate species to be considered outstanding statewide, the species had to be planted at 11 or more project sites which had a wide range of climates and soil conditions and the majority of ratings had to be 4 or 5. Of the 43 candidates, three ranked as outstanding: *E. botryoides*, *E. camaldulensis* *rostata* and *E. aggregata*. Three species were given a special ranking for salinity tolerance: *E. platypus*, *E. spathulata* and *E. sargentii*. Much more information is included in the Report on Evaluations of Several *Eucalyptus* Species, edited by W. B. Davis.

b) The Landscape *Eucalyptus* Tree - An Evaluation Study 1971-78, is the title of a study conducted at the University of California Deciduous Fruit Station in San Jose by W. Douglas Hamilton, Cooperative Extension. Seed sources were botanical gardens in Australia. The plants

Abstract: Ninety-two species of *Eucalyptus* were evaluated at the University of California research station in San Jose. The purpose: to find acceptable new street and park trees. Growth rates and horticultural characteristics were noted. Forty-three species were studied in locations statewide to evaluate site adaptation and landscape usefulness; flooded, cold, dry, saline. Susceptibility-to and recovery-from the prolonged freeze of December 1972 was studied and published. Species response was wide. Prevention of unwanted resprouts was studied. Four alternatives for success were offered.

were grown under the direction of Andrew Leiser, Department of Environmental Horticulture, UC Davis. Ninety-two species were planted; about half in April, 1971, the others in October, 1971. Several observations were recorded.

The April planting quickly became established. The October planting was stunted by the winter temperatures and recovered slowly the following spring, although no difference could be noted after the first year.

All species were measured for height and trunk circumference annually and growth habit, whether mallee or single trunk was noted. Notes were also taken on relating strength of branch angle attachment and flowering. Also, all species were evaluated regarding injury-and-recovery to the 1972 freeze.

Leaf, twig, fruit litter accumulation was measured each month for one year in an effort to evaluate fire hazard and trashiness.

Thirteen species were rated as "most promising" by the author and by industry groups: landscape architects, principal park people, etc. Growth habits, adaptation to the site and possible usefulness were considered among the "winners": *E. accendens* (street tree), *E. archeri* (small, cold tolerant, florist trade), *E. blakelyi* (street tree for cismontaine California), *E. bosistoana* (attractive in nursery, "clean" skyline tree), *E. burdettiana* (small, boxy, exudes character for non-frosty locations), *E. grandis* (50 feet in 5 years, self pruning to single trunk and thus "dirty," fast growing windbreak in mild climate), *E. gunii* (narrow upright, "clean" on droughty soils), *E. intertexta* (a weeping "mayten," excellent patio tree, variable), *E. scoparia* (a more open and "weeping" *E. viminalis*). The report is available from the Hayward Extension office.

2. Damage and Recovery to *Eucalyptus* Resulting from the December 1972 Freeze.

From December 8 through December 15, minimum temperatures at the San Jose research station and

¹Presented at the Workshop on *Eucalyptus* in California, June 14-16, 1983, Sacramento, Calif.

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generally in the San Francisco Bay Area were below freezing; 23°F to 28°F, maximum temperatures ranged from 36°F to 48°F, but mostly near 40°F. This provided an opportunity to evaluate injury and recovery to all the Eucalyptus and note effect of spring and fall planting dates to 1.5 years before. The injury rating scale was: 1 - no visible damage; 6 - above-ground plant dead. An early recovery rating was made on January 4, 1973. A late recovery rating was made on July 26, 1973: 1 - complete recovery or no damage; 6 - dead or no recovery.

Regarding freeze injury, planting date did not appear to affect freeze injury although no one species was planted on both dates. Cold tolerance and recovery of promising species mentioned earlier is as follows:

<u>Ratings (average)</u>		
<u>Species</u>	<u>January 4</u>	<u>July 26</u>
<u>E. accendens</u>	3	3
<u>E. archeri</u>	planted after freeze	
<u>E. blakelyi</u>	1	1
<u>E. bosistoana</u>	4	2
<u>E. burdettiana</u>	4	5
<u>E. grandis</u>	2	1
<u>E. gunii</u>	1	1
<u>E. intertexta</u>	2	1
<u>E. scoparia</u>	1	1
<u>E. microtheca</u>	1	1
<u>E. spathulata</u>	3	3
<u>E. maculosa</u>	2	2
<u>E. populnea</u>	1	1

3. The top-kill of between 2 and 3 million bluegum and river redgum Eucalyptus in the Oakland-Berkeley hills raised many questions: how to avoid a fire danger from the litter and resprouts, how to open fire lanes and biking trails, protect views and how to generally prevent Eucalyptus from resprouting where they were unwanted. Methods used in Australian forests were untenable in the urban areas. In view of this, field research was initiated in 1973 and numerous trials were conducted through 1978. Two methods were successful (+97 to 100 percent control). One was to cut the stump to 4 to 6 inches below the ground surface. A survey of the points of attachment for bluegums indicated that all sprouts originated between ground level and 4 inches below. The second method was to make a fresh cut near the ground level, into the wood. It is essential that the cut be continuous. Into this cut, whether it be the whole cross-section or just the ax frill, is poured a solution (50 or 100 percent); 2,4-D water soluble amine (Weedar-64), glyphosate (Roundup), or the granular material ammonium sulfamate (Ammate-x). Other materials were tested on an experimental basis, but are not available or not registered for this use.

4. Control of trunk sprouts with growth regulators on the landscape tree was successfully tested more than 10 years ago by R. W. Harris,

R. M. Sachs and R. E. Fissell at UC Davis. Sprouts on E. camaldulensis and E. viminalis were prevented from developing by the application of 1 percent naphthalene acetic acid (NAA). Results were significant at the 1 percent level. Translocations of materials stayed at the sprout attachment, so no injury to the trees was observed.

5. The storms of late 1982 and early 1983 in the San Francisco Bay Area resulted in considerable limb breakage and tree blow-over. A survey of November-December storms damage involving 35 communities indicated that Eucalyptus species in general and several Eucalyptus species in particular (bluegum, ironbark, silver dollar, peppermint and sugargum) had severe blow-over problems. Limb breakage was noted to be the highest for any one problem species. Twenty-five surveys mentioned Eucalyptus and acacia as problem trees. The genetic habit of the species plus splitting crotches, dense tops, closely-spaced limbs and large limbs of equal size were most often cited as causes of problems. In fairness, however, much of the problems observed were termed catastrophic failures; unpreventable.

Somewhat akin to folks devoted to native plants, the species Eucalyptus has its devotees and detractors. Generally, detractors are people familiar only with the bluegum. While it is true that few people are planting bluegums, others have found that in general, Eucalyptus have an aggressive root system which tends to be shallow and fast-growing; thus there are root-pavement problems and problems of sufficient irrigations of companion plantings. Many of the Eucalyptus grow too large for the small properties where they are planted and the litter produced by many becomes an unwanted nuisance. Some nurseries indicate a slowing demand for Eucalyptus. For Eucalyptus to maintain or serve their useful place in the landscape, it will be necessary to recognize certain species and extoll their usefulness.

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Creating a Database on *Eucalyptus* for California¹

Miles L. Merwin²

Increasing interest in rural woodlots for fuelwood and low-maintenance ornamental plants has sparked a resurgence in eucalyptus plantings in California. Those concerned with planting, propagating and maintaining trees are turning to public and private land use advisors, e.g. University of California Cooperative Extension, Calif. Department of Forestry and U.S. Soil Conservation Service, for detailed information on the many eucalyptus species that have been introduced into the state. Despite the fact that eucalyptus have been planted in California for over a century, up-to-date, reliable information on the growth, yield and suitability for different uses of individual species is not readily available. While a number of past and present species trials have been performed, the results of this work have not been collected systematically into a form readily useable by those called upon to provide information to the public.

Interest in eucalyptus planting as well as organized field trials are likely to continue in future. Therefore, a coordinated effort to collect and disseminate information about eucalyptus species in California would benefit a wide variety of people concerned with the genus. This information would be useful to public and private agencies that advise landowners on land use decisions, nurserymen that propagate the trees, landscapers that incorporate eucalyptus into the urban landscape for amenity and shade, and ultimately the individual citizen interested in planting the trees.

INITIAL SPECIES SURVEY

In 1982, a compilation of information was begun on a number of eucalyptus species that have been planted or proposed for trial in California. The purpose was to collect the following information: (1) results of past and present planting trials in the state; (2) data on the typical growth, climate and soils of the native range in Australia; and (3) other relevant information on

¹Presented at the Workshop on Eucalyptus in California, June 14-16, 1983, Sacramento, California.

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Abstract: While public agencies, nurserymen and landscapers are receiving more inquiries about individual eucalyptus species for California plantings, little information is readily available to them on the potential usefulness or adaptability of these species. A survey of eucalyptus species was undertaken to collect information on their performance both in California trials, their native range and other overseas countries. It is proposed that this survey form the basis of a printed handbook and computer database on eucalyptus in California as an on-going interagency project.

the performance of individual eucalyptus species when planted as exotics (introduced species). This species survey was intended primarily as a useful reference for public land use advisory agencies, foresters, farm managers, nurserymen, landscapers and researchers. It was not intended as a popular guide for the average landowner, except those cooperating in research trials.

The species survey was initiated under the direction of Dr. Andrew Leiser, Dept. of Environmental Horticulture, University of California, Davis. Species chosen for study were taken in part from earlier unpublished work by Dr. Leiser on drought resisting plants (Leiser, 1983) and in part from a review of the literature on other species exhibiting some degree of frost and/or drought tolerance. Over 100 species were initially chosen for study.

Using standardized data collection sheets, information was first compiled on the growth, climate, soils, wood and uses of each species in its native range in Australia, and the comparative success and productivity of those species when planted commercially overseas. After this initial review, several species not adaptable to cultivation as exotics or suitable only as ornamentals were eliminated from further consideration.

Information on the remaining 79 species was summarized in a standard format. This first draft was then sent to a number of reviewers in California with requests for information on past and present planting trials, uses and other practical experience with their cultivation in the state. The literature was also searched for published reports on past trial and commercial plantings of eucalyptus species. Only those species for which well documented information on trial plantings is available are included in the final selection. The particular selection of species covered in the published report (Merwin, 1983) does not mean to imply that other species have not been tested or would not also be potentially successful if introduced into California.

FORMAT AND CONTENT OF SPECIES SURVEY

A standardized format was used for the compi-

GROWTH IN NATIVE RANGE: Tree usually 80-120 ft. (to 150 ft.) tall with an often crooked trunk 3-7 ft. in diameter and a thin crown. Vigorous coppicer. Fairly fire resistant. Fast growing.

NATIVE RANGE: All states except TAS, along year-round and seasonal watercourses, esp. the Murray-Darling River system, at 100-750 (to 1800) ft. elevation. Latitudinal range 15.5°-38°S.

CLIMATE OF NATIVE RANGE: Annual rainfall mainly 10-25 in. (to 40 in.). Relies on seasonal flooding or high water table in areas of 10-15 in. rainfall. Hot dry summers with temps. to 115°F. Lowest temp. 23°F. (-5°C). Frosts 5-20.

CLIMATIC TOLERANCES: Drought. Reportedly tolerates 20-26°F as exotic.

SOILS OF NATIVE RANGE: Best on deep silty soils, clay soils and podsols. Ecotypes grow on poor soils, e.g. poorly drained flats wet for several months that don't completely dry out, acid sands, alkaline swampy clays. Becomes chlorotic on calcareous soils.

SOIL-RELATED TOLERANCES: Flooding. Heavy clay soils. Salinity (selected provenances). Coastal salt spray.

WOOD: Red, interlocked or wavy grain, gum veins or pockets common, hard, durable, termite resistant, density 980 kg/m³. May be difficult to split.

USES: Fuelwood, post/poles, shelter, amenity, honey, particle board, sleepers.

PROVENANCE: At least 8 distinct groups of provenances identified, each with significant differences in drought or frost resistance, growth rate and wood properties. 6845 Lake Albacutya, VIC proven consistently superior in tests throughout Mediterranean-type climates (FAO).

SUCCESS OUTSIDE AUSTRALIA: Important commercial species in Spain, Morocco, Israel, Turkey and other Mediterranean countries.

PRODUCTIVITY IN PLANTATIONS: Good sites: aver. 2.2-3.3 cords/ac/yr. Poor sites: aver. 0.2-1.1 cords/ac/yr (FAO).

GROWTH IN CALIFORNIA:

Chapman, 1982: "Spanish" selection from Florida Div. of Forestry gave best growth rate and survival of all species tested over a wide variety of Calif. sites.

Davis, 1978: Outstanding results. Species most tolerant of wide range of unfavorable soil and climatic conditions, e.g. salinity, flooding, poor drainage and drought. Survived 1972 freeze (15-25°F). Upright narrow growth form observed.

Ledig, 1983: In test of 23 provenances at Concord N.W.S. and other sites, Lake Albacutya, VIC was approximately 161 percent better than average for all provenances. This and other superior provenances all came from Murray-Darling River drainage [sic] in VIC and NSW.

Heavilin, 1978: Killed by frost at Redwood Exp. For.

King and Krugman, 1980: One of the best surviving, fastest growing spp. at Concord N.W.S.

McClatchie, 1902: Grows well on coast and in foothills, interior valleys and deserts. Fast growing. Open grown trees often very forked.

Metcalf, 1924: MAI of 26 plantations, average age 9 years, was 1.2 cords/ac/yr (range 0.4-2.8). Grows better in interior valleys and So. Calif. than along the coast.

Metcalf, 1967: Survives annual flooding along Sacramento River. Grows well in Imperial Valley with irrigation. Has survived temps. lower than 23°F in Sacramento Valley but tops killed back by 1932 freeze. Tree at Watson Arb. grew 14 ft. with 1.6 in. dbh in 2 yrs.

Sachs and Low, 1983: Two year old coppice growth at Davis from 5000 trees/ac with flood irrigation (fertilizer at planting only) yielded 16.81 ODT/ac/yr (aver. 2.0 ODT/cord). Yield for hybrid with E. rudis in same trial was 16.94 ODT/ac/yr.

PLANTING PROSPECTS: Excellent with careful provenance selection.

PAGATION: Adaptable to containerized nursery production but liable to be quickly overgrown. Light essential for full germination.

OTHER: Hybridizes with E. botryoides to form E. X trabuttii, and also with E. rudis.

REFERENCES: Boland, et. al., 1980; Coate; FAO, p. 369; Hall, p. 100; Hemstreet.

Figure 1--Example of standardized format for compilation of species information.

lation of species information, an example of which appears in Figure 1. Species nomenclature conforms to the most recent classification of the genus (Blakely, 1965). The "Blakely Number" assigned to each species or subspecies is listed after the Latin binomial.

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Native Range

The first few headings describe the common growth form, geographic and topographic locations, average climatic conditions, soil factors, wood characteristics, main farm and/or commercial uses, latitudinal range and provenances (if any) for each species in its native habitat in Australia.

Under the heading "Growth in. Native Range," the range of observed heights for each species, as a tree or mallee, are given along with crown characteristics and the diameter, form and length relative to total tree height of the trunk. Observations from the native range are also included on relative growth rate, coppicing ability, fire sensitivity and other details.

Australian states included in the native range of each species appear under "Native Range." Topographical distribution, elevations, and latitudinal range are also listed here. The more widespread the geographic and topographic distribution of a species, the more diverse the local ecotypes are likely to be. Thus careful selection of provenance for seed collection becomes more important (F.A.O., 1979).

Average climatic data for the native habitat is listed under "Climate of Native Range." Annual amount and seasonal distribution of precipitation is listed along with the relative length and severity of the dry season. Rainfall and dry season length are indicative of the relative tolerance of low moisture and high summer temperature conditions that the species may exhibit as an exotic. Lowest recorded temperatures in the native range and the frequency of frost are also given. While this information may indicate the relative cold hardiness of a species, widely distributed species will exhibit high variability in this trait. In some cases, species may tolerate lower temperatures when planted as exotics than in the native range (F.A.O., 1979).

Edaphic factors for each species are listed under "Soils of Native Range." Listed first are the preferred types of soils on which best growth occurs, then those soil types on which the species also occurs but where its development is not optimum. Among the characteristics noted of these soils are texture, structure, relative depth and drainage, pH, presence of salts or limestone and overall quality.

Environmental Tolerances

Data on growth form, climate and soils recorded under the headings described above is representative for each species in their native range and is intended as a benchmark for each species.

Their growth and environmental tolerances when planted as exotics, e.g. in California, may be different than that found in the native range. Thus information listed under the headings "Climatic- and Soil-Related Tolerances" summarizes observations from both the native habitat and plantings outside Australia. Comparative tolerance to the most important limiting factors, e.g. drought, cold, flooding, salinity, etc., are listed under these headings.

For the introduction of these species into California, cold tolerance is generally a more important limiting factor than drought (since plantings are usually at least established with irrigation), thus determining their adaptability to different geographic regions of the state (Hemstreet, 1983). However, drought tolerance is also an important factor since many eucalyptus species are used in low-water, low maintenance situations specifically because of their resistance to drought. Soil factors may be less important in determining the suitability of individual species to exotic plantings, except in extreme situations such as heavy clays, infertile sands, shallow or poorly drained soils, and highly alkaline or saline soils.

Characteristics described of the wood of each species as harvested under native range conditions include color, grain, hardness, structural strength, durability (in contact with soil as a fencepost), ease of splitting, and density. Traditional or commercial uses for each species and its products in Australia are recorded under "Uses." Feasible uses for the trees when planted as introduced species in California may be different from those listed.

Provenance

Seed provenances that have been identified, collected and tested are listed under "Provenance." In some cases where the geographic and topographic distribution of a species is wide, recommendations for provenance testing or careful selections are noted. Due to the inherent seedling variability of these wide ranging species, proper selection of seed provenance can be crucial to the success of a trial or commercial planting (F.A.O., 1979). In prior evaluations of overseas trials of these species, the possibility should be considered that the provenance of the seedlings tested was mismatched to the test site or was atypical of the species. Current provenance trials in California and other countries are also noted under this heading.

Overseas Plantings

Then follow several sections related to species performance as exotics, i.e. successful plantings outside Australia, yield in intensive plantations, and growth in different areas of California. Growth rates and wood yields from intensively-managed, overseas industrial plantations, under "Productivity in Plantations," are reported with a word of caution that the yield

that can reasonably be expected from stands of any species is strongly dependent on site quality and level of management (Standiford, 1983). Mention of successful commercial overseas plantings under the heading "Success Outside Australia" is restricted to only other American states (e.g. Florida, Hawaii) and those countries that contain areas climatically similar to California (i.e. Mediterranean type), even though there may be other nations where a particular species has been planted.

Under the heading "Growth in California," published reports on field trials and commercial plantings in the state are summarized. Personal communications with individual researchers, foresters, nurserymen, etc. are also included here. When comparing the performance of a species in the various test plantings reported, consideration should be given to the existence of factors that affect seedling performance, e.g. differences in planting method, irrigation, spacing, provenance, etc. While efforts were made to report on as many plantings of eucalyptus in California as possible, there are obviously many others that are either not well documented or were unavailable to the author.

Propagation

The section entitled "Planting Prospects" is a consensus of opinion from the references cited on the relative usefulness of a particular species and its adaptability to different regions of the state. Species are rated under "Propagation" for their relative adaptability to containerized production in commercial nurseries based on information supplied by two experienced California nurserymen (Coate, 1983; Solomone, 1983). While most eucalyptus species are adaptable to containerized propagation, fast growth during the early seedling stages makes them susceptible to quickly becoming overgrown and rootbound, thus timing is more critical than with slower-growing species (Coate, 1983). Finally, additional information on hybrids, varieties, cultivars, seedling variability, disease and pest resistance, storm damage, pruning needs, etc. are listed when available under "Other."

PROPOSED HANDBOOK AND DATABASE

The information contained in the written survey of eucalyptus species described above lends itself to adaptation for an electronic database accessible by microcomputer. This database would be designed for use in conjunction with a printed, looseleaf handbook on eucalyptus, published as an on-going interagency project. It is proposed that this initial survey form the basis for the creation of such a handbook and database.

Most of the inquiries about eucalyptus received by land use advisors, nurserymen and landscapers will likely be to identify those species adaptable to a particular set of climatic and edaphic conditions, and useful for particular purposes. With

a computerized database, this information can be retrieved with relative speed and ease compared to manual searching of printed documents. Several database management programs are commercially available that could be used to cross-index succinct categories of information, or "fields," for individual species, such as growth rate, drought tolerance and uses. Thus, for example, one could use several "keywords" each relating to a different field to ask for a list of species adaptable to moderately cold winters and summer drought on heavy clay soils that are useful for windbreaks or firewood. Once such a list was retrieved, users could then refer to the printed handbook for a current, detailed description of each species, listing such information as seed provenances, commercial availability of seedlings and research contacts.

Creating the Database and Handbook

The primary task of creating the database will be to define the individual characteristics of each species that will be cross-referenced by computer, either in relative or absolute terms. Once the necessary software is modified and the original database is completed, periodic updating of species information could be done simply by issuing supplemental pages for the handbook. Researchers and others involved in field evaluations could report their results as available to one agency whose responsibility would be to update the handbook with this new information. Such updates would probably only be necessary one or two times per year. The handbook could also be expanded to include narratives on topics such as propagation, establishment and management.

Online access to the database could be arranged through local offices of the public agencies involved using any compatible terminal or microcomputer. This is facilitated by the fact that more of the public agencies receiving requests for eucalyptus information will soon have microcomputer systems in their local offices, e.g. University of California Cooperative Extension and U.S. Soil Conservation Service (Finch, 1983; Standiford, 1983). Those offices without such equipment could request searches to be done at a central office and the results printed out and mailed to them. Alternatively, the database could be accessed from remote terminals to a central computer via appropriate telecommunications equipment.

Funding

The bulk of the funding for this project would be needed in the first year, since the major tasks will be to create the initial database and printed handbook. The database can then be reproduced on inexpensive "floppy diskettes" and copies distributed to local offices. From then on, the relatively low cost of periodic updates and distribution could be covered by sales of the handbook and database or fees charged to the cooperating agencies or the individual

end users. It has been suggested that the University of California, through the U.C. Davis Dept. of Environmental Horticulture and/or U.C. Berkeley Extension Forester's office, be the lead agency for the database if foundation funding can be secured for the project. Since its purpose will be to benefit public land use advisory agencies, nurserymen, landscapers, etc. in California, these groups must necessarily be involved in determining the format and content of the handbook and database that best serves their needs.

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Part 3. Products, Uses, Economics

Using Eucalypts in Manufacturing¹

William A. Dost²

The eucalypts as a group are attractive because of their rapid growth. This results in very high yields on a volume basis and in combination with the comparatively high specific gravities, the yields of dry fiber can be truly impressive. Maximum yield of dry fiber is the logical goal when the anticipated use is for fuel, or as a chemical feedstock for processes such as destructive distillation. However, for solid wood products such as lumber and veneer, high specific gravity and the more complex anatomical structure may be quite disadvantageous when compared with softwoods.

The softwoods as a group are more efficient as a structural material, with a quite high strength to weight ratio. This superior rating relative to the hardwoods is not a consequence of any differences in chemical composition or relative amounts of cellulose and lignin present. The softwoods are composed almost entirely of a single cell type, the tracheid, with a length roughly 100 times the diameter. Hardwoods on the other hand have a more diverse anatomy (for oaks, 20 percent vessels, 40 percent fibers, 25 percent rays and 15 percent parenchyma). The fibers are the longest but length

Abstract: Eucalypts have a number of characteristics affecting processing and utilization that distinguish them from other woods. The major current interest in the eucalypts is as a fuel. Possible demand as a chemical feedstock, for pulpwood, panel products, lumber or round timbers should be considered in initial planning and management as a hedge against changes resulting from economic, political or environmental pressures. In general, returns to the grower will be maximized by concentration on maximum yield (cubic volume x specific gravity) for energy, chemical feedstock and pulpwood uses. Specific gravity, as an indicator of strength, is also important for sawn products, round products and some panel products although processing considerations such as internal stresses and drying characteristics are important. Permeability of the wood for penetration by pulping chemicals or preservative solutions is important to pulpwood, and to sawn and round products. Characteristics such as specific gravity and fiber length can be manipulated to a considerable degree by species and seed source selection as well as by silvicultural manipulation.

The implications of these and other characteristics for utilization will be reviewed.

is generally one-third to one-eighth that of the softwood tracheids and with a poorer length to diameter ratio (only 40:1). In addition, other properties of the hardwoods make them more difficult to process.

The eucalypts, in addition to these general hardwood characteristics, typically contain high internal stresses and are prone to excessive shrinkage and distortion on drying. The net effect of these is to severely reduce the yield of usable material. Nonetheless, there are opportunities for the use of these woods for other products than energy or chemicals. They should be considered in planning any eucalyptus plantation since choices made then can substantially affect alternate use potential. Pulpwood is already in established use in California, as well as elsewhere. However, use in solid products such as sawn lumber and plywood and in round form for poles and piling, is not.

Use for Energy

The fuel value of woody cell wall substance is relatively independent of species, with a potential yield of between 8000 and 8500 BTU per dry basis. The differences between species result largely from the character of the extractives; those with a cyclic molecular structure are higher in value than straight chain structures such as sugars and starches. Burning characteristics generally improve with specific gravity although any hardwood above about 0.5 seems to burn very well when dry. Industrial fuel is sold on a dry weight basis and income will be maximized by concentrating on the yield of dry fiber. Cordwood for home heating is sold on a volume basis so income will be maximized by concen-

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trating on yield on that basis, as long as the specific gravity is high enough so it is perceived to be a "quality" fuel.

The eucalypts characteristically exhibit interlocked grain, in which the stem alternates between left hand and right hand spiral grain. While this has no significance for heat content, it does increase the effort required in splitting cordwood and also will result in rough look pieces that are somewhat more difficult to handle. Wetwood occurs in the heartwood of mature trees and drying is made more difficult. This may not be a problem in plantations where the young stems will be substantially sapwood.

Chemical Feedstocks and Charcoal

Although neither of these are at present a particularly viable primary product the possibility exists that either economics or process technology may change so that these could become attractive. The best strategy for maximum raw material value is the same as for industrial fuel, maximum yield on a dry weight basis. However, if the process eventually adopted requires penetration of the wood by a solution, the species should be one that does not develop tyloses in the sapwood cells after felling in order that the process liquor may penetrate the wood.

Pulpwood

It is well established that young eucalypts are well suited for pulping by a full range of processes to yield pulps suitable for a wide range of end uses. Pulps from high density species are often blended with those from low density species or softwood to yield high quality pulps. In short, the potential for young eucalypts to provide good quality pulpwood appears to be very attractive.

Panel Products

The different panel products that are manufactured of wood are usually classified as plywood, hardboard, particleboard and insulation board, although the distinctions between these classes have become blurred as technology has advanced.

High quality hardboard is produced in volume from the mature wood of a large number of eucalypt species. This indicates that, at least for wet process production, the eucalypts in general are well suited. Eucalypts can also be used for insulation board manufacture without excessive problems, but species of lower specific gravity are generally preferred.

Panels of intermediate density in the range of 40-60 pcf are usually classed as particleboards although they may also be described as medium density fiberboards and hardboards. *E. saligna* is used commercially for production of particleboard at one plant in Brazil. In general, the eucalypts are not as well suited for particleboard production as lower density species, especially softwoods.

However, it should be noted that technology is advancing rapidly in this area and, at the 1982 annual meeting of the Forest Products Research Society, the keynote speaker observed that "It is now possible to manufacture panels whose properties are more dependent upon the process used than upon the species." Under this circumstance, the potential of the eucalypts should not be underestimated.

A small but significant portion of Australian plywood production is based on veneer from mature trees of several eucalypt species. Specific gravities below about 0.65 are required as is careful control of cutting parameters. Collapse and other forms of abnormal shrinkage are a problem and recovery of usable veneer is relatively low. Specific adhesive formulations and careful control are necessary to achieve good glue bond quality. "Excessive" end splitting of veneer logs, along with high shrinkage losses and kino defects, has contributed to the low veneer recovery from fast-grown young eucalypts. The wood makes a strong panel for structural use but appearance quality panels are not generally produced. Veneer for use green in wire-bound produce crating was successfully produced in Santa Cruz, California from *E. globulus* for a number of years.

Lumber

Eucalyptus lumber is widely used by the Australians for the equivalent of our structural light framing. However, there is some preference for radiata pine because it is less prone to warp. Some of the characteristics of the eucalypts that affect lumber manufacturing have been noted earlier. Internal stresses lead to splitting, brittleheart and shake in the log, change in shape of the log during sawing and to warp of the sawn lumber. Kino, in pockets or veins, is a defect that is peculiar to the eucalypts and the wood of many species characteristically exhibits excessive cracking, shrinkage and collapse on drying.

Quite a bit of information has been developed on drying techniques to minimize degrade in timber from both mature and fast-grown young stands. However, checking, warp, shrinkage and collapse are all reported to be more severe in material cut from young trees.

Round Timber

Utility and construction poles, marine and foundation piles, posts and rails are all produced from eucalypts in other countries and these applications certainly represent potential markets in California. The characteristics of young, fast-grown timber of each species need to be examined carefully for suitability. The splitting of log ends and development of circular checks or shake, both due to growth stresses, are a serious defect that is commonly reported. Maximum sapwood thickness is a desirable goal and thin sapwood species are unsuited. Ease of preservative treatment is critical and so, while sapwood is generally presumed to be treatable, this needs to be verified. Soft

rot attack of eucalypt poles well treated with arsenical salts is a problem of widespread concern and investigation. Heartwood of high durability is a plus and the higher strength of the eucalypts in comparison to the currently used softwoods is also very attractive.

Management to Improve Utilization Opportunities

A number of basic properties have been noted as being important for their effect on utilization potential and are to some degree [sic] under the control of the forest manager. These include wood density, cell dimensions, sapwood thickness and permeability, and growth stresses. Seed source is often but not always related to density and does not appear to be an important factor in fiber length. Seed source seems very important to growth stress intensity. Increased growth rate achieved by fertilization results in decreased fiber length and vessel diameter, a decrease or no change in density, no change in growth stresses, and an increase in sapwood thickness. When increased growth rate is achieved by thinning, fiber length and growth stresses are increased. Higher environmental temperatures improve fiber dimensions (longer and more slender) and frost may increase the occurrence of kino. Longer rotations decrease the percentage of product lost in conversion due to growth stresses. High soil moisture during harvest can result in higher residual stresses and techniques to reduce tree vigor in advance of harvest will reduce them.

These generalizations are based on observations of a large number of workers on a range of species

in diverse areas of the world and should not be considered as certainties for any given species and cultural practice.

SUMMARY

The eucalypts are very attractive for their potential to augment wood supplies. There is little or no problem in their use for fuel or pulpwood and they have been shown to make excellent hardboard. There are impressive difficulties in conversion to solid wood products such as lumber and plywood but generally these problems can be managed at some cost. For those species with a wide and permeable sapwood, use as roundwood products represents an excellent opportunity provided that end splitting can be controlled.

The potential of the eucalypts for utilization in California has been clouded by the choice of E. globulus as the principal species for planting, since it is one of the more difficult species to process. Establishment of other, more readily processed, species will lead to a change in attitudes and in use. However, none of the species can be considered to be easily converted to solid wood products.

REFERENCE

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California Wood Energy Program¹

Gary Brittner²

The California Department of Forestry Wood Energy Program was established in 1978 and has been actively participating in many research and demonstration projects to increase utilization of wood for energy. The Wood Energy Program came about partly in response to the energy crisis of the 1970s, but a more important reason was a need to improve the management of the wood resource. The Department of Forestry recognized that an extensive resource was being undermanaged; there were uncoordinated research efforts and many unanswered questions about wood energy. California is rich in wood energy; forests and brushlands have been producing this natural and renewable energy resource for centuries. The timber industry in California has for many years been using captive waste from mills for energy, pulp, and composite products. One purpose of the Wood Energy Program is to expand utilization of the wood resource from more than just sawlogs and captive waste. Only about 40 percent of a tree's fiber is actually removed from the forest. The remaining portions are usually left because they cannot produce lumber and are uneconomical to harvest for pulp or fuel. The Wood Energy Program has worked on pilot projects to expand the utilization of unmerchantable wood, including: gasification, densification, chemical extraction, and charcoal production.

The California Legislature has authorized the Department to conduct research concerning the economic and environmental cost, benefits, and feasibility of utilizing wood for energy production. We are also able to provide technical and other assistance with respect to forest management and species selection to encourage energy production. The projects with which we are involved cover a broad range of fields including equipment design, chemical extraction, nutrient cycling, consumer information, and fuelwood plantations.

It is fuelwood plantations that I would like to discuss [sic] today. Our experience with plantations comes from both contract and in-house fuelwood projects. California has a long history of

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Abstract: Many varieties of eucalyptus adapt well to growing conditions in the coastal and central valley regions of California. The California Department of Forestry is conducting growth research on a variety of sites throughout the state with many species. Eucalyptus is an excellent fuelwood and has potential for other uses, including chemical feedstocks. Plantations established on marginal sites may be an alternative to grazing or agricultural crops.

eucalyptus plantations dating back to the turn of the century when there was a strong push to plant groves of eucalyptus for sawlogs and railroad ties. Unfortunately, the species planted did not lend themselves well for manufacturing into lumber. We are again experiencing rising interest in the use of eucalyptus, primarily for fuelwood. The renewed interest in eucalyptus has been brought about by a variety of factors such as: rising heating costs for conventional fuels, favorable return on fuelwood sales, and for many individuals, energy independence for winter heating.

The California Department of Forestry has two major projects investigating the use of eucalyptus and other fast-growing species for use as fuelwood. The projects are the Biomass Tree Farms and an in-house program growing fuelwood plantations on lands adjacent to Department facilities. The Biomass Tree Farms project was mandated by the legislature in late 1980 under sponsorship of Senator Greene. The purpose of the legislation is to demonstrate the production of biomass on marginal sites. The Department of Forestry has contracted for establishment of 9 plantations throughout the state, which include 8 genera and 17 eucalyptus species. We have also established our own program within the Department to grow fuelwood. This project is in conjunction with our energy conservation program to provide alternative energy for CDF facilities such as fire stations and offices. At some CDF facilities we are growing our own fuelwood to burn in woodstoves. This fuelwood program provides a demonstration to small landowners, reduces our energy costs, and provides research information. Most of the plantations were established in early 1982, and it is too early to present results to make recommendations. However, after one year of experience, we can present some general observations on our initial experiences.

The high rainfall and late rains in the winter of 1981-82 kept soils at field capacity and delayed site preparation and planting until late spring. Adequate soil moisture at the time of planting, relatively mild summer temperatures, and irrigation provided favorable growing conditions. The survival rate in most plantations exceeded 90 to 95 percent. Planting stock was commercially grown containerized seedlings. The most injurious agents we have noted are rodents and deer. *Eucalyptus camaldulensis* has been

heavily browsed in San Luis Obispo and Lake counties by both deer and rabbit. In Lake County, rabbits browsed seedlings to the root collar, but they are sprouting back vigorously. Animal repellents will be used to discourage browsing, and pruning may be required in order to stimulate apical dominance; growth form is very poor.

Gophers were a severe problem in San Mateo County. Site preparation consisted of scalping, and the root mass of competing vegetation provided food supply for gophers. Eucalyptus seedlings which were being irrigated became a preferred food during the dry period when annual grasses died. These incidents reconfirm the importance of adequate site preparation. Control of surrounding vegetation is important because it decreases the competition for seedlings and reduces protective cover for rodents. An aphid species was observed on one specimen of *E. gunnii* in Fresno County, but no other insect or disease problems have been observed. In Yolo County under similar conditions, black locust (*Robinia pseudoacacia* L.) was killed by phytophthora root rot while *E. camaldulensis* showed no sign of infection.

One plantation was established in Merced County on saline alkaline soils; of five species, only *E. grandis* and *E. viminalis* survived, but their growth is not robust. The mild winter temperatures throughout the state may have given us more favorable results than usual. Slight frost damage was noted on tips of *E. camaldulensis* at 750-foot altitude because trees did not harden off. At an 1800-foot site, no damage on *E. globulus* or *E. dalrympleana* was observed. At 3500 feet, all *E. robusta* near the bottom of a drainage were killed by frost; *E. globulus*, *E. rudis*, and *E. macarthurii* at the same site, but higher on slope, received some slight frost damage.

Various silvicultural trials including spacing, fertilization, and irrigation are being performed on the plantations; but it is too early to present any results. Information from these plantations can be used by the small landowner wishing to put marginal lands to use. At the present, we see fuelwood plantations being established for personal use or the commercial firewood market. Large-scale plantations to supply wood-fired power plants are farther in the future. The

current supply of boiler hog fuel is adequate since demand is low. As more wood-fired boilers come on line and hog fuel demand goes up, the feasibility of large-scale plantations will be more practical. At the present time, a small woodlot is the most logical choice. The small plantation of 1 to 10 acres offers many advantages; once established, a fuelwood plantation has fairly low maintenance costs, and the coppicing characteristic of eucalyptus eliminates replanting costs. Fuelwood also stores (and grows) quite well on the stump so harvest is up to the desires of the landowner. This characteristic also allows one to take advantage of changes in the marketplace. The fuelwood market is the least value use for the trees. As fiber values rise from increased demand, we can look forward to higher values and potential pulp or composite markets.

The Department has just completed work with GeoProducts Corporation testing manzanita (*Arctostaphylos* spp.) using the acid hydrolysis process developed by Dr. David Brink at the University of California Forest Products Lab. Tests of manzanita and other types of wood have yielded impressive results. From 1 ton of chipped manzanita, we were able to extract 514 pounds of hexose sugars and 341 pounds of pentose sugars. Fermentation of the sugars produced 36.7 gallons of ethanol. A variety of other chemicals including furfural, torula yeast, and butanol can also be produced. Lignin waste from the chemical process can be used as boiler fuel to complete utilization of the feedstock. Eucalyptus has not been tested, but we would expect it to be a suitable feedstock.

GeoProducts Corporation is studying the feasibility of constructing its first operational plant in another state. This type of plant creates demand for woody material unacceptable for lumber or pulp and provides jobs. Within the next decade I anticipate that one or more wood chemical facilities will be operating within California.

Demand for fiber, energy, and other products from forestlands will require intensive management of our resources. Research we are doing now may provide information key to the most efficient production. Hybrids, eucalyptus, and other exotics can help us meet these challenges.

Large-Scale *Eucalyptus* Energy Farms and Power Cogeneration¹

Robert C. Noronla²

The initiation of a large-scale cogeneration project, especially one that combines construction of the power generation facility as well as the establishment of the fuelwood source, is a major undertaking worthy of extensive preliminary investigations.

For the purposes of this paper a large-scale energy farm shall be one in excess of 100 acres. This size of wood producing farm by itself will not support a large commercial cogeneration facility (i.e., 1 mega watt or more), thus it will be assumed that some supplemental fuel source must be sought if the cogeneration facility will consume more fuel than the available acreage will supply.

Because a thorough analysis of fuelwood cost must be an integral part of the overall economic evaluation, all aspects of establishment of a stand, processing and handling of the fuelwood must be investigated.

Seven basic areas of concern must be studied for a complete economic analysis. A detailed discussion of all these is not possible in such a limited paper, however, each will be outlined to indicate specific items which can considerably affect the cost effectiveness of the installation.

Selecting Your Eucalypt Species

Site evaluation -- is extremely important in determining which species will adapt well

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Abstract: A thorough evaluation of all factors possibly affecting a large-scale planting of eucalyptus is foremost in determining the cost effectiveness of the planned operation. Seven basic areas of concern must be analyzed:

- | | |
|----------------------|-------------------------------|
| 1. Species Selection | 5. Irrigation |
| 2. Site Preparation | 6. Harvest Planning |
| 3. Planting | 7. Economics of Co-generation |
| 4. Weed Control | |

Only after detailed analysis has been completed, can the decision to move forward with major capital expenditures be made.

Present pay-back is marginal depending on cost of installations, operating expenses and "avoidable rate" payments from utilities.

to the existing conditions. An exhaustive soil analysis is prerequisite to the successful establishment of any stand of trees and should be studied thoroughly to determine what problems if any might exist. The following outline lists several important factors which will weigh heavily on the decision as to the correct eucalypt species for the site in question. These factors are not, however, the only factors which will influence the final selection decision. Each site is a separate case in point and must be treated as such.

- A. Site Evaluation
 - 1. Fertility
 - 2. Slope
 - 3. Water Table
 - 4. Site Specific Problems
 - a. Alkalinity/Acidity
 - b. Clay/Hardpan
 - c. Salt Deposits
 - 5. Soil Type Variability
- B. Species Evaluations
 - 1. Adaptability to Conditions
 - a. Based on Literature
 - b. Existing Site Evaluations
 - c. In-House Evaluations

Species evaluation -- is the next step in the analysis procedure. After the site has been evaluated and the species which are compatible with the specific site are selected, the final decision can be approached as to the one species best suited to the site or the combination of species which would give the best overall performance.

The final selection will be tempered by such influences as seed or seedling availability and cost, macro - or micro-climatic conditions, tree growth habit and other unmentioned site specific problems.

As with any integral part of an economic analysis, the consideration should be the production of the greatest amount of the best quality end product for the least amount of money.

Site Preparation

As with any farming operation, site preparation is first and foremost to assure a successful conclusion. Without proper site preparation, the successive operations of planting, weed control, irrigation and harvesting become at best difficult and at worst impossible. The proper scheme for land preparation is dependent on soil topography and structure. Obviously, certain operations may not be needed if site conditions do not warrant them. The following outline lists the most common operations that might be required prior to planting.

- A. Leveling
 - 1. Planned for irrigation method
- B. Ripping/Chiseling
- C. Plowing/Discing
- D. Seedling Bed Preparation
- E. Pre-Irrigation and Fertilization

Leveling -- may only be needed on sites which are relatively flat and are slated for flood, check or furrow irrigation. Under drip, solid set sprinkler, pull hose, center pivot or other minimal water-use types of irrigation, leveling may be an unneeded [sic] and expensive operation. Rolling or hilly sites may do poorly if leveled due to the depth of cut and the consequent loss of fertility. Thus serious consideration should be given to both the economics and prudence of leveling the site.

Ripping/Chiseling -- again may only be necessary where hard or clay pans exist. Sandy or sandy loam soils generally will produce excellent crops of eucalyptus without the use of deep tillage. Many other soils although tighter than the sandy types will also produce well without the expense and trouble of deep tillage.

Plowing/Discing -- is the generally accepted form of ground preparation in California for most soil types, but may not be needed if alternative methods of competitive plant growth control are used. The economics of discing versus chemical control should be investigated if the present cover is not desired for green mulch.

Seedling Bed Preparation -- is only required when future plans are established for furrow irrigation, mechanical planting or where site specific problems such as salt crusting are present. Flat planting (Direct planting into level surface) under most circumstances is much more desirable than bed planting. Later operations such as weed control and harvesting are simplified by the lack of beds.

Pre-Irrigation and Fertilization -- are very desirable when planting eucalyptus. If planting can be scheduled for fall after first rains have arrived or early spring before the onset of hot

weather, the need for pre-irrigation is eliminated. If planting is conducted where hot dry conditions exist and follow-up irrigation is not immediately available, the planting is almost assured of failure. With most types of potting mixtures the movement of moisture out of the root ball to the surrounding soil occurs within a few hours. If the dry condition is allowed to persist for 8-12 hours a potting mixture with a high percentage of peat will actually resist the infusion of water into the root ball during irrigation. Thus it is essential that adequate moisture be present at planting or immediately thereafter. Fertilization prior to planting can be accomplished in a number of ways, but must be weighed against post-plant fertilization. Economics and availability of equipment are the deciding factors in this instance. Broadcasting a dry fertilizer such as 16-0-0 is a relatively inexpensive means of applying the seedlings initial nitrogen need, but this method is inefficient with respect to placement of the nutrient near the root zone. Banding a dry or liquid fertilizer below and to the side (4 inches and 6 inches respectively) of the seedling will place the nutrients near the root zone but not so near as to burn the lateral root system or displace the tap root. This probably is the most effective application but not the least expensive. Water-running anhydrous ammonia into the irrigation water source would be the least expensive but is relatively short-lived in its effectiveness.

One other important factor that should be considered during site preparation evaluations is the level of pest infestation within the seedling root zone. Most eucalypts are resistant to Fusarium, Phytophthora, nematodes and other common pests, but under severe infestation conditions the performance of the stand could be impaired. If the eucalypt species has a history of susceptibility to an infestation present at the site, an alternate species or an alternate site should be considered.

Planting

The planting costs may vary widely depending on a number of factors. The first decision to be made is whether the seedlings to be planted will be purchased or propagated. If the decision is to purchase, the cost per seedling need merely be multiplied by the requirement for the planting. If self propagation is selected a much more extensive and tedious analysis is required. In most cases the cost of propagation is much lower than purchasing, however, convenience is lost in the process. Some of the precautions that must be considered when preparing seedlings are listed below. These are only precautions to be taken that are over and above those which are necessary to germinate, transplant and grow viable seed spots. It is assumed that a sound basic knowledge of eucalyptus seedling propagation is already at hand.

Seedling preparation -- must include the following important procedures.

1. Hardening of the seedling
2. On-site protection
3. Proper growing media
4. Topping or pruning
5. Container style

The success of the planting may depend upon close attention to the above procedures as well as the proper planting method for the site.

Mechanical versus hand planting -- is an economic decision to be made based on available equipment and labor.

Root ball coverage -- is very important for survival of the seedling during the first days and weeks after planting. Depending on the composition of the growing medium, any exposed portion of the root ball will act as a wick to allow moisture to leave the root zone and dissipate into the atmosphere. Survival of the plant under these conditions is questionable. Total coverage will assure retention of moisture during the all important first year of growth.

