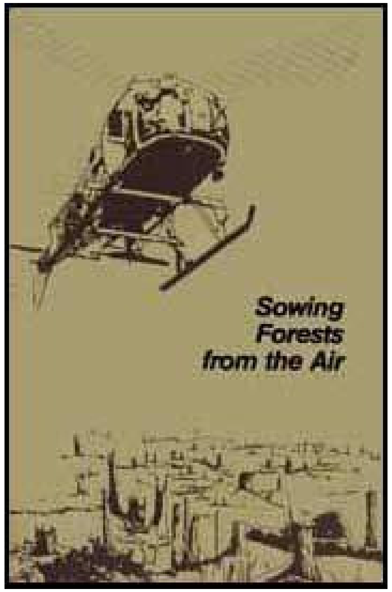

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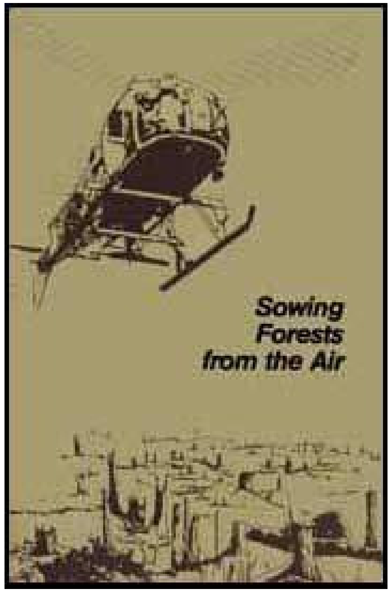

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