Planting density -- is a widely argued point. Many studies have been conducted with claims of tremendous yields per acre made by the investigators. In practice many different tree spacings can produce comparable yields. The important point to remember is the end product desired should dictate the planting density. Cogeneration facilities differ in their fuel requirements, therefore the composition of the fuel to be grown should be manipulated to match the fuel burning equipment.

High moisture contents can be tolerated by some firebox/boiler combinations. In these instances [sic] a very high density planting may be appropriate. High moisture content with a high leaf-to-stump ratio would yield a level of volatile compounds that would increase the BTU per pound and thus the effective output of the cogeneration facility. If very low moisture contents are required by the boiler design, a high stump-to-leaf ratio will be more appropriate.

The planned harvesting method, weed control and irrigation method will all modify the decision-making process. A wealth of publications are available to help a prospective biomass grower decide on an eventual planting pattern and density. Many of these studies have been conducted on the species most adaptable to California conditions and contain valuable statistics. To be prudent one should investigate the method of obtaining the statistics. If extrapolations have been made from single tree samples or very small plots, the results should be viewed with reserve.

Weed Control

Evaluation of weed species -- is the first step in establishing a successful weed control program. Once the full spectrum of weed species has been identified [sic] and the species' growth habits known, a plan for their control can be developed. Many publications are available to assist in species identification, one in particular is the University of California Weed Identification Handbook.

Mechanical versus chemical control -- is a decision to be made early on in the analysis of the entire project. Some soil types do not lend themselves to mechanical weed control, thus it is wise to have an alternative plan that uses either partial or complete chemical control.

Selection of Materials -- should be made with advice of a properly qualified pest control adviser (PCA). Many of the most effective chemicals are restricted materials and therefore cannot be purchased over the counter without proper PCA recommendation or possession [sic] of a commercial applicators certificate.

If farming operations are in existence in the immediate area of the site, it is advisable to ask the operator what materials they have found most effective. Practical experience is worth much in this situation.

Irrigation

For many areas of California irrigation is an absolute necessity. For those areas it is advisable to base the irrigation scheduling on the needs of the trees. There are many types of devices available which will objectively measure soil moisture. Among these are the tensiometers and neutron probes. By the use of these types of devices, the tree's need for moisture can be predicted before it shows any sign of stress. It also allows irrigations to be timed to avoid excessive watering.

Irrigation Method -- is also a very important economic and practical decision to be made. Many sites will only be served well by one type of irrigation method while other sites are adaptable to several types of irrigation systems. In most areas of California irrigation is only needed for the first two or three years of the trees' growth. If plantings can be spaced 3 years apart, the same irrigation equipment can be reused on each successive planting thus reducing the cost per acre for irrigation over the entire planting. This type of planning may preclude the use of the more permanent types of systems such as solid set or underground drip. The cost of the irrigation equipment is of prime concern, however, labor cost and the cost of water and/or pumping will weigh heavily on the eventual selection of the irrigation method to be used. Again, the cost of all components of the irrigation system will determine which system is the most economical.

In some irrigation districts in California the cost of water can be as low as \$3.00 per acre for as much as 6 acre feet per year with very low labor costs to apply the water. In other areas the cost can be as high as \$4.00 per acre for a much lower quantity of water per unit of area. These cost differences make it impossible to recommend one best system for all circumstances. In some cases the high initial cost of a drip system may be quickly offset by the savings in high cost water. In other cases the low cost of water may make it unjustifiable to make any capital expenditures.

The final concern with regard to irrigation is selecting the proper system for the site. The economic concerns mentioned above are in no way the only considerations. If a sprinkler system is to be used, the prevailing wind patterns are a very important consideration. Soil type will also determine the adaptability, to such systems as drip or mist application. Extremely sandy soils will not disperse water well and may require several emitters to give adequate coverage. Topography will determine the initial selection of irrigation equipment. Irrigation specialists are available through the cooperative extension offices to assist in the proper selection of irrigation equipment or, if desired, private consultants can be hired to supply more detailed and specific economic information.

Harvest Planning

The planning of the eventual harvest of the biomass crop is difficult because estimates must be made a minimum of 4 years in advance and in some cases as much as 8 years prior to the first harvest. Several factors are important to consider and are discussed briefly below.

Labor Cost -- is always the first cost input to consider. If the projected wage rate is low enough to offset equipment purchase or rental, the biomass farmer may consider total harvest of the crop by manual means. For large acreages it is unlikely that hand labor can compete with some form of mechanical harvest.

Hauling Cost -- is another cost input that must be estimated far in advance with a high likelihood of error in the estimates. With fuel and labor rates fluctuating as they have in the past 5 years, an accurate estimate of future hauling cost will be extremely difficult. Costs may be reduced or virtually eliminated if the cogeneration facility is located at the farming site, but this sometimes is difficult when cost of land and the eventual point of usage of the power to be generated are conflicting.

Processing Equipment -- is available in several forms. All of the types mentioned below have their proper application, economics and efficiencies being the deciding factors.

1. Tub Grinders - have been adapted from use on hay processing to biomass use with some success. Biomass materials which are brushy and tend to bridge across the tub are not handled well in tub grinders that have no positive feed system. Tub grinders are the least expensive of the systems presently available. Examples: Medallion 905, W.H.O.400NP
2. Hoggers/Chippers - are more adapted to in-field processing where the chips are fed directly into a transport hopper from the hogger. With this type of system the hogger is semi-stationary and has facility for feeding whole trees of the diameter specified by the manufacturer directly into the chipping drum. Again, extremely brushy material is not handled well by this type of equipment, but is very efficient when processing whole trees 3" to 6" in diameter. Example: Nicholson PRC.
3. Down-The-Row Harvesters - are new and experimental at this point, but show a good deal of promise for the future. The only operational unit presently working, to the knowledge of the author, is the Nicholson-Koch mobile chipper. This unit is capable of felling and chipping trees up to 12 inches in diameter at a speed of 1 M.P.H. It is also capable of picking up and chipping previously felled trees up to 19 inches in diameter. The operational production rate is approximately 1 acre per hour on sites yielding 25 tons per acre or green biomass. For very large farms this type of machinery may be worth the investment of \$200,000 to \$300,000.

On-Site Drying or Direct Firing -- of biomass fuel is a decision to be made based on two basic factors.

1. Is the biomass farm located at the cogeneration site?
2. Is the cogeneration plant capable of burning high moisture fuel (40 percent - 60 percent moisture).

If the answer to the first question is positive, the decision to dry the fuel or not stands on its own without consideration for the cost of hauling wet fuel. The decision is then whether to dry the fuel and/or how much to dry it.

The drying process need not be expensive. Proper stacking of the wet fuel will cause internal heat to build in the stack without running the risk of spontaneous combustion. Fuel can be dried to 10 percent to 20 percent by this method. Caution should be exercised in stacking high moisture fuel above 12 feet in height unless the stack can be turned before combustion temperatures are reached.

The simplest of all worlds is to have the biomass fuel source and the cogeneration facility on the same site, and to purchase a firebox/boiler combination that is capable of producing the desired power output using high moisture fuel.

Economics of Cogeneration

Cost of installations--- will vary as with any major cogeneration installation based on the design and location of the facility. Most large cogeneration facilities will cost approximately 1 million dollars per megawatt of power produced if the facility is in the 1 to 20 megawatt range. Beyond the 20 megawatt capacity the cost per megawatt begins to rise rapidly.

Interest costs are a major concern for the cogeneration facility builder. If the return on investment from the sale of the power is not significant on a yearly basis, it may be difficult to repay the debt on construction. To be safe, the interest rate to be paid must be balanced against the revenue to be received using the lowest possible ROI rate for the life of the indebtedness.

Operations Problems -- will in all likelihood [sic] spell the difference between success and failure. Most cost estimations are based on relatively efficient operation of all components of the generation facility, while in actual practice many problems arise that prevent operation of the facility for extended periods of time. A list of recommendations follows that may be helpful in anticipating where problems will occur and how to contend with them.

A. Downtime will be encountered over and above the scheduled yearly maintenance procedures. Knowing that unexpected mechanical failures will occur, protection from income loss during these periods is a necessity. Insurance policies are available to assure income when manufacturer-caused mechanical failures cause loss of income beyond a specified period of time. Depending on premiums paid, a delay in payments from the insurance carrier is made to give the operator time to correct mechanical problems to the best of their abilities. When the more severe failures occur, payments from the insurance carrier will begin after the delay period and will continue for a specified period of time or until the failure is corrected.

B. To abide by the contracts for power production arranged with the utility destined to receive the power, the facility should be designed to operate at the rated output capacity of the generator with the boiler-operating at 75 percent of capacity. If at all possible, the design of the boiler should be such that a partial shutdown of the boiler may be accomplished while continuing to operate at the rated output of the generator. A modular design or multiple cell boiler would accomplish this end.

Contracts being signed at this time have capacity guarantee clauses which allow for higher payments to the energy producer if specified levels of production are adhered to.

- C. Consideration must be given to obtaining a sufficient quantity of high yielding fuel to supplement existing supplies. If price movement on fuel supplies appears to be stable or moving up, it would be wise to establish long-term contracts with suppliers. If movement is downward, of course one would want to withhold contracting until the price is more favorable. In any event, the fuel should be well matched to the firebox conditions. Some boilers operate at very high temperatures (2000°F+). In these instances a fuel with a high percentage of ash, especially ash with a low fusing temperature is highly undesirable. The following sample analysis would be very helpful in determining the suitability of the potential fuel to the boiler. Boiler manufacturers can assist in evaluating a potential fuel to assure the proper operation of their equipment, and should be consulted well in advance of facility construction.

Fuel Analysis

Source of Sample:	Biomass Fueled Boiler		
Sampling	November 4, 1980		
Appearance:	Almond Shells (Fines)		
pH of 1% solution in water	11.0		
Moisture	= 5.98 %		
Ignition Loss	= 74.34 %	Ash - 19.68%	
Sulfur (as SO ₃)	= %	(Via BaCl ₂ on aliquot of HCl extract)	
Silicon (as SiO ₂)	= 9.91 %		

The following elements are determined by atomic absorption spectrophotometry on appropriate aliquot portions of a stock solution which contains the hydrochloric acid extraction of the deposit.

Vanadium	(as V ₂ O ₅)	Nil	ppm
Nickel	(as NiO)	48	ppm
Iron	(as Fe ₂ O ₃)	10310	ppm
Copper	(as CuO)	105	ppm
Manganese	(as MnO)	136	ppm
Aluminum	(as Al ₂ O ₃)	60940	ppm
Sodium	(as Na ₂ O)	2700	ppm
potassium	(as K ₂ O)	14060	ppm
Magnesium	(as MgO)	3010	ppm
Calcium	(as CaO)	4206	ppm
Zinc	(as ZnO)		ppm
Cobalt	(as CoO)		ppm
Accounted for: (including Ignition Loss, Sulfur as SO ₃ , and Silicon as SiO ₂).		98.8	%

As can be seen this fuel would be undesirable because of the high ash content and high silicon content in the ash. In high temperature fireboxes this fuel could cause serious problems with fusing of the silicon on the boiler tubes.

- D. Emissions control is of prime concern to any operator, in particular to those who will operate within metropolitan areas. No shortcuts should be considered in this area of concern. Many facilities recently constructed have gone through extensive and costly modifications to meet emission control standards as a result of incomplete consideration during the engineering stages.

Adequate equipment is available to control any emission problem that may arise in a biomass boiler. It would be wise prior to engineering a system to contact as many cogeneration facilities as possible to ascertain what the potential problems might be.

- E. The boiler and firebox are generally trouble free if operated within design limitations. Problems arise in attempting to operate a piece of equipment above its rated capacity.

In the design phase of developing a cogeneration facility, a sufficient amount of excess capacity should be designed in to allow for such eventualities as low B.T.U. fuel, partial loss of heat transfer due to silicon fusing on boiler tubes, low fire temperature due to firebrick or refractory disintegration or mechanical problems in fuel feed systems.

By always assuming that a portion of the boiler system will be inoperable, the chance of not meeting the rated output of the generator will be greatly reduced.

- F. A good deal of consideration should be given to the selection of the turbine and generation equipment. Users of operating facilities should be contacted for their opinions on the performance of the machinery being considered.

Because the entire effort of the operation culminates in the generation of power, an inadequate turbine or generator would be disastrous to the operation. Some typical problems that the manufacturer should be questioned about are:

Turbine

1. Performance history at existing facilities.
2. Seal construction and leakage control.
3. Gearbox reliability.
4. Oil supply and leakage control.
5. Scheduled maintenance shutdown requirements.

Generator

1. Performance history at existing facilities.
2. Bearing life.
3. Scheduled maintenance shutdown requirements.
4. Parts availability and major repair procedures.

Return on Investment -- can be measurably affected by the variable rate of the "avoidable cost" payments from the utility company.

The tables below are taken from the PG&E publication "Cogeneration and Small Power Production Quarterly Report."

PACIFIC GAS AND ELECTRIC COMPANY

PURCHASE PRICES (¢/kWh) FOR ENERGY FROM QUALIFYING FACILITIES FEBRUARY 1980 THROUGH JULY 1983

Seasonal Period *	Time of Delivery Basis			Average Basis
	On-Peak	Partial-Peak	Off-Peak	All kWh
<u>Period B</u>				
February '80 thru April '80	4.496	4.250	3.794	4.121
<u>Period A</u>				
May '80 thru July '80	5.675	5.459	4.700	4.994
August '80 thru September '80	6.100	5.868	5.052	5.368
<u>Period B</u>				
October '80	5.858	5.536	4.943	5.368
November '80 thru January '81	6.226	5.884	5.254	5.706
February '81 thru April '81	6.580	6.219	5.553	6.030
<u>Period A</u>				
May '81 thru July '81	7.783	7.487	6.446	6.850
August '81 thru September '81	8.072	7.765	6.685	7.104
<u>Period B</u>				
October '81	7.752	7.326	6.542	7.104
November '81 thru January '82	7.725	7.302	6.519	7.080
February '82 thru April '82	7.759	7.334	6.548	7.111
<u>Period A</u>				
May '82 thru July '82	6.397	6.102	5.895	6.178
August '82 thru September '82	5.967	5.692	5.499	5.641
<u>Period B</u>				
October '82	6.049	5.912	5.769	5.854
November '82 thru January '83	6.049	5.912	5.769	5.854
February '83 thru April '83	6.209	6.068	5.922	6.009
<u>Period A</u>				
May '83 thru July '83	6.108	5.826	5.629	5.774

* Period A comprises May through September, and Period B, October through April.

PACIFIC GAS AND ELECTRIC COMPANY TIME PERIODS

Seasonal Period A (May 1 through September 30)	Monday through Friday ²	Saturdays ²	Sunday and
On-Peak	12:30 p.m. to 6:30 p.m.		
Partial-Peak	8:30 a.m. to 12:30 p.m. 6:30 p.m. to 10:30 p.m.	8:30 a.m. to 10:30 p.m.	
Off-Peak	10:30 p.m. to 8:30 a.m.	10:30 p.m. to 8:30 a.m.	All Day
<u>Seasonal Period B (October 1 through April 30)</u>			
On-Peak	4:30 p.m. to 8:30 p.m.		
Partial-Peak	8:30 p.m. to 10:30 p.m. 8:30 a.m. to 4:30 p.m.	8:30 a.m. to 10:30 p.m.	
Off-Peak	10:30 p.m. to 8:30 a.m.	10:30 p.m. to 8:30 a.m.	All Day

The tables show that by manipulation of peak production of the cogeneration facility to hours in which the higher rate of return prevails, the amount of return can be significantly increased. Also it is obvious that if a cogeneration facility is planned and returns calculated with "avoidable cost" payments such as were made during August, 1981 through September, 1981, the downward trend in recent payments could render the facility non-profitable.

Another set of factors that weigh heavily on the eventual success of the facility are the variable cost factors. Three of the major factors are listed below and should be given very serious consideration.

1. Labor
2. Materials
3. Fuel

Wherever possible, long-term commitment should be made to guarantee profit for the sup-

plier as well as the cogeneration facility. If possible, contracts for the three factors listed above should be tied closely to fluctuations in "avoidable rate" payments so the facility will remain viable throughout its life.

Misconceptions -- abound in the biomass cogeneration industry. Many assume the return on investment is very high, when in fact it can be marginal to unprofitable. Only the most astute operators can be guaranteed a profit. Systems efficiencies are generally overrated. Fuel sources are estimated to contain more B.T.U.s per pound than they actually contain, boilers are overrated in their efficiency, turbines and generators are generally more prone to maintenance problems than manufacturers will admit and many more exaggerations of performance exist. The potential operator must keep all of these factors in mind to assure a successful conclusion to the establishment of a biomass farm and cogeneration facility.

Economic Evaluation of Eucalypt Energy Plantations¹

Richard B. Standiford and F Thomas Ledig²

An evaluation of the economic feasibility of investment in a eucalypt energy plantation must involve an assessment of the costs of the various cultural practices (planting, weed control, irrigation), the costs of processing the standing tree into a usable form (logging costs, transportation costs, chipping, cutting to firewood length) and the returns expected from the sale of the processed product (firewood, chips), all compounded or discounted to a constant point in time at an interest rate selected on the basis of management objectives.

Presented below are two different analyses of eucalypt energy plantations. First, two possible management scenarios are presented, drawn from a survey of planting and cultural practices throughout California, and a "break-even" price is calculated. This break-even price is the necessary return on a cord of firewood or ton of chips, to earn a given rate of return on money invested in the plantation. The second analysis calculates a benefit-cost ratio from an actual case study of a commercial planting of eucalypts at the U.S. Naval Weapons Station in Concord, California, using actual cost and return data from early trials by the USDA Forest Service's Institute of Forest Genetics.

BREAK-EVEN PRICE ANALYSIS

With the new flurry of interest in planting eucalypts, there have been many proposed manage-

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Abstract: An analysis is made of the break-even price at a 6 percent and 10 percent real interest rate for "intensive" and "minimally managed" scenarios for managing eucalypt energy plantations. The break-even price is greater than the average stumpage price reported for firewood and chipwood by the State Board of Equalization. However, a conversion surplus approach shows that eucalypt firewood plantations are profitable for both the intensive and minimally managed scenario. For plantations producing chips for energy, only the minimally managed scenario, with yields greater than 58 dry tons per acre at harvest, appears to be profitable, assuming delivered chip prices of \$35 per bone dry ton. The benefit-cost ratio for a commercial planting of eucalypts at the Concord Naval Weapons Station, California, showed that a return of at least 10 percent on establishment costs was highly probable with proper choice of species.

ment scenarios statewide. These range from the use of intensive agronomic practices such as cultivation, irrigation and fertilization, to a more extensive "wildland" type of planting, with little management input after initial tree planting. For the purpose of this analysis, two theoretical cases were developed to represent the range of management proposals. Table 1 presents the cost data for two different levels of management, namely intensively managed and minimally managed eucalypt energy plantation. The cost data presented are based on some average figures for actual eucalypt plantations in California and some general costs derived from managed plantations of other tree species (Klonsky et al, 1983; Rose et al, 1981). All costs and returns in this analysis are in constant 1982 dollars, and the interest rates used are real interest rates (net of inflation).

Methods

The objective of the analysis was to calculate a break-even price for a eucalypt energy plantation for the two levels of management. The first step in the process was to discount all costs back to the present time at a 6 percent and 10 percent real interest rate using equation 1 below. Costs were assumed to occur at the beginning of the year.

$$DC = C / ((1+i)^n) \quad (1)$$

where:

DC = discounted cost
C = actual cost
i = interest rate
n = year when cost occurs.

An 8-year rotation length was chosen for this analysis because it is near the point of culmination of mean annual increment for several species reported in the literature (FAO, 1981; Metcalf, 1924). Because many eucalypt species coppice readily from the stump following harvest, no additional investment in stand establishment costs are

Table 1--Costs per acre for intensively and minimally managed eucalypt energy plantations in California. 1st rotation assumed to be 8 years and the 2nd and 3rd rotations assumed to be 7 years.

Cultural Practice	Year(s)	Cost/Acre (1982 Dollars)		Discounted Cost (1982 Dollars)			
		Intensive Management	Minimal Management	Intensive		Minimal	
				6 pct.	10 pct.	6 pct.	10 pct.
Site Preparation ¹	1	150.00	50.00	150.00	150.00	50.00	50.00
Pre-emerg5nt Herbicide	1	27.00	27.00	27.00	27.00	27.00	27.00
Seedlings ²	2	363.00	204.00	342.45	330.00	192.45	185.45
Planting Labor	2	62.40	35.36	58.49	56.36	33.96	32.73
Irrigation ³	Annual	100.00	--	620.98	533.49	--	--
Initial Watering	2	--	200.00	--	--	188.68	181.82
Weed Control	2	40.00	40.00	37.74	36.36	37.74	36.36
Fertilization ⁴	2	30.00	--	28.30	27.27	--	--
	3-8	56.00	--	294.93	247.85	--	--
Management Costs	Annual	5.00	5.00	31.05	26.67	31.05	26.67
Land Rental	Annual	150.00	40.00	931.47	800.24	248.39	213.40
TOTAL DISCOUNTED COSTS-- 1 Rotation				2522.41	2235.24	809.27	753.43
TOTAL DISCOUNTED COSTS-- 3 Rotations				4009.51	3111.58	1071.70	908.08

¹Intensive-- Disc and rip; Minimal-- Disc only

²Intensive-- 1210 seedlings/acre at \$.30/each; Minimal--680 seedlings/acre

³Includes labor, depreciation, water

⁴76 lbs.-N 1st year, 152 lbs.-N subsequent years

needed for at least the next two or three harvests. In subsequent rotations, some replanting may be necessary to replace stumps which fail to coppice (Fahraeus, 1974). For this analysis, the break-even price was calculated on the basis of 3 rotations. The second and third rotations were assumed to be 1 year shorter than the first rotation because the well-developed root system of the coppiced trees will allow full site occupancy more quickly than occurs with seedling trees. The total period for the 3 rotations is 22 years. The discounted costs for the first rotation were summed up, and the results are shown in table 1. It was assumed that all costs except stand establishment costs (site preparation, seedlings, planting labor) would remain the same for the second and third rotations. These costs were also discounted back to the present, and table 1 shows the total discounted cost for the 3 rotation period.

Based on the costs presented in table 1, the break-even price is calculated for the sale of eucalypt stumpage for the intensive and minimally managed scenarios, at the 6-percent and 10 percent real interest rate. Break-even price has been defined as the necessary price per unit required to earn a given rate of return on money invested in the plantation. To solve for this value, the discounted costs are set equal to the discounted returns.

$$DC = DR \quad (2)$$

where: DC = discounted costs
DR = discounted returns.

Since the discounted returns can be expressed

as:

$$DR = (YxBEP) / ((1+i)\exp(r)) \quad (3)$$

where:

DR = discounted returns
Y = yield
BEP= break-even price
i = interest rate
r = rotation length.

then equation 2 can be transformed to:

$$DC = (YxBEP) / (1+i)\exp(8) + (YxBEP) / (1+i)\exp(15) + (YxBEP) / (1+i)\exp(22). \quad (4)$$

This equates the discounted costs from the three rotations to the discounted returns from the three rotations (occurring in years 8, 15, and 22 respectively). Equation 4 is transformed to:

$$DC = YxBEP((1+i)\exp(-8) + (1+i)\exp(-15) + (1+i)\exp(-22)). \quad (5)$$

Because the merchantable yields for these management scenarios are not precisely known, the break-even price (BEP) is calculated for a range of potential yields. For each assumption about merchantable yield, the break-even price was calculated using equation 6.

$$BEP = DC / Y((1+i)\exp(-8) + (1+i)\exp(-15) + (1+i)\exp(-22)). \quad (6)$$

Table 2--Break-even stumpage price per cord and per dry ton for intensive and minimal management of eucalypt biomass plantations based on merchantable yield and interest rate. Rotation length for the first rotation is 8 years and 7 years for the second and third rotations.

Merch. Yield at Rotation			Intensive Management				Minimal Management			
			6 pct.		10 pct.		6 pct.		10 pct.	
Cubic Ft.	Cords ¹	Dry Tons ²	\$/cord	\$/Ton	\$/cord	\$/Ton	\$/cord	\$/Ton	\$/cord	\$/Ton
1360	16	29					50	28	68	38
2720	32	58					25	14	34	19
4080	48	86	63	35	78	43	17	9	23	13
5440	64	115	47	26	59	33	13	7	17	10
6800	80	144	38	21	47	26				
8160	96	173	32	18	39	22				

¹Assumes 85 cubic feet of solid wood per cord

²Assumes 1.8 Tons per cord

Results

The results of the analysis are shown in table 2. For example, for a merchantable yield of 64 cords of firewood at the end of an 8-year rotation (or 7-year coppice rotation) using the intensive management scenario, the grower needs \$47 per cord for firewood stumpage to receive a 6 percent real return on the planting investment, or \$59 per cord to receive a 10 percent real return on the investment. For comparison, under the minimally managed strategy, with yields only half of the intensive management option, or 32 cords, then table 2 shows one would only need to receive \$25 for a 6 percent return on investment and \$34 for a 10 percent return. Table 2 also shows the break-even price per dry ton for individuals selling eucalypt trees on that basis of measure.

The differences between the break-even price for the intensive and minimally managed cases points out that one must carefully evaluate whether the intensive cultural costs and the resulting yields would really give an acceptable return on a tree planting investment.

Assessing Market Prices

Once the break-even price for an investment in eucalypts has been calculated, an assessment is needed of how this compares with the actual market price being received for stumpage in an area. Many owners are looking at the delivered firewood prices being paid in metropolitan areas in the state, and assuming they will receive the same price for their standing trees. This does not consider the considerable costs involved in getting a standing tree harvested, processed into firewood, and transported to a market. Owners who consider marketing chips to a biomass cogeneration facility need to assess the costs of harvesting, chipping, and transportation.

Firewood

Since the California Yield Tax applies to harvested firewood, the California State Board of Equalization (SBOE) annually collects information on the average stumpage price received for firewood statewide, and reports the figures in the Harvest Value Schedules to serve as the basis for the yield tax owed by the landowner. In the most recent Harvest Value Schedule, the average stumpage value for hardwood fuelwood was \$15 per cord, and \$8 per cord for non-hardwood fuelwood (SBOE, 1982). It is quite obvious that for the relationships shown in table 2, only the minimally managed management scenario at yields greater than 48 cords per acre would be close to this statewide average for fuelwood stumpage. These figures, however, tend to be collected mainly from commercial forest areas of the state, and due to the rugged terrain, which results in high harvesting costs, and the long distance to market, the Harvest Value Schedule values may be lower than individuals would receive for planting eucalypts on fairly level terrain, close to the eventual firewood market.

To get a better idea as to what market price might be possible, we worked backward from a final delivered firewood price to arrive at a stumpage value using a "conversion surplus" approach.

In general the final market price for any wood product can be expressed as:

$$SP = STP + HC + PC + TC + MPR \quad (7)$$

where:

SP = selling price
STP = stumpage price
HC = harvesting cost
PC = processing cost
TC = transportation cost
MPR = margin for profit & risk.

Table 3 gives the result of a study of firewood harvesting and processing carried out in New England (Dammann and Andrews, 1979). The study cal-

culated the most efficient mix of equipment for a firewood harvest based on the average log skidding distance and the annual production of the firewood harvesting/manufacturing firm. The average harvesting, processing, and transportation cost, including a 15 percent margin for profit and risk (HC, PC, TC, MPR terms in equation 7) ranged from \$33 to \$48 per cord for a 20-mile one-way distance to market, and from \$66 to \$94 per cord for a 90 mile one-way distance to market.

Table 3--Contract harvesting, processing and transportation costs for firewood, 15 percent margin for profit and risk (1982 dollars). Source: Dammann and Andrews, 1979.

Transportation Distance	Cost/Cord ¹	Equipment Type ²
20 miles	\$33-48	Chainsaw; Ground Skidder; Splitter; Loader
90 miles	\$66-94	Dump Truck

¹ Cost varies based on skidding distance, yearly production, and type of equipment.

² Type of equipment chosen on basis of skidding distance and yearly production to minimize total harvesting, processing and transportation costs.

If we assume a final selling price of \$150 per cord (SP term in equation 7) for firewood, then by subtracting these figures in table 3, we can get an idea as to the conversion surplus left for firewood stumpage. For a 20-mile haul, the maximum possible value for stumpage using these harvesting and processing costs would be \$102 to \$117 per cord. This would require a commercial firewood planting located in very close proximity to a major market center such as Sacramento, the San Francisco Bay Area, or Los Angeles. It can be seen that the conversion surpluses exceed the break-even price figures in table 2, and thus the return on planting would exceed the 6 to 10 percent real interest rates used in the analysis.

It is much more likely, based on the high land prices of areas surrounding the major market centers, that eucalypt planting would be distributed 90 miles from a final market center. If this

were the case, the conversion surplus left after subtracting the harvesting, processing and transportation costs from the firewood selling price would be \$56 to \$84 per cord, which also appears feasible at our expected levels of yield.

Biomass Chips

The California State Board of Equalization (SBOE) also reports the average stumpage price for chipwood in its Harvest Value Schedule. The most recent schedule reports average stumpage for hardwood and softwood chipwood as \$1 per green ton, which would convert to \$2 per bone dry ton, assuming a moisture content of 100 percent on an oven-dry basis. This average stumpage price is far below the break-even prices reported per dry ton in table 2.

We used the conversion surplus approach to calculate the residual value left after harvesting, processing, transportation, and a margin for profit and risk were subtracted from the delivered price for chips at a biomass cogeneration facility. According to a recent Pacific Gas and Electric (PG&E) report, there are currently 13 biomass cogeneration facilities in California, and another 15 facilities projected to be in operation in the near future (PG&E, 1982). To date, these plants mainly operate on residue from wood product and agricultural processing industries. Some residue from orchard prunings and urban tree removals are also purchased. A survey of several of these purchasers shows that the delivered prices paid by the facilities ranges from \$22 to \$35 per bone dry ton.

Table 4 shows the costs of harvesting, processing, and transporting biomass chips to a cogeneration facility. These data were collected from various studies. All the reports calculated costs on the basis of approximately 2000 hours of equipment use per year, which means that a considerable acreage would be needed to justify the capital expense of purchasing the equipment.

At the \$35 per bone dry ton for delivered chips, and \$22 per ton for harvesting, chipping, and transportation on level terrain with a high level of mechanization, then the conversion surplus for stumpage would be \$13 per ton. Table

Table 4--Contract harvesting, processing and transportation costs for wood chips, 20 mile haul, 15 percent margin for profit and risk (1982 dollars).

Costs (\$/Dry Ton) 1	Terrain	Equipment Type	Reference
\$21.95-28.70	level to rolling	Feller buncher, grapple skidder, chain flail, whole tree chipper, chip van	Arola & Miyata, 1981
\$19.56-24.45	level to rolling up	same as above	Rose, Ferguson, et al, 1981
\$34.50	>50% slope	Snyder feller buncher, Skyline yarder,	Scheiss, 1982
\$47.15	>50% slope	Chainsaw, accumulator, Pewee yarder,	Scheiss, 1982

¹ Range in price due to different average tree diameters and volume per acre harvested.

Table 5--Costs for establishment of eucalypt plantations with contract labor at Concord Naval Weapons Station (Data on file at USDA Forest Service Pacific Southwest Forest and Range Experiment Station).

Operation	Year	Current Costs(\$)		Discounted Costs(\$)					
		Seedlings per Acre		Interest Rate/Seedlings per Acre					
				5 pct.		6.2 pct.		10 pct.	
		435.6	810	435.6	810	435.6	810	435.6	810
Site Preparation									
Discing	1	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00
Spraying	1	44.00	44.00	44.00	44.00	44.00	44.00	44.00	44.00
Discing	2	20.00	20.00	19.05	19.05	18.83	18.83	18.18	18.18
Spraying	2	44.00	44.00	41.90	41.90	41.43	41.43	40.00	40.00
Planting									
Seedlings	2	130.68	243.00	124.46	231.43	123.05	228.81	118.80	220.91
Planting	2	56.63	97.20	53.93	92.57	53.32	91.53	51.66	88.36
Cultivation									
Spraying	3	44.00	44.00	39.91	39.91	39.01	39.01	36.36	36.36
Irrigation									
Monthly	3	178.60	332.13	162.00	301.25	158.35	294.48	147.60	274.49
TOTAL				505.25	790.11	497.99	778.09	476.6	742.30

2 shows \$13 per ton to be greater than the break-even price for only the minimally managed scenario at yields greater than 2720 cubic feet (58 dry tons) per acre. At \$22 per bone dry ton for delivered chips, then only the costs of harvesting, chipping, and transportation are covered, which means no price could be paid to the landowner for stumpage.

In Washington on very steep terrain for mechanized harvesting of biomass, preliminary studies shown in table 4 indicate that the costs of harvesting, chipping, and transportation alone are greater than the delivered price of wood chips.

It is anticipated that as more biomass conversion facilities come on line, and as the real price of energy continues to increase, competition will drive the real price of wood chips up, although it is difficult to predict to what level. Our analysis shows the sensitivity of a eucalypt energy plantation to the delivered price for wood chips.

CASE STUDY-- CONCORD NAVAL WEAPONS STATION

Our objective in this section is to evaluate the economic viability of a eucalypt planting program at the Concord Naval Weapons Station by dividing present value of benefits by present value of costs, both discounted at various interest rates. The benefit-cost ratio is useful

to determine if a project is returning an acceptable return on the public resources invested.

Actual costs of the various cultural operations required to establish eucalypts at Concord refer to contract labor, and include a margin for profit and risk (table 5). Experience at Concord indicates that the site requires intensive cultivation for eucalypt production. The planting site should be disced and sprayed with herbicide for one year before planting, at the time of planting, and one year after planting. Summer irrigation by tank truck is budgeted for the first year. Two planting densities were considered, namely 435.6 seedlings per acre, which was the density used for species trials at Concord, and 810 seedlings per acre, which should produce a well-stocked stand even after considerable mortality.

Methods

The analysis reported here was completed in 1980 and is reported in 1980 dollars. All costs were discounted to the (then) present time using equation 1 at a 5 percent, 6.2 percent, and 10 percent real interest rate. The bulk of evidence suggests that 5 percent is the rate most commonly applied to public investments (D.E. Teeguarden, pers. comm.). The rate actually used by the Forest Service in its analyses under the Resources Planning Act is 6.2 percent. The 10 percent rate was chosen because it was felt to be closer to the

Table 6-- Yields and current value for 9-year-old eucalypt plantations at Concord Naval Weapons Station. Source: King and Krugman, 1980.

Species	Survival (pct.)	Trees (#/acre)	Volume (cords/acre)	Green Weight (tons/acre)	Current Value	
					Firewood (\$25/cord)	Chips (\$8/ton)
<u>E. dalrympleana</u>	60	261	25.86	77.58	646.50	620.64
<u>E. grandis</u>	91	396	24.21	72.63	605.25	581.04
<u>E. nitens</u>	94	409	26.60	79.80	665.00	638.40
<u>E. viminalis</u>	75	327	15.98	47.94	399.50	383.52

Table 7--Benefits per acre on a 9-year coppice rotation for *E. dalrympleana* (D) and *E. viminalis* (V) fuelwood at Concord Naval Weapons Station (Assuming stumps will coppice 4 times before replanting is necessary).

Cutting Cycle	Year	Value at Harvest ¹ (\$/acre)		Present Value (\$/acre)				
				D			V	
		D	V	5 pct.	6.2 pct.	10 pct.	5 pct.	6.2 pct.
1	11	761.54	470.59	467.52	417.30	293.61	288.89	257.87
2	20	870.74	538.07	344.58	277.67	142.37	212.93	171.53
3	29	995.60	615.22	253.97	184.76	69.04	156.94	114.17
4	38	1138.36	703.44	187.19	122.93	33.48	115.67	75.97
5	47	1301.58	804.31	137.96	81.80	16.23	25.25	50.55
TOTAL				1391.22	1084.46	554.73	859.68	670.14

¹ Assuming a real price increase of 1.5 percent per year and a current stumpage of \$25 per cord.

rate of return for private investors. Table 5 gives the actual and discounted costs per acre in 1980 for the two planting densities.

Data from a eucalypt species trial at Concord (King and Krugman, 1980) were used to estimate yields (table 6). These yield data were collected from trees planted at the 435.6 seedling density level and reduced by natural mortality. Mean annual increment was probably at a maximum around 8 to 9 years.

In one respect the yield data could be considered inflated: trees were planted in small plots (16 trees) and because of mortality in adjacent plots, trees of the successful species were relatively free of competition at the plot edge. On the other hand, it is now obvious that these early trials were not planted with the best seed sources and current tests indicate that yields could well be doubled with proper choice of seed. Furthermore, yields were certainly underestimated for the coppice rotations. The eucalypt species mentioned here, with the exception of shining gum (*Eucalyptus nitens* Maid.), will sprout back readily after cutting, and regeneration by sprouting is anticipated for at least four cutting cycles. The sprout generations should grow more rapidly than the initial seedling generation because they begin on an established root system. Because there was no way to estimate the increased growth, yields were assumed to be the same as those for the first generation, giving a conservative estimate of returns.

For the higher planting density, there was no data to evaluate yields. Volume per tree will likely be less at the higher density, but volume per acre may well increase, particularly at rotations as short as 9 years. The higher density option was included because it is a commonly used spacing in eucalypt plantations around the world. For our analysis we used a conservative assumption; i.e., that yields at the closer spacing would be the same as yields at the wider spacing. Although we do not have a good estimate of the benefits of closer spacing, the scenario may have importance in evaluating the profitability of a

high planting density when high mortality is expected. Plantings on a large scale and at various spacings are needed to develop better estimates of yield, but on balance, the present estimates seem to be conservative.

The discounted benefits (returns) from 5 cutting cycles for mountain and manna gums (*E. dalrympleana* Maid. and *E. viminalis* Labill.) are shown in table 7. As the previous section pointed out, it is difficult to assess the stumpage price for eucalypt energy products. Our analysis assumed a stumpage price of \$25 per cord, which is close to the stumpage price of \$8 per ton for chips. Since stumpage prices for wood products in general are projected to increase at about 1.5 percent annually in real dollars (Haynes, Connaughton, Adams, 1980), a real price increase was included in the calculation of the benefits.

Results

Table 8 shows the benefit/cost ratio, determined by dividing the discounted benefits in table 7 by the discounted costs in table 5. It appears that planting mountain gum on Navy land will return at least 6.2 percent on the investment (the B/C ratio is greater than 1), and even 10 percent at the low planting density. It will not return 10 percent on the investment at the high planting density (the B/C ratio is less than 1), at least with our conservative estimates of yield and liberal estimates of costs.

Table 8--Benefit/Cost ratio for plantations of *E. dalrympleana* and *E. viminalis* at the Concord Naval Weapons Station using contract labor.

Seedlings per acre	<i>E. dalrympleana</i>			<i>E. viminalis</i>	
	5 pct	6.2 pct.	10 pct.	5 pct.	6.2 pct
435.6	2.75	2.18	1.16	1.70	1.35
810.0	1.76	1.39	0.75	1.09	0.86

In general, the economic returns used in these

calculations were probably conservative. Yields will be higher because coppice growth is more rapid than seedling growth; biologic productivity is probably not maximized at the 435.6 seedling density level which is the limit of this data; and selection within species can be used to improve yields (Ledig, this proceedings). Contract costs are often higher than in-house costs, so the benefit-cost ratios reported may be higher if in-house labor is used. All of these factors suggest the economic outlook for eucalypt production is even better than that summarized in table 8, yet even the present scenario indicates that eucalypt culture is quite profitable.

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Part 4. Growth and Yield

Growth and Yield of Some Eucalypts of Interest to California¹

Roger G. Skolmen²

For more than 100 years, eucalypts have been generally recognized around the world as among the fastest growing trees. Height growth of 10 m (32 ft) a year during the second or third year of growth has frequently been recorded. Yields of 20 m³ per ha per year (286 ft³/acre/yr) are generally considered as only better than average in Brazil and the Republic of South Africa. Even in California with its long summer drought, some remarkable yields have been measured. In addition, the trees will often grow reasonably well on impoverished sites where other species barely survive.

Everywhere Eucalyptus has been introduced, there has been, and still is, an ongoing search for better-growing species. I, for one, suspect that the nine best eucalypt species for pulp or timber plantations have already been identified for most parts of the world.

In the moist tropics, E. deglupta and E. urophylla; in the intermediate tropics to warm temperate zone, E. grandis (saligna), E. robusta, E. citriodora, E. tereticornis; and in the cooler humid temperate or semi-arid and arid temperate zone, E. globulus ssp. globulus, E. viminalis, and E. camaldulensis.

I have combined E. grandis and E. saligna because they are so frequently mixed. So actually, there are 10 species, perhaps even 11 if E. sideroxylon is thrown in, and that illustrates the problem. It is very easy to just go on adding species.

For this discussion, I have arbitrarily chosen four species that I consider to be of most economic interest to California:

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Abstract: Eucalyptus globulus ssp. globulus, E. viminalis, E. grandis, and E. camaldulensis were selected as the species of interest in California. Yield data for these species from around the world indicate that wide variation can be expected among species, provenances, sites, and management systems. Large gains in yield can be achieved by careful selection within this wide variation to suit California conditions. Growth characteristics of the eucalypts and distribution of the more important plantation species around the world were also reviewed.

Eucalyptus globulus ssp. globulus
Eucalyptus viminalis
Eucalyptus camaldulensis
Eucalyptus grandis (saligna)

I will discuss their behavior as plantation trees in various countries around the world.
GROWTH Height

Many eucalypts have a capacity for phenomenal height growth. The tallest hardwood tree in the United States is a E. saligna growing in North Kona on the island of Hawaii, which in 1980 was about 50 years old and 84 m (276 ft) tall (Petteys 1983). Most height growth occurs while the trees are still young. Usually, within the first 5 to 10 years of age, 60 to 70 percent of total height growth is achieved among the tall forest eucalypts. As an example, in the course of a plantation spacing study in Hawaii, one tree measured was 32 m (106 ft) tall at 5 years of age. In the same stand at 15 years dominants were 43 to 46 m (140 to 150 ft) (Walters 1980). These trees grew 4.3 m (14 ft) per year for 5 years, then 1.2 m (4 ft) for 5 years, and then 0.3 m (1 ft) per year for 5 years.

Diameter

Diameter growth, although quite rapid, is less dramatic than height growth. In Hawaii, in the saligna/grandis complex we work with, we find that for trees up to 5 years old, spaced at 2 by 2 to 3 by 3 m (6.5 to 10 ft), the ratio of height in meters to diameter in centimeters is close to 1.0. A tree 4 m tall will usually be about 4 cm in diameter-at-breast-height (d.b.h.) (3 ft of height per 0.4 inch of diameter). This ratio, of course, varies with species, site, climate, stocking, and age.

A comparison of 10-year growth of three species at different locations indicates that the height-to-diameter ratio in trees of this age is usually more than 1.0 (table 1). In widely spaced stands, such as those of

E. camaldulensis in Morocco, diameter growth is still sufficient at age 10 to maintain the ratio at about 1.0. Site has a stronger influence on the ratio with the other species and levels of stocking. Eucalyptus grandis in South Africa greatly exceeds the other species in height growth. The criteria for separating good, fair, and poor sites are height measurements at age 10,

Table 1--Ratio of height in meters (h) to diameter in centimeters (d) at age 10 by species, site, and stocking.

Species and location	Stocking (stems/ha)		Site		
			Good	Fair	Poor
<u>Eucalyptus globulus</u>	2500	Height	22.0	16.0	13.0
North Spain		h/d	1.57	1.42	1.31
<u>Eucalyptus globulus</u>	1100	Height	27.0	19.0	11.0
Portugal		h/d	1.39	1.26	1.29
<u>Eucalyptus camaldulensis</u>	800	Height	15.6	13.0	10.4
Morocco		h/d	0.95	0.95	0.95
<u>Eucalyptus grandis</u>	1100	Height	34.8	28.4	20.2
South Africa		h/d	1.76	1.55	1.19

Source: FAG 1979, P. 310.

YIELD

Volume

Tree volume is measured and reported in many different ways around the world, so it is important to look at what is being measured when reviewing the literature. Frequently, this important information is not reported. Most commonly, total stem volume over bark is used. It is determined with d.b.h., total height, and a form factor, which in Third World countries is usually a ratio of volume to basal area times height--the old "artificial form factor" of European forestry (Assman 1970). Some volume tables allow for stump height, some are to a top diameter, some are for volume under bark, and some are of stacked volume (FAO 1979). The volume figures I report here are all for total height over bark, unless otherwise specified.

Biomass

Data on total biomass are scarce, but of great interest currently. In Australia, Cromer and others (1975) found E. globulus ssp. globulus seedlings to have a weight yield at 4 years made up of 55.5 percent stemwood, 11.5 percent bark, 16.5 percent branchwood, and 16.5 percent leaves (table 2). At age 6, the percentage of stemwood had increased slightly while the percentage of branchwood decreased (FAO 1979); percentage of leaves remained the same. Data I collected in three ssp. globulus coppice stands in Hawaii gave 72 percent of the dry weight yield in stems and bark at age 3, 76 percent at age 4, and 77 percent at age 5. So it appears that with both seedlings and coppice of this species we can expect 70 to 75 percent of weight yield of young trees to be in stems and bark.

Other data (FAO 1979) indicate that by volume rather than weight, stems of ssp. globulus in Italy were 15 to 20 percent bark, depending on their diameter. For pulp yields this is important because ssp. globulus bark is used in most pulping processes. On the other hand, E. camaldulensis bark, which is not used in pulp, made up 20 to 30 percent of stems under 20 cm (8 inches) in Italy. Eucalyptus grandis bark, also not desired in pulp, was about 15 percent in small trees in three countries reported.

Table 2--Biomass percentages in Eucalyptus globulus grown in Australia.

Material	Age (years)	
	4	6
Stem	67.0	71.7
Wood	55.5	57.1
Bark	11.5	14.6
Branches	16.5	12.7
Live	12.0	9.8
Dead	4.5	2.9
Leaves	16.5	15.

Source: FAO 1979, p. 315.

Weight

Weight is an important consideration in growing fuelwood or pulpwood. Most eucalypts produce light-weight wood when very young and then increasingly denser wood with age. During the first 5 to 10 years, wood density increases along radial and height gradients, and in trees of the same age, the wood of highest average specific gravity will be found in the largest and tallest trees. Rapid diameter and height growth do not necessarily result in reduced average wood density as would be expected (King 1980). However, wood density of young trees is often much less than that of mature trees, which is the density usually reported in the literature. In Hawaii, a study done in 1978 indicated that dry weight of 2- to 5-year-old ssp. globulus coppice ranged with stand age from 421 to 494 kg/m³ (26 to 31 lb/ft³) in samples from the lower 2 m (6.5 ft) of the stem (Skolmen 1980). This is only 70 percent of the dry weight of mature wood. Three years later, in 1981, we sampled 40 trees in the stands, which were then 7 and 8 years old. Specific gravity at breast height remained the same, but samples from 6 m (20 ft) averaged 511 kg/m³ (32 lb/ft³). The wood density increased with height. Elsewhere in Hawaii, specific gravity at 2 years of age was 0.39 for E. saligna and 0.36 for E. grandis (Bioenergy Dev. Corp. 1983). Mature trees of these species have wood that ranges from 0.50 to 0.60 in specific gravity. It may be necessary to carry eucalypts

for a longer rotation than planned merely to increase average density.

EUCALYPTUS GLOBULUS SPP. GLOBULUS

Eucalyptus globulus ssp. globulus is the common bluegum that was originally introduced into California from Tasmania or the southern part of the state of Victoria. Probably because its juvenile foliage is unpalatable to cattle, it was favored in early introductions and widely planted (FAO 1979). Today, because of its rapid growth and adaptability to a wide variety of site conditions, it is one of the most planted of all eucalypts around the world. It has been particularly successful in countries with a Mediterranean climate such as California, Portugal, Spain, Chile, and the western part of the Republic of South Africa.

In Portugal, where it is by far the most common species planted, there are 238,000 ha (588,000 acres) of E. globulus (FAO 1979). Most plantations are near the coast in northwest Portugal where the annual rainfall normally exceeds 850 mm (33 inches). Stands are worked on a coppice rotation of 10 to 12 years for the production of paper pulp and firewood. Mean annual increment (MAI) ranges from 12 to 30 m³/ha/yr (172 to 429 ft³/acre/yr) (Turnbull and Pryor 1978).

In Spain, bluegum grows on 205,000 ha (492,000 acres) (FAO 1979). In the Huelva Province near sea level, where the very seasonal annual rainfall is 440 mm (17 inches) bluegum produces only 4 to 8 m³/ha/yr (57 to 114 ft³/acre/yr) of wood which is used for pulp and mine props. In the north, where rainfall is evenly distributed and exceeds 1000 mm (39 inches), production is more like that in Portugal, ranging from 12 to 20 m³/ha/yr (172 to 286 ft³/acre/yr).

In Chile, large areas of bluegum are managed on coppice rotations of 5 to 20 years for firewood, charcoal, and mine props. In a zone of annual rainfall of over 1200 mm (47 inches), ssp. globulus withstands temperatures down to -7° C (20° F) and is reported to grow in areas with annual rainfall as low 350 mm (14 inches). It also grows extensively in Argentina, Uruguay, Peru, Bolivia, and Ecuador (Turnbull and Pryor 1978).

In Hawaii, bluegum was planted in the early 1900's and did quite well at higher elevations of 1200 to 1800 m (4000 to 6000 ft). At this elevation range, good yields sometimes exceed 1400 m³/ha (100,000 fbm/acre) in 60-year-old stands. At lower elevations in Hawaii, the species frequently produces short, stunted trees with extremely spiralled grain.

Bluegum coppices very well and forms lignotubers, which will live for many years in the soil if the stem dies back due to suppression. These will sprout after the rest of the stand is logged. In our coppice stands in Hawaii we normally get coppice on the stumps as well as coppice from these buried lignotubers. In addition, a stand of seedlings usually becomes established along with the coppice (Skolmen 1980).

In Hawaii we studied E. globulus coppice that came in after logging four 64-year-old stands. These bluegum stands were similar to those in California of about the same age and diameter. Four stands involved in this study were growing at an elevation of about 1200 m (4000 ft) and receiving 1250 to 2000 mm (50 to 80 inches) of rain per year. The four stands had been logged during consecutive years between 1973 and 1976. When measured, 2, 3, 4, and 5 years had passed since logging. Despite the age of the stumps, 70 to 80 percent of them had coppiced. But we found that about half the volume in the stands was from stems that had sprouted from buried lignotubers that had been present before logging. These lignotubers were the remnants of suppressed stems that had died and disappeared. In addition to the coppice, all stands had seedlings, which made up more than 20 percent of the total number of stems in all stands but contributed very little to the volume as they were usually suppressed by the coppice. MAI varied from 10.4 to 14.0 m³/ha/yr (150 to 200 ft³/acre/yr) among the unmanaged 2- to 6-year-old coppice stands over two years of measurement (Skolmen 1980).

In this coppice study, stems with bark intact averaged 60 percent moisture content calculated on a fresh weight basis. During normal logging in Hawaii, when stems are converted into chips we find that moisture content is generally reduced to about 50 percent if the bark is included. This is often considered high moisture content by boiler engineers who usually specify no more than 42 percent. In Hawaii, we cannot deliver freshly felled E. globulus with this low a moisture content unless the stems are debarked.

In coppice yields worldwide, first coppice crop volume generally exceeds the volume of the seedling crop by 20 to 25 percent (FAO 1979). Studies in Portugal (FAO 1979) indicated that the second coppice crop with E. globulus ssp. globulus should be about 80 percent of the initial seedling crop and the third coppice crop less than 80 percent. In our coppice study in Hawaii, the mean annual increment of total above-ground biomass ranged from 7.8 to 10.6 t/ha/yr (3.5 to 4.7 tons/acre/yr). Seventy percent of the weight was in the stems (Skolmen 1980). Distribution of weight among the different types of stems was 50 percent coppice on stumps, 11 percent seedlings, and 39 percent coppice from buried lignotubers.

In Australia, Cromer and others (1975), found that at age 4, unfertilized seedlings of ssp. globulus produced 12 t/ha (5.3 tons/acre) of total biomass (dry) including branches and leaves. These same plots at age 6 produced 25 t/ha (11.1 tons/acre) for a mean annual increment in weight of 4 t/ha/yr (1.8 tons/acre/yr). Plots that were fertilized produced 90 t/ha (40 tons/acre) or 15 green t/ha/yr (6.7 tons/acre/yr). It was further found that the percentage of weight in stems versus branches and leaves did not vary with the various fertilizer or control treatments.

With bluegum, MAI of 10 m³/ha/yr (143 ft³/acre/yr) is considered typical on poor sites, while very good sites yield up to 35 m³ (500 ft³) (FAO 1979).

Considerable growth information has been gathered for ssp. globulus in Portugal and Spain (FAO 1979). For a good site in Portugal, at age 2, there was a MAI of 10 m³/ha/yr (143 ft³/acre/yr), which peaked at age 12 (fig. 1). At age 10 MAI was 38 m³ (543 ft³). The dry weight of ssp. globulus wood is about 600 kg/m³ (37 lb/ft³). The green weight, because the stem is about 50 percent water, would be 1200 kg/m³ (74 lb/ft³). The weight increment at 10 yr is therefore about 45.6 t/ha/yr (20 tons/acre/yr) on the best site. This is the elusive 10 dry tons/acre/yr of biomass that managers strive for. The poor site at 2 years had a MAI of only 2 m³ (28.6 ft³) and similarly at age 10 only 8 m³ (114 ft³), so site has a major effect on yield.

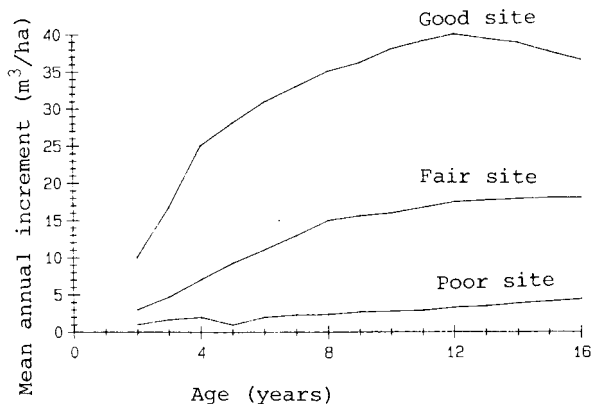


Figure 1--Eucalyptus globulus ssp. globulus, Portugal 1100 per hectare.

In northern Spain, with stocking double to triple the stocking of the stands in Portugal, at age 4, MAI was 27.5 m³ (393 ft³) on the best site (fig. 2). At age 10, it was up to 44 m³ (629 ft³). The northern Spain sites are quite comparable to the sites in Portugal. On the fair site in northern Spain, MAI began to

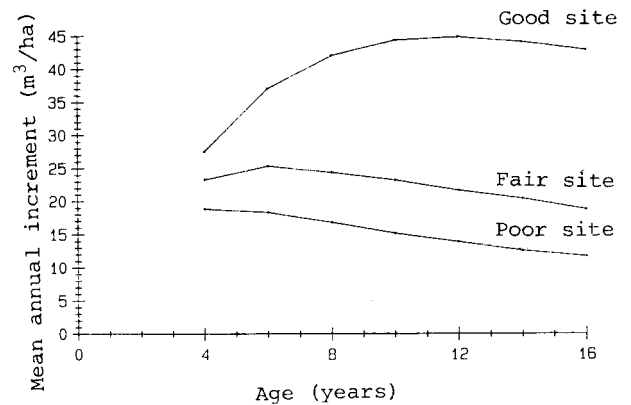


Figure 2--Eucalyptus globulus ssp. globulus, N. Spain 2700 per hectare

drop off after 6 years. By age 10, on the poor site, yield was down to 15.2 m³/ha/yr (217 ft³/ha/yr), whereas at the close spacing used, 18.8 m³ (263 ft³) was achieved at age 4.

In southwestern Spain, on a much drier site, a much wider spacing had to be used, and MAI was much less (fig. 3)--at age 9, on the very best site, only 8 m³/ha/yr (114 ft³/acre/yr). On the worst site at age 9, yield was only 0.8 m³/ha/yr (11.4 ft³/acre/yr). I suspect this might be comparable to the conditions in southern California in most years. At a somewhat better area in southwestern Spain at 9 years on the good site, MAI was 16.2 m³/ha/yr (232 ft³/acre/yr) (fig. 4). On the poor site, this went down to 0.9 m³/ha/yr (13 ft³/acre/yr).

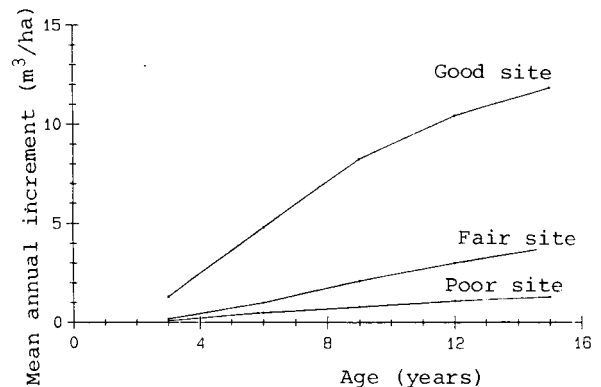


Figure 3-- Eucalyptus globulus ssp. globulus S. W. Spain (sandy) 600 per hectare.

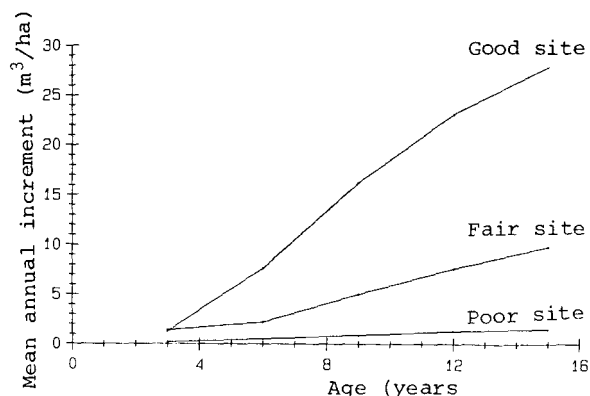


Figure 4--Eucalyptus globulus ssp. globulus, S.W. Spain (shale) 600 per hectare.

EUCALYPTUS VIMINALIS

The principal advantage of E. viminalis as a plantation tree over the other three eucalypts is that it will withstand cooler temperatures. It is suitable for cool climates such as in northern California, that are subject to moderate frosts. This species has been widely planted in southern Brazil, Argentina, Italy, and the Black Sea area of the Soviet Union. It is also considered promising in Chile, Portugal, Spain, and Turkey.

Its main use is as a short-rotation fiber crop for pulp and hardboard production. In Spain, several thousand hectares have been planted on sites that are too cold for ssp. globulus, and at 450 m (1500 ft) elevation it yields about 12 m³/ha/yr (172 ft³/acre/yr) (FAO 1979). Eucalyptus viminalis is considered a good plantation species. It coppices very well, and the coppice does not die back easily in winter. In Australia, the species has a wide latitudinal range and many provenances, so is a very suitable one for provenance testing. The trees can withstand temperatures of -10° C (15° F), but in Russia were killed by temperatures of near -16° C (0° F) (FAO 1979).

EUCALYPTUS CAMALDULENSIS

Eucalyptus camaldulensis is the widest ranging eucalypt in Australia, so there are many provenances suitable for a great many different sites. Its principal desirable feature as an introduced plantation tree is its ability to withstand lengthy and severe drought. The tree can also withstand periodic flooding and was one of the first species to be taken from Australia and planted elsewhere, having been planted in Italy as early as 1803. Today, around the world, there are estimated to be more than a half million hectares of E. camaldulensis in plantations, especially around the Mediterranean. Spain has more than 100,000 ha (247,000 acres). In Morocco, there are about

87,000 ha (215,000 acres). It is also the tree most commonly planted in Israel.

In addition to its ability to withstand long drought, camaldulensis also has some resistance to frost and is a vigorous coppicer. However, the stem is usually more crooked than E. globulus or grandis, two of the other most frequently used trees. Also, the crowns are rather thin so stands are more prone to weed invasion than those of some of the other denser crowned eucalypts. This, incidentally, might be considered a desirable characteristic by those concerned about creating biological deserts by planting eucalypts that prevent understory growth. The wood is heavier, harder, and, more deeply colored than E. globulus or grandis and therefore, not as good for pulp. However, the wood is better than either of the other species for fuelwood because of its high density (FAO 1979).

There has been more provenance testing with this species than any other of the eucalypts, probably because it has more provenances. Some of the results obtained suggest the extreme importance that provenance testing be done in the areas where unknown seed sources are already doing well. An example is a test done at Afaka in Nigeria (table 3). Five-year-old trees had MAI that ranged from 17.3 m³/ha/yr (247 ft³/acre/yr) to 5.1 m³/ha/yr (73 ft³/acre/yr), depending on where in Australia the seed had come from. This demonstrates a possible three-fold increase in yield achieved simply by selecting seed source location.

Table 3--Eucalyptus camaldulensis provenance test at Afaka, Nigeria.

Seed source	Latitude	Rain-fall	Eleva-tion	5-year growth Height	MAI
		mm	m	m	m³/ha/yr
Petford, Q.	17°20'	716	518	17.8	17.3
Katherine, N.T.	14°20'	958	110	15.1	14.1
Wiluna, W.A.	26°38'	249	490	14.2	11.3
Alice Springs, NT	23°08'	252	580	14.8	9.4
Bourke NSW	31°54'	234	210	11.4	8.3
Wohlpoor V	37°00'	606	300	13.2	7.6
Menger's Hill S.A.	34°30'	1182	610	10.4	5.4
Walpole NSW	34°10'	247	90	12.4	5.1

Source: FAO 1979, p. 375.

¹MAI = Mean annual increment.

Growth varies greatly according to climate and soil. On good sites MAI of 2 m (6.5 ft) in height and 2 cm (0.8 inch) in diameter may be maintained for the first 10 years. But on poorer and drier sites, growth is reduced to 1 m (3.3 ft) in height and 1 cm (0.4 inch) in diameter per year. Volume yields of 20 m³/ha/yr (286 ft³/acre/yr) are reported from Argentina, and on the very best sites in Israel, as much as 30 m³ (425 ft³) may be obtained. In Turkey, 20 m³ (286 ft³) can be obtained on good sites in the initial seedling rotation and 30 m³ (425 ft³) in subsequent coppice rotations. However, on poorer and drier sites,

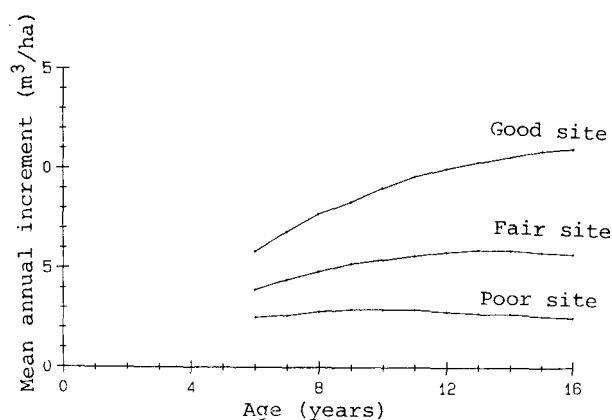


Figure 5--*Eucalyptus camaldulensis*, Morocco 800 per hectare.

much lower yields can be expected. Other countries report corresponding yields (FAO 1979).

Most *E. camaldulensis* plantations are managed on coppice rotations of 7 to 10 years on better sites, and longer on poor sites. In Spain, for example, rotations are 14 to 15 years. The first coppice rotation is expected to produce a higher yield than the initial seedling rotation and the length of the rotation may be adjusted accordingly. For example, in Morocco, a seedling rotation of 12 years is common followed by 7 years for the first coppice rotation and 10 years for the second (FAO 1979).

Yield variation of *E. camaldulensis* on three sites in Morocco at a spacing of 3.5 by 3.5 m (11.5 by 11.5 ft) is believed to be typical for this species (fig. 5). MAI at age 6 was 5.8 m³ (83 ft³) and at age 10 it was 9 m³ (129 ft³) and still rising. On the medium site, at age 6, MAI was only 3.9 m³ (56 ft³) and at age 10, 5.4 m³ (77 ft³). On the poor site, at age 6 MAI was 2.5 m³ (36 ft³) and at age 10, 2.9 m³ (4 ft³). On the medium site, MAI peaked at 14 years. On the poor site it peaked at 11 years. On the good site, the trees at this somewhat wide spacing of 800 stems/ha (324/acre) were 16.5 cm (6.5 inches) diameter at 10 years (FAO 1979).

EUCALYPTUS GRANDIS

Eucalyptus grandis is more suited to the semitropics and in California is probably limited to the southern part of the state in those locations where water is sufficient. It is killed back by frost and in general has about the same temperature sensitivity as citrus. This species was not segregated out by botanists until 1918. Before then, much of the *E. saligna*

that was introduced around the world was really *E. grandis* because until 1918, the trees that were recognized as *E. saligna* included *E. grandis*. For this reason, in many parts of the world, there is a mixture of *E. grandis* and *E. saligna* present and also hybrids between them. This is particularly true in South Africa and also in Hawaii. South Africa has now taken to calling their trees *E. grandis*, while in Hawaii, we call them *E. saligna*. Many trees in any stand in Hawaii will show the characteristics of either species. However, *E. grandis* is a distinct species and where it has been compared, it has usually been found that *E. grandis* will outgrow *E. saligna* on the same site. On the other hand, *saligna* has somewhat denser wood than *grandis* and for that reason may be preferred on some sites as a fuelwood producer (FAO 1979).

Provenance comparisons in Hawaii (BioEnergy Dev. Corp. 1983) have shown average yields at 3 years of 15 and 42 m³/ha/yr (215 and 600 ft³) for *E. grandis* at two different sites where *E. saligna* in the same tests produced 12 and 32 m³/ha/yr (172 and 458 ft³/acre/yr). At the better site the best *E. grandis* provenance had an increment of 56 m³/ha/yr (800 ft³/acre/yr) while the worst provenance had 28.8 m³/ha/yr (412 ft³/acre/yr). On the poorer site this 2:1 ratio between the best and the worst was increased to 2.5:1, so seed source selection clearly pays dividends. These provenance test yields are blown up from trees growing in randomized plot designs which create reduced competition for the best growing provenances. Therefore they are overestimates of true yield.

Eucalyptus grandis is one of the most important introduced eucalypts. There are well over half a million hectares planted in countries other than Australia, particularly South Africa and Brazil, and also in Angola, Zimbabwe, East Africa, India, Argentina, and Uruguay. If we combine what is called *saligna* with *grandis* as one species, then this *E. grandis/saligna* complex is unquestionably the most widely planted eucalypt in the world with well over 1 million ha (2,470,000 acres) planted (FAO 1979).

Eucalyptus grandis/saligna is the most commonly planted eucalypt because it is the fastest growing exotic that has been found for vast semitropical areas in the southern hemisphere that have been developed in the 1900's. It grows very rapidly in height at 2 to 3 m (6.5 to 10 ft) a year over the first 10 years. The excellent self-pruning stem is very straight. It forms a dense crown which will shade out weed competition at an early age. It flowers and seeds at 3 to 4 years and coppices freely when young. Coppicing has become more difficult after 10 to 12 years in stands in Zambia. The tree will not withstand a severe

frost and generally does best where rainfall is evenly distributed, although in some locations, it has been shown to withstand droughts of 3 to 4 months. *Eucalyptus grandis* can be propagated from cuttings relatively easily so long as the cuttings are taken from young coppice on stumps. By using this method it may be that soon seedling plantations will become rare (FAO 1979). A prime example of this is at the Aracruz Corporation's holdings in Brazil, where they have not only increased growth to the phenomenal rate of 73 m³/ha/yr (1044 ft³/acre/yr) by using clonal plantations, but have also increased cellulose yield by 10 percent over initial seedling plantations (Campinhos 1981).

Generally, around the world, a 6- to 10-year rotation is used for pulpwood, fuelwood, or wood for mine supports. In most countries, short rotations are not thinned. Spacing of 2 by 3 m (6.5 by 10 ft) is most commonly used in such plantings. Usually, one seedling rotation is followed by at least two coppice rotations (FAO 1979). Aracruz Corp. in Brazil buries the stumps of the seedling crop to prevent them from coppicing and replaces them with clonal plantations. With these they expect to grow one rotation from planted ramets followed by four rotations from coppice, although at this point this is still speculation (Campinhos 1981).

Generally, in the countries where *E. grandis* has been most widely used, reported annual yield figures fall in the range of 14 to 35 m³/ha/yr (200 to 500 ft³/acre/yr). A yield of 20 m³/ha/yr (286 ft³/acre/yr) is considered normal above average growth for stands less than 15 years old (FAO 1979).

Because the species has been widely planted around the world, yield information is abundant (FAO 1979). Data from Uganda show some of the highest yields; with stocking of 1680 trees per ha (680/acre) even average sites maintained more than 20 m³ (286 ft³) over 15 years (fig. 6). This figure gives stem volume under bark, rather than over bark as with the previous data presented. On the poor site, stem volume had already peaked at age 4 with 24 m³/ha/yr (343 ft³/acre/yr). On the medium site it had also already peaked at 4 years at 36 m³/ha/yr (514 ft³/acre/yr), but on the good site, MAI did not peak until age 6 or 7, when it achieved an amazing 52.4 m³/ha/yr (750 ft³/acre/yr).

On a good site in South Africa, with a stocking of 1100 trees per ha (445/acre), the MAI (under bark) at age 3 was 19.1 m³ (273 ft³) and at age 9 was 45.5 m³ (650 ft³) (fig. 7). On the medium site at age 3 MAI was 10.7 m³ (153 ft³) and at age 10, 27.4 m³ (392 ft³). On the poor site, MAI was 5.1 m³ (73 ft³) at age 3 and 12.5 m³ (179 ft³) at age 10. On the poor site MAI peaked at 12 or 13 years whereas on the medium site it peaked at 10 years (FAO 1979).

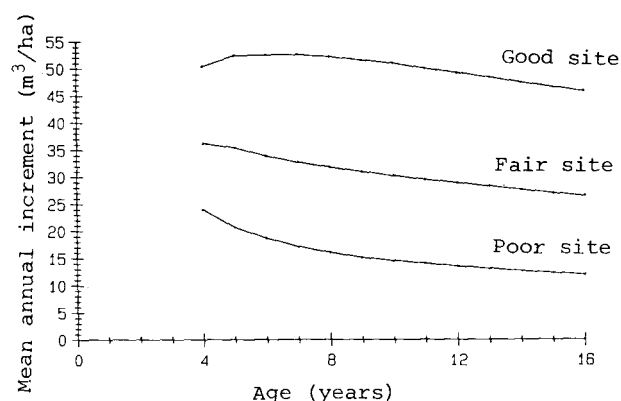


Figure 6--*Eucalyptus grandis*, Uganda 1680 per hectare (volume under bark).

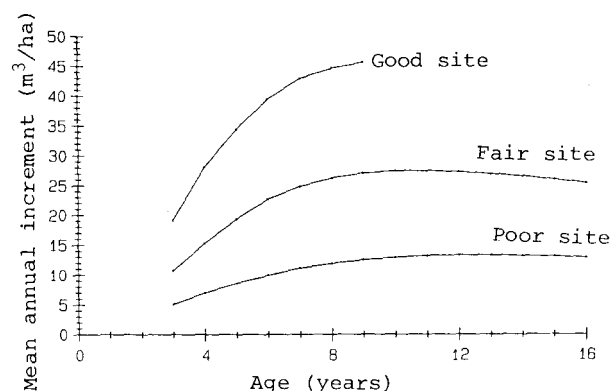


Figure 7--*Eucalyptus grandis*, South Africa 1100 per hectare (volume under bark).

Four years after cutting a 44-year-old mixed stand of *E. saligna*, *E. grandis*, and *E. microcorys* in 1978 in Hawaii, we found the coppice stand to contain 5200 stems per hectare (2080/acre)--most of which were seedlings rather than sprouts. These stems contained 197 m³/ha (2810 ft³/acre), representing MAI of 49 m³/ha/yr (700 ft³/acre/yr). A sample of 20 stems in the stand gave a moisture content of stems with bark of 60 percent of the fresh weight and specific gravity of 0.41. The green weight increment was 50 t/ha/yr (28 tons/acre/yr), which is a dry weight yield of 20 t/ha/yr (11.2 tons/acre/yr) and the highest we have measured in an unmanaged coppice stand in Hawaii.

Walters (1980) found that *saligna/grandis* spaced at 2.4 by 2.4 and 3.0 by 3.0 m (8 by 8 and 10 by 10 ft) in Hawaii achieved peak MAI at just under 5 years on a particularly good site. The MAI (over bark) at 2.4-m (8-ft) spacing was 59 m³/ha/yr (844 ft³/acre/yr). Also on this site was a tree 106 feet tall at age 5. This growth is quite exceptional and generally requires year-round rainfall with perhaps 254 mm (10 inches) of rain per month and rapid soil drainage. The four spacings compared in this study were 2.4, 3.0, 3.7, and 4.3 m (8, 10, 12,

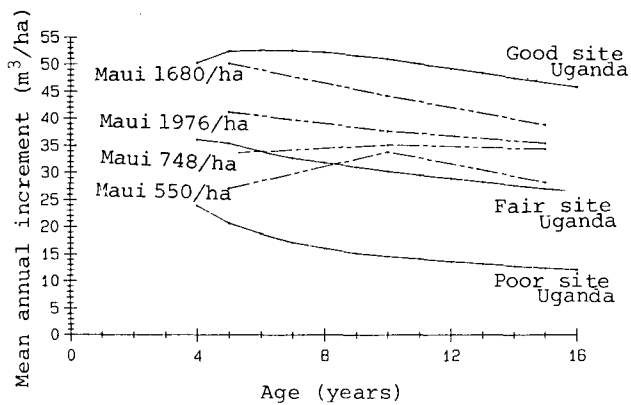


Figure 8--*Eucalyptus grandis* Uganda (1680/ha), *Eucalyptus saligna*, Maui (var. spacing) (volume under bark).

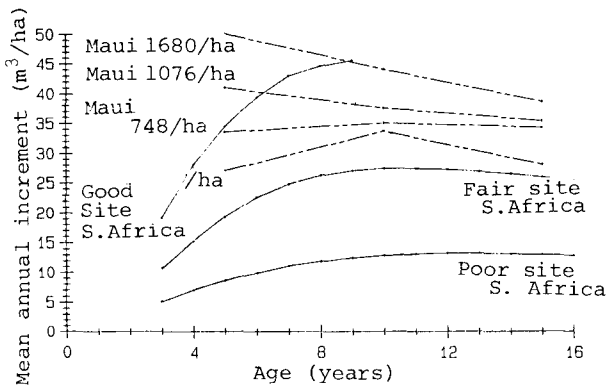


Figure 9--*Eucalyptus grandis*, South Africa (1100/ha), *Eucalyptus saligna*, Maui (var. spacing) (volume under bark)

and 14 ft). When the MAI at ages 5, 10, and 15 years, here reduced by 15 percent to adjust for overbark measure, are superimposed on the curves for Uganda, it can be seen that spacing has a large influence on yield (fig. 8). The yield curve at 8-ft spacings (1680 trees/ha) generally follows beneath the best Uganda site, whereas wider spacing produced lower yields on the Hawaii site. The Hawaii data bracketed the good site data for South Africa (fig. 9). Again the most similar spacing, 1076 trees per hectare, had a yield most similar to that in South Africa. It should not be assumed that close spacing is most desirable because it produces higher yields. It also reduces diameter growth and increases the number of trees per unit land area, both of which increase harvesting costs if short rotations are intended. Trees that are 12.5 cm (5 inches) in diameter are the most expensive to harvest with modern feller-bunchers.

CONCLUSIONS

Eucalyptus should certainly have a place in fulfilling California's fuelwood and pulpwood needs. It might even supply an exportable crop.

The national standard for identifying prime forest land in the United States was that it can produce at least 3.1 m³/ha/yr (45 ft³/acre/yr). This standard was intended for natural forests rather than plantations. However, it provides a basis for comparison of the many yield figures presented here. Few of them, even for the most arid sites, are as low as 45 ft³, which serves to illustrate that the eucalypt growth is very good.

The importance of provenance selection for different sites was brought out in the data for *E. camaldulensis*. In addition, the various annual increment graphs on different sites indicated that plantation spacing must be increased on arid or difficult sites. The large differences in yield on different sites were also apparent as were those caused by spacing variation on the same site.

For convenience some of the data presented earlier are combined in tabular form for comparison (table 4).

This review is intended to help potential California eucalyptus growers recognize the need to: (1) select the proper species for the site; (2) test provenances of the selected species; and (3) adjust cultural practices, such as plantation spacing, rotation, and harvesting techniques, to fit the site and the species.

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Table 4--Site characteristics, growth, and yield of three Eucalyptus species at various locations.

Species	Location	Mean annual rain-fall (mm)	Min. temp. (°C)	Dry season (mo.)	Typical stocking (no/ha)	Size and yield ¹											
						Good site				Average site				Poor site			
						Dia (cm)	Ht (m)	(m ³ /ha)	Max MAI (yr)	Dia (cm)	Ht (m)	(m ³ /ha)	Max. MAI (yr)	Dia (cm)	Ht (m)	(m ³ /ha)	Max. MAI (yr)
<u>Eucalyptus globulus</u> asp. <u>globulus</u>	N. Portugal	1100	5	2	1100	19	27	380	12	15	19	160	15	8	11	28	20
	NW Spain	1200	7	0	2700	14	28	443	12	11	21	232	6	10	18	152	4
	SW Spain ²	550	4	3	500	15	17	91	18	11	11	24	18	9	7	9	16
	SW Spain ³	550	4	3	500	20	21	190	20	15	15	61	20	8	8	10	20
<u>Eucalyptus camaldulensis</u>	Morocco	500	8	5	800	16	16	120	18	14	13	54	13	11	10	29	9
<u>Eucalyptus grandis</u>	Uganda	1100	12	4	1680	-	40	508	5	0	30	301	4	-	20	145	3
	S. Africa	900	4	2	1100	20	40	450	10	18	32	274	10	15	23	129	12

¹At age 10 and age at culmination of mean annual increment by site.

²Sandy soil.

³Shale soil.

Evaluating Trees as Energy Crops in Napa County¹

Dean R. Donaldson and Richard B. Standiford²

The Cooperative Extension office in Napa County started a biomass evaluation project in 1977 in cooperation with several local landowners. The purpose was to: (1) evaluate several tree species for potential as a biomass crop; (2) develop baseline growth and yield data for future economic feasibility studies; (3) serve as demonstration areas to illustrate management required for silviculture biomass farming; and (4) evaluate several experimental designs for efficient data collection for future biomass trials.

STUDY SITES

Two study areas were established in 1977 and 1979 near Calistoga, California, at the north end of Napa Valley. Areas planted are on the Napa Valley floor and receive 34 to 36 inches of rainfall per year, most of which occurs between November and March.

Virtually all of the interest in growing trees as an energy crop in Napa County has come from individuals owning small farms, usually less than 10 acres. Experimental design at the two areas had to meet three requirements: (1) to fit into the small space available for trials at the cooperator's property; (2) to obtain the maximum possible information from a small number of trees planted; and (3) to allow for sufficient replications for valid statistical conclusions to be made from the planting. Since there was no benchmark data on expected variance from these trials, each of the two study areas had a different experimental design so that the efficiency of each in giving reliable answers could be evaluated.

Area 1, Grant Street

Six species were chosen for evaluation at this site: Eucalyptus viminalis (manna gum), E. camaldulensis (river red gum), E. dalrympleana

Abstract: An evaluation of tree species for energy crops was initiated at two areas in Napa County, California. At one area, Eucalyptus viminalis at 39 months was significantly taller than E. camaldulensis at 50 months. Also evaluated were five clones of Pinus radiata, Juglans regia X hindsii, and Sequoia sempervirens; and these were 1/4 to 1/2 the height of the Eucalyptus species in this time period. At the second area, after 27 months, Eucalyptus camaldulensis was significantly taller and had a larger diameter-at-breast-height than Eucalyptus dalrympleana.

(mountain gum), Pinus radiata (Monterey pine), Juglans regia X hindsii (Paradox hybrid, a sterile walnut hybrid), and Sequoia sempervirens (coast redwood). All trees were first-year seedlings, except Monterey pines, which were rooted cuttings from five different clones collected from the Monterey peninsula and from New Zealand. There were five individuals of each of the five clones in each Monterey pine replication.

Ground preparation included cross-ripping and disking before planting. Trees were planted by hand, except walnuts, which were planted with an auger. Each species was block-planted, 5 trees by 5 trees (25 per block), at a square spacing of 2.4 by 2.4 meters (8 by 8 feet). Replications of species were arranged in a randomized block design.

In May 1977, river red gum, mountain gum, and walnut were planted. Due to poor survival, mountain gum was discontinued and replaced by manna gum in April 1978. Coast redwood was also planted in 1978. Young trees received periodic overhead sprinkler irrigation the first two seasons, and no irrigation since. Chemical weed control has been carried out annually.

Area 2, Bale Lane

River red gum and mountain gum were evaluated at this site. The area was cultivated and hand-planted in April 1979. Two blocks of each species were planted with approximately 100 seedlings per block. Trees were planted at a square spacing of 1.5 by 1.5 meters (5 by 5 feet). The area has been irrigated with an overhead sprinkler system during the summer. Chemical weed control has been carried out annually.

All trees were measured in July 1981 (39 and 50 months after planting in area 1, 27 months after planting in area 2). Diameter at 1.4 meters (breast height [DBH]) and total height were measured. Tree measurement comparisons between outside border trees and inside trees were statistically evaluated. Wood volume per block of trees to a 5-cm (2-inch) top was calculated for the eucalyptus species in area 1 using the following volume equation derived from work reported by W. Metcalf in 1924 and J.P. King and S.L. Krugman in 1980:

¹Presented at the Workshop on Eucalyptus in California, June 14-16, 1983, Sacramento, California.

²Farm Advisor (Napa County) and Forestry Specialist (Berkeley) respectively, Cooperative Extension, University of California.

$$\text{Volume (cubic feet)} = 0.00245 (\text{DBH [inches]})^2 \times \text{height [feet]} - 0.3318$$

Volume converted to cubic meters using 1 cubic foot = 0.02832 cubic meters

This 5-cm small-end diameter is felt to be the approximate minimum size of a firewood product. Other species have not reached a size to allow calculation of volume using this standard.

RESULTS

No statistical differences in tree diameters and heights among these trees were found between the interior and exterior portions of each planting. Therefore, all tree measurements were combined for volume estimation.

At area 1, eucalyptus were by far the fastest growing of the four genera evaluated (see table 1). The two eucalyptus species were 1' to 2 times taller in height and 1/ times larger in diameter than the next fastest growing species, Monterey pine (Clone Z-6). Manna gum, *Eucalyptus viminalis*, at 39 months was already significantly taller in total height than river red gum, *E. camaldulensis*, at 50 months.

At area 2, river red gum was significantly larger than mountain gum at 27 months (table 2). The trees were still too small for volume to be calculated.

Average volume yields for the two fastest growing species in area 1 were 24.7 and 19.1 cubic meters per hectare (353.3 and 272.8 cubic feet per acre) for manna gum and river red gum, respectively, and from these figures the mean annual increment was calculated (table 3). Manna gum is producing an estimated total energy yield of 20 million kcal per hectare (32 million BTU per acre) per year, and river red gum 15 million kcal per hectare (25 million BTU per acre) per year.

Future growth will be periodically measured, and height, DBH, volume, and energy yield will be calculated. It is expected that these future measurements will show higher annual wood volume increments, because root and canopy development will allow for more complete utilization of the resources at the site. This information will be useful to landowners evaluating the potential of growing biomass crops. Similar trials should be established in other areas of the state where energy plantations are being considered.

Table 1 -- Summary of data from area 1, Grant Street, Calistoga, Napa County, July 1981¹

Species	1981 age (mo)	Survival	Average height ²		Average DBH ²		Average volume/area ²	
			meters	(feet)	cm	(inches)	cu. m/ha	(cu. ft/a)
<i>Eucalyptus viminalis</i>	39	56/70	8.3	(27.3)	7.9	(3.1)	24.7	(353.3)
<i>Eucalyptus camaldulensis</i>	50	³ 88/100	6.7	(21.9)	7.9	(3.1)	19.1	(272.8)
<i>Pinus radiata</i> (5 clones)	39	62/72						
Z-6		14/15	4.4	(14.4)	5.2	(2.0)	--	--
Z-3		13/15	4.3	(13.8)	5.1	(2.0)	--	--
MM-13		10/15	3.8	(12.5)	5.0	(2.0)	--	--
MM-6		11/15	3.4	(11.2)	4.0	(1.6)	--	--
Z-5		14/15	3.0	(9.8)	2.9	(1.2)	--	--
<i>Juglans regia</i> X <i>hindsii</i>	50	³ 99/100	2.2	(7.1)	2.1	(0.8)	--	--
<i>Sequoia sempervirens</i>	39	66/75	1.5	(5.0)	--	--	--	--
<i>Eucalyptus dalrympleana</i>	Survival less than 50%, terminated March 1978.							

¹Soil: Bale Loam (Rocky Phase), irrigated by overhead sprinklers first two growing seasons. Chemical weed control. Area average annual rainfall = 36 inches. Planted 2.4m x 2.4m (8' x 8') square spacing.

²Means connected by bars do not differ significantly at 5 percent level.

³Planted during a drought year (1977); first-year sprinkler irrigation could not be carried out after July.

Table 2 -- Summary of data from area 2, Bale Lane,
Calistoga, Napa County, July 1981¹

Species	Age (mo)	Survival	Average height		Average DBH	
			meters	(feet)	cm	(inches)
<i>Eucalyptus camaldulensis</i>	27	179/198	4.9	² (16.1)	5.1	² (2.0)
<i>Eucalyptus dalrympleana</i>	27	156/212	3.8	(12.5)	3.6	(1.4)

¹Soil: Bear Creek clay-loam, irrigated with overhead sprinklers during summer. Spacing: 1.5m x 1.5m (5 ft x 5 ft). Chemical weed control. Average annual rainfall: 34 inches.

²Means significantly different at the 0.01 percent level.

Table 3 -- Volume and energy calculations for two
field-planted eucalyptus species in area 1, at
Calistoga, Napa County¹

Species	Age (yr)	Average volume yields	Calculated mean annual yield		Total energy yields ¹	
		m ³ /ha	m ³ /ha/yr	cords/a/yr	million btu/a/yr	million kcal/ha/yr
<i>E. viminalis</i>	3.2	24.7	7.8	1.3	32	20
<i>E. camaldulensis</i>	4.2	19.1	4.3	0.8	25	15

¹Using specific gravity information reported by H.E. Dadswell, 1972, "The Anatomy of Eucalypt Woods," Commonwealth Scientific and Industrial Research Organization, Australia, For. Prod. Lab. Div. of Applied Chemistry Technological Paper No. 66, and wood energy values in A.J. Panshin and C. deZeeuw, 1970, "Textbook of Wood Technology," Vol. 1, McGraw-Hill Book Co.

Growth and Yield in *Eucalyptus globulus*¹

James A. Rinehart and Richard B. Standiford²

Various species of *Eucalyptus* have been of interest in California since their introduction in 1860 (Metcalf, 1924), with *Eucalyptus globulus* (Blue Gum) being the most widely planted. While its wood has limited use as lumber, its rapid growth has caused it to be favored as windbreaks and ornamentals. The recent increase in demand for firewood and a growing market for hardwood fiber has caused renewed interest in planting eucalyptus.

The purpose of this article is to present a model for growth of *Eucalyptus globulus* and to use this model to generate variable site-density yield tables. These yield tables are then used to determine optimum stocking levels and rotation length under various site conditions. This model deals solely with biological growth and does not consider economic implications of stand establishment and management.

The models derived represent unmanaged stands only. Certain management practices increase site quality and some means of assessing this increase must be applied in order for the models to be meaningful under intensive management conditions.

Within this article, the following topics are discussed:

- The source, limitations, and adjustments made to the data used to generate the model.
- A description of the model itself and how it

¹Presented at the Workshop on *Eucalyptus* in California, June 14-16, 1983, Sacramento, California.

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Abstract: A study of the major *Eucalyptus globulus* stands throughout California conducted by Woodbridge Metcalf in 1924 provides a complete and accurate data set for generating variable site-density yield models. Two models were developed using linear regression techniques. Model I depicts a linear relationship between age and yield best used for stands between five and fifteen years old. Model II depicts a sigmoidal relationship between age and yield with slightly poorer statistical fit but greater reliability beyond fifteen years of age. Significant independent variables used in Model I are: initial plantation density; site index; and an interaction variable consisting of age x site index. Significant independent variables in Model II are: natural log of initial plantation density; site index; and inverse age. Variable site and density yield tables are developed from Model II for stands under minimal management. Culmination of mean annual increment occurs at age ten under all conditions. Assuming a goal of maximization of mean annual increment of merchantable cordwood, planting densities of 435, 680 and 1210 trees per acre are recommended for low, medium, and high sites respectively._

is used to generate variable site-density yield tables.

- Conclusions drawn from analysis of the yield tables.
- Suggestions for further analysis and research.

THE DATA

The data used in this analysis was gathered by Louis Margolin in 1910 (Margolin, 1910) and by Woodbridge Metcalf in 1924 (Metcalf, 1924) in their studies of the major Blue Gum stands in California. As described in his article, in order to generate site and yield functions, Metcalf used data collected in these two studies, which included a total of 96 stands. This data was adjusted to result in the data set used in the current analysis.

The Metcalf and Margolin Data

Location of Stands

Stands were located in 19 counties throughout California, from Arcata in Humboldt County to Escondido in San Diego County, representing a wide variety of soil and climatic conditions.

Information Collected

Information collected for each stand includes the following:

- Stand age
- Initial plantation density in trees per acre
- Surviving trees per acre

- Average diameter, height, and volume of surviving trees
- Volume per acre in cubic feet and cords
- Soil and water characteristics

Also, in order to develop a measure of site quality, height was measured on the tallest 10 per cent of trees in most of the stands.

Methods of Collection

Selection of Plots--In the data collected by Metcalf, "one or more of the rows running through representative portions of the stand" were selected for measurement. The method of row selection was not described and therefore randomness of the sampling procedure is not assumed.

In the Margolin data, sample areas were $\frac{1}{4}$ -acre plots within the interior of each grove. Usually only one such plot was taken per stand and these were selected to show average conditions. This method of plot selection is not random and could result in bias toward higher yield.

Surviving Trees Per Acre--Metcalf states that "each surviving tree" was measured, as well as blank spaces and "scrubby trees." A scrubby tree is not defined and no lower diameter limit is given for surviving trees. In assessing trees per acre at time of measurement, one must assume that none of the "scrubby" trees are survivors of the original plantation.

In the Margolin study, all trees with dbh of $1\frac{1}{2}$ inches or more were measured. As with the Metcalf data, one must assume that trees less than $1\frac{1}{2}$ inches dbh were not counted as survivors of the original plantation.

Average Diameter of Surviving Trees--In the Metcalf data, since "scrubby" trees are assumed not to be survivors, it must also be assumed that the distribution of diameters of surviving trees has some lower diameter limit. Since we do not know what this limit is, it is difficult to assess the amount of variation around the average diameter. Diameters measured by Margolin, however, were recorded by 1-inch diameter class, giving a diameter distribution, or stand table, for each stand sampled.

Height of Surviving Trees--Total heights, including stump and top were measured for as many trees as possible. A height-diameter curve was derived in order to estimate heights on trees not measured.

Calculation of Volume--Volumes were calculated using the following formula:

$$V = BA \times H \times ff \times TPA$$

where: V = Volume in cubic feet per acre
 BA = Basal area in square feet of the

average single tree.

$$(BA = [\text{Average Diameter}/24]^2)$$

H = Total height of the average single tree

ff = Form factor relating stem volume to $(BA \times H)$. Stem volume is from the top of a one-foot stump to a minimum diameter of two inches at the top.

TPA = Number of surviving trees per acre at time of measurement

Site Classification

In order to develop a height-age relationship as a measure of site quality, Metcalf measured the tallest 10% of the trees sampled and plotted heights of these dominant trees against age. Groves in which overcrowding was thought to have interfered with height growth were not included. In all, Metcalf included 45 of the Metcalf groves and 26 of the Margolin groves in his site classification.

An average age-height curve was drawn through the data and harmonized curves were drawn to intersect with maximum and minimum values. The area between the maximum and minimum curves was then divided into three zones, labeled Site I, II, and III. Figure 1 represents the Metcalf site classification curves.

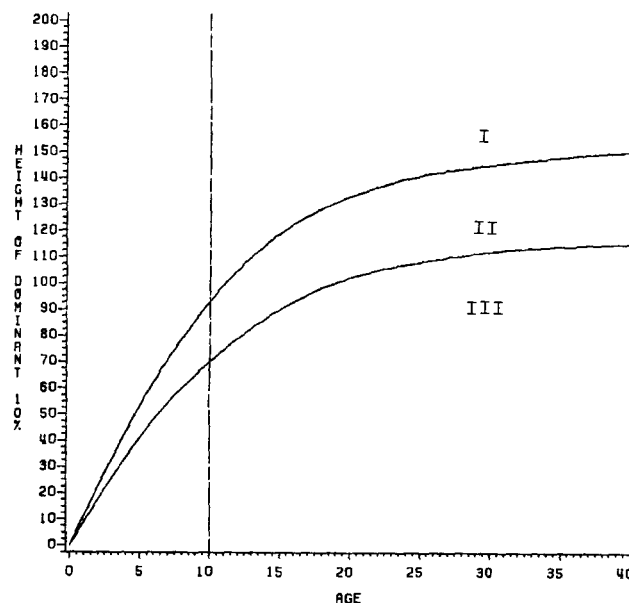


Figure 1 -- Metcalf Site Classifications

The Current Data Set

Adjustments

The following adjustments were made in the above data to result in the data set used in the analysis.

Elimination of Observations--Only those stands for which the height of dominant trees was recorded are included, thus eliminating 20 of the stands. An additional stand was eliminated because it had been thinned.

Addition of Observations--Eight of the Metcalf stands were measured twice at different points in time. Metcalf used only the first measurement in his estimation of site. The current data set includes the eight remeasurements, with the assumption that site remains constant over time. A total of 78 stands are included in the current data set.

Volume Estimation--The method used by Margolin to estimate volume was not specified other than by reference to volume tables. In order to merge the two data sets, volumes for Margolin stands were recalculated using the formula noted above.

Developing a Site Index Measurement

Metcalf's site quality measure resulted in site ratings of I, II, or III. In order to be consistent with other yield studies for Eucalyptus globulus, a site index was developed from Metcalf's age-height curves in figure 1, using a base age of 10. The following table represents the relation between Metcalf's site class and the site index derived from it.

Table 1 -- Site Class-Site Index Relationship

Site Class	Site Index (Height of Dominants at 10 Years)
I	Greater than 93
II	65 to 93
III	Less than 65

Site indices for the stands in the data set ranged from a low of 41 to a high of 118.

The method used was to locate age and height of dominants for a given stand on figure 1 and then to follow a harmonized curve through that point to its intersection with the base age 10 reference line. For instance, a dominant height of 126 feet at age 25 would equate to a site index of 82. In this way, figure 1 can be used to determine site index for any stand where age and height of dominants are known.

Range of Ages

The ages of stands in the current data set ranged from 2 to 40 years. Only 12 (15.4 percent) of the stands were in excess of 15 years of age. Models derived from this data show best fit in younger age classes and caution must be used in estimating volume in age classes between 15 and

40. Models should not be used for extrapolation beyond age 40. This limitation is not significant for commercially-grown stands since harvest is likely to occur prior to age 15.

ANALYSIS

Analytical Systems Used

Linear regression analysis was performed using the Statistical Analysis System -- General Linear Model (SAS-GLM) program package.

Yield Models

The analysis yields two production models with statistically significant fit. The first gives a linear plot of predicted yield against age. The second gives a plot of predicted yield against age which more closely approximates a sigmoidal biological production function which one might anticipate. Figure 2 depicts these models for a given site and initial plantation density. Both models can be used, given certain constraints, as explained below.

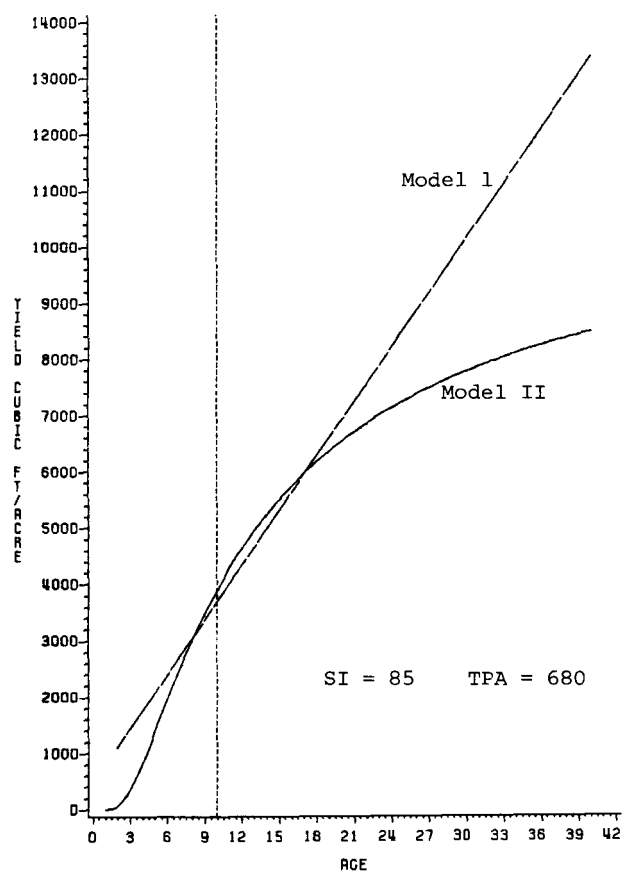


Figure 2 -- Model I and Model II Yields

Model I

Model Form--Model I takes the form of:

$$Y = -3177.17 + 1.70(TPA1) + 29.47(SI) + 3.77(AGSI)$$

where: Y = Yield in cubic feet per acre
 TPA1 = Initial plantation density in trees per acre
 SI = Site index in feet at age 10
 AGSI = Age x site index

Analysis of Variance--Table 2 presents the analysis of variance for Model I.

Table 2-- ANOVA - Model I

Source of Variation	DF	Sum of Squares	T	F	R ²	C.V
Intercept			-4.28			
TPA1	1	3.19 x 10 ⁷	3.07			
SI	1	30.15 x 10 ⁷	2.95			
AGSI	1	53.34 x 10 ⁷	18.95			
Residuals	74	11.04 x 10 ⁷				
Total	77	97.72 x 10 ⁷		193.7	.887	34.6

Note the high correlation coefficient (R²) of .887 and the coefficient of variation (C.V) of 34.6.

Discussion -- Because site index appeared to have a greater effect on yield with increasing age, an interaction variable consisting of Age x Site was anticipated. As indicated by its high T value relative to other variables, AGSI is the most significant independent variable. This is logically sound since, with a given initial plantation density, site quality will have a strong effect on rate of growth while total volume will vary most directly with age.

While this model gives a good prediction of volume within the range of most of the data, it does not give an intuitive depiction of growth, as shown by figure 2. The linear relationship between age and yield results from the fact that 80 percent of the data falls between the ages of 5 and 15, the linear range of the anticipated sigmoidal function. This data so weights the model in this form that statistical significance is high even though the model is linear.

Model II

Model Form--Model II takes the form of:

$$\ln Y = 4.86449 + .02547(SI) + .34896 (\ln TPA2) - 10.41628 (I/A)$$

where: lnY = The natural log of yield in cubic feet per acre
 SI = Site index in feet at age 10
 lnTPAI = The natural log of initial stocking density in trees per acre
 I/A = Inverse age

Analysis of Variance--Table 3 presents the analysis of variance for Model II.

Table 3--ANOVA - Model II

Source of Variation	DF	Sum of Squares	T	F	R ²	C.V.
Intercept			5.80			
SI	1	27.11	8.52			
lnTPA1	1	1.34	2.75			
1/A	1	42.38	-15.81			
Residuals	74	12.54				
Total	77	83.37		139.3	.850	5.3

Note that while the statistics for Model I are slightly better than those for Model II, the differences are relatively minor. The lower C.V. for Model II is a result of the dependent variable being a logarithm. Exponentiating results in a coefficient of variation similar to that of model I.

Discussion--Schumacher (1939) and Clutter (1963) suggested methods of generating linear models to express nonlinear production functions by transforming dependent and independent variables into natural logarithms. Model II is essentially the Clutter model using lnTPA1 rather than Clutter's ln of Basal Area.

As shown in figure 2, when lnY is transformed back to cubic foot yield and plotted against age, the result is close to the expected sigmoidal curve. Since the Clutter-based model gives nearly as good a fit as Model I with greater confidence when using the model for stands older than 15 years, this model was used to generate subsequent yield tables.

Variable Site-Density Yield Tables

In generating yield tables under varying site and initial stocking conditions, one will wish to know average diameter of the stand as a measure of merchantability, as well as total yield. A diameter of two inches is generally considered to be the lower merchantable limit for cordwood and the diameter distributions shown in the Margolin data indicate that for an ASD of six inches, virtually all trees in the stand will be in excess of two inches dbh. The expression for average diameter of the stand is:

$$AD = \sqrt{\frac{BA}{TPA2 \times .00545}}$$

where: AD = Average diameter of the stand in inches
 BA = Basal area per acre in square feet
 TPA2 = Surviving trees per acre

In order to predict AD, then, it is necessary to construct models for basal area and surviving trees.

Basal Area Model

Because basal area is also a measure of production, it is logical that BA could be predicted by the same independent variables as cubic foot yield. The following model results:

$$\ln BA = 2.07854 + 0.496(SI) + .33354(\ln TPA1) - 6.55518(I/A)$$

where: $\ln BA$ = Natural log of basal area per acre
 SI = Site index in feet at age 10
 $TPA1$ = Initial stocking in trees per acre
 I/A = Inverse age

The correlation coefficient for this model is .79. Affective coefficient of variation is about 40.0.

Surviving Trees Per Acre

The only significant predictor of surviving trees per acre is initial stocking density, which gives the following model:

$$TPA2 = 183.69 + .56 TPA1$$

where: $TPA2$ = Surviving trees per acre
 $TPA1$ = Initial stocking in trees per acre

While R^2 for this model is only .54, it is acceptable since it is used only to calculate a rough estimate of the average diameter of the stand.

Final Yield Tables

The final yield tables were generated by combining the three models derived above and iterating through variations in site index, initial

stocking, and age. Tables 4a-c are representative tables for $SI = 60$, 85, and 105 and initial stocking of 680 trees per acre.

Variable Site Yield Functions

By plotting yield against age for a given stocking level under varying site conditions, one may see graphically how yield varies with site. Figure 3 represents yield with initial plantation density of 680 under three site conditions.

DISCUSSION

Refer to table 4 and figure 3 for the following discussion.

Explanation and Interpretation of Yield Tables

Surviving Trees Per Acre ($TPA2$)

Note that $TPA2$ varies only with $TPA1$ and that mortality occurs immediately. This indicates that survival is linked with establishment and that once established, the stand remains stable over time.

When initial stocking is 300 trees per acre, $TPA2$ exceeds $TPA1$. This may be loosely explained by sprouting on under-utilized sites, though this explanation is somewhat weak. As noted earlier, the mortality issue is clouded by problems in interpreting the data as well as by ingrowth from sprouts and volunteers. $TPA2$ is a rough estimate of survival.

Table 4a--Yield Table ($SI = 60$, $TPA1 = 680$)

SITE INDEX = 60			TREES/ACRE: Initial = 680; Surviving = 519					
Age (years)	Average Diameter (inches)	Basal ea (Ft^2/Ac)	Yield		Mean Annual Incr.		Current Annual Incr.	
			Ft^3/Ac	Cds/Ac	$Ft^3/Ac/Yr$	Cds/Ac/Yr	$Ft^3/Ac/Yr$	Cds/Ac/Yr
2	1.5	6.5	31.8	.4	15.9	.2		
4	3.4	33.5	430.3	4.8	107.6	1.2	199.3	2.2
6	4.5	57.9	1025.1	11.4	170.9	1.9	297.4	3.3
8	5.2	76.1	1582.2	17.6	197.8	2.2	278.5	3.1
10	5.6	89.7	2052.9	22.8	205.3	2.3	235.3	2.6
12	5.9	100.0	2442.1	27.1	203.5	2.3	194.6	2.2
14	6.2	108.1	2764.5	30.7	197.5	2.2	161.2	1.8
16	6.4	114.6	3033.9	33.7	189.6	2.1	134.7	1.5
18	6.5	120.0	3261.5	36.2	181.2	2.0	113.8	1.3
20	6.6	124.4	3455.8	38.4	172.8	1.9	97.2	1.1
25	6.9	132.9	3835.2	42.6	153.4	1.7	75.9	.8
30	7.0	138.8	4111.0	45.7	137.0	1.5	55.2	.6
35	7.1	143.2	4320.1	48.0	123.4	1.4	41.8	.5
40	7.2	146.6	4483.8	49.8	112.1	1.2	32.7	.4

Table 4b--Yield Table (SI = 85, TPA1 = 680)

SITE INDEX = 85			TREES/ACRE: Initial = 680; Surviving = 519					
Age (years)	Average Diameter (inches)	Basal Area Ft ² /AC	Yield		Mean Annual Incr.		Current Annual Incr.	
			Ft ³ /Ac	Cds/Ac	Ft ³ /Ac/Yr	Cds/Ac/Yr	Ft ³ /Ac/Yr	Cds/Ac/Yr
2	1.8	9.5	60.2	.7	30.1	.3		
4	4.1	48.8	813.5	9.0	203.4	2.3	376.6	4.2
6	5.5	84.2	1937.9	21.5	323.0	3.6	562.2	6.2
8	6.3	110.6	2990.9	33.2	373.9	4.2	526.5	5.9
10	6.8	130.3	3880.6	43.1	388.1	4.3	444.8	4.9
12	7.2	145.4	4616.3	51.3	384.7	4.3	367.9	4.1
14	7.5	157.2	5225.8	58.1	373.3	4.1	304.7	3.4
16	7.7	166.6	5735.1	63.7	358.4	4.0	254.7	2.8
18	7.8	174.4	6165.3	68.5	342.5	3.8	215.1	2.4
20	8.0	180.9	6532.6	72.6	326.6	3.6	183.7	2.0
25	8.3	193.1	7249.8	80.6	290.0	3.2	143.4	1.6
30	8.4	201.7	7771.1	86.3	259.0	2.9	104.2	1.2
35	8.6	208.1	8166.3	90.7	233.3	2.6	79.0	.9
40	8.7	213.1	8475.8	94.2	211.9	2.4	62.0	.7

Table 4c--Yield Table (SI = 105, TPA2 = 680)

SITE INDEX = 105			TREES/ACRE: Initial = 680; Surviving = 519					
Age (years)	Average Diameter (inches)	Basal Yea (Ft /AC)	Yield		Mean Annual Incr.		Current Annual Incr.	
			Ft ³ /Ac	Cds/Ac	Ft ³ /Ac/Yr	Cds/Ac/Yr	Ft ³ /Ac/Yr	Cds/Ac/Yr
2	2.1	12.8	100.1	1.1	50.1	.6		
4	4.8	65.8	1353.9	15.0	338.5	3.8	626.9	7.0
6	6.3	113.5	3225.1	35.8	537.5	6.0	935.6	10.4
8	7.3	149.2	4977.8	55.3	622.2	6.9	876.3	9.7
10	7.9	175.8	6458.5	71.8	645.8	7.2	740.3	8.2
12	8.3	196.1	7682.9	85.4	640.2	7.1	612.2	6.8
14	8.7	212.0	8697.2	96.6	621.2	6.9	507.1	5.6
16	8.9	224.8	9544.9	106.1	596.6	6.6	423.8	4.7
18	9.1	235.2	10260.9	114.0	570.1	6.3	358.0	4.0
20	9.3	243.9	10872.2	120.8	543.6	6.0	305.6	3.4
25	9.6	260.5	12065.8	134.1	482.6	5.4	238.6	2.7
30	9.8	272.1	12933.4	143.7	431.1	4.8	173.6	1.9
35	10.0	280.7	13591.1	151.0	388.3	4.3	131.6	1.5
40	10.1	287.4	14106.2	156.7	352.7	3.9	103.0	1.1

Average Diameter of the Stand (AD)

This variable behaves as one might expect, increasing with age and site index, but decreasing as initial plantation density increases.

Yield (YFT3)

Gives volume at various ages.

Cords

Gives volume in cords where:

$$\text{CORDS} = \text{YFT3}/90$$

Mean Annual Increment (MAIFT3 and MAICD)

Gives mean annual increment in cubic feet and cords per acre per year, where:

$$\text{MAI} = \text{Yield}/\text{Age}$$

Note that for all variations of site and initial stocking, MAI culminates at age 10. Thus, for maximum biomass production, given the two-inch merchantability standard for volume determination, harvest will occur at about age 10.

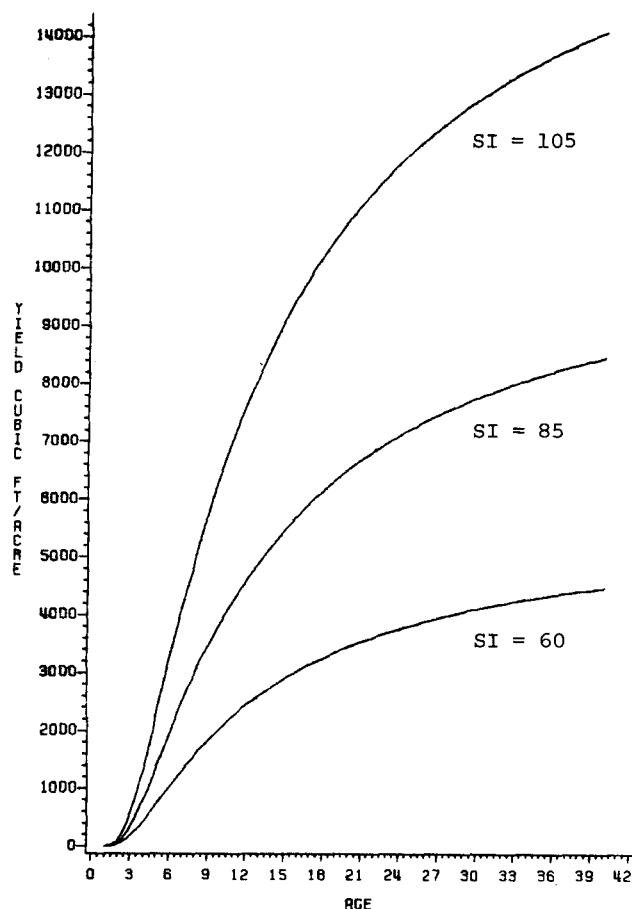


Figure 3--Yield-Age Relationships Varying Site Index (TPA1 = 680)

Current Annual Increment (CAIFT3 and CAICD)

Gives current year's growth in cubic feet and cords. Note that CAI culminates at age 6, somewhat before MAI, as one would anticipate. Note also that at culmination of MAI, MAI approximately equals CAI, again as one would expect.

Recommended Planting Densities

Assuming a goal of maximum merchantable cordwood, the yield tables generated from the models in this analysis can be used to determine optimal spacing for any given site. Optimal spacing will be that which yields highest. MAI at age 10 with minimum ASD of 6 inches. Table 5 represents recommended planting density to achieve this goal for a range of site indices.

NEEDS FOR FURTHER RESEARCH

Site Quality - Soil Correlation

The above analysis assumes that a 10-year site index for *Eucalyptus globulus* is known at time of planting. If Blue Gum has not been grown before

Table 5 -- Recommended Planting Densities for Maximum Merchantable Cordwood

Site Index	Recommended Planting Density
55	300 TPA
60	435
65	435
75	680
85	680
95	1210
105	1210
115	1210

on the site, and if there are no stands growing on similar sites available for comparison, this assumption may not be met. *E. globulus* appears to grow best on well-drained, sandy-loamy soils with a 10- to 12-foot water table. This relationship between edaphic-climatic-geomorphological conditions and site index requires further research so a site index may be estimated prior to planting.

For the present time, individuals who wish to use these models and yield tables to assess growth and yield can use some general observations of the soil-site quality relationship provided by Metcalf. This information is shown in table 6.

Table 6 -- Relationship Between Site Index and Soil-Site Characteristics

Approximate Site Index	Soil-Site Characteristics
Greater than 93	. Soils - loamy-sandy loam - deep bottomland . Agricultural quality -- high . Water table -- near surface during most of the year . Slope - flat
65-93	. Soils - sandy-sandy loam . Agricultural quality -- fair to good under irrigation . Water table -- low; irrigation required . Slope -- medium to flat
Less than 65	. Soils - sandy, adobe . Agricultural quality - low . Water table - low; irrigation infeasible . Slope - steep . Windy

Older Stands

As noted earlier, the data analyzed was heavily weighted to stands 5 to 15 years old, making extrapolation of the model to older stands somewhat risky. Similar data should be gathered for stands 15-60 years old to see if a better fit can be obtained.

Economic Analysis

This analysis assumes that maximum biomass production is the only management goal. Costs of site preparation, irrigation, fertilization and harvest are not considered; nor are projected stumpage prices or (demand for fuelwood or chips. Further analysis should combine biological growth potential with economic factors to give a return on investment analysis for Eucalyptus globulus plantations.

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Industrial Planting of *E. viminalis* in Mendocino County¹

Peter C. Passof and John W. Sweeley²

The Masonite Corporation started up its forestry operations in Mendocino County in 1948 with the acquisition of approximately 21,044 hectares (52,000 acres) of mixed Douglas-fir (*Pseudotsuga menziesii* [sic] (Mirb.) Franco) and redwood (*Sequoia sempervirens* (D. Don) Endl.) timber including oak-grass woodland. Their only manufacturing facility was a hardboard plant at Ukiah although beginning in 1969 they did acquire several lumber mills in northern California.

In 1956, Masonite forester Jack Sweeley became interested in testing and evaluating several species of Eucalyptus as potential sources of fiber for the hardboard plant. A total of 32 plots involving a variety of species were planted throughout the County in an attempt to observe growth performance over a range of environmental conditions.

Sweeley established some basic selection criteria to help narrow down the vast array of species. These characteristics were as follows: (1) fast-growing (2) ability to coppice (3) frost-resistant (4) easy to plant as bare root seedlings and (5) compatibility with the hardboard plant's processing requirements.

The latter criterion was provided by Masonite's wood technologists in Australia who rejected certain species such as Karri (*E. diversicolor* F. Muell.) because of the undesirable red color of the wood and Messmate stringybark (*E. obliqua* L'Herit.) because of fiber instability.

In the next four years (1957-61) Masonite expanded its small plot testing program to a few larger plantings. Seedlings were raised under contract to the Parlin Fork Nursery operated by the Department, of Forestry. It

Abstract: The authors trace the development of a Eucalyptus reforestation program on private industrial forest land from early testing to production planting. Data is presented on a 14.2 hectare manna gum plantation which has produced an estimated yield of 481 cubic meters/hectare after 20 years. Because manna gum has about 60 percent greater density than Douglas-fir or redwood, total dry weight yield from such stands may be about 3 times the equivalent of the two native species.

should be pointed out that Masonite was also interested in spot seeding as a regeneration method. They borrowed an idea from Australia using pelletized seed where fertilizer and peat was added to the seed and then cubed. However, their preliminary trials indicated the procedure was not effective.

Early problems with deer browsing the first growing season were resolved with deer-proof exclosures. The foresters also found that site preparation procedures such as brush raking and burning helped to improve survival and growth performance.

It was during this period that Masonite's interest in Eucalyptus attracted scientists from all parts of the world who came to see how the various species were doing in north coastal California. Each scientist contributed views as to which species might do best under Mendocino's growing conditions.

By 1962, Sweeley had come to the conclusion that two species, manna gum (*E. viminalis* Labill.) and mountain gum (*E. dalrympleana* Maid.) had passed all the preliminary screening and therefore deserved special recognition for production planting. In February 1963, a 14.2 hectare (35 acre) planting was established in the Albion River drainage at a location romantically called Slaughter House Gulch. It was on an east-facing site with slopes ranging from 30 to 70 percent. Elevation averaged 122 meters (400 feet) with an average minimum January temperature of 4.4° C (40° F) with extremes to -6.7° C (20° F). It had been clearcut of redwood, Douglas-fir and grand fir (*Abies grandis* (Dougl. ex D. Don) Lindl.) and then prepared for burning. The burning was not completed successfully because of changing climatic conditions. Mean annual rainfall is 114 cm (45 inches). About half the area was fenced to reduce deer browsing pressure. A total of 14,000 *E. viminalis* and 5000 Monterey pine (*Pinus radiata* D. Don) were planted on an approximate 2.4 x 2.4 meter (8 x 8 foot) spacing.

A total of 10 plots were established to check survival and growth. After 3 years the plots averaged 78 percent survival and the average

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height of the seedlings was 95 cm (38 inches). There were no significant differences between the 5 plots in the enclosure and the 5 outside the fenced area.

In 1968, the senior author and Masonite forester Ralph Duddles returned to the Albion site and measured several trees as part of a preliminary yield study of manna gum existing on the Company's various plantations.

At Slaughter House Gulch, the trees averaged 7 meters (23 feet) in total height, and 3 meters (10 feet) to a 5 cm. (2 inch) top. Average diameter at a .46 meter (1.5 foot) stump was 6.8 cm (2.7 inches). These last two measurements were incorporated into a volume equation known as Smalian's formula where $V = A_1 + A_2/2 \times (L)$. The geometric figure is a truncated paraboloid and most nearly represents a log that has one end larger than the other and uniform taper.

Assumptions were made that annual radial growth would continue over the next 15 years as it had over the previous 5 years. However the same could not be said for height growth. The literature indicated that a flattening of the height/diameter curve occurs before age 20. By adjusting height growth, we estimated that heights would range from 22 to 31.7 meters (72 to 104 feet) at age 20 with an average of 27.1 meters (89 feet).

The last ingredient in this yield study was to project the number of trees/hectare. Our estimate called for 520 trees/hectare (210 trees/acre) and thus our yield prediction to age 20 was estimated to be 378 cubic meters/hectare (5408 cubic feet/acre) for the plantation.³

Fifteen years elapsed with only an occasional visit to the site. About two months ago, a mixed contingent of "Eucalyptus enthusiasts" decided to spend some time remeasuring the trees to get an accurate estimate of current volumes/acre. Trees were measured at d.b.h. (diameter-at-breast-height) and total height. A newer volume equation (King and Krugman 1980) was applied to the stand data and with the aid of a computer program, we found that the average stand volume equalled [sic] 481 cubic meters/hectare (6870 cubic feet/acre).

Instead of the 520 trees/hectare stocking, our data indicated we had a range from 667 to 865 trees/hectare (270 to 350 trees/acre). If we were permitted to adjust the original estimate

upward to 660 trees/hectare our projected volume yield using the crude Smalian formula would produce a perfect match!

However it should be noted that only a small number of trees were selected and measured in 1968 and although we used a much greater number in 1983, great statistical variability in the data were found.

Nevertheless, a current volume of 481 cubic meters/hectare for 20 years is quite respectable growth for an area that has had no supplemental irrigation and considerable competition from brushy species such as blueblossom (Ceanothus thyrsiflorus Eschsch.). The site is listed as a Site III, Hugo soil series with an average depth of 1.5 meters (5 feet).

It is important to note that E. viminalis is approximately 60 percent heavier than the average of redwood and Douglas-fir; this is of great importance to the perspective of a hardboard plant that buys its raw material on a bone dry weight per unit volume basis. This means that the equivalent dry weight yield of manna gum, measured in tonnes/hectare, is about 3 times that of our native fast-growing redwood in a short rotation of 20 years.

By 1969, Masonite's wood technologists discovered that Eucalyptus' unique fiber properties could be emulated by the native conifers and thus the technical demand for Eucalyptus came to a rapid close.

At the conclusion of the Corporation's Eucalyptus reforestation program in the winter of 1968-69, a total of 104 hectares (256 acres) of manna gum and mountain gum had been planted, thus ending a period of 13 years of intense forestry interest in a most promising species.

ACKNOWLEDGMENTS

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³Data on file, Timber Realization Co., Calpella, California.

Yields in High Density, Short Rotation Intensive Culture (SRIC)—Plantations of *Eucalyptus* and Other Hardwood Species^{1,2}

R.M. Sachs and C.B. Low³

From the outset the major goal of our research has been to determine the feasibility of growing fuelwood as an alternate crop on underutilized but otherwise high valued farmlands (say \$1500 a⁻¹). An economic analysis, which has essentially driven our studies on yields, revealed that profitability of fuelwood plantations depended upon production rates greater than 15 tons per acre per year (t a⁻¹ yr⁻¹) of oven dried wood.

Methods

The parameters used in the analysis are listed in table 1. The costs assumed are those applicable for well-managed farmlands in the Central Valley of California. Budget generators, available from the department of Agricultural Economics, University of California, Davis, have many more line items from detailed studies with several field crops. A goal of our research was to verify or alter the assumed costs that we have used in our analysis, using input data from cooperators wherever possible. Keeping the limitations in mind, the break-even, farm-gate price for wood chips, with a 15 t a⁻¹ yr⁻¹ yield, is about \$43 t⁻¹ for the first harvest and \$20 t⁻¹ for subsequent harvests. These prices are competitive with wood chip prices quoted in the Sacramento area for March 1983.

¹Presented at the workshop on Eucalyptus in California, June 14-16, 1983, Sacramento, Calif.

²Useful conversion factors:

$$T \text{ ha}^{-1} = 2.24 \times t \text{ a}^{-1} \\ a = 0.4047 \text{ ha}$$

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Abstract: Initial high density (17,200 trees ha⁻¹, 6961 trees a⁻¹) plantations of *Eucalyptus grandis* yielded up to 22 oven dry tons (ODT) ha⁻¹ yr⁻¹ (10 ta⁻¹ yr⁻¹) on an approximate 6 month rotation. Border effects could not be eliminated from the small sized plots used. Also within 4 years of planting there were substantial differences in tree vigor and survival such that the effective density was reduced by half. Subsequent plantations of several hardwood species at 5000 trees a⁻¹ and with somewhat better border protection were harvested 2 years after planting; tree survival was greater and in some *E. camaldulensis* plantings yields were in excess of 37 ODT ha⁻¹ yr⁻¹ (16.5 ta⁻¹ yr⁻¹). Accounting for border pct. *E. camaldulensis* and *E. cam x rudis* out-yielded *Salix*, *Acacia*, *Populus* and *Ailanthus* sp. tested. Current trials are with greater border thickness and compare seedling and clonal plantations of some fast growing eucalyptus selections at planting densities from about 1900 trees a⁻¹ down to 600 trees a⁻¹.

Results

Survey Studies

Small *E. grandis* plantations at Santa Ana, Calif., with over 6900 seedlings per acre (on 30 in. centers) and harvested twice annually yielded about 10 t a⁻¹ yr⁻¹ in the third year following planting out (table 2), and the 4th year from seeding (Sachs and others 1980). Although at the time this yield was considered high for plantations at this latitude and climate, we realized that it was probably substantially below what could be achieved with altered management practices and better selection of planting material (Skolmen, 1983). (Many herbaceous crops, C₄ plants well-adapted to the Central Valley, could outyield the eucalypts, although higher cultural costs may be required annually raising the breakeven price for biomass above that for perennial species. These herbaceous species could well be utilized as primary fuel crops under certain economic and fuel delivery systems). The *E. grandis* seedlings were from a non-selected seed lot in which some of the individuals were quite vigorous, but also in which variability was extremely high. (Seed from collection of A. Leiser, Professor of Environmental Horticulture, University of California, Davis, Calif.). The plots were self-thinning in that weak individuals could not compete and large holes developed in the borders as well as sampling areas. In 1982 the blocks were thinned with trees on approximately 5-ft centers, to about 1700 trees a⁻¹. These plots can no longer be used to obtain accurate estimates of yields for large-scale plantations because the borders are not sufficiently dense. They will show, however, what is to be expected from wind-break plantings of moderate height. Based on current growth rates we estimate harvest rotations of three to four years and yields approaching 20 t a⁻¹ yr⁻¹.

Table 1--Economic Analysis for Woody Biomass (Cordwood and Chips) in Short Rotation, Intensive Culture Plantations in California

Estimated Woody Biomass Costs

Calculations based on:

Planting approximately 1000 trees per acre for cordwood or 1200 trees per acre for chips. 4-year harvest cycle.

Cost of land, labor, and operations.

<u>Operations</u>	<u>Assumed cost a⁻¹ (cordwood)</u>	<u>Assumed cost a⁻¹ (chips)</u>
----- Dollars -----		
Land Rent	150	
Site Preparation	150	
Weed Control	100	
Plant Materials (0.35/tree)	350	420
Irrigation Installation	300	
Planting	75	
Pesticides	50	
Fertilization	50	
Total	<u>1,225</u>	<u>1,295</u>
----- Dollars -----		
<u>Annual maintenance</u>	<u>Assumed cost acre⁻¹ yr⁻¹</u>	
Land Rent		150
Irrigation		100
Fertilization		50
Subtotal		300
Total for 3 years		900
----- Dollars -----		
<u>Harvesting</u>	<u>Cordwood</u>	<u>Chips</u>
Cutting and stacking	<u>1,000</u>	400
Total for 4 years (excluding transportation)	<u>3,125</u>	<u>2,595</u>

Estimated Yields for Intensively Cultured Wood Lots

Cordwood

7 cords a⁻¹ yr⁻¹

Harvest 700-1000 trees a⁻¹ every 4 to 6 years. Wood will have approximately 50 pct. moisture content and need one year to air dry.

Wood Chips

15 dry tons a⁻¹ yr⁻¹

Harvest 1000 trees a⁻¹. Whole tree harvesting.

Break-Even Prices

----- Dollars -----		
First harvest (4th year)	<u>112/cord</u>	<u>43/ton</u>
Subsequent harvests (every 4 years)	<u>43/cord</u>	<u>20/ton</u>

Table 2--Yield from Eucalyptus grandis plots, spacing of 2.5' x 2.5' ft at a density of 7600 trees a⁻¹, Santa Ana, California¹.

Plot	Harvest dates				
	11-77	6-78	9-78	6-79	9-79
	ta ⁻¹				
1	7.5	2.5	2.9	6.9	4.3
2	4.6	5.1	2.5	5.1	3.2
3	3.8	5.5	2.8	6.0	3.6
4	3.3	2.1	1.3	5.8	3.5
Avg.	4.8±1.9	3.8±1.7	2.4±0.7	6±0.7	3.7±0.5

Plot	Annual harvest totals		
	11-77 to 9-78	6-78 to 6-79	9-78 to 9-79
	ta ⁻¹		
1	5.4	9.8	11.2
2	7.6	7.6	8.3
3	8.3	8.8	9.9
4	3.5	7.1	9.3
Avg.	6.2±2.2	8.3±1.2	9.7±1.2

¹Source: Sachs and others (1980).

²10-month harvest.

Clonal vs Seedling Plantations

The Santa Ana site is being used to obtain performance data for selected seedling plantations of E. grandis and clonal plantations of E. camaldulensis. (E. grandis seedlings were obtained from the Florida Division of Forestry; E. camaldulensis clones C-1 and C-2, Low and others, 1983). No yield estimates are yet available for any of the plantations. For E. grandis growth rates are very high for selected individuals, but variance is once again very large (fig. 1). Holes are developing in the plantations in the first year from planting; hence, large variations in yield can be expected depending upon the area sampled. In practice variance of this magnitude will result in lower yields on short rotation cycles simply because part of the land area will not be covered with photosynthesizing tissue.

It is too soon after planting to analyze variance in the clonal plantations of E. camaldulensis at Santa Ana, but experimental blocks at Davis of a mixture of four clones of E. camaldulensis x rudis show greatly reduced variance (fig. 2). For this reason establishing clonal

RELATIVE SEEDLING TREE SIZES (DBH)

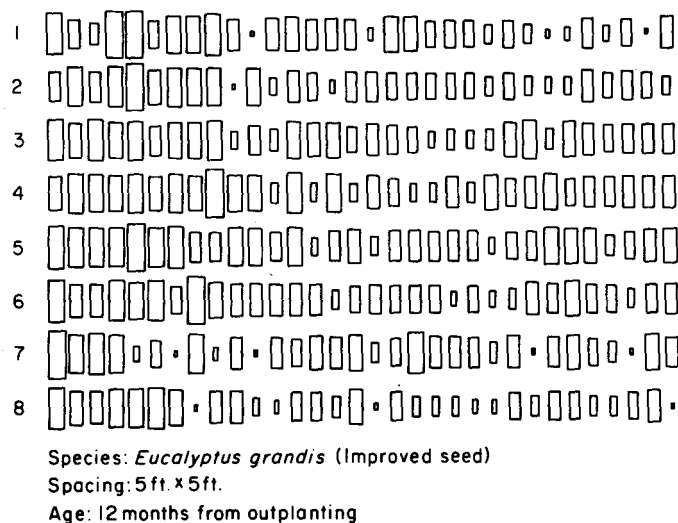


Fig. 1. Schematic computerized diagram of trunk diameters at breast height (dbh) of seedling plantation of *E. grandis*, 1 year after planting out at Santa Ana, California. Trees are on 5 ft centers in and between 8 rows; dbh is not to the same scale as that of the plantation.

Eucalyptus camaldulensis x *rudis* (1981) Relative tree sizes (DBH)

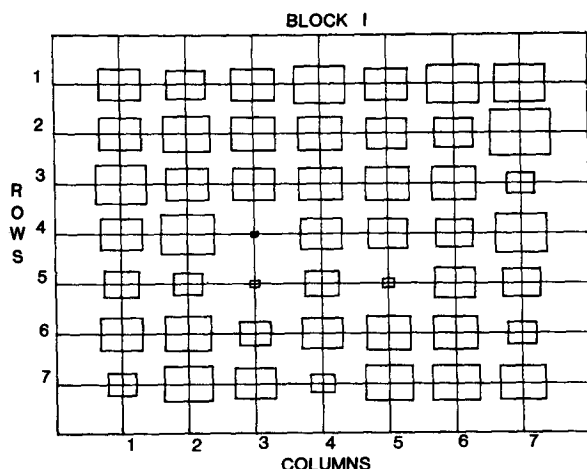


Fig. 2. Schematic diagram of dbh of mixed clonal plantation of *E. camaldulensis* x *rudis*, 22 months after planting out at Davis, California. Trees are on 5 ft centers in and between rows; dbh is not to the same scale as that of the plantation.

plantations of selected seedlings has become an important goal in our program. The clones we now use are limited to species that are easy-to-root, (*E. camaldulensis* and *E. cam. x rudis*), and from a very limited examination of performance at relatively few trees (ramets) at relatively few sites (Low and others 1983). We are expanding

the program to include clonal propagation of *E. grandis*, cold-tolerant selections of *E. gunii* x *dalrympleana* (see papers by Boulay and Chaperon, this proceedings), as well. as improved selections from other eucalyptus species and provenance trials.

Species Selection

There is little question that eucalyptus plantations are very fast-growing, but there is no head-to-head comparative data for yields for other highly touted genera (sequoia, pine, acacia, poplar, willow, etc.) and very little from within the eucalyptus genus (Standiford, 1981; Skolmen, this symposium; Mariani and others, 1981). We made one small study at Davis with high density plantings (3' x 3' ft spacings) of several species (table 3).

Table 3--Species trials of six Eucalyptus species, planted in Oct. 1979 and March 1980, at spacing of 3' x 3' ft and at a density of 5000 trees a University of California--Davis, harvested 1982.

Species	Block ¹		
	A	B	
	ta ⁻¹		
<i>Ailanthus altissima</i>	13.05	--	4.36
<i>Acacia melanoxylon</i>	13.40	--	5.09
<i>Salix babylonica</i>	15.11	4.44	7.22
<i>Eucalyptus camaldulensis</i>	16.81	13.28	20.3
<i>E. camaldulensis</i> x <i>rudis</i>	16.94	15.9	7.9
<i>Populus</i> ('Fry' poplar)	16.76	3.06	5.17

¹yields include leaves and small branches. In some blocks, yield values in error owing to insufficient border. Overestimate incurred is about 10 pct. Missing values and much of the variation among blocks reflect loss of trees when plantings made in late fall.

Results for a few coniferous species are not shown because their two year growth rates were very far below that for any of the hardwood species. Owing to financial limitations these blocks could not be maintained to evaluate copice yields, long term border effects, management practices and variability. Nevertheless the comparative growth data were highly instructive and permitted us to narrow our search for species adapted to short rotations. Currently we are comparing selected clones of *Populus deltoides* and *E. cam. x rudis*. Plantations of *Alnus rhombifolia*, established at the same time are considerably slower growing and could not qualify as a candidate species for prime lands. They are maintained to demonstrate comparative performance of a potential N-fixing species. Absence of mycorrhizal organisms may account for some of the reduced vigor in the olders. The poplar crop may match that of *E. cam. x rudis* in volume growth, even though we had initial establishment problems. Also, at a waste-water treatment plant in

Davis, this same selection of *P. deltoides* is out performing all other species in the first year from outplanting.

15/Ton/Yr Plantation

At the outset of this paper we stated that approximately 15 dry tons of biomass per acre per year were required to make wood production an economically feasible alternative crop on under-utilized farmland. This yield figure seems achievable with *E. camaldulensis* and *E. cam. x rudis* at Davis and probably elsewhere in California's Central Valley. *E. camaldulensis* plantations in Israel have maintained high yields for more than 80 years and 6 rotations (Kolar 1963) at sites harsher than those typical of farmlands in the Central valley. Probably higher yields can be expected in the milder winter' climates of southern California (e.g., Santa Ana), but cultural costs will be considerably higher there at these locations. For example, irrigation water is sold above \$200 ac. ft⁻¹ and at close to \$400 ac. ft⁻¹ in some locations below the Tehachapi. In all cases that we have examined waste waters will be required for irrigation of plantations in southern California and we have no idea whether or how much the higher salt contents of such waters will depress biomass yield.

Discussion

There is an obvious paucity of comparative data for species performance in short rotation, high density plantations, and there are many other important unanswered questions concerning yields. Our current tests are limited to examining the problem of density and planting pattern (two-row spacings and three within row spacings). Harvest rotation must be established on the basis of growth rate. Non-destructive methods must be developed to establish growth rate (annual volume increment); in collaboration with F. Thomas Ledig and Richard Standiford, we plan to develop volumetric tables for a few eucalyptus species. If we can accurately establish annual volume increments and can use these figures to estimate when growth rate begins to decline, we will have a relatively simple method to determine optimum harvest rotations (and planting densities).

It seems evident from our early studies with very high density *E. grandis* plantations that yields are depressed with frequent harvest rotations (semiannual in that case). *E. grandis* should not be treated as a hay crop (an initial goal in our work) if maximum biomass production is desired. Tree establishment time is probably a species specific trait related to development of the root system. This establishment time is probably of no immediate practical significance if one uses volume increment to estimate growth rate and set the harvest cycle accordingly, but it is of theoretical and perhaps, ultimately, practical interest. One would guess that,

everything else being equal, species that require less root system development (that is, have a relatively high shoot-to-root ratio) will be among the highest yielding. Reduced root development is, of course, no advantage under non-irrigated, droughty conditions, but our economic model assumes up to 3-acre-feet irrigation during the spring to fall interval. We are using a soil hydroprobe (neutron meter) to determine soil moisture depletion. In this way we will regulate irrigation frequency and amount to make certain that the plantations are not stressed for lack of available soil moisture.

Yields will be dependent upon providing (or returning) to the root depletion zone the minerals extracted at each harvest. Our current goal for the first harvest cycle is to monitor soluble foliar nitrogen and to feed nitrogen at rates sufficient to maintain levels close to that of trees irrigated with half-strength Hoagland's solution. We are far from understanding the nutritional requirements for species (or clones) in our plantations and, as our experimental data improve, expect future modifications of the current practice of adding 100 lbs a⁻¹ nitrogen yr⁻¹.

How many clones should we have in a plantation - or in backup gene banks - to protect against catastrophic losses from environmental hazard? For all their advantages in reduction of variance, mono-cultures are particularly susceptible to environmental disease or pest-related losses owing to the absence of genetic-variation, with inherent resistance in at least part of the population. Libby (1980), in addressing the question of the safe number of clones per plantation, concluded that the answer cannot be simple. Mono-clonal plantations are frequently the best strategy because they can maximize genetic gain, but some notion must be had of the maximum acceptable economic loss and likely hazards (risk to genotypes) before one can decide to go with only one clone. For eucalyptus in California the most severe hazard has been the infrequent intrusion of polar air with sustained temperatures below freezing. In December 1972, there were 3 days of temperatures below 20° F and in 1932 there were about 7 days with temperatures below 20° F in the San Francisco Bay area and surrounding counties. With the introduction of cold-tolerant clones we should be able to minimize these losses. In copiced plantations the freeze-induced losses should be limited to the current rotation and only rarely lead to death of entire trees. Diseases and pests of eucalyptus are not unknown, but we have too little information for California to estimate the risk and economic loss.

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Part 5. Cultural Requirements

Vegetation Management in *Eucalyptus*¹

Clyde L. Elmore²

Weeds are plants that compete for water, nutrients and light, or in *Eucalyptus* plantations may interfere with the management and operations of the growing and harvesting of trees. Weeds when dry may also be a fire hazard. *Eucalyptus* species are grown in California for wood products, ornamental trees along roadways or around buildings and as an ornamental for cut foliage. This paper will refer principally to the control of weeds prior to, or during the early establishment of trees.

Unwanted vegetation (weeds) are found in all sites that will be considered for planting. The plants found will generally be a mix of material and will represent broadleaf and grass weeds. The weeds will usually be a mixture of annual, biennial and perennial plants. The majority of plants will be annual and will complete their life cycle from seed to foliage, bloom and seed within a year. Plants that germinate in the late winter and spring are called summer annuals because they mature in the summer but die with a frost. When plants start in the cool moist season (fall) and grow through the winter they are called winter annuals.

Biennial plants usually start in the fall and form a rosette during the first winter. They form a flower stalk in the following year, flower, form seed, then die.

The life cycle of the third type of plant is called perennial. They possess the capability of continuing growth year after year. They not only seed but generally will form an above and/or below ground storage organ that helps maintain the stand of the weed. Perennials may be herbaceous johnsongrass (*Sorghum halapense*), field bindweed (*Convolvus arvensis*) or California blackberry (*Rubus vitifolius*).

¹Presented at the Workshop on *Eucalyptus* in California, June 14-16, 1983, Sacramento, California.

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Abstract: Weeds and weed control are a major problem in the growth and management of *Eucalyptus* trees. Annual, biennial and perennial weed species are common in sites to be planted. These weeds should be controlled before planting. Preplant, preemergence and postemergence herbicides are discussed. Safe preemergence herbicides include oryzalin, napropamide, oxadiazon, linuron and to a lesser degree simazine, atrazine and diuron. Glyphosate, amino triazole and paraquat have been used safely and efficaciously [sic] postemergence. Combinations of mechanical and chemical weed control help allow maximum tree establishment and growth.

TYPES OF CONTROL STRATEGIES

Site selection

The site can be selected to optimize the growth of trees without the interference of unwanted vegetation. Annual weeds though a problem are not as difficult to control as the perennial plants. Sites infested with perennial herbaceous weeds, woody brambles or shrubs should be avoided if possible. Increased costs are required when reducing perennial weed populations. A site that can be cultivated for annual weed control during early tree establishment will reduce chemical costs. A site that has water (irrigation) available allows for controlling moisture for tree growth. The freedom to apply water (time and amount) is beneficial in increasing herbicide efficacy. In an irrigated plantation weed competition for water may not become a limiting factor. In dryland (natural rainfall) sites weeds must be reduced or eliminated to maintain moisture for the trees.

Site Preparation

Weeds should be controlled before planting the trees. Brush species should be removed and resprouting species controlled before planting. Perennial weeds such as bermudagrass, johnsongrass, nutsedge or field bindweed should be reduced before planting. Postemergence herbicides are effective for these weeds. Annual species can be reduced by cultivation followed by an irrigation to germinate new weeds before the second cultivation. A contact herbicide can be substituted for the cultivation.

A cultivation will reduce seed production and subsequent weed infestations. Where erosion can be a concern, mowing the weeds may be more desirable than a cultivation. Mowing weeds promotes low growing (prostrate) species, especially bermudagrass.

Preplant (Aquiar, 1975) and preemergence (Bazan, 1974 and Veiga, 1969) herbicides have been used prior to planting of seedling trees.

Preplant fumigants have been effective and safe. They are expensive for large areas but reasonable for nursery production sites.

Preemergence herbicides (monuron, diuron, simazine and atrazine) have been injurious when applied prior to planting.

Control in New Plantings

The control of weeds is most critical to the growth of trees during the first 2 years after planting. Various control measures (Starr, 1980) were compared on a sandy clay and podsolic soil. Mowing of weeds allowed greater tree growth than weeding. On a sandy clay soil the best growth resulted from treatment with a black plastic mulch. In the podsolic soil there was no difference in tree growth when treated with black plastic, wood mulch, hand weeding or a combination of paraquat and diaquat. Ramalho and Zunti (1975) in Brazilian plantations reported using mowing at right angles reduced manual labor. Prolonged weedings (Brandi, 1974) were needed to give maximum tree growth.

Preemergence herbicides (table 1) have been evaluated on Eucalyptus species. The tolerances of the species are listed with the reference. Post-emergence herbicides (table 2) can be used selectively as a directed spray. These same preemergence and postemergence herbicides have been evaluated in establishing plantings.

In sloping sites where soil erosion occurs it has been observed in pine plantations that a strip treatment of preemergence herbicide down the tree row and leaving vegetation between the rows reduces erosion. The vegetation between the rows should be mowed periodically to reduce moisture loss and to decrease a fire hazard.

Preemergence studies on E. sideroxylon var. rosea (table 3) indicated no significant phytotoxicity or difference in growth with simazine, napropamide, oxadiazon, or combinations of simazine plus trifluralin or oxadiazon plus trifluralin applied annually over a 3-year period.³ The control of annual weeds was excellent with all treatments (table 4). Similar studies using the same herbicides were conducted in container Grown E. nicholii. Field plantings of E. pulverulenta⁴ have been treated with preemergence herbicides (table 5) without phytotoxicity and, in general, good weed control.

Eucalyptus as a Weed Tree

Since some species are very site tolerant, such as moisture, salts, fertility and soil depth, they may be considered weed trees in certain locations. These sites seem to be preferred for pines (Minko, 1981) or in some California Douglas-fir (Pseudotsuga)

in some locations, annual crops in others. Eucalyptus found as weed species include E. cambageana, E. largiflorens and E. populnea.

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Table 1--Preemergence herbicides evaluated on Eucalyptus species

<u>Herbicide</u>	<u>Reference</u>	<u>Comments</u>
alachlor	Elmore, 1973	selective
atrazine	Bazan, 1974; Brasil, 1976a; Ethiopia, 1974; Schie, 1978	toxic to seedlings
bromacil	Bazan, 1974; Brasil, 1976a	toxic to seedlings
DCPA	Bazan, 1974; Brasil, 1976b; Elmore, 1973	nontoxic to seed germination
dichlobenil	Flinn, 1979	injured 3 species
diuron	Brasil, 1976a; Veiga, 1969	safe on some species established .
EPTC	Veiga, 1969	safe but short residual
hexazinone	Schie, 1978	toxic to E. globulus
linuron	Bazan, 1974; Brasil, 1976a; Brasil, 1976b; Dorsser 1973	nontoxic to seed germination
monuron	Veiga, 1969	injures plants
napropamide	Elmore, 1973	highly selective
oryzalin	Brasil, 1976b; Elmore, 1973; Starr, 1980	highly selective
oxadiazon	Elmore, 1973	highly selective
propyzamide	Flinn, 1979	selective for grasses
propazine	Flinn, 1979	selective
secbrometon	Bazan, 1974	toxic to seedlings
simazine	Brasil, 1976a; Elmore, 1973; Ethiopia, 1974; Flinn, 1979; Revell, 1976; Schie, 1978	tolerant on most young or established plantings at low rates and in medium to heavy soil
terbumeton	Bazan, 1974	toxic to seedlings
trifluralin,	Elmore, 1973	highly selective

Table 2--Postemergence herbicides evaluated on Eucalyptus species

<u>Herbicide</u>	<u>Reference</u>	<u>Comments</u>
aminotriazole	Magnani, 1976; Schie, 1978	effective grass control when used with atrazine or simazine
dalapon	Veiga, 1969	injurious to <u>E. saligna</u>
glyphosate	Ethiopia, 1974; Starr, 1980	effective postemergence on grasses and some woody species (brambles)
paraquat	Ethiopia, 1974; Revell, 1976	control of young annuals

Table 3--Phytotoxicity and Growth Indices of E. sideroxylon var. rosea

Herbicide	Rate A.I./A	Phytotoxicity ¹			Growth ² Indices
		3 MO.	5 MO.*	2 MO.**	
simazine	0.5	0.0	0.0	0.5	299.2
simazine + trifluralin	0.5 + 2	0.0	0.0	0.6	314.7
napropamide	4	0.5	0.0	0.3	334.8
napropamide	16	0.8	0.0	0.0	280.6
oxadiazon	2	0.2	0.0	0.0	289.8
oxadiazon + trifluralin	2 + 2	0.0	0.0	0.0	270.0
untreated	-	0.0	0.0	0.0	282.3 (N.S.)

¹Phytotoxicity:0 = no effect; 10 = dead plants.

²Growth indices = $\frac{\text{height (m)} \times \text{width (m)}}{2}$ mean of 2 plants per plot
x 4 replications.

*Months after 2nd application.

**Months after 3rd application.

Table 4--Weed Control in E. sideroxylon var. rosea ¹

Herbicide	LB. A.I./A	(Months)			
		<u>3</u>	<u>4</u>	(<u>4</u>)	(<u>5</u>)
simazine	0.5	7.3	6.6	8.4	8.0
simazine + trifluralin	0.5 + 2	6.4	6.8	9.0	9.1
napropamide	4	9.3	8.6	8.6	9.2
napropamide	16	9.6	9.2	9.9	9.9
oxadiazon	2	7.9	7.2	8.5	8.8
oxadiazon + trifluralin	2 + 2	6.7	6.8	9.1	9.0
untreated	--	3.2	4.7	1.8	0.2

¹Weed control: 0 = no control, 10 = complete control

Applications: 7/23/71, 12/21/71, 11/21/72*,
(simazine rate doubled)

Table 5--Preemergence herbicides in field planting of 1 year old E. pulverulenta

Herbicide	LB A.I./A	Weed Control ¹				<u>Phytotoxicity</u> ²
		<u>1 Mo.</u>	<u>2 Mo.</u>			
		All Weeds	Cheeseweed	Goosefoot	All Weeds	<u>2 Mo.</u>
simazine	1.0	5.5	8.8	10.0	8.5	1.0
simazine	2.0	7.0	10.0	9.0	9.0	1.0
linuron	0.5	6.5	9.8	5.0	7.8	1.0
linuron	1.0	6.8	9.8	8.2	8.8	1.0
diruon	1.0	6.5	9.8	8.5	8.0	1.0
simazine + oryzalin	1 + 4	7.2	9.0	10.0	9.0	1.0
simazine + napropamide	1 + 4	7.0	9.5	9.8	9.0	1.0
oryzalin	4	6.2	9.8	7.2	7.5	1.0
napropamide	4	5.5	8.0	5.8	7.0	1.0
oxyfluorfen	0.5	9.4	10.0	10.0	8.8	1.0
oxyfluorfen	1.0	8.8	10.0	10.0	9.5	1.0
oxyfluorfen	2.0	9.8	10.0	10.0	9.8	1.0
		3.8	3.2	1.0	4.2	1.0
untreated	-					

¹Weed control: 10= complete control; 1 = no control.

²Phytotoxicity: 1 = no effect; 10 = dead plants.

Spacing Trials Using the Nelder Wheel¹

Walter B. Mark²

The productivity of short rotation biomass plantations will vary with many factors including the spacing utilized in the planting. The nature of energy plantations, where productivity is to be maximized in an extremely short rotation, necessitates determination of optimum planting density. The early yield studies dealing with eucalyptus plantations made no attempt to determine what the optimum spacing might be (Metcalf 1924). Most of the yield data for eucalyptus are for relatively long rotations, conventional spacing and merchantable volumes. Many of the early feasibility studies on energy plantations utilized this yield data for determination of the production possible. Spacings in these yield studies varied up to 16 by 16 feet (USDA Forest Service 1975). More recent spacing studies have been conducted using several different spacings, such as 8 by 8 feet, 10 by 10 feet, 12 by 12 feet, and 14 by 14 feet (Walters 1980). When a plantation project was planned at Cal Poly, San Luis Obispo one of the first questions was that of the optimum spacing to use for the species that were being considered. No answers to that question were available. As a result, the Cal Poly plantings were made with one of the goals being to determine optimum spacings for the species, products, and rotations desired.

The plantation area was limited to 17.5 acres. The size limitation forced the utilization of an experimental design that would allow the testing of many spacings in a small area. The Nelder wheel or fan design was selected.

NELDER WHEEL DESIGN

Concept

Experiments designed to produce specific answers to questions are the best source of data for deriving models of growth. Much of the

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Abstract: The Nelder wheel is a single tree systematic experimental design. Its major application is for plantation spacing experiments. The design allows for the testing of a number of spacings in a small area. Data obtained is useful in determining the response of stem diameter and crown diameter to spacing. Data is not compatible with data from conventional plots unless single tree modeling is utilized. The design is sensitive to individual tree losses. Nelder wheels were planted at Cal Poly, San Luis Obispo with eight species of eucalyptus and a hybrid poplar in 1980. First year growth results are presented.

available data on plantation growth was obtained from the measurement of existing plantations that were planted with a specific objective in mind. Most often that objective was not to maximize total biomass production, but rather to produce a certain product. If the productivity of those plantations is measured for that product, the data is valid. If the plantation is measured for another product, the model may not be applied to a stand planted with other products in mind.

Experiments should be set up to answer specific general questions rather than to select the best of a set of treatments. The Nelder wheel design is a single tree systematic design with the main application toward spacing experiments in a uniform forest. Systematic designs like the Nelder wheel are laid out in a specified pattern to economize on the size and cost of the experiment. Treatment locations are not randomized and data generated cannot be analyzed by analysis of variance. The data is useful, however, in regression parameter estimation. Nelder wheel experiments have most commonly been utilized for modeling of individual tree growth.

Design and Layout

Nelder wheels are circular plots with a variable number of spokes per plot and rings per spoke (fig. 1 & 2). In the examples shown the plots have 24 spokes and 10 rings. This design provides 240 planting spots per plot. In the Nelder wheel design the innermost and outermost rings should not be included in the data because these planting spots do not have a uniform spacing. The design shown in fig. 1 and 2 would have 192 data trees, assuming 100 percent survival. Any time a tree dies in the plot the four trees in the adjacent planting spots must also be eliminated from the data, because their spacing has been changed.

Before the plot is laid out in the field, the spacing trials desired should be determined. The plot design works best if the interval spacing or radial spacing for planting spots on the spoke is approximately the same as the cross spacing between the planting spots on the spokes. The

cross spacing can be determined from the following formula:

$$C = \sqrt{2a^2(1 - \cos\theta)}$$

where C = cross spacing
a = interval spacing
θ = angle between spokes

Plot layout in the field takes a great deal of time and requires a high degree of accuracy. The angle between the spokes must be turned accurately or the spacing between the planting spots will not be accurate. This can be checked most easily by measuring the distance between the spokes at the plot perimeter. The interval spacing along the spokes should also be measured with a high degree of accuracy. Planting spots should be staked prior to planting to assure that planting is carried out over a short time interval.

Nelder wheel plots are frequently divided to provide for varied treatments or replications of species tests. Most frequently the plots will be used for from one to three species or for one to three treatments. This type of plot division can present a problem in data interpretation if the species or treatments vary widely in their growth pattern. Edge effects may be created between treatments or species tests.

Another type of systematic design provides square and rectangular spacing trials. In this design the spacing between trees is increased by a constant for each successive planting in both the x and y axis (fig. 3). This results in spacings of all distances in both a square and a rectangular trial.

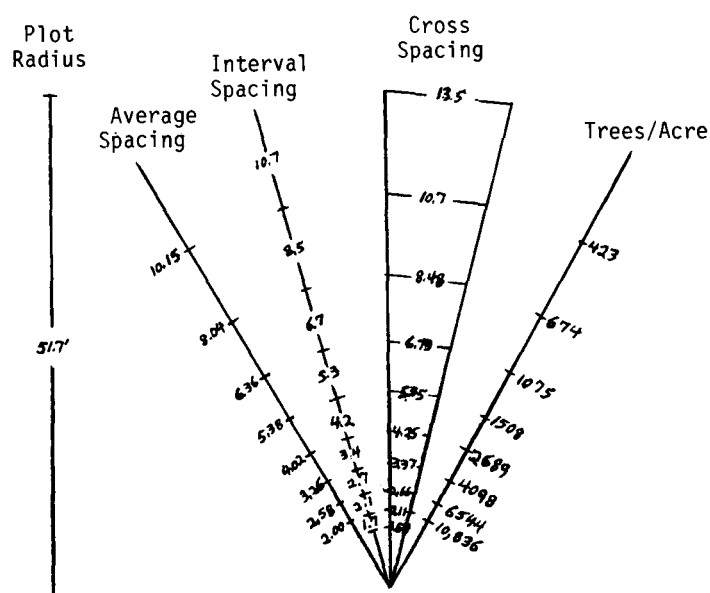


Figure 1--Nelder wheel layout showing planting spots, cross spacing, ring interval spacing, and average spacing.

Plot 7

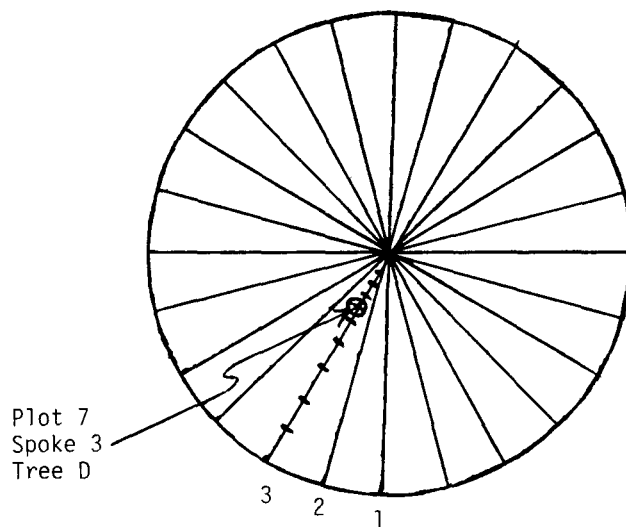


Figure 2--Illustration of labeling of planting spots in Nelder wheels. Planting spot indicated is Plot 7, Spoke 3, Tree D. Tree A is closest to the center.

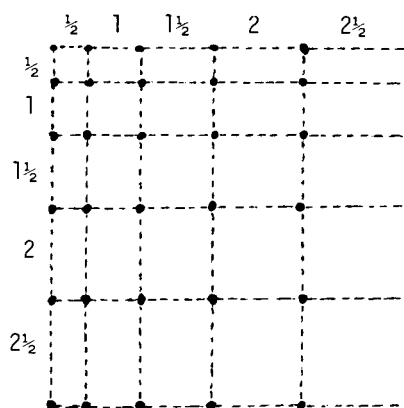


Figure 3--Systematic experiment design using a rectangular design.

CAL POLY NELDER WHEEL EXPERIMENTS

Plot Design

The Nelder wheel design for the Cal Poly spacing trials had 24 spokes with 10 rings on a spoke (fig. 1 & 2) (Kirkley, Pillsbury and Mark 1981). This provided 240 planting spots and 192 data trees per plot. The plot radius to the outermost planting spot was 51.7 feet and each plot occupied 0.23 acres. The average spacing

distances varied from 2.01 by 2.01 feet to 10.15 by 10.15 feet (Table 1). The angle between the spokes was 15 degrees. These spacings were selected on the assumption that they would bracket the range of optimum spacing for the species being planted.

Plot Layout

Plot layout on the plantation site was complicated by the variable terrain and soils. The plantation site was range land with slopes varying between 5 and 22 percent. The first step was to map the plantation site, including unplantable sites (gullies and rock outcroppings), developments, soils, and topography. This map was utilized in the office to position the plots prior to field location. Once the plot location was determined on the site map, the plot centers were located at the plantation site. The preliminary site preparation, consisting of bi-directional ripping and tilling with a vibrashank, had been done prior to plot location. Plot layout was done using a transit, Clinometer, and steel tape. Spoke angles were turned from the plot center and the outermost planting spot on each spoke was staked. The spoke spacing was checked before staking planting spots along the spokes. Planting spots were determined on the spokes by measuring out the prescribed horizontal distance from the plot center.

Plantings

Eight species of eucalyptus and hybrid poplars were planted in 26 plots. The species of eucalyptus included Eucalyptus camaldulensis (Dehnh.), E. cinerea (F. Muell. ex Benth), E. citriodora (Hook.), E. globulus var. compacta (Labill.), E. polyanthemos (Schau.), E. pulverulenta (Sims), E. stellulata (Sieb. ex DC.), and E. viminalis (Labill.). All the stock was container stock and was obtained from the California Department of Forestry or commercial nurseries.

Prior to planting, the plots were sprayed with "Round-up" to control vegetation which had emerged after the initial site preparation. Plots were not planted within 48 hours of herbicide application. Planting in each plot was finished in the day it was started. Initial planting was completed between February 13 and March 20, 1980. Planting and fertilizing was done using KBC planting bars. Fertilizer treatments included 10 and 21 gram tablets with a 20/10/5 formulation. All plots were planted with one species; however, the plots were split for fertilizer and herbicide treatments.

Pre-emergent herbicide application was started on April 4, 1980. Two herbicides were utilized, "surflan " and "Devrinol". Applications were made on 10 of the 26 plots with each half of the plot treated with a different herbicide. No detrimental effects were recorded from the application of the pre-emergent herbicide, in fact, the only plot that had no mortality by May 1, 1980 was planted on February 22 and treated. All other weed control was by mechanical means.

RESULTS

The tree growth on the plots was measured in January and February, 1981, approximately one year after planting. The results for six species from the plots of each with the lowest mortality rates are presented in table 2. The tree diameters were measured at the base since the trees had no dbh when planted, and most had none after 1 year of growth. The average height and diameter of the planting stock were as follows:

<u>Species</u>	<u>Height (m)</u>	<u>Diameter (cm)</u>
<u>E. camaldulensis</u>	0.12	0.15
<u>E. cinerea</u>	0.10	0.10
<u>E. citriodora</u>	0.28	0.30
<u>E. globulus</u>		
var. <u>compacta</u>	0.32	0.29
<u>E. pulverulenta</u>	0.54	0.33
<u>E. viminalis</u>	0.11	0.15

Table 1--Nelder wheel spacing and density as utilized in the Cal Poly, San Luis Obispo spacing plantation

<u>Radius (ft)</u>	<u>Interval Spacing (ft)</u>	<u>Cross Spacing (ft)</u>	<u>Average Spacing (ft)</u>	<u>Trees per acre</u>	<u>Tree Code</u>
51.7	--	13.5	-----	---	I
41.0	10.7	10.7	10.15	423	H
32.5	8.5	8.48	8.04	674	G
25.8	6.7	6.73	6.37	1,075	F
20.5	5.3	5.35	5.38	1,508	E
16.3	4.2	4.25	4.03	2,689	D
12.9	3.4	3.37	3.26	4,099	C
10.2	2.9	2.66	2.58	6,544	B
8.1	2.1	2.11	2.01	10,836	A

Table 2--Height and basal diameter after one year of growth in Nelder wheel plots at Cal Poly, San Luis Obispo.

Tree Species	Percent Survival	Plot Number	Measurement	Tree Code							
				B	C	D	E	F	G	H	I
<u>E. camaldulensis</u>	91	32	ave hgt m	0.25	0.30	0.29	0.27	0.30	0.28	0.28	0.25
			ave dia cm	0.73	0.82	0.94	0.82	0.84	0.78	0.77	0.79
			max hgt m	0.52	0.45	0.47	0.49	0.52	0.52	0.52	0.36
			max dia cm	1.47	1.52	1.72	1.53	1.56	1.54	1.36	1.39
<u>E. cinerea</u>	73	2	ave hgt m	0.56	0.55	0.53	0.53	0.58	0.54	0.54	0.59
			ave dia cm	0.74	0.78	0.81	0.89	0.94	0.84	0.82	0.91
			max hgt m	0.77	1.20	0.87	0.87	1.19	1.10	0.95	1.46
			max dia cm	1.39	1.80	2.16	1.58	1.80	2.29	1.69	2.18
<u>E. citriodora</u>	71	12	ave hgt m	0.74	0.92	0.67	0.73	0.74	0.63	0.86	0.57
			max hgt cm	1.39	1.44	1.38	1.13	1.19	0.97	1.42	1.20
<u>E. globulus</u> var. <u>compacta</u>	60	6	ave hgt m	0.79	0.63	0.71	0.67	0.58	0.60		
			ave dia cm	0.96	0.69	0.67	0.87	0.74	0.73		
			max hgt m	1.08	0.97	1.05	1.01	0.87	0.87		
			max dia cm	1.78	1.28	1.23	1.46	1.06	1.22		
<u>E. pulverulenta</u>	71	3	ave hgt m	0.61	0.69	0.65	0.68	0.67	0.68	0.68	0.78
			ave dia cm	0.66	0.71	0.67	0.77	0.75	0.76	0.74	0.82
			max hgt m	0.86	1.03	0.91	1.03	1.27	1.21	1.00	1.40
			max dia cm	1.00	1.05	0.96	1.40	1.52	1.24	1.38	1.50
<u>E. viminalis</u>	92	13	ave hgt m	0.94	0.89	0.92	0.93	1.04	0.79	0.86	0.91
			ave dia cm	1.24	1.67	1.71	1.75	1.93	1.65	1.78	1.87
			max hgt m	1.45	1.33	1.36	1.33	1.64	1.28	1.52	1.50
			max dia cm	2.40	3.04	2.80	2.48	2.80	2.65	3.14	3.00

In general the height growth was lowest in the innermost rings, peaked between rings C and F, and dropped off again in the outer rings. Diameter growth generally increased from the innermost rings to the outer rings. This pattern of diameter growth would be expected because of the nearly open-grown status of the trees in the outer rings through the first year. In the Cal Poly unirrigated experiments E. viminalis had the greatest average height and diameter growth (1.04 m and 1.93 cm respectively) of all species tested. The best growth occurred in plot 13 ring F, at an average spacing of 6.37 x 6.37 feet. A few trees were remeasured in October, 1982. By that time E. globulus var. compacta had the best growth with a maximum height of 5.1 m, basal diameter of 10.5 cm, and dbh of 5.7 cm.

The mortality was lowest in plots which had good weed control and which were not on ridgetops. Deer browse was a problem with all the plots

planted to Eucalyptus camaldulensis, while all other species were lightly browsed or left alone.

LIMITATIONS AND APPLICATIONS OF THE NELDER WHEEL

The Nelder wheel experimental design is well suited to experimentation to determine the optimum spacing for maximum production at a certain rotation. The data will provide single tree data on diameter and crown growth. This data can be applied to uniformly spaced forest situations provided that a single tree model has been developed. The experimental design is excellent for preliminary testing of newly introduced species or for species that are being tested for new product markets or rotation ages.

The Nelder wheel design has also been utilized to make genetic selections based on individual tree performance (Namkoong 1966). The design can

be utilized to select trees that will out-perform others at the same spacing distances and can be utilized to choose the maximum performers at varying rotation ages.

CONCLUSIONS AND RECOMMENDATIONS

Application of the Nelder wheel

The Nelder wheel design is an excellent experimental design for determining the optimum spacing distance for tree species. The design allows for the testing of several different spacings in a relatively small area. The small size of the plots may distort the growth data because of the edge effect that has been observed in small, dense, open sided row plantings of some species (Zavitkovski 1981). The effect has been shown to extend through several rows along the border of small plots. Similar studies have not been conducted on the edge effect in Nelder wheels.

The design should be utilized only for determining optimum spacing distance. It is best applied in situations where the plots are relatively level. If the plots are placed on a slope, the spacing distances do not really represent the distances intended in the design. The plots are laid out using horizontal distance measurements. If the plots are viewed from directly above, they are circular and the crown space is representative of the spacing design. The opportunity for lateral interception of solar radiation is greater and the available rooting zone is larger. If the plot is viewed perpendicular to the slope, the plot will appear elliptical in shape. This distorts growth data because of the varied spacing, especially if the plots are split with different species or treatments. The Nelder wheel design should be applied where the chance for high survival rates are great. Like all single tree experiments the design is highly sensitive to tree mortality. If a single tree dies, not only is the data for that tree lost, but the data on the four adjacent trees is also lost. The death of a tree upsets the arrangement of the design so that the spacing distances are not as planned.

The data must be analyzed using regression analysis. The data is good for predicting regression parameters. The analysis of variance technique should not be applied to the data, since the design is systematic and not randomized.

One common error made in using the Nelder wheel design is to make yield predictions based on an expansion of the growth data obtained. The average growth for a certain spacing is multiplied by the number of trees per unit of land area and a yield is predicted. This is not accurate unless single tree modeling has been applied.

For yield prediction a randomized block design is superior to the systematic design. The plot data is applicable to forest stand yield prediction, is not as sensitive to tree mortality, and can be analyzed using the analysis of variance technique. Stand culture is simpler because of the row arrangement and is better suited to mechanization.

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Establishing a *Eucalyptus* Energy Plantation on the Central Coast of California¹

Norman H. Pillsbury and Nelson L. Ayers²

Woody biomass plantations are gaining national attention for their conversion properties into energy feedstocks. Research is continually being conducted to demonstrate this biomass potential for alternative energy sources. Information obtained from biomass studies will help relieve our dependence on fossil fuels. For example, the U.S. Forest Service has set a national goal of an increase of 4 Quads (4 quadrillion BTU's) by 1990 (from wood residue). This represents 5.5% of the nations energy budget. The California Energy Commission has a similar goal of meeting 5% of the States energy budget by the year 2000 from all biomass energy production or 400 trillion BTU's.

THE ENVY PLANTATION CONCEPT

Tree species selected for biomass production must be resistant to insect and disease, demonstrate rapid growth and have high energy yield during short rotations, and respond to intensive cultural treatments. Additional plantation management may include fertilization and irrigation at various times during the rotation (Pillsbury and Ayers 1982).

Hardwood species are thought to have the greatest potential for energy farming. They have the added advantages of not competing with timber and product uses of commercial conifer species and they can be coppiced. Examples of hardwoods being examined in trial plantings in the United States include Alnus, Eucalyptus, Platanus, and Populus.

¹Presented at the Workshop on Eucalyptus in California, June 14-16, 1983, Sacramento, California

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Abstract: A 17.5-acre non-irrigated biomass energy plantation has been established near San Luis Obispo. This joint California Polytechnic State University - California Department of Forestry project is measuring plot growth response of seven eucalyptus species for three spacing trials and for the effect of fertilization. All study plots are replicated. Site preparation strategy, planting, and maintenance and protection problems are discussed. The most important problem is the heavy weed growth. Herbicides and mechanical methods were used to control competing vegetation. A continuous effort is necessary for successful plantation establishment - especially during the first year.

A number of Eucalyptus species appear most promising in California. Of the 700 plus species in the genus, perhaps 20 or 30 could be used in the various climate regimes of California (Pillsbury 1980). Their density in the plantation may range from 400 to 11,000 trees per acre.

The energy plantation must be of sufficient size to guarantee a reliable long-term supply of fuel, on scheduled demand, to the power plant. Additional support acreage for storage, road network, and facilities ranges from 10 to 40 percent above the planted area (Kirkley et al 1981).

Energy yield from plantations is a subject of much debate. Variables to be considered are species selection, spacing, cultural treatments, fertilizers, irrigation, soil and site quality, rotation number since initial planting, and weed control. Estimates obtained from available literature references for model studies and some plot data show yields ranging from 3.5 dry tons/ac/yr for Populus in Wisconsin to 15 dry tons/ac/yr for high-quality tropical fuel plantations. Values used for California range from 5 to 13 dry tons/ac/yr. The lower value assumes minimal management on marginal sites while the higher value reflects intensive management practices on higher quality land. Most authors were optimistic [sic] about future increases as management practices are improved and research studies identify optimum yield species and soil conditions. One model study shows California potentially producing 22 dry tons/ac/yr under ideal conditions (Fege et al, 1979).

The cost of producing energy feedstocks is equally debatable. Regional differences are created by land lease, interest and taxes, transportation costs and distances, the cost of investment (affected by current prime lending rates), land steepness (which defines the cost of harvest equipment) and water availability (Fege et al. 1979). Costs per dry ton ranges from \$20 to \$34 with most authors showing reduced costs following future technological advancements.

No reliable cost estimates were found for marginal lands in California. Cost per million BTU is \$1.20 to \$2.50 based on 17 million BTU per dry ton, while 1985 costs for coal are projected at \$1.50 per million BTU.

THE CAL POLY - DEPARTMENT OF FORESTRY EUCALYPTUS ENERGY PLANTATION

A joint California Polytechnic State University and California Department of Forestry Eucalyptus Energy Plantation is currently being grown near San Luis Obispo. The plantation is designed to demonstrate the effectiveness of growing non-irrigated eucalyptus trees for biomass energy. The project was initiated in 1979 to evaluate the suitability of several eucalyptus species by measuring mortality and single tree growth rates (Mark *et al.* 1980). Results from this initial study were used to select species for a second planting currently being evaluated for growth and yield.

The general purpose for this long range biomass study is two-fold. First, the project data will help land owners understand techniques and difficulties involved in establishing a commercial non-irrigated eucalyptus plantation. It will identify management practices and potential problems which influence the success of plantation establishment, maintenance and continued growth. Also, it will provide a source of growth and yield information for energy farmers. Our specific objectives can be best understood by these eight commonly asked questions.

1. What species should be planted?
2. What spacing should be used?
3. What yield can be expected and when?
4. Should the tree be fertilized?
5. What are the requirements for an effective site preparation?
6. How can weed and pest problems be controlled?
7. What is the energy benefit-cost relationship?
8. What rotation age will provide optimum yield?

Site Description

The study area is located about mid-way (6 miles) between the Pacific Ocean and San Luis Obispo. The planted and support area is 17.5 acres in size and is located on sites typically found along the central coast of California. The elevation is approximately 580 feet and the site is predominantly south-facing with slopes ranging from 5-22 percent. Weather patterns are typically Mediterranean with wet winters and dry summers. The mean annual precipitation in San Luis Obispo for the 1963-1983 period is 27.62 inches; 75 percent occurs from December through March.

However, rainfall for 1982-1983 was the third wettest on record, 47.59 inches. The average frost free season exceeds 300 days. The mean annual temperature for the last 20 years was 63.8 degrees Fahrenheit. The soils are classified as Los Osos variant clay loam. The surface layer is grayish brown clay loam about 12 inches deep and the subsoil is pale brown clay about 27 inches thick. The underlying material in the subsoil is moderately alkaline and consists of calcareous clay loam extending to a depth of greater than 60 inches. Several rock-outcroppings are located on the site. Grass species such as wild oats (*Avena fatua* L.), annual rye grass (*Lolium multiflorum* Lam.), and soft chess (*Bromus mollis* L.) are prevalent. The land was previously used for cattle grazing.

Site Preparation

The study area was burned in October 1982 to eliminate all weeds and competing vegetation. A single shank was used to rip each row to an approximate depth of 2.5 feet. The site received 2 inches of precipitation prior to cross discing. The purpose of cross discing was to close the gap and seal the moisture into the ground. Planting was delayed several weeks due to high soil moisture conditions; excessive weed growth occurred during that period. To eliminate weed growth prior to planting Round-up, a non-selective post-emergent herbicide, was applied. The rate of application was 4.5 ounces of active ingredient in 2.5 gallons of water per acre. Simazine which is a pre-emergent herbicide will be applied shortly before the first Fall rains to prohibit annual weed emergence. It will be applied at a rate of 4 pounds of active ingredient in 25 gallons of water per acre.

Plantation Design

The Eucalyptus plantation consists of a split plot randomized block design for seven species. Each species is being tested for its response to a fertilizer treatment and for three spacings of 3 x 12 feet, 6 x 12 feet and 9 x 12 feet. The spacing between rows for all plots is 12 feet to accommodate farm machinery sizes normally available for planting, maintenance, and harvesting. Control plots (non-fertilized) were also established for these spacings as shown in figure 1. Each spacing trial contains 6 rows with 6 trees per row or 36 trees. The treatment and control plots contain 108 trees each (36 trees x 3 spacings) or 216 trees per species. Each species was replicated to complete the randomized block design shown in figure 1. The data collected from these plots will be used for yield analysis. Several buffer rows were planted adjacent to the plots to protect yield trees from external influences. These buffer trees will not be used in the evaluation of plantation yield.

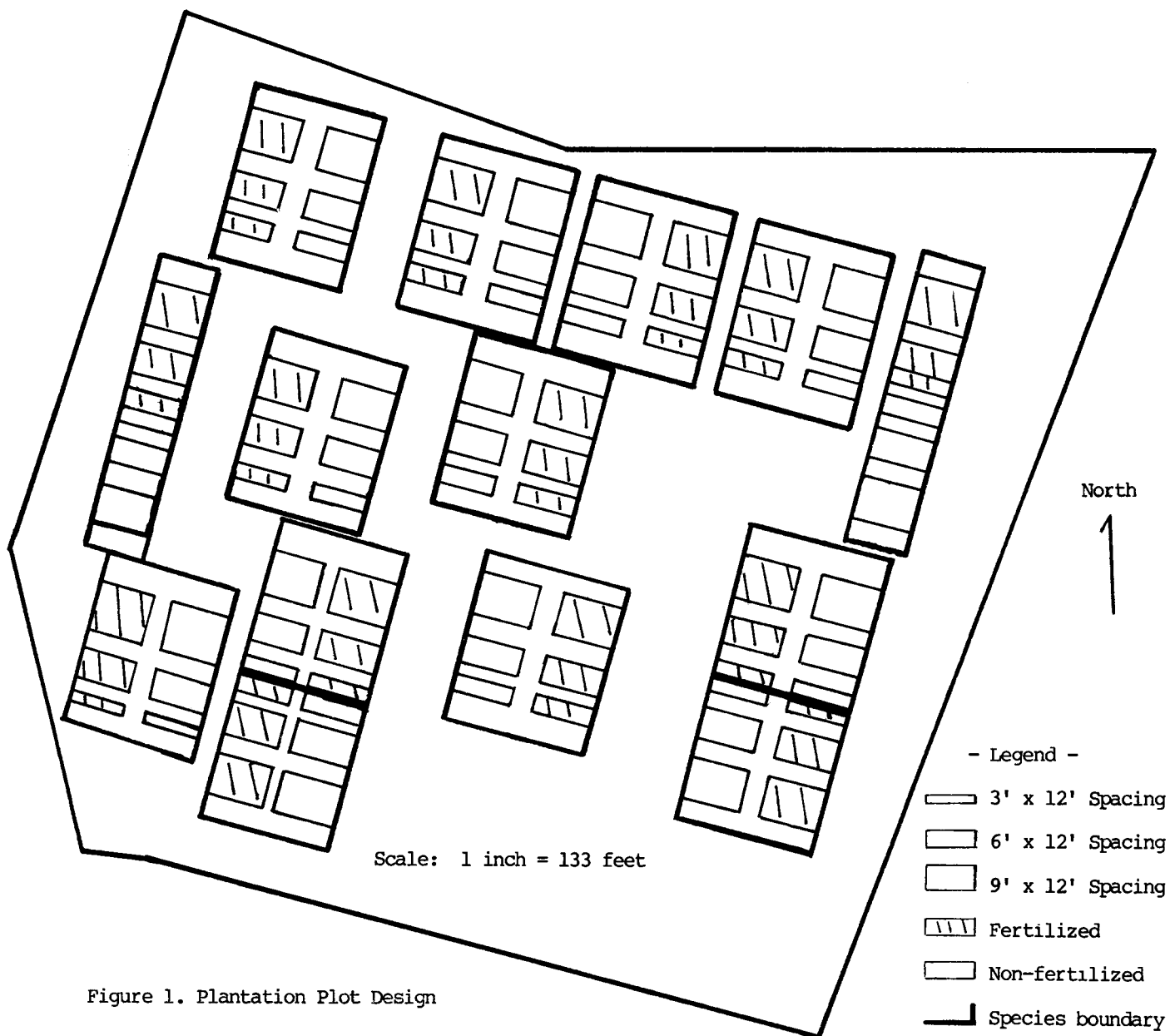


Figure 1. Plantation Plot Design

Species Selection And Seed Source

The seven species to be evaluated are;

1. Eucalyptus camaldulensis
(Dehnh. var. camaldulensis)
2. Eucalyptus citriodora (Hook f.)
3. Eucalyptus dalrympleana (Maid. subsp. dalrympleana)
4. Eucalyptus globulus (Labill. subsp. globulus)
5. Eucalyptus grandis (Hill ex Maid.)
6. Eucalyptus sideroxylon (A. Cum. ex, Woolfs subsp. sideroxylon)
7. Eucalyptus viminalis (Labill.)

E. dalrympleana, E. grandis, and E. sideroxylon were selected for the study because they have demonstrated excellent potential for biomass production in other regions in California (Mariani et Al. 1978 and Sachs et al. 1980). The other species demonstrated rapid growth, ease in regeneration and establishment, tolerance to insects and pathogens, and their suitability to the soil and environmental conditions of the central coast area in a previous study. All species were closely matched to the temperature and precipitation patterns for San Luis Obispo County.

The seed source for all species except E. citriodora originated in Australia. They were

propagated in 1 by 6 inch squared plastic containers having a medium of 90 percent peat moss-vermiculite and 10 percent perlite. The California Department of Forestry Nursery at Davis cultivated the seedlings in their greenhouse-nursery complex where seasonal moisture and temperature conditions were simulated. The eucalyptus seedlings were 1 year old at the time of planting. The E. citriodora was purchased from a private commercial nursery and no information was available to describe its origin and propagation history. They were approximately 3 months old when planted.

Planting and Maintenance Problems

The Eucalyptus Energy Plantation was planted during a 2 week period in mid-February 1983. Trees in fertilized plots were given a 21 gram slow-release Agri-form fertilizer tablet containing 20 percent nitrogen, 10 percent phosphoric acid and 5 percent soluble potash. The pellet was placed about 3 inches below the root zone (1 foot from the soil surface) during planting.

During the initial 4 month growing period the plantation became heavily infested by weeds. However, only sparse weed coverage occurred along the rows compared to the inter-row area. It appears that ripping, in this case to a depth of 2.5 feet, in addition to breaking up any hard pan soil layers to provide for better root penetration, also provides a form of weed control.

A preliminary investigation shows that the majority of seedling mortality on the plantation occurred in E. citriodora where over 95 percent died. This exceptionally high rate may be due to age of the delivered stock (3 months) or to improper "hardening" practices. It is recommended that all species be the same age for comparing growth rates.

Deer browsing was prevalent throughout the plantation although most of the damage was located in one area. Species that were browsed include; E. viminalis, E. camaldulensis, E. grandis, E. dalrympleana and E. sideroxylon. Continued deer browse caused the seedlings to develop extensive lateral branching. This may require pruning to maintain the desired tree form.

Several perches will be located throughout the plantation. By attracting predators, it is anticipated that the rodent population will be controlled.

Productivity Measurements

Plot productivity measurements will include height and diameter beginning in the first year. A correlation between height, diameter, weight, and energy yield will start the second year; by the third year sprouts will be evaluated.

The data will be used to compare productivity by species and spacing and to test the effect of fertilization.

Project Timetable

In addition to information about site preparation techniques discussed earlier, more information will be available on mortality, weed control, deer browsing and plantation establishment problems by summer 1984. By 1989 the remaining questions relating to yield, energy benefit-cost ratio, optimum spacing, and best rotation age can be more fully answered.

ACKNOWLEDGMENTS

Acknowledgments: We thank Gary Brittner, California Department of Forestry, Sacramento; David Soho, California Department of Forestry, Monterey; and the California Conservation Corps, San Luis Obispo for their project and manpower support. This study is supported by Grant 3-080-019, California Department of Forestry.

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Fertilization and Irrigation of *Eucalyptus* in Southern California¹

Paul W. Moore²

In 1981 the California Department of Forestry's Wood Energy Program awarded 9 grants for the establishment of biomass tree farms to satisfy research needs for wood energy production.

One of the grants was made to the University of California at Riverside.

The experiment is located on the Moreno Ranch of the University of California at Riverside. The site is located south-east of the community of Sunnymead, California at 117° 11' W longitude, 33° 54' N latitude.

The soil is classed as Romana Sandy loam with a 1 percent slope.

The source of irrigation water is an on-site well. Total dissolved solids is 550 ppm. Boron is present in the well water at 0.77 ppm. Although the boron content has been toxic to sensitive crops no injury has been observed on previous *Eucalyptus* plantings served by the same source.

Weed control was started pre-plant by laying out the planting furrows and pre-irrigating to germinate weeds. Germinated weeds were killed by contact herbicides before planting. Subsequent weed control has been done by contact sprays and relative little hand hoeing. Disking was performed between rows following the winter rains. Future weed control will be by a combination of disking and contact sprays as required.

The research at Riverside was designed to study the interaction of:

1. Three planting spacings: 12' x 12', 12' x 8' and 12' x 4' giving stocking densities of 302, 453 and 907 trees per acre.
2. Three irrigation levels: dry, intermediate and wet, and
3. Three levels of fertility: 0, 100 and 300 pounds of nitrogen per acre per year.

¹Presented at the Workshop on *Eucalyptus* in California, June 14-16, 1983, Sacramento, California.

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Abstract: An experiment to determine the interaction of three levels of irrigation, three levels of fertility and three densities of planting was started at the University of California Moreno Ranch in 1982. Differential irrigation and fertility treatments will begin in June of 1983.

Some current practices of irrigation and fertilization by southern California growers are discussed.

Each of the combinations were replicated 4 times. Each plot consisted of 16 trees planted 4 rows wide by 4 trees long. The center 4 trees are the record trees from which all data will be taken. The record trees are *E. camaldulensis*. The seed source was the Lake Albacutya Provenance of Australia. The surrounding 12 trees are used as guard rows and include a total of 16 *Eucalyptus* species. Some species are represented by more than 1 provenance. It is anticipated that the use of different species in guard rows will give additional information on their performance compared to *E. camaldulensis*.

Guard row species are *bicostata*, *camaldulensis*, *camphora*, *deanei*, *globulus*, *grandis*, *nova-anglica*, *saligna*, *tereticornis*, *trabuti*, *urnigera*, and *viminialis*.

The trees were planted during the period of July 21 to August 11, 1982. The seedlings were grown in seedling trays and were approximately 8" tall at planting. Irrigation followed immediately after planting.

Each seedling received 8 to 10 grams of a slow release 21-8-8 fertilizer, broadcast on the soil surface at the base of the plant and irrigated in at the third irrigation.

Irrigation and fertilization were uniform throughout the planting for the remainder of 1982 until the first significant rain which fell on November 11, 1982.

Differential irrigation and fertilization began on June 2, 1983.

For the 1983 growing season the dry plots will be irrigated at 8-week intervals, the intermediate treatments at 4-week intervals and the wet treatments at 2-week intervals.

Water use will be monitored by neutron probe.

Irrigation will be by means of lateral furrows.

The first year fertilizer application was drilled in the furrow bottoms ahead of the June 2 irrigation.

DISCUSSION

Differential treatments were initiated on June 2, 1983. It is much too early to collect any data from the plots. It is anticipated that differences

due to treatments will be observed by the end of the 1983 growing season. The trees were planted on Ramona loam with a water holding capacity of 6" to 8" of water in the soil profile.

Observations On Water Requirements

Prior to establishing the above experiment, water stress measurements were made on 3-year-old E. camaldulensis and E. dalrympleana trees during the 1982 growing season.

The trees were growing in a Sam Amigdio loam with a water holding capacity of 6" to 10" of water in the soil profile.

One treatment was irrigated at 3-week intervals, the second treatment was non-irrigated. Leaf water potential was measured for trees in each treatment by the pressure plate method.

Although drought stress occurred [sic] in the non-irrigated trees during the day, recovery was complete by the following morning. No significant reduction in tree growth was observed during the growing season.

Greenhouse studies on water stress of E. camaldulensis in containers are being conducted by a graduate student. It has been much easier to produce drought symptoms in containers than in the field.

Tip and marginal leaf tissue necrosis followed by abscission of young mature leaves occurred at tensiometer readings of 70 centibars.

Immature and older mature leaves did not develop necrotic areas.

Inasmuch as no research data from field experiments have been developed, we do not have scientifically based irrigation recommendations to offer.

Three considerations related to irrigation need to be resolved:

1. Consumptive use and timing for optimum growth.
2. Critical timing of irrigation where water supplies are limited.
3. The economics of irrigation based on cost-benefits analysis.

It is anticipated that the experiments which have been described above will provide answers to these questions.

For those who have water available it is suggested that tensiometers could be used to schedule irrigations. Experience with using tensiometers for irrigation management in other tree crops has been good and has proven that the instrument is a reliable tool. Irrigation when tensiometer readings reach 70 centibars is recommended until addi-

tional data can be developed.

Some Current Practices

Three irrigation practices are being used in the young Eucalyptus plantings in southern California: drip, sprinklers and furrows.

Drip irrigation is most commonly used on the steeper, rolling terrain, sprinklers are being used on the sandy open soils and furrows on flat lands.

Two growers have irrigated for the first 2 years and have discontinued future irrigations. One grove is planted on river bottom land and the roots have reached the water table. This is an unusually good special situation that provides this grower with an economic advantage.

Another special situation exists with a dairyman who is using waste washdown water from his milk sheds to both irrigate and fertilize with what was previously a problem waste product. He has utilized non-agricultural alluvial slopes at the base of a mountain.

Fertilizer Practices

No research data on fertilization for Eucalyptus in southern California is available. Within 3 years some useful data will be obtained from the U.C. Moreno experiment. Current recommendations are based on observation.

Turnbull and Pryor state that many Eucalyptus have the capacity to respond to higher levels of nitrogen and phosphorus but give no further information regarding species or fertilizer levels exhibiting favorable responses.

They also state that in Tasmania, E. delegatensis has not shown a significant response to various nitrogen/phosphorus/potassium fertilizers.

In Victoria, Australia there has been a good response to applications of nitrogen and phosphorus fertilizers by young trees of E. globulus. In Gippsland, superphosphate is applied shortly after planting, followed by nitrogen/phosphorus fertilizer 1 year later.

In Australia, the survival and early growth of E. nitens has been substantially increased by applications of magamp, a slow release fertilizer, at planting time.

Cremer et al have written that field trials in Victoria and West Australia showed responses to nitrogen and phosphorus. In Papua, New Guinea [sic], E. deglupta responded to nitrogen but not to phosphorus or potassium. E. globulus fertilized with a total of 202 Kg/ha and 90 Kg of phosphorus in the first months after planting yielded a total above-ground biomass at 4 years of age of 30.4 tons/ha. The unfertilized control yielded only 6.3 tons/ha.

Geary, in unpublished data, reported increased growth by 3.5-year-old E. grandis on Florida's acid palmetto prairie land to pre-plant incorporation of 1120 Kg/ha of ground phosphate rock. E. robusta and E. viminalis responded to a lesser extent to applications of 560 and 1120 Kg/ha.

In most California locations it is unlikely that Eucalyptus would respond to either phosphorus or potassium fertilizer. Most of southern California soils are amply supplied with both macro-nutrients but are deficient in nitrogen. However there are exceptions.

Some of the Ramona soils in foothill locations, the Aiken series in the Sierra Foothills and the Altamonts around Northwest San Diego County are known to be low in phosphorus. Citrus in these areas has responded to phosphorus applications but no data has ever been collected for Eucalyptus.

Imperial Valley soils are also deficient in phosphorus and some of the soils of Coachella Valley are borderline.

Most of the valley floor soils throughout the remainder of southern California are amply supplied and no response to additional applications would be anticipated.

In as much as we are dealing with a new crop some plantings of which may come under intensive management practices, it appears prudent to take pre-plant soil analyses to determine the nutrient status of the soils at the planting site.

Leonard Tanner, a Eucalyptus nurseryman, cites responses to phosphorus by newly planted seedlings of E. grandis on certain soils in San Diego County.

This may indicate that newly planted trees of some species with limited root systems can respond to phosphorus. However, no indications of phosphorus deficiency have been observed by the author in Riverside and Imperial Counties. A small planting of E. camaldulensis in soil considered to be low in phosphorus has grown remarkably well during the first year with no signs of nutrient deficiencies.

Most of the plantings which have been established since 1979 have received some nitrogen fertilizer. Typical practice under drip irrigation is to distribute soluble nitrogen through the drip system at the rate of approximately 32 pounds of actual nitrogen per acre every second irrigation. On an annual basis, this amounts to approximately 100 pounds of N per acre per year.

Similar rates are applied to sprinkler and furrow irrigated plantings.

Generally speaking no fertilization has been used on the older wood lots in the State.

In summary, the nutritional requirements of Eucalyptus in California are not well enough known to make fertilizer recommendations nor can increases in yield from fertilization be predicted. Suggested fertilizer practices can only be inferred from known responses of other tree crops and observations on existing plantings.

Until actual requirements are developed from current research the following guidelines are offered for Eucalyptus groves under intensive cultivation:

1. For newly planted trees use slow release forms of complete fertilizers such as Sierra Chemical Companies Planting Tablets, Osmocote and Magamp. This will assure that all macro-nutrients are available for stimulating early growth. Placement should be to the side and below the root ball and in the amount of 1/2 to 1 1/2 ounces per tree.
2. Follow with annual applications of nitrogen fertilizers equivalent to 50 to 100 pounds per acre per year. These may be applied through the irrigation water, drilled, or broadcast. If drilled or broadcast during the growing season placement should be such that it is dissolved by the irrigation water and moved into the rootzone. Broadcasting the total amount before the end of the rainy season will also assure that rainfall will move the fertilizer into the rootzone.
3. Establish test areas in your plantings on which different amounts of nitrogen phosphorus and potassium are applied. No fertilizer should be one of the treatments. Measure the D.B.H. annually on several trees in each treatment and evaluate the responses.
4. Calculate cost benefits to determine if fertilization pays off.

Such testing is a part of good management and should be used as a tool to check on the economic benefits of any practice. It has the advantage of giving specific answers related to the immediate site and management practices.

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Managing a Coastal Bluegum (*Eucalyptus globulus*) Forest¹

Ralph S. Osterling²

HISTORY

In 1853 eucalyptus was introduced from Australia into California by Mr. Abbot McKinley³. At first, plantings were scattered over several areas on an expanded trial basis. Some fifty years later eucalyptus plantings experienced a boom. Grand scale plantings were made based on predictions of tremendous monetary profits.

The March and September 1909 issues of The Early Sunset (predecessor to the current Sunset) carried an article "Eucalyptus - Hickory's Younger Brother". The author, F.D. Cornell, portrays this genus as having specimens so large they rival the sky-piercing sequoias. The most common species, Eucalyptus globulus is noted for its rapid growth. In 1909 it was being utilized for farm implements and insulator pins. The article states that many species of eucalyptus will adapt to the hills and valleys of California, however, bluegum is the most promising for the coastal areas. The article continues to say that it is also used for pilings that will last up to 50% longer than any other species used on the West Coast. Eucalyptus cladocalyx (sugar gum) also shows great promise, especially for the southern California area. "In my judgment E. cladocalyx and E. globulus will replace oak, hickory, and ash in the manufacture of implements, vehicles and kindred products."

A few years ago (about 1909) the commercial culture of eucalyptus was not numbered among the great opportunities offered by California...³ Advertisements in 1909 heralded, "A Fortune For You In Eucalyptus". Land with trees already

¹Presented at the workshop on Eucalyptus in California, June 14 - 16, 1983, Sacramento, California.

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³Cornell, F.D. "Eucalyptus - Hickory's Younger Brother", Sunset Magazine, March and September, 1909.

Abstract:

Eucalyptus was thought to be a replacement to oak and other hardwoods for many products. Thousands of acres have been planted and now are in need of management. Management techniques are discussed in context with a coastal stand of approximately 300 acres of mixed aged bluegum. Potential markets are explored.

planted near willows sold for \$250.00 an acre. "We expect an average diameter growth of 1½ inches per year. A 7-year-old tree averaging 10 inches in diameter is conservatively worth \$6.00. Five acres growing 2500 trees would then be worth \$15,000. Cut 1/7th each year and your annual income will be \$2,000.³"

During the 120 year history of eucalyptus in California, this species has probably been tested for more uses than any other species. Everything from handles, toys, charcoal, to paving blocks have been investigated. Some 3,000 were even felled for the movie, The Good Earth. Obviously, history has set the pace and has crossed many bridges and many potential products have been proven infeasible. The problem now is how to best manage the present crop. The real question now remains, "What are the best products for this timber crop?"

The property described in this paper is surmised to have been part of the early eucalyptus high-profit program, however, the harvesting and intensive management did not occur as suggested in 1909. In 1929 a catastrophic fire raced through the property. Newspaper accounts described the trees as exploding like shots during the conflagration. Following the 1929 fire the forest regenerated to a fully stocked condition; then in November 1946 a second fire burned much of the parcel. The only known management activity is in a small clear cut, probably for pulp logs during the mid 1950's. Again the forest regenerated until today it is a very dense uneven aged stand with over 1,130 stems (average) per acre.

MARKETS

Contrary to the spectrum of uses suggested by the historical accounts, the present markets for eucalyptus are limited. Two primary markets exist, namely fuel materials and pulp chips. Other minor products include bumper logs, poles and some pilings. Fuel materials include firewood for the consumer market and hog-fuel or biomass fuel for industrial boiler applications. The consumer fuel wood market has increased dramatically with the increased cost of heating oil and natural gas. The popularity of fire place inserts and other wood burning heating

devices has increased many fold in the past few years. The demand for wood has likewise jumped. It is difficult to accurately access the total demand due to the large number of firewood operators. The author made a brief survey which resulted in confirmation of the doubtful results. Some operators tend to boost sales figures while others hedge or just "don't know". Eucalyptus pulp chips have a specialized and rather limited market due to their fiber characteristics and the limited number of pulp mills within an economic haul radius. Unfortunately, from the San Mateo County coast, any chip trucking operation must cross the entire Bay Area traffic pattern to deliver the chips to the nearest pulp mill located in Antioch.

MANAGEMENT

The goals of forest management are often product oriented. The product might be sawlogs, pulp wood or one of several other forest products. Within the unmanaged eucalyptus forest, product identification is often difficult. Past management activities of many eucalyptus stands have been extensive or nonexistent. Trees have been allowed to grow and reproduce in many stands for more than sixty years. Considering the dynamics of the species, this time frame is equal to perhaps 150 or more years for a western softwood plantation. The eucalyptus forest may well be in a condition to produce a desired product, but probably not in a condition to optimally benefit from a given management practice. The question remains where do we go now? Management of the forest should require maximum utilization of the resource into the desired product or products. Consumer firewood was chosen as our goal because of the adjacent Bay Area population and a less favorable chip market.

Paramount to a harvest operation is the development of a transportation system through the forested area. The forested area of this property was basically unroaded at the time of management planning. A network of roads was engineered to provide close road spacing and numerous landings where logs could be marshalled and wood processed. Benefits secondary to the harvest activities include management access, future harvest and perhaps most importantly fire control access. On this property adequate fire access is paramount due to fuel loading, winds, and the immediately adjacent residential neighborhood.

Topography of the eucalyptus forest consists of a primary ridge line running generally north-south in direction located at the easterly edge of the timbered area. Running nearly perpendicular to that main ridgeline are several spur ridges and drainages that form a watershed with a westerly aspect. Slope steepness ranges from nearly flat to isolated small areas of 70% side slope. The proposed road spacing is

engineered to be approximately 300-foot spacings between interconnected contour roads.

SILVICULTURE

Silvicultural application in this dense forest is very difficult due to the extreme amount of knock down and breakage damage that occurs with harvesting. Clear cutting would allow for a more complete utilization, however, adjacent to Highway 1 and the close proximity to the residential area, clear cutting is politically impossible. Stand density creates a relatively high damage level to the residual stand.

For clarity, average spacing of the trees is shown below:

Table 1

DBH	Count (per acre)	Average Spacing
All	1,131	6.2 feet
6 in. +	314	11.8
12 in. +	226	13.9
18 in. +	92	21.8

The trees ten inches and larger average 110 to 245 feet in height. The combination of over stocking, heights and the visual sensitivity create a unique situation where careful harvesting and close supervision are paramount.

HARVEST

Proposed harvesting operations will be a selective thinning utilizing staged falling procedures and other techniques to minimize damage to the residual stand. Following large log removal, the clean-up operation will include added harvest of firewood size chunks, branches and the smaller damaged trees. The secondary fuelwood removal is very beneficial for it will reduce the logging debris and decrease the fire hazard while producing added product.

Skidding will be accomplished with a combination of crawler tractors and rubber tire skidders. Many of the slopes are too steep for rubber tire skidder operation, however, the roads may be used as skidways on which the rubber tire equipment can effectively operate.

POST-HARVEST

Post-harvest management includes road maintenance, erosion control and coppice management. Coppice management is now being researched in cooperation with UCCE; no conclusions have been drawn at the time of this writing. We are optimistic that through prudent coppice management, the yields will be increased, cash returns will be increased and a shorter rotation will be realized. Intermediate crops may also result.

Harvesting to Get a *Eucalyptus* Coppice Crop¹

Thomas F Geary²

When eucalyptus trees are felled, new stems often grow from the stumps to produce another crop of trees. This new crop is called the coppice crop to distinguish it from the seedling crop. Coppice crops can be important in growing eucalypts profitably. Replanting costs are saved and coppice crop rotations are usually shorter than those of seedling crops, because coppice stems grow faster than seedlings. Several successive coppice crops are possible, but getting a coppice crop depends on planting the right species in the right environment and harvesting with the right method.

PLAN FOR COPPICE

The time to plan for a coppice crop is before planting the seedling crop. Not all eucalyptus species coppice. Choose a species that coppices vigorously and predictably, that grows well, and has the desired wood qualities. Eucalypts For Planting (FAO 1979) describes coppicing ability of species commonly used for wood production. However, relying on a species' reputation for good coppicing is risky, because it might not coppice reliably everywhere. Also, the species may coppice well on average, but some seed sources may not. Before planting a new species in a new environment on a large scale, establish enough experimental plantings to determine coppicing ability at different seasons and ages by periodic fellings.

Spacing and harvesting methods need to be carefully considered in developing a coppicing system. The spacing pattern must allow harvesting equipment to move about without damaging stumps. In irrigated plantations the harvesting plan must include protection of the irrigation system.

¹Presented at the Workshop on Eucalyptus in California, June 14-16, 1983, Sacramento, California.

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³T.F. Geary studied eucalyptus coppicing in Florida for the Southeastern Forest Experiment Station, Forest Service, U.S. Department of Agriculture.

Abstract: Coppicing of eucalypts saves replanting after harvesting, but plan for coppice before planting seedlings. Select a species that coppices in the planned season of harvest; plan spacing and harvesting methods so that harvesting will not damage stumps; plan coppice management. Best coppice is produced by spring harvest with chain saws, low stumps, no bark or root damage, and no debris left on stumps. Problems are fire hazard, regeneration from seeds, coppice reduction, and killing an unwanted coppice crop.

Seasons of harvest and rotation age should be planned too. Will coppicing occur in the months in which harvesting must be done? The power to coppice decreases as trees age. Will the trees coppice at the end of the planned rotation? Typically, eucalyptus plantations with rotations up to 12 years are regenerated by coppice, while plantations with rotations longer than 20 years are regenerated by replanting.

THE DO'S AND DON'TS OF HARVESTING

Make A Low Stump

The higher on the bole that a tree is cut, the more likely it is to coppice and to produce many coppice stems. The absurd extension of this principle is to lop off branches, so that the bole becomes covered with shoots. Low cuts rather than high cuts are standard in eucalyptus plantations for at least three reasons. Firstly, the height at which coppice stems are felled is usually above the height used for felling seedling stems, to avoid cutting the ever-thickening stump. The cutting height progressively raises with each coppice crop. If a high cut were used initially, then the cutting height of later coppice crops could become too high. Secondly, stems produced on high stumps are reputedly less wind firm than stems on low stumps. Finally, harvesting equipment may not be able to pass over high stumps.

A stump height of 10 to 12 cm above ground is common. A slanted, smooth cut, which allows water to run-off the stump's surface is preferred.

Do Not Damage The Stump's Bark

Buds in the stump's bark or in underground lignotubers produce coppice shoots. Coppice in plantations usually comes from bark buds. Lignotubers are a reserve source of coppice and some species do not have lignotubers. Therefore, the bark needs to be kept intact and tight to the stump. A stump can coppice

if some of the bark is damaged, but the more bark damaged, the more likely the stump will not coppice, even though stumps occasionally develop coppice shoots on a barkless area.

Do Not Damage The Stump's Roots

Coppice grows rapidly because the new stems feed from the root system of the seedling stem. Therefore, roots should not be damaged during harvesting. Root damage apparently has not been studied, perhaps because much of the world's eucalyptus plantations are harvested with light-weight equipment. Eucalyptus roots are concentrated in the top few inches of soil. In the United States there is a tendency to use very heavy equipment in forestry, and this equipment can compact soil and break roots, especially if harvesting is done in wet weather, so that ruts are deep.

Remove Debris From Stumps

Remove logging debris from stumps, because coppice shoots are deformed if they must snake their way through debris.

Harvest At The Right Season

Eucalyptus grandis Hill ex Maid. illustrates the variation in coppicing that can occur in different seasons depending on where the trees are grown. In the Republic of South Africa, E. grandis is grown extensively and adequate coppicing occurs no matter when young plantations are felled. In Florida, coppicing decreases drastically in summer. Often no stumps coppice following August harvesting. In its native New South Wales, Australia, E. grandis coppices poorly in fall and winter.

Season of harvest affects coppicing of Eucalyptus camaldulensis Dehnh, in Israel (Heth and others, 1982). Trees felled in winter do not coppice until spring. Trees felled in spring coppice soon after felling, while trees felled in the rest of the year coppice sporadically over several months. Prolonged coppicing causes a great variation in stem sizes in a stand, which complicates management. However, in contrast to experience with E. grandis elsewhere, the percentage of stumps that coppice is the same no matter when harvesting is done.

Other seasonal effects must be guarded against. Bark on stumps can crack if trees are felled during a drought, or if freezing weather occurs. Season affects the number of coppice shoots produced, for example, on E. camaldulensis in Israel. It seems likely that coppice vigor might be affected by when trees are felled. After considering all factors, it seems that spring felling usually makes the best coppice.

Choose The Right Harvesting Equipment

Felling

Eucalypts felled with axes coppice satisfactorily in the few places where ax felling is still done. However, felling with chain saws results in consistently better coppicing than ax felling. Bow and other kinds of manual saws are very effective in making cuts that favor coppicing, but are rarely used.

A chain saw is the common tool used for felling eucalypts. It has the advantages of making a clean cut that can be slanted and bark damage is rare. In Florida, eucalypts have been cleanly felled by Georgia-Pacific Corp. with chain-saw heads attached to a grapple-skidder.

Anvil-shears are commonly available for harvesting in many parts of the U.S.A. Anvils squeeze the tree as they sever it and this may damage the stump's bark. In Florida harvesting with anvil-shears was compared to harvesting with chain-saws. Although the test was not conclusive, anvil-shears appeared to give coppicing comparable to that of chain saws, if the shears were sharp and the stumps were not struck with the machine's wheels. Dull shears badly damaged bark, split stumps, and even pulled stumps out of the ground. Damage to roots by vehicles mounted with either chain-saw heads or anvil-shears needs study.

Extraction

Felled trees can be bucked into short lengths in the stand, or removed as whole trees. Either option can damage stumps if not done carefully. Bucked trees are commonly extracted from eucalyptus plantations, with light-weight equipment, such as agricultural tractors, or even with animals and by hand. Cable removal is common on slopes. During extraction care must be taken not to strike the stumps, although in Portugal racks of logs on slopes are rolled by cable over stumps without damaging stumps significantly. Root damage by different extraction systems has not been studied, but some damage must occur, and it could be appreciable with heavy equipment or the skidding of heavy loads.

Extracting trees whole, including the crown, eliminates a debris problem, and decreases seedling regeneration from seeds stored on the trees. Skidding whole trees has potential for damaging many stumps unless extraction is well planned and the plantation is designed for it.

PROBLEMS AFTER HARVESTING

Fire

The debris left in the plantation is a fire hazard. Information on fire effects in recently harvested stands of eucalypts is scarce. A light fire that occurs before coppice shoots erupt from the bark might not do any damage. After shoots erupt, a hot fire will surely kill young coppice, but if the bark is not badly damaged the stumps might coppice again.

Regeneration From Seeds

Many eucalyptus species store massive amounts of seeds in capsules in their crowns. If crowns are left on the site, the seeds are released. If soil and weather conditions are suitable, germination occurs and a thick stand of seedlings arises. These seedlings usually are suppressed by coppice, but if spacing is wide some seedlings develop into large stems. In plantations established with genetically improved seeds or clonal plants, the seedlings from natural regeneration are of poorer genetic quality than the parent stand. Thickets of seedlings are a nuisance because they complicate coppice reduction.

Coppice Reduction

A stump that has recently coppiced is frequently covered with clusters of shoots. Only one shoot usually survives the competition in a cluster. This still can leave many shoots. Within a few years competition among the remaining shoots reduces their numbers, but that number may still be more than may be wanted for management purposes. The more stems on the stumps in a plantation the more wood produced in short rotations. But as number of stems increases, stem diameter decreases. Too many stems may produce wood too small in diameter for its intended end-use and may increase harvesting costs.

In eucalyptus plantations outside the United States, hand labor reduces the number of stems on a stump to one to three, depending on product goals. A mechanical method for reducing coppice does not exist. Before planting eucalypts with the intention of producing coppice crops, determine if coppice reduction will be necessary and, if so, if it can be afforded. The references FAO (1979), Poynton (1981), and Wattle Research Institute (1972) are good sources of information on reducing coppice.

Killing An Unwanted Coppice Crop

A number of reasons exist for wanting to kill the living stumps. Growing eucalypts may no longer be desired. Other reasons are more common. Some stumps die after each harvest. Eventually too few living stumps remain to produce a well stocked stand, so a new seedling crop would be more productive. Genetically improved seeds or another species may have become available since the original planting, and it may be more productive to replace the existing trees with superior ones.

Understocked coppice stands are not commonly planted with new seedlings without killing stumps, because mixed stands of seedlings and coppice are not uniform, which complicates management. However, understocked eucalyptus plantations can be interplanted (Wattle Research Institute 1972).

A way to kill stumps is to remove them and this is done where there are markets for stump wood. More commonly the stumps are debarked, poisoned with herbicides, or covered with soil. Another alternative is to break off coppice shoots repeatedly until the stump runs out of food reserves or buds, and stops producing shoots.

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Part 6. Propagation

Propagation and Planting of Containerized *Eucalyptus* Seedlings in Hawaii¹

Gerald A. Walters²

Eucalyptus seedlings are propagated and planted in Hawaii through a container reforestation system. The dibble-tube system, which was researched and developed by the Forest Service, U.S. Department of Agriculture, and the Hawaii Division of Forestry, has increased seedling survival and growth rates over those obtained with the old bare-root system (Walters 1981b, Walters and Horiuchi 1979).

The basis of the system is the Hawaii dibble tube (fig. 1)--a specially designed plant container of high-density polyethylene. Its size, about 5 inches deep and 1 1/8 inches in diameter at the top, represents a trade-off between biologic and economic considerations. The dibble tube is large enough for adequate seedling development but small enough for economical handling. The tube has four ridges on the inside that extend from top to bottom. These ridges prevent the lateral roots from spiraling within the container.

The tubes and their racks reduce the number of biological and mechanical variables involved in growing, transporting, and planting seedlings. The dimensional uniformity of the tubes and racks provides potentially the same rooting and aerial volume for each seedling and allows mechanization of nursery and planting operations.

This paper describes the specialized equipment and procedures used in Hawaii to propagate and plant containerized *eucalyptus* seedlings.

¹Presented at the Workshop on *Eucalyptus* in California, June 14-16, 1983, Sacramento, California.

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Abstract: A container reforestation system has been researched and developed in Hawaii which results in consistently high survival and growth rates for *eucalyptus* seedlings. Mean survival of containerized *saligna eucalyptus* (*Eucalyptus saligna* Smith) seedlings is 90 percent with a standard deviation of 4. Because transplant shock is minimal, seedlings begin to grow quickly. Mean survival of bare-root *saligna eucalyptus* seedlings was only 56 percent with a standard deviation of 32, and about 70 percent of the seedlings suffered stem dieback. The containerized system includes the nursery, transport, and field phases of reforestation.

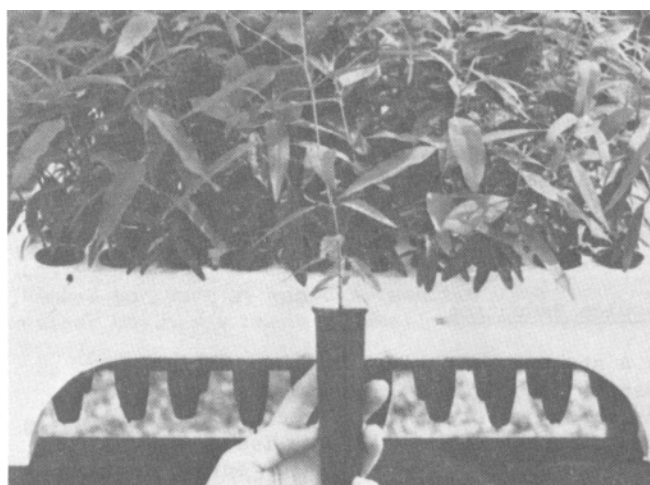


Figure 1--*Eucalyptus saligna* seedlings growing in the dibbling tubes. A rack holds 100 seedlings.

DIBBLE-TUBE SYSTEM

The dibble-tube system closely links the nursery, transport, and field phases of reforestation (fig. 2). Sufficient technology has been developed or borrowed to allow for a smooth progression from processing seed in the nursery to planting seedlings in the forest.

Nursery Phase

The nursery phase includes headhouse operations and seedling culture. The headhouse is divided into storage and work areas. Sufficient tubes, racks, rooting medium, and gravel (seed cover) are stored to produce about 500,000 seedlings. The work area is designed so that tubes are put into racks, cleaned, filled, seeded, covered, and transported to the seedling culture area in one continuous flow (fig. 3). Eight people can process 100,000 tubes per day.

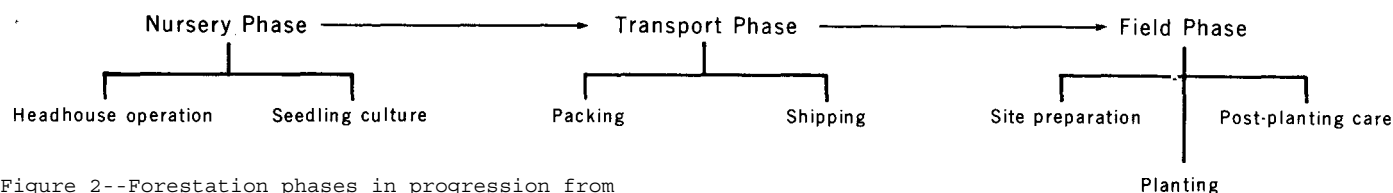


Figure 2--Forestation phases in progression from seed in the nursery to established tree in the forest.

Preparing Tubes and Rooting Medium

Tubes and racks are cleaned and chlorine-rinsed in a commercial dishwasher with a water-saving system at a rate of 8000 tubes per hour. A more automated dishwasher could increase the rate.

The rooting medium--a 2:1 by volume mix of sphagnum peat and vermiculite--is prepared in a self-cleaning soil mixer with 1-yd³ capacity. Bales of peat and vermiculite are placed in the mixer and then their covers are slit and removed. This loading method reduces the dust problem. Mycorrhizae spores or mycelium are added if available. To ensure that each batch of medium has the same moisture content, a recycling timer allows a specified amount of water to be added during mixing from nozzles on the mixer lid. The mixed rooting medium falls through the bottom hatch of the mixer onto a conveyor, which carries the medium to a hopper over the tube-filling machine.

Three racks (300 tubes) are filled with rooting medium at one time in an automatic

impact loader. The impact loader raises the racks then lets them drop; the sudden stop at the bottom forces the rooting medium into the tubes. Filled tubes are carried on a dead-roller conveyor to a simple revolving drum press, which compresses the medium to make room for seeds. The press can be adjusted for compaction to different depths, depending on the size of the seeds to be sown.

Sowing Seeds

Eucalyptus seed is cleaned using sieves and a blower, and then is pelletized by a commercial company. Pelletized seeds are about 1/16 inch in diameter and can be sown accurately and precisely with a simple manual seeder (Walters and Goo 1980).

The seeder consists of three plates with holes held by a frame (fig. 4) so that the holes in the top and bottom plates do not line up; the middle plate slides between the top and bottom plates. Seeds are put on the top plate. The middle plate is positioned so that the holes in

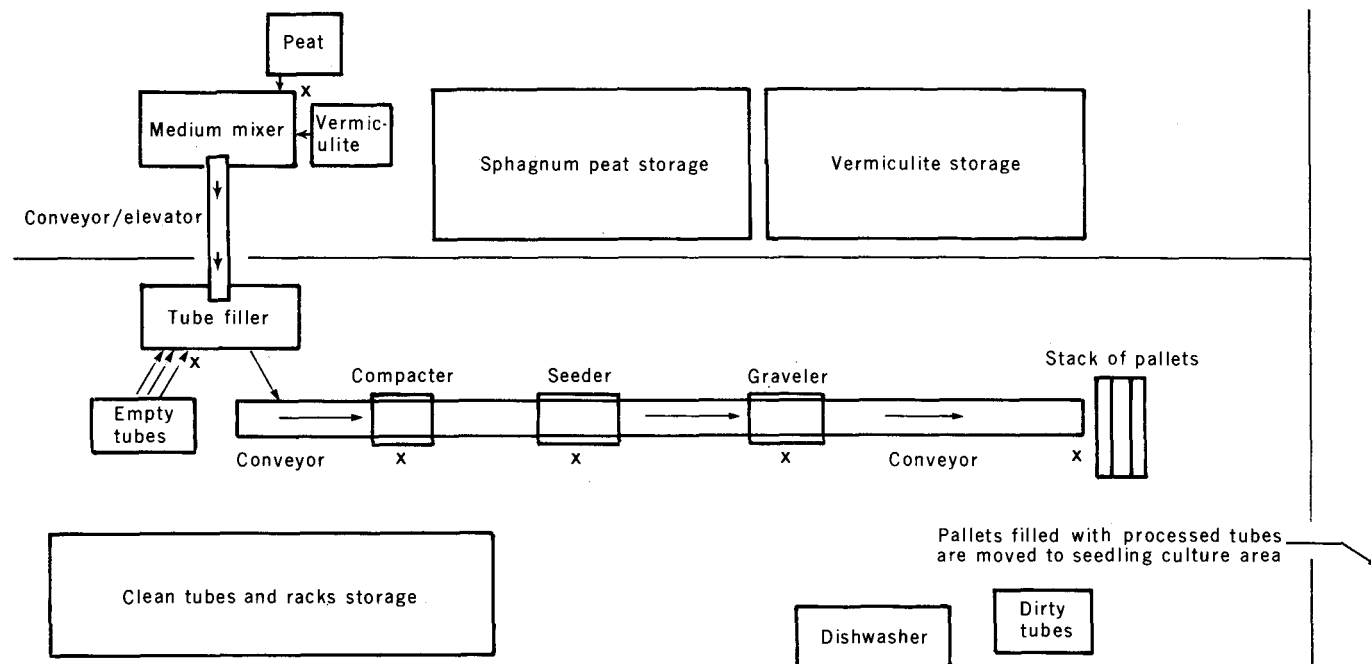


Figure 3--Layout of headhouse showing storage areas and processing equipment for tubes and racks.

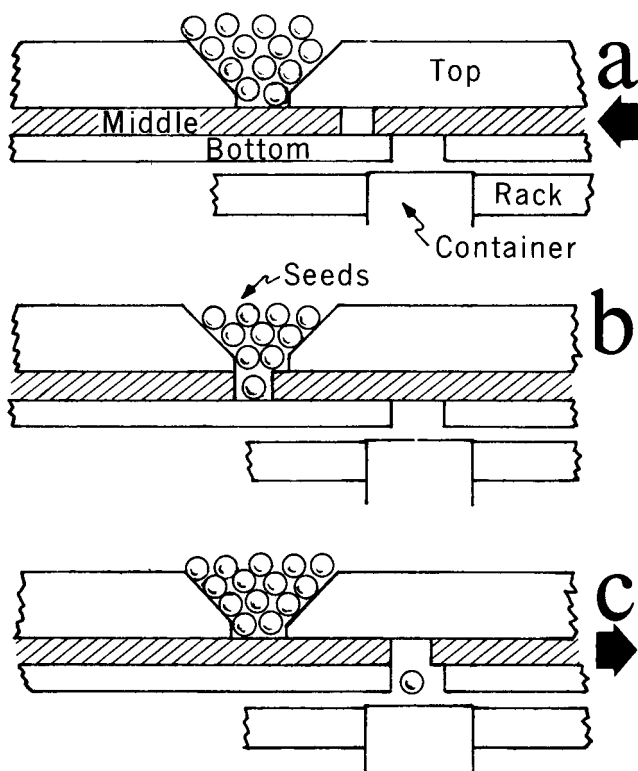


Figure 4--How the manual seeder works: (A) A hole in the top plate is filled with seeds; (B) the middle plate is moved so the hole in it lines up with the hole in the top plate, and a seed drops into the hole; and (C) a seed falls into the container as the middle plate is moved so the hole in it lines up with the hole in the bottom plate.

it line up with the holes in the top plate, and seeds fall into the holes in the middle plate. Then the middle plate is moved so that the holes in it line up with the holes in the bottom plate, and the seeds fall through into tubes. A number of seeds can be sown in each tube by moving the middle plate back and forth as many times as the number of seeds desired per tube, as determined on the basis of germination tests.

Seeds are covered with a 5-millimeter layer of crushed basalt by a device similar to the manual seeder (Walters 1981a). Gravel prevents the seeds from being washed away during irrigation and prevents the buildup of moss and algae on the top of the soil.

Transfer of Tubes and Racks to Seedling Culture Area

A stack of specially designed pallets is placed at the end of the conveyor. When a rack of tubes is complete, it is placed on a pallet. When the pallet is filled with 12 racks (1200 tubes), a forklift picks up the load and moves it to the plant shelter. The next pallet in the

stack is there to receive more racks. In the plant shelter, a pallet is set on four cement blocks so that it forms a bench top.

Seedling Culture

In the plant shelter, pallets are supported several feet off the ground to prevent disease organisms from being splashed up to the roots, to provide air space so air pruning of the root systems occurs, and to provide a convenient height for workers to weed and thin the seedlings. During germination and early seedling growth, light intensity is kept at about 50 percent sunlight with plastic screens. An overhead irrigation system applies water daily. When the seedlings have several true leaves, nutrients are applied twice a week through the irrigation system at a rate of 75 to 100 parts per million (nitrogen basis) of a 12.5-25-25 commercial [sic] formulation. Pesticides are applied as necessary.

After about 6 weeks or when the seedlings are several inches tall, they are moved outside. There, only watering and feeding can be controlled. Water is applied daily through impact irrigation heads. The system provides about 120 percent overlap, which is necessary because of the frequent winds that often reach 20 mi/h at the nursery site. Nutrients are injected through the irrigation system twice a week. The nutrient solution initially is about 75 parts per million (nitrogen basis) of 20-20-20. After several weeks, the concentration is increased to 250 parts per million (nitrogen basis). When seedlings are about 10 inches tall, the formulation and rate are changed to 75 parts per million (nitrogen basis) of 12.5-25-25.

Transport Phase

When seedlings are 12 to 14 inches tall, they are shipped to the field for planting. The roots and rooting medium form a mass that holds together during handling. In the packing area seedlings are removed from the tubes and packed horizontally in wax-lined cardboard boxes so the roots face toward the box ends and the tops overlap. Box flaps are held closed with string instead of staples or tape. These boxes, even when stacked on pallets, protect the 200 seedlings inside and fulfill government regulations for shipping plant material between islands. Pallets of boxed seedlings are transported to the planting site by trucks, or to other islands by air freight.

Field Phase

Planting sites are generally prepared by clearing or crushing weeds and slash with a bulldozer.

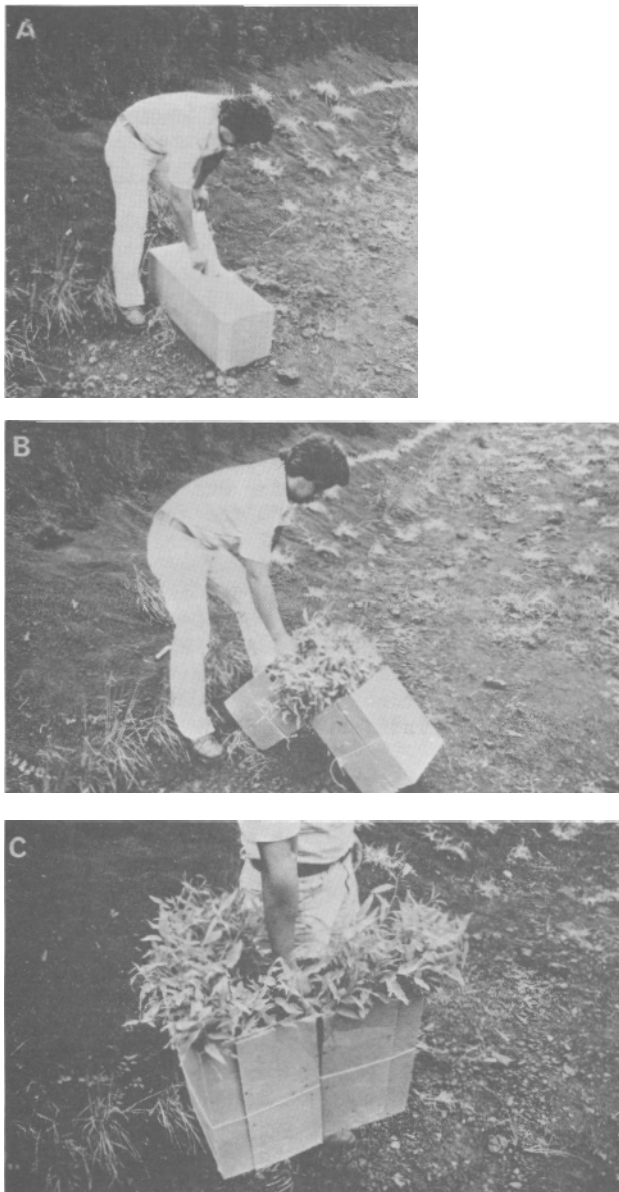


Figure 5--A seedling packing box is easily converted to a carrying box. This is done by: (A) cutting along lines marked on three sides and (B) folding ends together. A pre-cut handhold (C) makes the box simple to carry. When the box is empty, it is flattened and shipped back to the nursery. The cut section is taped for reuse.

Packing boxes are quickly converted to carrying boxes by making several cuts and folding the box (fig. 5) (Walters 1978, Walters and Goo 1978). Packing seedlings in one end of the box before packing the other end will allow the tops to separate easily when the box is cut and folded into a carrying box in the field. When the box is empty, the strings are cut allowing the box to be flattened. Boxes are shipped back to the nursery. When the box is needed again, the cut section is taped and the box is reused.

Seedlings can be planted by hand or by machine. For hand planting, a dibble is used to make planting holes the same size and shape as the seedling root mass. A worker places the root mass into the hole and presses it down to ensure maximum contact between roots and soil, then puts soil over the root system. Dibble planting works well in clay soils and in lava rocklands. Using this method, one worker can plant 750 to 1000 seedlings in 8 hours. In the same time, a single-row planting machine on a clay or loam soil can plant 3000 to 7000 seedlings, depending on spacing and terrain.

Forest plantings are not irrigated, but are commonly fertilized with 1 to 2 ounces of 10-30-10 fertilizer at the time of planting. The fertilizer is poured into a hole made about 3 inches from the seedling root system. The fertilizer stimulates growth enough to reduce the need for weeding (Walters 1982).

SEEDLING SURVIVAL AND GROWTH

Sufficient biological data have been collected to allow seedlings to be grown in the nursery that have a high survival and growth potential in the field. Mean survival for forestry plantings of containerized saligna eucalyptus is 90 percent with a standard deviation of about 4. Under the old bare-root system, mean survival was 56 percent with a standard deviation of 32, and about 70 percent of the seedlings suffered stem dieback. When stem dieback was severe, 3 months or more were often required for the seedling to attain its original height. Under the new system, seedlings grow quickly because transplant shock is minimal.

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Micropropagation of Frost-Resistant *Eucalyptus*¹

Michel Boulay²

For 10 years now, AFOCEL has inscribed micro-propagation of forest trees into its research and development program of intensive silviculture.

Eucalypt is a genus which is studied for 6 years. After research on micropropagation of very juvenile trees (seedlings) our association has tried to develop the method for mature trees selected in nursery, experimental plots or plantations.

Numerous workers have shown that vegetative propagation of eucalypt was possible at the industrial level using physiologically and onto genetically mature plants. This kind of propagation needs the use of rejuvenated shoots which can be obtained by intense pruning, grafting and successive graftings (with a great attention to take cutting or graft on the precedent generation as soon as possible) or cutting back. HARTNEY published a detailed review on this topic.

Under french climate, the use of such methods as cutting back (which is very efficient in Congo or Brazil) has numerous drawbacks

- important variability (even for small climatic variations) in a few days of the rooting ability of the cuttings which have been obtained from sprouts, pruned trees or cuttings from the preceding generation. Such phenomena involve a number of complications in the organization of the supply of cuttings even if cuttings from the preceding generation are used ;

- low productivity by unit area of mother tree orchards in cuttings of good quality which increases the cost of cuttings ;

- important difficulties to overcome problems linked with rejuvenation by successive graftings ;

¹Presented at the Workshop on Eucalyptus in California, June 14-16, 1983, Sacramento, California.

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Abstract: A method for the in vitro propagation of frost resistant eucalyptus is presented. It was used for the propagation of 2-30 years old trees. This method is presently used for the fast production of mother trees from selected trees.

- very low multiplication coefficient of vegetative propagation on such material which involves a long period between the selection of the tree and the disponibility of the genotype for reforestation.

Such difficulties always present in our two nurseries which are involved in vegetative propagation are the main reason for our interest in developing an in vitro method for supplying reforestation plots or industrial nurseries.

Micropropagation of eucalypts is not new. After the first pioneer works of DURAND-CRESSWELL, numerous researchers, de FOSSARD, HARTNEY, LAKSHMI et al, developed and applied the method to different species. A recent paper by DURAND-CRESSWELL et al gives all indications on the question.

At AFOCEL, research has begun in 1976 and several communications, have been done : LODEON, FRANCKET and BOULAY, DEPOMMIER. In this paper we will present the more recent results which have been obtained on in vitro cloning of selected trees two years old or older.

PLANT MATERIAL

Taxonomic entities of eucalypts which can resist to frost to minus 18°C or 20°C or to late spring frost in France are very rare. They are essentially species from tasmanian mountains, as Eucalyptus gunnii and Eucalyptus coccifera or from australian south eastern mountains as Eucalyptus pauciflora (Eucalyptus niphophila). Species from good forest value like Eucalyptus dalrympleana or Eucalyptus delegatensis have shown in trials which have been planted earlier in France irregular success.

Actually, we have now in France three kinds of plant material

- category A : trees of good forest value which have resisted the "historic frosts" from 1956 and 1963. These trees are over 20 years old ;

- category B : trees from 5 to 15 years old which have been planted in AFOCEL or INRA³ collections. These collections are provenance trials with Eucalyptus dalrympleana or Eucalyptus delegatensis or progeny tests with off springs from category A trees. Many hybrids have been observed among these progenies. This lets us assume that the mothers may be hybrids.

³National Institute of Agronomic Research

- category C : young vigorous seedlings selected in progeny or provenance trials and raised in big containers. This kind of culture allows to submit them to natural frosts for selection purpose, according to a method imagined by LACAZE and realized by DESTREMAU and CAUVIN and MARTEN. This selection for two criteria (juvenile growth and frost resistance) on seedlings 2 or 3 years old, give clones from which scions or sprouts can be taken after cutting back. Later with progress in artificial hybridization such seedlings will be replaced by controlled hybrids of the same age and selected in the same way.

For most of these selected trees, it is difficult to undertake vegetative propagation without rejuvenation. For this reason, mobilization of the selected genotype by graft or cutting (from sprout or from graft) is necessary.

Rejuvenation can be obtained totally or partially in vivo by the means of successive graftings onto young seedlings. In any cases, the in vitro primary cultivation is possible only with this kind of material (cuttings, sprouts and more frequently grafts). The mother trees obtained can be cultivated under good nutrient conditions and a great attention is paid to the sanitary status of the plant (spraying with systemic fungicides every two days specially the week before primary culture). When sprouts are used (category C), they are also treated with fungicides. In vivo and in vitro introduction is done very soon after cutting the sprouts.

IN VITRO MICROPROPAGATION

General conditions

Culture media which are used, have been established by de FOSSARD, DURAND-CRESSWELL et al, LODEON, FRANCLLET and BOULAY and DEPOMMIER.

Three kinds of medium are commonly used

- multiplication medium : M
- root induction medium : RI
- root and stem elongation medium .. : RA

For all these media the pH is 5,5 - 5,6 before sterilization. The agar concentration is 7 gl⁻¹. The sterilization occurs at 115°C-116°C during 25 minutes. After plantation, cultures are put under controlled environment with the following conditions

- photoperiod ; long day D : 16 h ; N : 8 h
- thermoperiod ; D : 24°C-25°C ; N : 18°C-20°C

Primary culture

After severance, the shoots are sealed at both ends with paraffin and treated with a disinfectant. Calcium hypochloride is commonly used (filtration of a mix containing 10 percent solid solution) but a twofold dilution of a commercial solution of sodium hypochloride is also efficient.

Once planted on agar medium, cultures (nodes + petiole + piece of leaf) are put one week in the dark. This operation is done to limit the formation of brownish compounds in the culture medium.

If we start with sprouts (explants from category C of plant material) a 30 to 40 percent infection is generally obtained with primary culture. With plant material coming from greenhouse conditions (mobilization or successive grafts or cuttings) it is necessary to decrease the time of disinfection (3 to 5 minutes instead of 8). Under such conditions, the percentage of infection varies from 10 to 50 percent.

The primary culture medium is comparable to the multiplication medium M. The composition is the following : half concentration of macronutrients of Murashige and Skoog medium and vitamins from de Fossard. The sugar is sucrose at 30 gl⁻¹.

The difference with M medium is only at the level of cytokinin concentration. B A (benzyl adenin) is used at a concentration varying from 0,1 mg l⁻¹ to 1 mg l⁻¹, depending upon clone, season of cutting and lignification of stems. In every case, auxin concentration (N A A : naphtalen acetic acid) is always 10⁻² mg l⁻¹. Other medium have also been used for this first culture, some with activated charcoal for example, give also good results.

The experimentation on primary culture with more than 25 clones, has shown that several problems arise.

- There is a very small percentage of explants which are able to react (reaction means in vitro development of the axillary buds which are present at the basis of petiole) with regard to the number of introduced uninfected explants (about 2 to 40 percent of living explants react). So, the "vitro-plants" obtained from in vitro culture are coming from a very small number of cultures (Table 1).

The limitation of experimentation at this level is due to the small number of rejuvenated explants obtained after mobilization or successive graftings or cuttings for each genotype (20 to 30 nodes are often available for this stage of culture).

- A large number of explants show also a friable brownish callusing place of budding reaction. To solve this problem frequent subculturing every 15 days from the first 2 to 3 transfers are needed.
- Hyperhydric transformation (water-logging) can also occur at this level of culture on the axillary bud developed in vitro.

These different problems are presently partially solved by frequent subculturing, decreasing cytokinin dosis, use of activated charcoal and adjustment of the time of disinfection.

Subculture and in vitro cloning

The primary culture leads when the explant reacts to elongated axillary buds. Two to four axillary buds can be obtained by reacted nodes. The separation of these axillary buds developed in vitro from the initial explant occurs progressively. Hormones (cytokinin and auxin) are necessary to obtain axillary budding. The best balance is : B A 0,2 mg l⁻¹, N A A 0,01 mg l⁻¹.

The propagation process is comparable to that of de FOSSARD et al. Cluster of buds are obtained by axillary budding. Multiplication is obtained by cutting these bushy explants in smaller pieces every three to four weeks. The time between two subcultures is a very important parameter. For maintaining a very active culture, four weeks is a maximum delay.

In subculture, during the, first transfer, all clones do not react in the same way at the multiplication level.

Figure 1 shows the evolution of six clones after five transfers. They are among the first selected clones introduced in vitro.

In transfer five, some of the clones have multiplied by 49 the initial number of introduced cultures (clone 041), some others show no evolution but stay living (clones 032, 039). With these last clones, we can obtain after eight to twelve transfers, a multiplication coefficient comparable to the first one. Depending upon the clone, there is different responses to the medium M, but this difference disappears progressively with subculturing once primary culture is successful.

An example of the delay to obtain exponential multiplication is given by the clone 16. This clone comes from a 30 year old selected mother tree. It has been introduced in vitro by taking an explant from the fourth successive grafting. On figure 2, we can see that this clone has been maintained just living to the eighth transfer. The number of copies from the ninth subculture onward from this clone is increasing, exponential multiplication is obtained for transfer 12.

We don't know actually what are the reasons responsible of such a phenomenon : stem selection for their sanitary qualities, modification of endogenous hormonal equilibrium, habituation to the medium, none of the experiments we conducted could permit us to choose between these various hypotheses (which are not necessarily exclusive).

Under exponential multiplication conditions, with our method, the multiplication rate amounts to about 4 to 5 for each subculture and every three weeks.

Rhizogenesis, root and stem elongation, acclimatization

With the propagation medium M, we obtain stems 10 to 20 mm in height which are rooted and grown in two steps

- root induction on R I auxin containing medium ;
- root and stem elongation on R A medium with activated charcoal and no auxin.

Using an elongation medium after propagation as first recommended was leaved for the above described method.

Rhizogenesis induction

The culture medium used is the Knop medium full strength [sic] for macronutrients, micronutrients and vitamins are similar to that of M medium except I K and riboflavine which are eliminated from the medium. Sugar (sucrose) is often used at 15 gl⁻¹. Two parameters are modified according to the clone : length [sic] of dark period and auxin concentration of the medium (I B A).

A dark period is used during root initiation because it has a positive effect on root primordia formation (DRUART et al),

Just after subculturing on R I medium cultures are put for 10 to 20 days in the dark. Concerning the rhizogenesis hormone, we use I B A (indol butiric acid) added to the medium at 1,5 mg l⁻¹ or 3 mg l⁻¹. The best combinations which are used for different clones (i.e. hormone concentration, sucrose dosis, length [sic] of dark period) are indicated in table 2. The rooting percentage often exceeds 60 percent. The time on multiplication medium M before rhizogenesis has a great influence on rooting success. Stems put in induction must be taken after no more than 3 to 4 weeks in culture on medium M to get a good rooting percentage and few apical necrosis.

Figure 3 shows the rooting cinetic for the clone 047 (hybrid between gunnii and globulus). After 25 days on R I medium, about 80 percent of plants are rooted.

Root and stem elongation, acclimatization

Once stems are been induced, or when root primordia develop, rooted stems are cultivated on R A medium which has the same composition than R I but with activated charcoal added and without auxin. The sucrose concentration: is increased to 30 gl⁻¹.

Subculturing on R A medium favours the development of roots which were induced on R I medium. Within 2 to 5 days, roots reach the bottom of the test tubes. 10 to 20 days later, ramifications and secondary roots appear. After root elongation, herbaceous stems begin to grow (15 to 30 days after transplanting) and the rooted stems develop leaves

and nodes which are quite similar to those of seedlings. Rooted stems at this moment can be let during 4 to 6 weeks on this R A medium.

The medium R A has several advantages:

- At the production level, it allows the nurseryman to group the transplanting operation which he carries out once a week.
- The media allows also the regeneration of the herbaceous stem after necrosis. Such neoformed stem grows from basal axillary buds of the explant after death of the stem put in rhizogenesis induction.
- The morphology of the rooted stem obtained in vitro on R A medium makes also acclimatization easier.
- Acclimatization takes place when rooted stems have a height compatible with culture in MELFERT⁴ containers. It means 30 to 50 mm. After transfer in such containers during 10 or 30 days depending upon the season (10 days in spring or summer, 30 days in winter), the young plantlets are put under plastic film confinement. When roots appears on the side of the containers, confinement is progressively removed and plantlets are placed in greenhouse for cultivation. Percentage of success in acclimatization are variable from 30 to 100 per cent depending upon clone and season.

DISCUSSION AND PROBLEM OCCURRING WITH THIS METHOD

The scheme of this method is given in figure 4. We can see four phasis and a preparatory one which is the following

Preparatory phasis : tree selection, and collection from this one of cuttings, sprouts and grafts after mobilization or successive grafts (rejuvenation). Cultivation of this material under greenhouse conditions.

Phase I : obtention of axillary budding in vitro ;
Ia : primary culture ;
Ib : obtention of a reactive culture with experimental multiplication by axillary budding ;

Phase II : in vitro cloning ;

Phase III: obtention of rooted plantlets ;
IIIa: rhizogenesis induction ;
IIIB: root and stem elongation ;

Phase IV : acclimatization of in vitro rooted plantlets.

The preparatory phasis is very important for the success of culture and specially for reducing the delay to obtain exponential multiplication and in vitro cloning. For all the plant material we selected, no success was obtained with material collected on the tree and introduced directly in vitro. This failure is often due to infection and difficulties encountered in disinfecting the plant material without killing the explant. Successive grafting and rejuvenation seems to be a need for mature plant material. In this way, the number of subcultures needed for obtaining a reactive cluster (exponential multiplication) is reduced.

Many problems occur in vitro specially when we started the development of the method at the industrial level.

Bacterial pollution can appear after 7 or 8 transfers, later after primary culture on selection of clean culture. ZIMMERMANN wrote about such contamination in micropropagation of fruit trees species. This problem shows that a particular attention must be paid during the phasis Ia and for industrial micropropagation. Indexation of culture must be done at the end of phasis Ib, before in vitro cloning. Indexation of culture can be done by addition of malt extract or peptone (10-100 mg l⁻¹) to the multiplication medium.

The small number of reactive cultures in phasis Ia can be bound to the disinfection method or hormonal endogenous gradients along the stem of cuttings. To obtain a clone under sterile conditions, it is therefore necessary to have a sufficient [sic] number of nodes for conducting factorials trials with combination of time of disinfection and cytokinin concentration.

Callus and brownish compounds released in the medium present also a problem at this point of the culture (phasis I) and we indicated earlier a method to decrease or avoid such problems.

During phasis II, waterlogging (hyperhydric transformation) and a too small elongation of the axillary bud are the two main problems.

Waterlogging often occurs in in vitro culture and the causes of this phenomenon have been investigated. When it occurs in our subcultures (phasis II), it is often confined to one or few buds and does not necessarily extend to the whole of the explant. Transferring the culture to medium A (elongation medium, i.e. medium M with activated charcoal added at the rate of 15 g l⁻¹) promotes the development of untransformed buds which may then be taken off for a new multiplication process. This type of activated charcoal containing medium, can also be used for the selection of stems, without callus on leaves or buds (clone 16), which can sometimes occur on multiplication medium.

A too small elongation of axillary buds is often a limitation to the obtention of a large number of stems which could be transferred on R I medium. Often, 2 to 4 buds only by culture, present the

⁴Melfert : patented containers Fertil Pot
Tour Maine Montparnasse 75755 PARIS Cedex 15

appropriate height of 10 to 20 mm. On a defined cytokinin concentration there is often a clonal response for elongation, even when decreasing the cytokinin concentration of M medium, some clones show a very small elongation. NKANKA has described [sic] similar problems with *Eucalyptus rudis* and he recommends to use vitamin E (D-L Tocopherol) to promote the elongation. Now, with this compound no or low improvement of elongation was observed in our cultures. Research to solve this problem should be oriented toward the mineral composition of the medium and also on the size of the explant in transfer. Using too small explants in transfer increase the budding but gives no elongation of the developed buds.

In phasis III, the main problems are formation of callus at the basis of the stem on R I medium and sometimes rooting of leaves in contact with the medium and also necrosis of the main stem.

Some hybrids as *gunnii* x *globulus*, root easily but with a very big and hard callus and a poor root system develops from this structure. Such callus is a problem for acclimatization because it is a source of root rot.

Decreasing sucrose concentration just limits the phenomenon but it is always present. A better definition of optimum mineral medium and the use of smaller concentration of auxins must be investigated to avoid such callus.

The ability of leaves to induce roots when they are in contact with an auxin containing medium necessitates the complete elimination of leaves at the basal part of explant before planting on R I medium. This operation is time consuming.

For necrosis of main axis at the end of rhizogenesis induction, it is possible that dark period is partially responsible for the phenomenon. R A medium corrects partially this drawback but attention must be paid to the growing time on medium M before root induction and works should be conducted to try to suppress this dark period without decreasing the rooting percentage. The substitution [sic] of agar for rockwool which gives a better aeration of the medium has begun with encouraging results.

CONCLUSION

The method presented in this paper allowed to produce about 20,000 plants from 10 to 12 clones. Most of these in vitro plantlets are used as mother trees for cuttings. But the cost of the plantlets do not yet allow to use it for reforestation. Nevertheless, the use of in vitro plantlets as mother trees for the production of cuttings is interesting and the rooting ability of cuttings taken from such plants is better than this of cuttings taken from scions or in vivo cuttings. The transfer on cytokinin medium for a long time increases the rooting potentiality. This is well demonstrated by clone 16 (old selected tree).

Another advantage of this method is to maintain the rooting ability of the clone. Some of our clones have been introduced in vitro for 3 years now and they kept their rooting potential

Most of the problems we described must be solved for "mass propagation of eucalypts" at a reasonable cost, but presently we can easily produce good mother trees, even from mature material.

It is also very interesting to see that the multiplication medium M can be used with some minor adaptation (cytokinin concentration) for various clones, species and hybrids.

We think that for obtaining the mass propagation of eucalypts by axillary budding under in vitro conditions, research should be conducted on the mechanization of the process.

The major part of the costs of a plant is labor. Some other ways must also be investigated, as somatic embryogenesis. But with this method, attention must be paid to the genetic conformity of the production.

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Clonal Propagation of *Eucalyptus* by Cuttings in France¹

H. Chaperone²

Genus *Eucalyptus* is so broad and so varied that one should avoid any generalization : However it seems possible to state that a revolution is setting on in afforestation thanks to the development of the technology of the horticultural propagation by cuttings.

This technology which has proved successful on thousand hectares in tropical countries (Congo, Brasil) is now developed under very different climates as countries like France or Morocco have chosen to create or to regenerate their forests by cuttings. There is not doubt that this trend is going to increase in the near future and reach the most part of the afforestation not only with *Eucalyptus* but also with other species.

The advantage of the propagation by cuttings depends, for *Eucalyptus*, on several factors

- It is a genus heavily employed as an exotic in afforestation with as main objective a strong biomass production from short rotation coppice. The stands are planted at final spacing : It will not be possible to improve the quality of the stand by silvicultural interventions so it is important to start from an homogeneous and high quality vegetal stock.

- The exotic characteristic implies that many afforestations are set up in zones where it is difficult to find both adapted and productive species. The possibility to hybridize adapted species with productive species allows the synthesis of high performance hybrids on marginal sites : afforestation of poor savannahs in Congo, dry sites in Morocco, cold sites in France. The mass propagation of these hybrids is only possible by cuttings.

- The particularity of the flowering of *Eucalyptus* induces a proportion of inbreds in the progenies which may be important. These trees, supply of heterogeneity and of lack of production, cannot

Abstract : A.FO.CEL has developed a technique for mass propagation by cuttings of *Eucalyptus* in France. This technique is described from the selection of the ortet to the mass propagation of the clone for afforestation : the first stage is the mobilization of the ortet, the second stage is called pre-propagation which includes rejuvenating and rooting conditioning, the third stage is mass propagation. The mass propagation is realized from successive propagations of mother trees; the number of which increases from generation to generation by including the new rooted cuttings. We give practical advices on atmosphere, treatments depending on the season which govern the success of the technique.

be detected in the nursery, the propagation by cuttings will allow to exclude them.

- It exists, in this genus, species or hybrids with a good rooting ability in rather simple conditions for allowing to develop the technique into economical conditions.

The consequences of the use of this type of propagation must be well understood : we will have to adapt an accurate and intensive silviculture to the clonal stands which will have to be at the level of the quality of the vegetal stock.

This evolution will change the aspect of the forest investment : its often weak considered rentability can reach a very attractive level while the lowering of the rotation is a favourable agent for the research of investment. At the wood product level, the industrial will profit by a rigorous homogeneous and well fitted material.

SELECTION OF VEGETAL STOCK

The exact copy of clones by cutting propagation assure the best valorization of a breeding program.

From the ortet selection to the mass propagation of the clone one can distinguish three successive stages

- The "mobilization" or first propagation allows to obtain the first vegetative copies and to assure the transfer of the clone to the nursery.

- The "pre-propagation" is the stage during which the first copies are handled so as to obtain new juvenile and more reactive copies suited to the conform mass propagation.

- The mass propagation is the final stage which allows to use the clone in afforestation.

Mobilization

Ortets are selected at a stage which permit them to express their qualities ; at this stage the vegetal has lost its rooting ability (this one disappears between two months to one year old according to the species).

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One can choose between two ways to mobilize the clone

Grafting

This way has the advantage to conserve the entirety of the ortet. The scions are taken off during the winter on a part of the tree in potential active growth.

The root-stock grown in a green house is cut at the level where the section of its stem corresponds to the section of the scion.

We use the cleft grafting by effecting an incision at the top of the rootstock in which we introduce the bevelled scion.

The good contact between the root-stock and the scion is secured by a tying with a cellophane bound.

The grafted plant is put in a warm green house and confined under a plastic cover ; the union between the root-stock and the scion is effective during the fortnight after the grafting operation, the growth of the grafted plant will occur one month after grafting.

The scion, which showed an adult morphology, can return during a short period to a juvenile stage (rejuvenating action of the root-stock) but will quickly show again senile features.

The rejuvenating effect of the root-stock is the more lasting as the level of the graft is the lower.

Felling down the ortet

It is a more destructive technique which presents advantages to simplify the "pre-propagation" stage.

The ortet is cut down at the end of the winter or at the beginning of the spring (March) at fifteen centimeters high. Sprouts will develop on the stump and will be cropped on June. The shoots are removed as soon as the rooting ability is set, each removing allows the departure of new shoots.

We have stated that the first emission of sprouts generally have a lesser rooting ability than the following ones. Sprouts can be cropped as soon as the foliage get a good chlorophyllian pigmentation; the emergence of axillary shoots on the sprouts is often the sign of a decreasing rooting ability.

Cuttings correspond with the lower part of the shoot from which we can prepare a four leaves cutting. The less coloured and hard to root upper part of the sprout is not used.

The cuttings prepared in this way have a good rooting ability and one can obtain as early as the mobilization stage juvenile and exact copies of the ortet.

Pre-propagation

This stage presents two different aspects according to whether the clone was mobilized by grafting or by felling down the ortet.

Pre-propagation after grafting

The clone is now represented by some grafted copies which can have shown a fugitive juvenile stage. The cuttings that one could crop on the grafts are unfitted for rooting : the clone must be rejuvenated.

The rejuvenation can be realized in two different ways

- Successive grafting : if we take off a scion on the first graft during the juvenile stage and if we make a new graft (as low as possible), we notice that this new graft exhibits a more lasting juvenile stage followed by a new reversion to adult stage. By taking again a new scion on this second graft in its juvenile stage, we will obtain a new progress in juvenility. At the fourth or fifth successive grafting, we can generally obtain a sufficient juvenility for considering the rooting of the cuttings taken off from the graft. This method is relatively long and costly.

- Felling down of the initial grafted plant, followed by the rooting of the new shoots initiated on the scion : instead of realizing successive grafting, one can prefer to let the grafted plant develop during one year or two years. The graft will be cut on March fifteen centimeters upon the grafting point in order to initiate new shoots. If the grafting level is sufficiently low, the rejuvenating influence of the root-stock allow to root the lower part of the new shoots.

In these two pre-propagation ways the rejuvenating of the clone is not complete : the rooting is possible but difficult and the rooted cuttings do not have a satisfactory growth.

A complete rejuvenating will occur by the complementary use of *in vitro* propagation or by successive horticultural propagation by cuttings : we have stated that *in vitro* propagation leads more quickly and surely to juvenile and reactive mother trees suited for mass propagation.

Pre-propagation after felling down the ortet

The rooting of the sprouts of stump allows to obtain exact and juvenile copies of the ortet. These copies have a good rooting ability and will be used as mother trees for a successive cutting propagation. The rooting ability is increasing from a generation to the following generation of cuttings, showing the improved reactivity of the mother trees. It seems that the best rooting is obtained after an *in vitro* propagation cycle which allows to obtain mother trees the quality (homogeneity and reactivity) of which answers the

requirements of a mass propagation by successive cuttings.

The propagation by successive cuttings can lead to the same result if we take care to select at each generation of cuttings the mother trees of best quality.

Mass propagation

It is the final stage during which a mobilized, rejuvenated and rooting conditioned clone is commercially propagated. The set up technique is the horticultural successive propagation by cuttings which is explained in the following developments.

The easiest way to reach this stage consists in cutting down the ortet then to root the shoots. The safest way for pre-propagation is the preparation of the clone by in vitro technology.

SUCCESSIVE PROPAGATION BY CUTTINGS

The mother trees

Origin

They originated from the pre-propagation stage which must give exact, juvenile and rooting conditioned mother trees.

These mother trees will be propagated by cuttings and give rooted cuttings which will be used as mother trees in their turns.

During the successive generations of cuttings, one will notice the apparition of a certain proportion of cuttings with a weak root system : it is important to avoid the propagation of this type of plants if we want to avoid to create, inside the clone, bad rooting ability lines.

The keeping of the quality and of the homogeneity of a clone during the successive generations of cuttings supposes either to be conspicuous to quality of the mother tree or to plan a periodical replacement of the mother trees (once a year) for mother trees produced by in vitro propagation.

The cycle of the successive propagation by cuttings is described in the diagram n° 1.

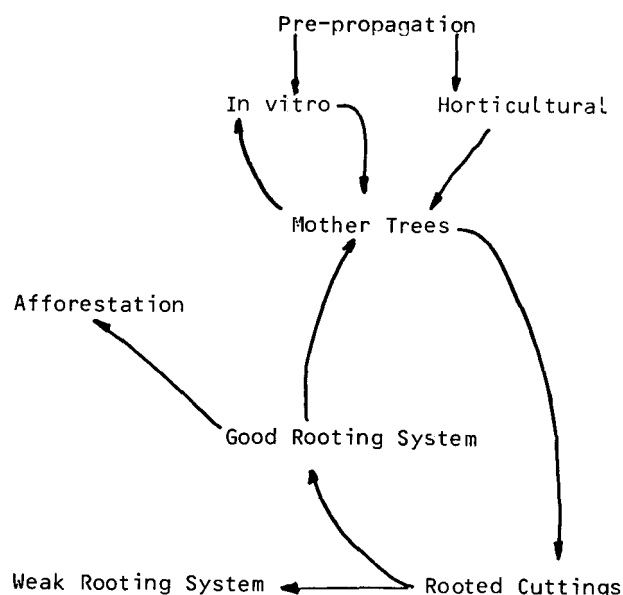


Diagram 1--Successive propagations by cuttings.

As we can see in the diagram, a light proportion of weak rooting system cuttings are eliminated from the cutting cycle. These cuttings can create a new convenient rooting system during the nursery breeding ; if it is the case one will send them for afforestation.

We use to make direct cuttings in the container used in afforestation (containers with roots permeable walls) because the advantage of the technique lies in not distinguishing the mother trees from the cuttings for afforestation. These mother trees are periodically cropped as soon as the shoots reach the size and the development level corresponding to the best rooting ability. When we obtained a sufficient number of cuttings (including the mother trees) corresponding to the afforestation program, we let the mother trees grow in order to reach the required size for afforestation.

The diagram 2 allows a better understanding of the successive propagations by cuttings.

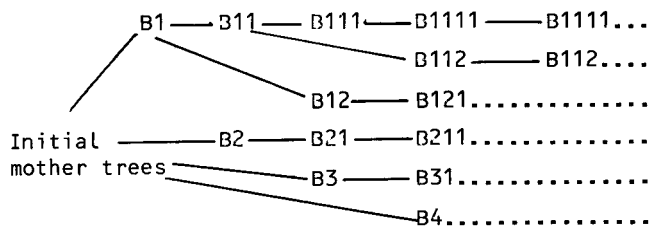


Diagram 2

The advantage of this system lies in its great flexibility.

- The successive propagation by cuttings permits to quickly obtain a great number of copies from a limited number of initial mother trees (multiplication rate superior to one hundred during a year).

- We can change the composition of the multi-clonal variety at every moment without financial losses because there is no immobilization in mother trees bank in the field. If a clone becomes obsolete all the mother trees can be used for afforestation before the mass propagation of a new clone.

Growing atmosphere

The growth conditions of the mother tree are essential for the rooting success : the mother tree must have a vigorous growth (appropriate level of water, light, warmth, fertilization) and it is recommended to avoid to multiply mother trees exhausted by too many crops.

The growing atmosphere of the mother tree is determined by the season and the rooting atmosphere : from a general point of view, the mother trees must grow in the same atmosphere used for rooting.

In winter, the mother trees are grown in green houses with a soil heating (substratum temperature 18°) and under a plastic cover (confined atmosphere). In Spring, mother trees are grown in greenhouses without soil heating and extra plastic cover, in Summer the mother trees are grown in the open air.

We will see later that these conditions correspond to the rooting atmosphere.

Rotation of crops of mother trees

The rotation on mother trees should be as short as possible : the shoots are cropped as soon as they reach a development level compatible with the propagation by cuttings.

In practice the rotation is fifteen days long and we can prepare on average one and half cuttings per mother tree.

It is important to know that mother trees are weaker in winter than in summer : their growth conditions should be more precise, the removal of cuttings should be made carefully and the number of crops

restricted in order to avoid to exhaust them.

Crop of the cuttings

The decision of cropping the cuttings on a mother tree is governed by a certain number of parameters which determine the rooting ability

- The minimal size of the cuttings allowing its handling is near five centimeters,
- The minimal number of well coloured and developed leaves is fixed to four (without counting the bad coloured and young leaves).
- The rooting ability decreases quickly as soon as ramifications appear on the shoots : one must imperatively propagate by cuttings before this stage.

The morphology of the shoots moves according to the season : in winter the internodes are short, the leaves small and well coloured ; from spring to summer the internodes grow longer, the size of leaves increases and they take their coloration more slowly.

The shoots are cut off just above the leaves of the lower part in order to initiate two new shoots at this level.

For avoiding a too great ramification of the mother tree which would lead to the production of shoots unsuited to rooting, the level of the size is lowered from time to time.

The cuttings are immediately placed in a water filled up vessel to avoid their fading.

Cuttings preparation

In winter the cutting is constituted by the whole shoot cropped on the mother tree. There is no special preparation unless the ablation of the leaves of the lower part when they impede the insertion of the cuttings in the substratum. The cutting corresponds generally to a four to eight leaves shoot.

In summer the cutting corresponds to the lower part of the shoot (we remove the bad coloured upper part). The cutting has generally four leaves.

The cuttings are dipped in a fungicide solution (six grams Benlate per ten liters water) then drained before hormonal treatment. This treatment [sic] is essential : the lower part of the cuttings is dipped in a commercial powder which contains one per cent Indol butyric Acid. Then the base of the cutting is inserted in the rooting medium after we made a hole in order to avoid to wound the herbaceous stem or to remove the hormone.

Cutting environment

The environment for the propagation by cuttings varies depending on the season for fitting the

needs of the plant in water, warmth and light.

We can discern the following periods

- From January to March : Winter cuttings,
- From April to Mai : Spring cuttings,
- From June to the 15th of August : Summer cuttings,
- From the 15th of August to October : Fall cuttings.

In November and December, the natural conditions are very bad for the growth of the mother trees and the rooting of cuttings : we have to bring a great quantity of additionnal [sic] heat and light to obtain weak results. So we recommend to stop to propagate at this time.

winter cuttings

The cuttings are put in an enclosed atmosphere by covering them with a polyethylene film just over the leaves.

This plastic cover keeps a good atmosphere humidity. Substratum humidity is weekly controlled when we do the phytosanitary treatments : the rooting medium must be always humid without excess (obligatory draining), the humidity is increased from January to March.

Rooting medium temperature is maintained at twenty degrees at the base of the cuttings : a too high temperature increases the risks of rooting, a too weak temperature inhibits the rotting.

Atmospheric temperature is not controlled.

Light is very important for rooting : we verify that the rooting percentage is directly proportion to the insolation duration. The minimal insolation duration is estimated to one hundred hours per month to obtain good results. This minimum is generally reached in the South west of France from January. Below this point we have to foresee an additional artificial illumination. From February we are obliged to reduce the natural light by a whitening of greenhouses in order to avoid the sun burn or an excessive temperature rising.

Spring or fall cuttings

The propagation by cuttings is realized in a greenhouse under a mist system. The mist is started by a clock fifteen seconds every ten minutes at the warm hours of the day in order to always maintain an humid film on the leaves.

The temperature of the greenhouse is controlled by aeration and whitening. we have to avoid the sun burn on the cutting leaves by arranging just above them a plastic shade (fifty per cent shade).

The overheating of the greenhouse (temperature superior to 30°) risks to lead at first to a too high substratum temperature (rotting) then necrosis of

the aerial part.

The temperature and the humidity of the substratum are not specially controlled.

Summer cuttings

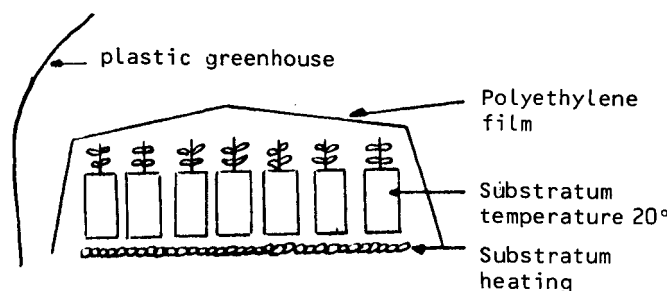
From June the increasing of the mean mensual temperature (20°) allows to propagate by cuttings in the open under a mist started by a clock at the warm hours of the day. This mist falls on a shade (fifty per cent) spread nearby the cuttings and which appears to have a double action

- to avoid sun burns which induce the depigmentation of the Eucalyptus leaves,
- to maintain a humid atmosphere near the cuttings.

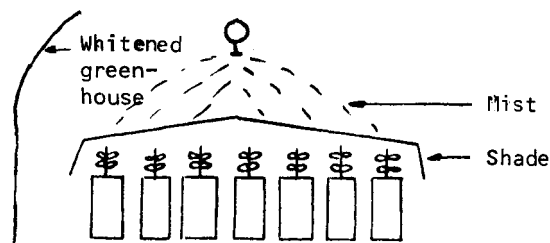
Rooting medium temperature and humidity are not specially controlled.

The three cuttings environments are described in the diagram n° 3.

. Rooting percentages are good in each of this three environments but we have noticed that simplicity and cost of the propagation become better from winter to summer.

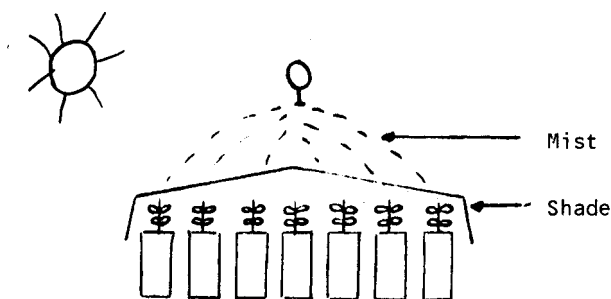


Winter cuttings



Spring cuttings

Diagram 3--



Summer cuttings

Diagram 3--(continued)

Rooting medium - Container

Rooting medium composition may change into large proportions without damage on rooting.

We have to watch over the rooting medium possesses the following qualities

- intermediate granulometry assuring a good draining, a good aeration and sufficient water retention. The granulometry will be also of importance on the architecture of the new root system,
- organic matter contents rather poor (rotting risks),
- free of pathogen elements or adventitious seed (desirable disinfection).

We obtained good results with a medium containing seventy five per cent crushed and composted bark, twenty five per cent Perlite and five kilograms Osmocote per cubic meter.

When the rooting mean percentage exceeds seventy per cent one can consider to propagate by cuttings directly in the container in order to avoid transplanting which is a costly and damaging operation.

The propagation by cuttings has no particular influence on the choice of the container. That may be .

- a rigid walled container with a special design to avoid root deformations,
- a permeable root walled container (nonwoven material).

The successive propagation by cuttings supposes a prolonged keeping in the nursery (to six months): the container volume should be big enough to assure a good growth to the cutting during this period. For the same reasons, we have to study carefully the medium fertilization during this period.

Rooting

Time for rooting is depending on the vegetative conditions of the mother tree and on the rooting atmosphere : this time varies from ten days in

good conditions to three weeks in bad conditions. It decreases from January to July then increases from July to October.

Hardening-off

The hardening corresponds to the period between the acquisition by the cutting of a functional root system and the recovery of an active aerial growth. This duration varies between three weeks and one month.

The hardening atmosphere is as near as possible of the rooting atmosphere

- In winter, the hardening consists to move away the plastic sheet from the contact of leaves (rooting atmosphere) to a certain distance (growing atmosphere). This modification is very light and can be done without any particular care.

- In spring and summer, we shall wait the aerial start of the cutting to suppress first the shade then for lessening the ON periods of the misting system.

The end of the hardening takes generally place two months after the insertion of the cutting in the rooting medium. At the end of this period the rooted cuttings is enough developed [sic] to consider to crop cuttings.

We can estimate that

- the duration between the insertion of the cutting and the first crop on the new mother tree is two months,
- the duration between the insertion of the cutting and its possible dispatch for afforestation (fifteen to twenty centimeters high) is two months and a half.

Diagram 4 indicates the time necessary for each stage

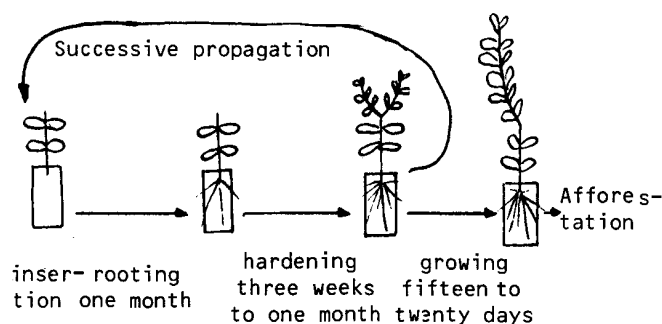


Diagram 4--

Results

Results of the propagation of Eucalyptus by cuttings depend on

- the selection level : it is important to select on the rooting ability which varies in

any great extent from one clone to another inside the same species : in *Eucalyptus gunnii*, the mean rooting success is near fifty per cent and the rooting success of the best clones is near ninety per cent,

- the rooting conditioning of clones : rooting ability of a clone increases after an in vitro propagation cycle or after several successive propagations followed by a selection of reactive mother trees. This "conditioning" of clones allows to increase very obviously the rooting success especially when the first copies of the ortets are not completely juvenile,

- the rooting season : the rooting in the open in June and July gives the better results.

In the best conditions, we reach a mean rooting percentage of eighty per cent for the selected clones in *E. gunnii* and *E. hybrid gunnii x dalrympleana*.

CONCLUSION

Research and development of the mass propagation by cutting of *Eucalyptus* have led to precise a technique of forest plant production which satisfies the economical requirements of afforestation and secure the mass propagation of clones selected for precise purposes.

The success depends on the conjunction of propitious factors

- Selection of the clone not only on production or resistance criteria but also on rooting ability,
- Conditioning the mother trees for the supplying of high rooting potential cuttings,
- Choice of the cutting environment adapted to the season.

The keeping of every factor at the optimal level governs the success of the technique but it is certainly the management of the mother trees which constitutes [sic] the more critical point : the propagator must have the perpetual care to keep the quality and the homogeneity of the mother trees by the elimination of the degenerating ones. The cyclic return to mother trees produced by in vitro propagation allows to avoid every risk of degeneration.

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Part 7. Breeding Programs

Eucalypt Improvement for California: Progress and Plans¹

F. Thomas Ledig²

California has a long history of flirtation with eucalypts, but little in the way of systematic programs to identify superior planting stock. Eucalypts (genus *Eucalyptus*) were introduced in California over 125 years ago and some have since become naturalized (Kirkpatrick 1977). Eucalypt windbreaks, road screens, and woodlots are so common that many laypeople believe eucalypts are native trees. But despite their familiarity, there have been few trials of eucalypts as timber trees. Most of our knowledge on their growth and adaptability is anecdotal, deriving from observations on scattered specimens (Metcalf 1924). Until recently there was little need of more intensive investigation because California has many fine conifers that are easily seasoned for construction lumber, while eucalypt timber is difficult to season. However, interest in eucalypts has increased because of their suitability for short-rotation fuel biomass plantations. Growers need a reliable source of rapidly growing planting stock, but development of eucalypt seed sources is not a small chore.

There are several stages in the development of any new crop. In the first stage, species trials are used to eliminate non-productive candidates and identify those with enough promise to justify further testing. However,

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Abstract: Six promising eucalypt species, suitable for fiber or biomass production, have been identified with some confidence: *Eucalyptus camaldulensis*, *E. dalrympleana*, *E. viminalis*, *E. nitens*, *E. globulus*, and *E. grandis*. The Forest Service's Institute of Forest Genetics has established provenance or seed source tests of *E. camaldulensis*, *E. grandis*, *E. nitens*, and the *E. dalrympleana*-*E. viminalis* complex. In *E. camaldulensis*, the Lake Alacutya source is outstandingly superior to any other, and can probably double yields previously achieved with this species in California. Growth among *E. grandis* provenances is more uniform, but gains of 32 percent may be made by seed source selection. Tests of other species are too young for firm conclusions. Once superior seed sources are identified, they should be used to fill planting demands in California. The next step is to begin selection and breeding within the most productive species.

even within a single species, the growth of one provenance (provenance = a population originating in a particular location, climate, and soil) may not be representative of the species. Therefore, species trials should include some minimum number of seed sources. Ideally, trials should be conducted on a number of sites to assure that results are not narrowly limited in application. Provenance testing is the primary objective in the second stage of introduction, to locate the best seed sources within the species. When yields are established for a range of provenances, the third stage can begin: intensive breeding methods are applied within the best adapted provenances to improve growth and economic value.

SPECIES TRIALS

Choice of species is the first consideration in growing eucalypts, but a complete survey of the genus would be a monumental undertaking. A recent compilation recognizes 550 eucalypt species (Chippendale and Wolf 1981). Of these, at least 70 are grown in California (McMinn and Shepherd 1973). Many are in arboreta and parks, and their range of adaptability or their potential as forest trees is unknown.

One of the most extensive trials of eucalypt species was undertaken by the University of California Cooperative Extension. The University tested 43 species and 18 sites, although not every species was represented at each site (Davis [1980?]). Plantings spanned a latitudinal range from Yuba County to San Diego. After 7 years, the species were given a subjective rating based on their value as landscape trees. Appearance was heavily weighted in the rating. The highest score was

Table 1--Survival and volume of eucalypt species from two plantings at Concord, California, 1977.

Species	1964 planting		1965 planting	
	Survival (pct)	Vol/tree (cu m)	Survival (pct)	Vol/tree (cu m)
<u>E. camaldulensis</u>	-- ¹	-- ¹	65	0.06
<u>E. dalrympleana</u>	65	0.29	60	0.02
<u>E. ovata</u>	29	0.28	24	0.10
<u>E. grandis</u>	13	0.20	91	0.07
<u>E. nitens</u>	54	0.19	94	0.13
<u>E. viminalis</u>	83	0.14	75	0.02
<u>E. glaucescens</u>	35	0.15	72	0.03

¹Not planted in 1964

received by southern mahogany (E. botryoides Sm.), and it was followed by river red gum (E. camaldulensis Dehnh.). Actually, growth of river red gum was better than that of southern mahogany wherever they were planted together, but river red gum was not considered as suitable a landscape tree as southern mahogany. Because of the concentration on ornamental trees, many common timber trees were not included in the trials.

Species trials that focused primarily on timber trees were established at Concord, California, in 1964 and 1965 as a cooperative venture of the Navy Department and the Forest Service's Institute of Forest Genetics (King and Krugman 1980). Of 36 species, 6 or 7 were very promising (table 1), and if marketed for fuelwood or chips, would return at least 6.2 percent on investment (Standiford and Ledig, this volume).

PROVENANCE TESTS

The species trials of both the University of California and the Institute of Forest Genetics suffer from a common deficiency; neither took into account intraspecific genetic variation. Wide-ranging species are usually subdivided into populations adapted to the varying climatic and edaphic conditions in which they occur. While seeds from one area may produce rapidly growing trees under Californian conditions, seeds of the same species, but from other areas, may fail miserably. Species trials that only sample a single population may give misleading results. Species introductions should sample at least the extremes and center of the range.

A further problem is that neither the University nor the Institute included blue gum (E. globulus Labill.) in its species trials, so there is no direct comparison of California's most commonly planted eucalypt.

In 1975 a series of seed source, or provenance, tests were initiated to determine the range of genetic variation within species of greatest potential as indicated in the Institute's species trials. Provenances of five species are now under test. A provenance trial of blue gum is also planned because it often shows phenomenal growth in California, and its supremacy for biomass production is well established in world forestry.

River red gum

A seed source, or provenance, test of river red gum was begun in 1975. Seeds of 23 provenances were sown in June, the seedlings transplanted into Tinus containers, and then outplanted at Concord in February, 1976. Details of cultivation are reported by Emery and Ledig (in preparation). By the time the planting reached age 5.5 years, results were clear (table 2).

All the top six seed sources (A-F) come from the Murray and Darling River drainages and adjacent watersheds of Victoria, South Australia, and New South Wales. Statistical techniques that link areas of similar climate, tend to cluster these sources into one group (fig. 1). The area is characterized by relatively low rainfall, rather cool maximum temperatures, and a long season in which frost can occur (>120 days).

One seed source, from a dry lake bed, Lake Albacutya, Victoria, stood out. Its volume growth was 161 percent better than the average and 598 percent better than the worst seed source. Mean growth for the Lake Albacutya seed source was substantially better than growth of river red gum in the adjacent 1964-65 species trials. Diameter was 6.6 cm and height 6.2 m at 6 years in the species trial, but the Lake Albacutya source already exceeded that at 5.5 years: 9.5 cm and 7.2 m, respectively. We have

Table 2--*Eucalyptus camaldulensis* provenance means
5.5 years after planting.

Provenance	Volume ¹ (cu m)	Height (m)	dbh (cm)	Straightness ²
Lake Albacutya, Victoria	.0684 a	7.17 a	9.5 a	2.4 ghij
Hamilton, Victoria	.0570 ab	5.97 be	8.9 ab	2.6 efghij
Nathalia, Victoria	.0463 abc	5.78 bcd	7.8 abc	2.9 cdefg
Angaston, South Australia	.0462 abc	5.85 bcd	8.5 ab	2.4 ghij
Darlington Point, New South Wales	.0421 bcd	6.32 ab	7.6 abcd	2.6 efghij
Forbes, New South Wales	.0297 cde	5.40 bcde	7.2 bcde	2.5 efghij
Port Lincoln, South Australia	.0270 cde	4.94 cdef	7.1 bcde	2.1 j
Petford, Queensland	.0253 cde	5.99 be	6.2 cdef	3.2 be
Mundiwindi, Western Australia	.0230 cde	4.98 cdef	6.0 cdef	3.4 ab
Agnew (AR), Western Australia	.0224 cde	4.85 def	6.1 cdef	3.0 bcdef
Alice Springs (I), Northern Territory	.0215 cde	4.54 of	5.7 cdef	2.8 cdefgh
Onslow, Western Australia	.0201 de	4.36 of	6.0 cdef	2.5 fghij
Quilpie, Queensland	.0200 de	5.19 cdef	5.8 cdef	3.1 bcd
Pentland, Queensland	.0194 de	4.85 def	5.8 cdef	2.6 efghi
Hughenden, Queensland	.0191 de	4.79 def	5.8 cdef	2.8 cdefgh
Wiluma, Western Australia	.0180 de	4.99 cdef	5.5 cdef	3.8 a
Alice Springs (H), Northern Territory	.0173 de	4.89 def	5.3 of	3.0 bcde
Agnew (AO), Western Australia	.0170 de	4.82 def	5.5 def	2.9 cdef
Quilpie (P), Queensland	.0148 e	4.55 of	5.5 def	2.2 ij
Thargomindah, Queensland	.0146 e	4.18 f	5.1 of	2.3 hij
Three Springs, Western Australia	.0124 e	4.29 f	5.2 of	2.7 defgh
Katherine, Northern Territory	.0107 e	4.36 of	4.6 f	3.0 bcde
Newcastle Waters Creek, Northern Territory	.0098 e	4.14 f	4.3 f	2.7 defgh

¹Estimated by $\text{dbh}^2 \times \text{ht}$

²Scored from 1 = most crooked to 5 = straightest

³Means followed by the same letter do not differ significantly at the 5 percent probability level, according to Fisher's protected least-significant differences multiple range test

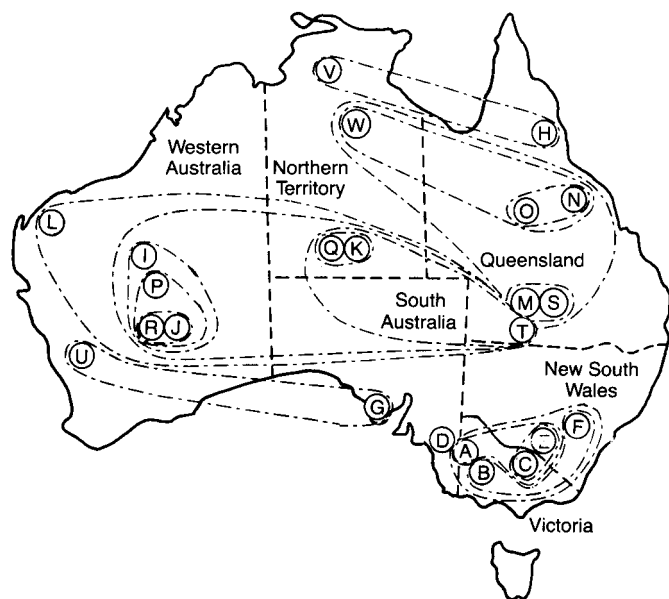


Figure 1--Location of *Eucalyptus camaldulensis* seed sources in Australia. Broken lines cluster seed sources of similar climate.

confidence in these results because the Lake Albacutya seed source has emerged superior wherever it was planted in a Mediterranean climate similar to California's; e.g., in Greece (Panetsos 1970), Israel (Karschon 1974; Moreshet 1981), Italy (Giordano 1974), Morocco (Destremau and others 1973), Rhodesia (Barrett and Carter 1976), Zambia, Spain, Algeria, and Portugal (Lacaze 1978). The Lake Albacutya source is also reported as highly salt tolerant (Sands 1981). It seems likely that this seed source will surpass any other previously planted in California. It should be able to withstand some cold and drought, as well as saline soils.

Flooded gum

Seed from 15 flooded gum sources (*E. grandis* Hill ex Maid.) was sown in September 1976, and outplanted at Concord in March 1978. Early results, at 3.25 years, show that there is less variation in flooded gum than in river red gum (table 3; Bailey and Ledig, in preparation). Nevertheless, the best seed source, Orara East in New South Wales, was 14 percent taller and had 32 percent greater volume than the plantation average.

Table 3--Eucalyptus grandis provenance means for relative volume, height, dbh, and straightness 3.4 years after planting.

Provenance	Volume (cu m)	Height (m)	dbh (cm)	Straightness ⁴
Orara East	³ 0.041	² 6.5 a	³ 7.5	³ 3.06
Tanban	0.039	6.4 ab	7.4	2.87
Newfoundland	0.037	6.3 ab	7.4	2.90
Tucker's Knob	0.041	6.1 abc	7.5	3.29
Pine Creek	0.033	6.1 abc	6.8	3.30
Orara West	0.032	6.0 abc	6.7	2.96
Yabbara	0.033	5.8 abcd	6.8	3.38
Newry	0.024	5.7 bcd	6.3	3.10
Wild Cattle Creek	0.035	5.4 cde	6.6	2.90
Lorne	0.026	5.3 cde	6.0	3.17
Nulla Five Day	0.021	5.1 de	5.5	3.14
Minmi	0.025	5.1 de	5.6	2.70
Queen's Lake	0.030	5.1 de	6.5	3.19
Brooloo	0.024	5.0 de	2.1	3.50
Bellinger River	0.019	4.8 e	5.1	2.61

¹All provenances were from New South Wales except Brooloo, Queensland

²Means followed by the same letter do not differ significantly at the 5 percent level of probability, according to Fisher's protected least significant differences multiple range test

³Not statistically different among provenances

⁴Scored from 1 = most crooked to 5 = straightest

Despite the early age of the test, results can be viewed with some confidence. The same seed sources performed similarly in South African trials. The correlation between seed source height in South Africa and height in California was 0.72, and for dbh 0.79.

The relationships between climate at the seed source and growth in California were weak in flooded gum. There is a slight association of growth with longitude ($r = 0.66$), but it is of little help in indicating where to find superior provenances in Australia.

Shining gum

Shining gum (E. nitens Maid.) is not well-known in California. However, it grew well in the 1964-65 species trials at Concord and suffered almost no damage from the record freeze of 1972. Since it was first planted at Concord, provenance tests established in Australia (Pederick 1979) indicate that the seed source used in the Concord plantings is one of the most slow-growing, at least, under Australian conditions. By implication, the already excellent performance of shining gum at Concord can be improved upon with proper choice of seed source.

In 1982, 25 provenances of shining gum were planted at Concord. Similar tests were

established near Ukiah in cooperation with Masonite Corporation. A third test near Santa Nella failed because it was planted late and did not receive necessary weed control or irrigation. It is much too early to draw any conclusions, but initial results after a year in the field suggest substantial differences among provenances (table 4).

Mountain gum and manna gum

The single most rapidly-growing eucalypt in the Concord species trial was mountain gum (E. dalrympleana Maid.). However, some of the trees in the test have leaves on basal sprouts that look more like manna gum (E. viminalis Labill.). It is possible that the seed supplied by the Commonwealth Scientific and Industrial Research Organization (CSIRO), Division of Forest Research in Australia was manna gum, a mixture of mountain and manna gum, or hybrids. The two species intergrade over an altitudinal gradient, and mountain gum could be merely the high elevational form of manna gum (Phillips and Reid 1980). We expect mountain gum to be more frost-hardy than manna gum because it occurs at higher elevations.

Because of the dubious taxonomic status of mountain and manna gums and the apparent ease with which they cross, it was decided

Table 4--Eucalyptus nitens provenance means for height and survival 1.3 years after planting.

Seed source and locality	Survival (pct)	Height (cm)
Rubicon, Victoria		
Tweed Spur	78	93.4
Snobs Creek	76	99.3
Barnewall Plain	78	81.5
Mt. Donna Buang	78	94.1
Toorongo, Victoria		
Toorongo Plateau	79	85.3
Upper Thomson	88	83.0
Marshall Spur	77	86.1
St. Gwinear	84	89.3
Mt. Erica	77	81.6
Mt. Toorongo	76	90.0
Tanjil Bren	68	94.6
Christmas Creek	75	81.9
Powelltown	92	90.7
Macalister, Victoria		
Mt. Skene	80	86.5
Connors Plain	85	86.9
Mt. Useful north	77	83.1
Mt. Useful south	85	90.8
Mt. Wellington	77	83.3
Errinundra, Victoria		
Errinundra north	84	102.4
Errinundra south	87	83.8
Goongerah	75	102.9
Southern New South Wales		
Nimmitabel	75	68.4
Tallaganda	83	70.2
Northern New South Wales		
Ebor	58	65.0

to include both forms in provenance trials. A trial of six provenances of mountain gum and two of manna gum was started earlier this year, 1983. Plantings were made at Concord, near Anderson in northern California, near Standard in the foothills of the Sierra Nevada, and at Santa Nella. It is much too early to tell whether these plantations will succeed, but the range of planting sites should provide a good test of adaptability. Subfreezing weather cannot be counted on at Concord each year; the Anderson and Standard sites will be more likely to provide a test of cold hardiness. The Santa Nella site will provide a test of tolerance for soil salinity.

Blue gum

Blue gum is a rapidly growing tree with some cold tolerance. However, the commonly

planted ssp. globulus suffered badly during the freeze of 1972. Large trees in the Berkeley Hills were killed back to their base. Subspecies maidenii and bicostata are considered more cold-hardy than ssp. globulus. These subspecies, along with ssp. pseudoglobulus, were formerly considered separate species from blue gum (Kirkpatrick 1974). The Australian Division of Forest Research (CSIRO) provided seed of 35 provenances of blue gum, including all its subspecies, and these will be field planted in 1985.

Other considerations

For species already provenance tested, large plot tests of the best seed sources should be established in several locations to judge their breadth of adaptability and to develop data on growth and yield. Tests of container methods, planting time and technique, and spacing are also needed to develop more effective systems of production. Other eucalypts that may be provenance tested include tingiring gum (E. glaucescens maid. and Blakeley) and swamp gum (E. ovata Labill.).

SELECTION AND BREEDING

To cover the wide variety of site and climatic conditions in California, it is likely that more than one eucalypt species will be used. Once superior provenances are identified, seed can be purchased from Australian seed dealers. But even greater growth and adaptability can be obtained by selecting and breeding eucalypts specifically for California. There is enough genetic variation within the commonly used species that we always find some outstanding individual trees even within the best provenances.

To capitalize on such variation requires selection of superior trees. The Institute of Forest Genetics has begun to select superior phenotypes in older plantations in California and in our own provenance tests at Concord. Trees in the older plantations have undergone one generation of selection under California conditions and have demonstrated their ability to withstand drought and cold. They constitute "land races." However, in an exotic species, there are limited possibilities for selection because the number of trees available is small.

Other eucalypt breeding programs, domestic and foreign, are another source of breeding material. The eucalypt breeding program in Florida has 40 clones of river red gum which should be tested in California. Perhaps even more valuable are selections of drought and saline tolerant

eucalypts made by the Agricultural Research Organization, Israel and by agencies in India. The Institute of Forest Genetics is proposing collaborative projects with both Israeli and Indian tree breeders working with fuel biomass programs.

Once superior individuals are selected, there are two approaches to produce improved planting stock; i.e., through seed production in seed orchards or by mass production of rooted cuttings. In seed orchards, selected trees are brought together, as grafted or rooted clones, and allowed to cross-pollinate. Eucalypts flower at an early age so seed orchards will produce commercial quantities of seed in a very few years. If selection has been effective, the seed should produce superior progeny. The alternative is to clone the selected individuals and use them directly, perhaps as rooted cuttings. While clonal production is more expensive than seed production, it also offers the possibility of greater immediate gains. Techniques for vegetative propagation are discussed by Boulay and Chaperon in this volume. Whatever the approach, seedling or clonal, the next step in eucalypt culture in California is to establish sources for superior planting materials, and it is likely to require a cooperative commitment between growers and the State and Federal governments.

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Realized Gain from Breeding *Eucalyptus grandis* in Florida¹

George Meskimen²

A small but intense eucalyptus research effort began in Florida in 1961 with the private, non-profit Florida Forests Foundation dedicated to investigating the commercial forestry potential of exotic hardwoods in south Florida. By 1965 we had established numerous eucalyptus experiments, including 14 screening trials testing a total of 156 seed sources representing 67 eucalyptus species. The Foundation was absorbed into the Southeastern Forest Experiment Station in 1967. Eucalyptus timber research was suspended until 1971 when a small research cooperative was formed with Federal, State, industrial, and private participants. Operational planting started in 1972 and in 10 years 8.8 million seedlings of *Eucalyptus grandis* Hill ex Maiden have been planted on 6,475 ha in southwest Florida. Every outplanted seedling was grown from genetically improved seed collected from local seed orchards.

Our tree improvement system had to accommodate two conditions:

(1) Imported seedlots will not produce commercial plantations in Florida. The most we can expect is that the better imported seedlots will produce occasional outstanding individuals which we can select and breed into a locally adapted strain.

(2) In 1972, industrial and private co-operators wanted to start commercial planting "immediately." Instant demand for improved seed dictated that provenance trials, tree selection, seed orchard establishment, and progeny testing be combined and accomplished concurrently instead of in the more conservative stepwise sequence.

¹Presented at A Workshop on Eucalyptus in California, June 14-16, 1983, Sacramento, Calif.

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Abstract: *E. grandis* is in the fourth generation of selection in southwest Florida. The breeding strategy combines a provenance trial, genetic base population, seedling seed orchard, and progeny test in a single plantation where all families are completely randomized in single-tree plots. That planting configuration closely predicted the magnitude of genetic gain realized through age 2.5 years in a simulated commercial plantation: up to 66 percent gain in tree height, 164 percent gain in stem volume, plus significant gains in stem straightness and freeze tolerance.

BREEDING METHODS

Grandis trees planted in southwest Florida constitute a landrace developed through three generations of selection and progeny testing in the local environment. Because of recurrent selection for local adaptation, the trees perform better in Florida than progenies of outstanding trees selected in Australia, South Africa, or elsewhere.

The breeding strategy involves importing as many *E. grandis* seedlots as possible--preferably collected from selected single trees in Australia. But some bulk lots have been included, plus many lots from exotic populations outside Australia. Each seedlot (called a family) contributes about 60 seedlings to a large outplanting called the genetic base population. All individuals of all families and all sources are completely randomized in single-tree plots. Stocking is 1,916 trees/ha in a precise row X column grid, mapped to preserve the location and pedigree of each tree. Trees are measured for growth rate and scored for cold hardiness, stem straightness, branch habit, and general adaptation. At 2.7 years (one-third of rotation age), the best trees are selected and the rest are rogued to convert the base population to a seedling seed orchard. The best families usually contribute three or four selects to the seedling seed orchard; most families contribute only one or two; and about one-third of the families drop out of the breeding population for lack of any worthy candidates.

Select trees exchange pollen in the first general bloom at age 3+ years. The following spring the resultant seed is collected and used to establish the next generation's base population, which is also the progeny test of the seedling seed orchard. Thus a generation is turned, from seed to seed, in 4 years. Progeny test results identify the best commercial seed trees as well as poor seed trees to be rogued from the orchard.

Each generation of selection enhances the landrace's adaptation to local conditions, but new families must be imported to broaden the genetic base and guard against inbreeding depression. The current grandis population, planted in 1977 (G-POP77), consists of 31,725 trees representing 529 families on 17.3 ha. Nine percent of the families are fourth generation (great grandmothers selected for excellence in a Florida plantation); 24 percent, third generation (grandmothers selected in Florida); 40 percent, second generation (mothers selected in Florida); and 27 percent, first generation (newly imported families). Geographically, 37 percent of the families trace their maternal pedigrees back to New South Wales; 32 percent originate in Queensland; 21 percent from South Africa; 4 percent from many miscellaneous nations; and 6 percent cannot be traced beyond Florida.

The Florida breeding strategy presents two radical departures from usual methods. We combine a provenance trial, a genetic base population, a seedling seed orchard, and a progeny test in a single plantation. We do that simply to compress development time and to concentrate our meager resources of staff and budget.

Our other departure is to plant all the individuals representing a family in completely randomized, single-tree plots. This contrasts with the replicated square plots or row plots used in most tree improvement plantings. Completely randomized, single-tree plots offer several advantages: (1) Each family is maximally dispersed across the planting site, encouraging a thorough sampling of microsites and an accurate estimate of site adaptation. (2) Maximal dispersion promotes random mating of select trees and eliminates the need to choose between outstanding sibling selection candidates standing side by side in the same multitree plot. (3) Different families can be represented by different numbers of individuals with no statistical or operational problems; likewise, mortality causes no problems. (4) Each tree is a replicate of its family and represents a statistical degree of freedom. This efficient, robust design enables us to screen more families with fewer trees.

INDICATED GAINS

In the current base population, G-POP77, comparison of first-, second-, third-, and fourth-generation families shows impressive evidence of genetic gain (fig. 1). At age 2.5 years the average first-generation tree contained 7.5 dm³ of stem wood and bark from groundline to tip. Second-generation stems grew nearly twice as large, averaging 14.6 dm³. Third-generation stems show an additional 16 percent increment up to 17.0 dm³, and fourth-generation yet another 16 percent up to 19.7 dm³.

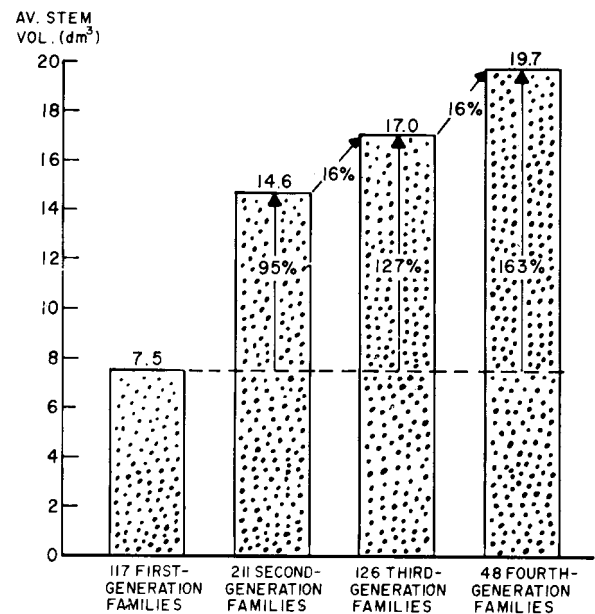


Figure 1--Family mean stem volume at age 2.5 years in G-POP77, the *E. grandis* base population planted in 1977.

These results imply that at one-third of rotation age, Florida landowners will be producing 2.6 times more wood from planting fourth-generation Florida seedlings instead of stock grown from imported seed. The case for local selection seems compelling considering that a large majority of first-generation families in G-POP77 are offspring of magnificent select trees in Australia and South Africa. But that parental magnificence is rarely reproduced by offspring planted in the Florida environment.

PERPLEXING QUESTIONS

Despite the promise, some thoughtful visitors and cooperators suggest that genetic gains measured in our combination base population-progeny test might seriously overestimate gains realizable in commercial plantations. The concern is that competition among trees might be far more severe in commercial plantations than in our base population.

Our base population-progeny test with its single-tree plots simulates commercial plantations in that offspring of all seed trees are randomly mixed on the planting site. Nevertheless there remains a perplexing difference between our base population and a commercial plantation: the range of genetic quality.

The difference is that our base population includes the entire spectrum of genetic resources

ranging from the most advanced families down to new introductions which lack adaptation and compete poorly. In contrast, commercial plantations are the truncated, compressed upper end of the genetic range. For example, G-POP77 consists of 529 families, but the 1979 commercial plantations include only the best 34 of those families--that's skimming just the best 6 percent of the cream off the top of our gene pool. The perplexing question is: What happens when these best families must compete just among themselves over hundreds of hectares? Does the "cream" stay sweet, or does it curdle from the intense heat of best competing against best?

A corollary question is: Can southwest Florida's poor soils, spring droughts, and summer flooding support such intense competition; or do environmental factors become limiting and render the most genetically advanced families no more productive than their ancestral, imported seedlots?

SEEKING ANSWERS

In 1979 we installed a small study called GAIN79 to answer those perplexing questions by measuring realized gain in a commercial plantation setting. This paper reports those gains and compares them with gains forecast by G-POP77.

GAIN79 compares three populations in four replications of 7- X 7-tree plots. The populations are:

Ancestral: Four imported seedlots from which many advanced-generation families descend. All Ancestral trees are first generation.

Commercial: The commercial seed mix for the 1979 planting season, composited from 34 advanced-generation families chosen for excellent early performance at G-POP77. Of the 34 commercial families, 22 are descended from Ancestral seedlots. The average Commercial tree is generation 2.9.

Premier: Six advanced-generation families, top ranked for the combined traits of volume production, cold hardiness, form, and coppicing. All six Premier families descend from Ancestral seedlots, and five Premier families are also among the Commercial families. The average Premier tree is generation 3.5.

GAIN79 simulates a commercial plantation as closely as possible. It was planted in the commercial site-preparation area at the same spacing employed by the landowner.

The G-POP77 and GAIN79 sites are located about 23 km apart in Glades County on a landtype known locally as palmetto prairie, a flat, naturally treeless expanse of saw-palmetto, wiregrass, runner oak, and wax myrtle. Soils are infertile, poorly

drained acid fine sands underlain by spodic hardpans. We hand planted both studies in July (G-POP77 in 1977, GAIN79 in 1979) on sites prepared in the spring by burning, broadcasting with 1,120 kg/ha of ground rock phosphate, double chopping (GAIN79) or triple chopping (G-POP77), then bedding. A major difference is planting density: 1,204 trees/ha at GAIN79; 1,916 trees/ha (59 percent more) at G-POP77. Our commercial recommendation is 1,495 trees/ha. The shortfall at GAIN79 is unfortunate but was dictated by the spacing of the commercially prepared beds.

We measured growth in both studies at 0.5, 1, 1.5, and 2.5 years and also scored tree form at 2.5 years. Additionally, GAIN79 was scored for damage following freezes at 1.5 and 2.5 years, and remeasured at 3.5 years.

EARLY GAINS

Growth Traits

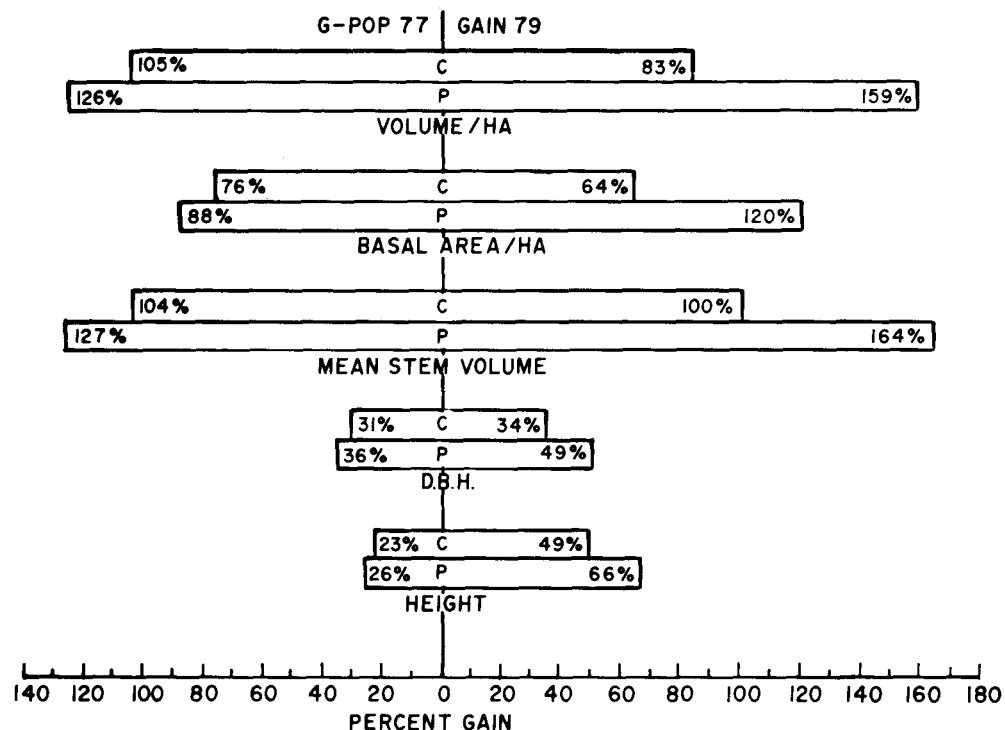
GAIN79 demonstrates impressive early growth gains similar to those forecast by G-POP77. Improved trees rapidly expressed superiority at both sites. Analysis of variance first detected highly significant gains for height growth at age 6 months in G-POP77 and at 1 year in GAIN79, and at 1.5 years for diameter and volume growth at both sites. At the oldest common measuring age, 2.5 years, Commercial and Premier trees stand a quarter to half again as tall as Ancestral trees with over twice as much wood in their stems (fig. 2).

Gains illustrated in figure 2 for GAIN79 amount to the following returns from breeding imported seedlots up to a Premier population: an average tree 2.3 m taller at age 2.5 years with 7.2 dm³ of additional stem volume or 3.3 kg more dry energy fuel; and an average hectare carrying 8 m³ more volume or 3.7 tons of additional dry energy fuel.³ Figure 3 characterizes breeding gains per stem, and figure 4 on a stand basis.

Figure 2 depicted percentage gains of comparable magnitude in both studies. The similar percentages are reassuring because they are based on markedly different growth rates at the two sites. The site difference is so extreme that the shortest population at G-POP77, Ancestral, averages taller at 2.5 years than the tallest trees, Premier, at GAIN79 (fig. 3). The pooled 2.5-year height of all three populations is 7.1 m at G-POP77 slipping to 4.8 m at GAIN79, a 32 percent reduction.

³Volume of stem wood and bark from groundline to tip; dry weight of wood and bark in stems and branches from ground to tip (formulas on file with Forest Service, USDA, Ft. Myers, Fla.).

Figure 2--Percentage gains in growth traits at age 2.5 year: for Commercial (C) and Premier (P) trees over Ancestral trees as predicted at G-POP77 and realized at GAIN79. All bars represent statistically significant gains.



Four factors could conceivably contribute to the site-growth differential: (1) inherent differences in site quality; (2) different stocking levels; (3) partially different growing years, July 1977-January 1980 at G-POP77 versus July 1979-January 1982 at GAIN79; or (4) the effects of competition within populations at GAIN79 versus competition among populations at G-POP77. Competition among populations would seem to disadvantage the unimproved Ancestral trees. Yet Ancestral trees grew 79 percent as tall as Premier trees while competing with them at G-POP77, but only 60 percent as tall while not competing with them at GAIN79. Empirically, stocking levels may play a large role in the site-growth differential. G-POP77, planted at 1,916 trees/ha had eliminated herbaceous competition by age 1.5 year; but GAIN79, with 1,204 trees/ha, still competes with a heavy ground cover after 3.5 years.

Whatever the adversities at GAIN79, improved trees coped better than unimproved trees. Ancestral trees grew only 55 percent as tall at GAIN79 as they had at G-POP77, but Commercial trees achieved 70 percent and Premier trees 76 percent of their G-POP77 performance. Our base population-progeny tests cannot be expected to predict actual growth on all sites. Nevertheless, in this case G-POP77 seems a reliable predictor of the magnitude of gains that improved populations will express in commercial plantations.

Tree Form

We evaluated tree form at age 2.5 years using the following scoring systems:

Stem straightness: 0 = too crooked for pulpwood, 1 = acceptable for pulpwood, 2 = good straightness, 3 = excellent straightness.

Branch habit: 0 = too limby for pulpwood, 1 = acceptable for pulpwood, 2 = good natural pruning and small branched, 3 = good natural pruning and fine branched.

G-POP77 forecast highly significant gains in stem straightness which were realized in GAIN79. G-POP77 also forecast highly significant gains in branch habit, but these were not realized in GAIN79 (fig. 5). The contradiction in the two traits is not surprising viewed in the context of tree selection.

As we search our base populations for selection candidates, the first trait we look for is vigor--candidates must be conspicuously larger than their neighbors or their siblings. We notice repeatedly that grandis stem straightness is independent of bigness, but branch habit is not. It is just as easy to find straight big trees as crooked big trees, and there is no need to compromise selection standards for either trait.

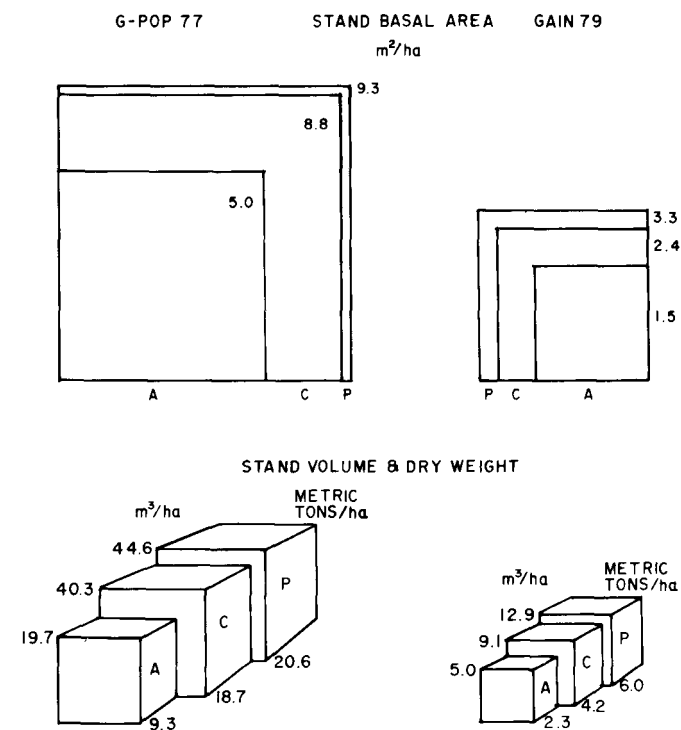
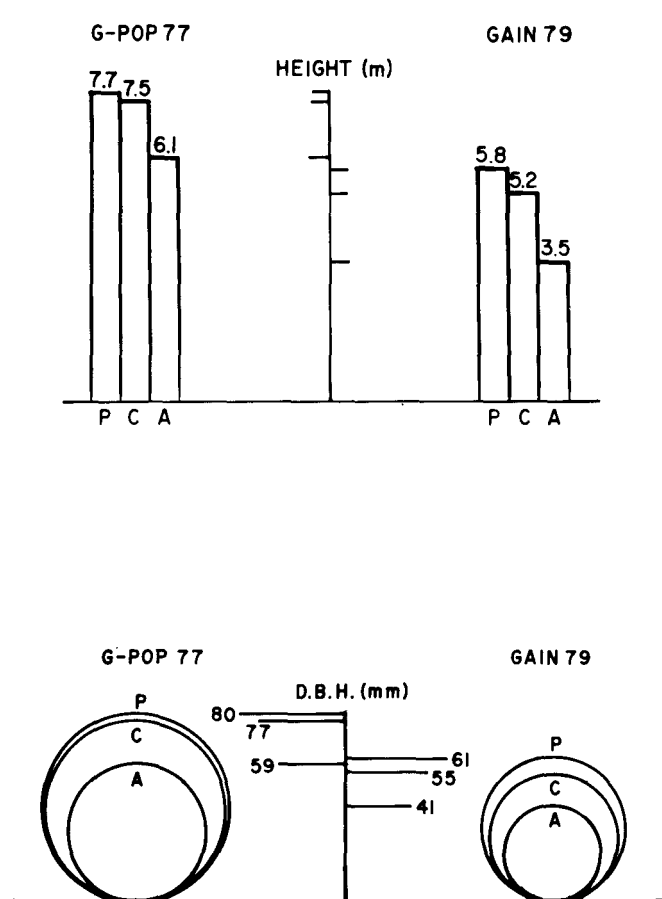


Figure 4--Stand basal area, volume of stem wood and bark from ground to tip, and dry weight of wood and bark in stems and branches for Ancestral (A), Commercial (C), and Premier (P) populations at age 2.5 years.

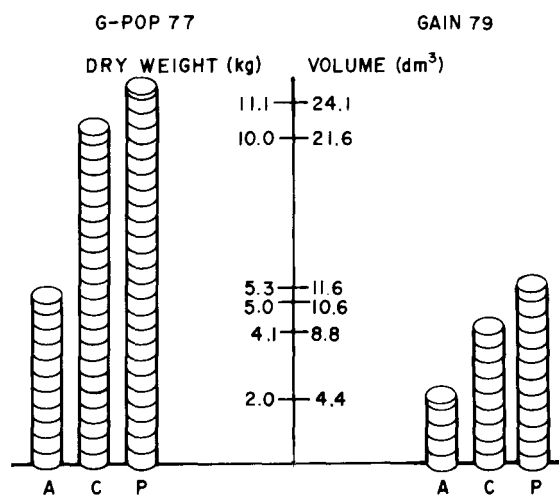


Figure 3--Mean stem values at age 2.5 years for Ancestral (A), Commercial (C), and Premier (P) trees.

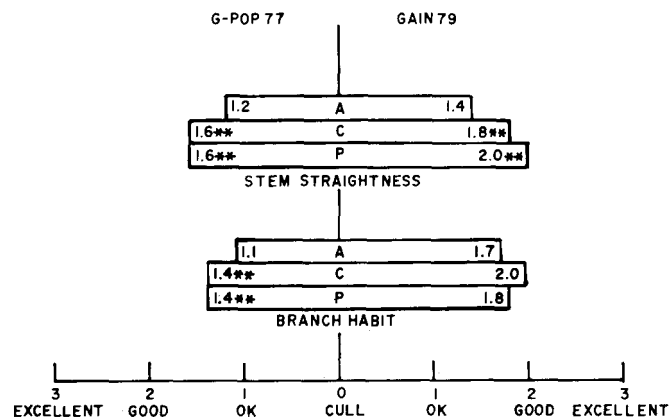


Figure 5--Mean scores for branch habit and stem straightness for Ancestral (A), Commercial (C), and Premier (P) trees, age 2.5 years, at GAIN79 and G-POP77. Asterisks signify significant (0.01 level) gains over Ancestral population.

In contrast, big trees have coarse branches far more commonly than fine branches. We have had to compromise--but never abandon--our standards on branch habit, especially when selecting from first-generation families.

The failure of GAIN79 to demonstrate predicted gains in branch habit may also be attributable to smaller tree size and wider spacing than at G-POP77. At the evaluation age of 2.5 years, trees at GAIN79 averaged 2 m shorter than at G-POP77. It is difficult to infer the mature relationship between branch size and bole size until saplings are quite advanced. Also the natural pruning aspects of branch habit are not evident until growth rate and stocking converge at partial crown closure. The natural expression of branch habit might also have been altered or delayed at GAIN79 by recovery sprouts arising after freeze damage 1 year earlier.

Gains in form may seem miniscule--no more than 0.6 of a scoring unit--but that perception changes if gain is expressed as the percentage of movement along the scale from the score of unimproved trees to the maximum score of 3. A sample calculation follows for Premier stem straightness at GAIN79:

$$\frac{\text{Premier score} - \text{Ancestral score}}{3 - \text{Ancestral score}} \times 100 = \text{percent gain}$$

$$\frac{2.0 - 1.4}{3.0 - 1.4} \times 100 = 38 \text{ percent gain}$$

So computed, the Premier and Commercial scores presented in figure 5 translate to the following percentage gains:

	<u>G-POP77</u>	<u>GAIN79</u>
<u>Stem straightness</u>		
Premier	22**	38**
Commercial	22**	25**
<u>Branch habit</u>		
Premier	16**	8
Commercial	16**	23

**Represents gain significant at the 0.01 level, based on ANOVA of actual scores.

Freeze Damage

Severe frost damages grandis even in the recommended planting zone, but the trees rarely die. They may freeze back, but they sprout and regrow vigorously. Frost has cost a season's growth several times but never a plantation. Southwest Florida usually has inversion freezes with temperatures coldest at ground level but moderating dramatically in the first meter or two above ground. Marginally hardy trees like E. grandis can reduce risk simply by growing fast--elevating tender crown tissue above lethal temperatures while building larger stems with

thicker, insulative bark close to the ground. Each additional year of growth reduces risk. Since research planting started in 1961, severe damage has been suffered 1 out of 3 years by seedlings in their first winter, 1 out of 4 years by saplings in their second winter, and 1 out of 11 years by trees in their third winter or older. We make freeze tolerance a prime selection criteria--whenever nature "blesses" one of our base populations with a severe freeze.

In its four winters to date, GAIN79 has been statistically unlucky with two significant freezes. A moderately hard freeze occurred January 13, 1981, with low temperatures near -8.5°C (16°F). Damage was moderate to severe at GAIN79, then in its second winter; in contrast, damage was slight at G-POP77 in its fourth winter.

One year later a catastrophic freeze struck with temperatures as low as -11.5°C (11°F), and subfreezing for 8 hours. The 1982 freeze devastated all grandis trees in Glades County, regardless of age or size. The eucalypts were particularly vulnerable to the 1982 freeze because of a total lack of preconditioning. The preceding month included 21 days with afternoon highs above 27°C (80°F). We scored damage from both freezes at GAIN79. At G-POP77, damage was too light to score in the first freeze, and other priorities precluded scoring the severe freeze.

We score cold damage on an 11-point scale ranging from 10 (undamaged) down to -1 (frozen dead); categories 9 down through 5 denote increasingly severe damage confined to leaves; and categories 4 down through 0 describe increasingly severe wood destruction in branches or bole. Figure 6 details the scoring system. Figure 7 profiles damage suffered by Ancestral, Commercial, and Premier trees at GAIN79.

Figure 7 starkly illustrates that while breeding has made substantial progress toward minimizing damage from moderate freezes, some south Florida freezes are so severe as to probably exceed the natural variation available for selection in the species. In the moderate freeze, Ancestral trees suffered bark splitting and injury to primary branches and main stems, but Commercial trees only lost their leaves, and Premier trees actually retained about 25 percent of their leaves.

If these gains in a moderate freeze are converted to percentages computed in the same manner as for tree form, they amount to a 31 percent gain for Commercial trees and a 53 percent gain for Premier, gains notably similar to the percentage gains for height growth presented in figure 2. We do not think that we are breeding a meaningful improvement in physiological cold resistance, but we do think we are breeding a significant improvement in cold tolerance based primarily on growing big enough, fast enough to avoid lethal temperatures in the inversion layer.

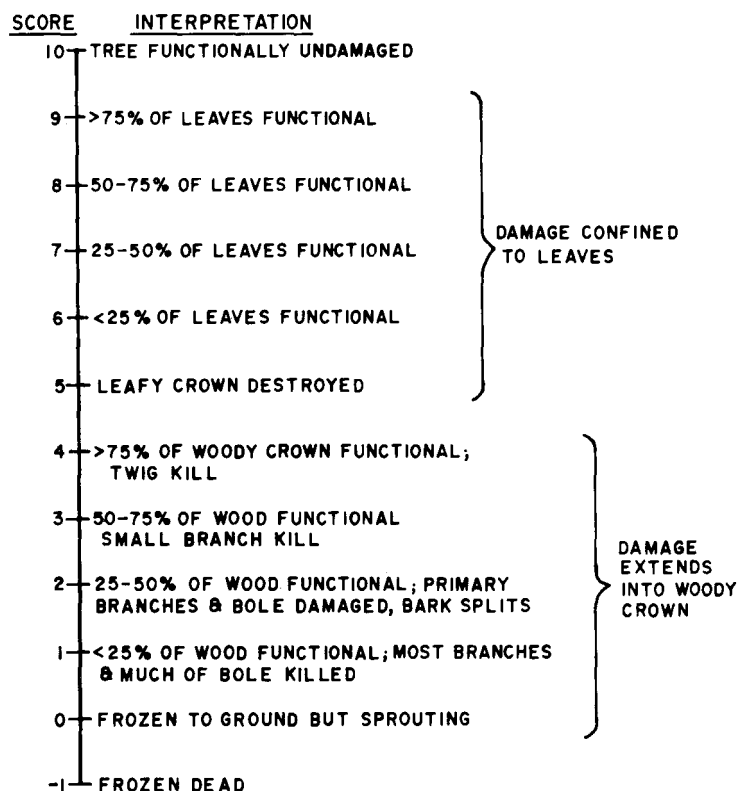


Figure 6--Cold damage scoring system.

Whatever the nature of our gains, the catastrophic freeze overwhelmed them. Ancestral, Commercial, and Premier trees averaged respectively 0.2, 0.6, and 0.8 on the damage scale (fig. 7), and no individual tree scored higher than 1. Converted to percentages as before, these miniscule gains amount to 4 percent for Commercial and 6 percent for Premier.

In a freeze of this magnitude, breeding gains need to be expressed in the most basic trait: survival. During the year following the great freeze, 22 percent of Ancestral trees died compared to 7 percent of Commercial trees and 4 percent of Premier trees, significantly heterogeneous mortality (χ^2 test, 0.01 level). Before the freeze, populations had not differed significantly in survival.

One year after the great freeze, GAIN79 has the following stand characteristics at age 3.5 years:

	Ancestral	Commercial	Premier
Survival (pct)*	73	81	89
Stocking (trees/ha)*	879	975	1,072
Mean height (m)**	3.2	4.7	4.8
Number of persistent freeze-recovery stems per stool	2.7	2.6	2.2

*Trait reflects population differences significant at the 0.05 level (χ^2 test); **trait reflects population differences significant at the 0.01 level (ANOVA).

MODERATE FREEZE 1-13-81, AGE 1.5 YEARS

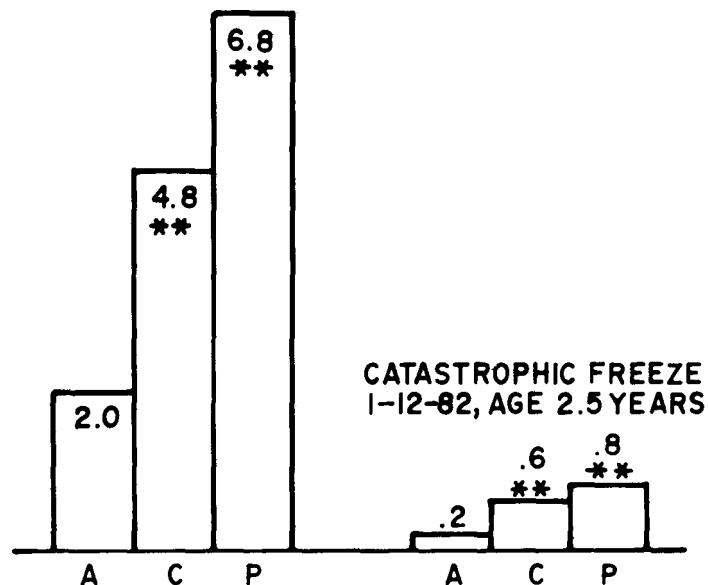


Figure 7--Mean cold damage scores for Ancestral (A), Commercial (C), and Premier (P) populations in two freezes at GAIN79. Asterisks denote scores significantly (0.01 level) above Ancestral score.

The 1982 freeze seems so devastating in the context of this report that we need to view it in broader perspective. The freeze was isolated, almost confined to a single county. Damage was slight to eucalyptus plantations in other suitable growing areas. Freeze damage approaching this severity has not been seen in southwest Florida since 1962. In the interim, two complete rotations could have been planted, grown, harvested, and regenerated. Within the freeze zone the loss of wood inventories depended on age class. Plantations in their first or second winter were frozen to the ground and regenerated from ground level coppice shoots. They will develop as normal coppice stands. Plantations in their fifth, sixth, seventh, or eighth winter suffered severe damage to crown tissues but not to product boles. Those age classes will refoliate and grow on to scheduled harvest with little economic loss. Plantations in their third and fourth winters (GAIN79) suffered profound damage to product boles; stems that recovered are often badly forked or so weakened that subsequent wind breakage seems likely. These age classes, however, would constitute only 25 percent of plantation area in an even distribution of age classes. Freeze damage is an acceptable investment risk that can be ameliorated by adding freeze resilience--swift, graceful recovery--to our tree selection criteria.

CONCLUSIONS

Back-to-back freezes savagely reduced growth and stocking at GAIN79 and converted it from a single-stemmed seedling stand to a multistemmed coppice stand. These transformations are not economically or esthetically pleasing, but they demonstrate graphically that breeding advanced-generation strains from local selections is probably the most important element in managing the investment risk of growing eucalypts in Florida.

Despite great discrepancies in stocking and productivity, G-POP77 either accurately or

conservatively forecast the magnitude of genetic gains realized at GAIN79. It seems both efficient and efficacious to breed local landraces in genetic plantings that combine the functions of provenance trial, base population, progeny test, and seed orchard. Completely randomized, single-tree plots seem to be a reliable planting design for ranking populations and predicting the magnitude of realized gains.

ACKNOWLEDGMENT: I thank Lykes Bros., Inc., for experimental sites and land preparation.

Standiford, Richard B; Ledig, F Thomas, technical coordinators. **Proceedings of a workshop on *Eucalyptus* in California, June 14-16, 1983, Sacramento, California.** Gen. Tech. Rep. PSW 69. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1983. 128 p.

To provide up-to-date information on *Eucalyptus* in California, researchers from California, Florida, Hawaii, Oregon, and France presented papers on species selection, products, uses, and economics, growth and yield, cultural requirements, propagation, and breeding programs. This Proceedings of the Workshop should serve as a useful reference for landowners, foresters, nurserymen, horticulturists, and others who are planning to plant *Eucalyptus*.

Retrieval Terms: *Eucalyptus*, short-rotation trees, biomass, wood energy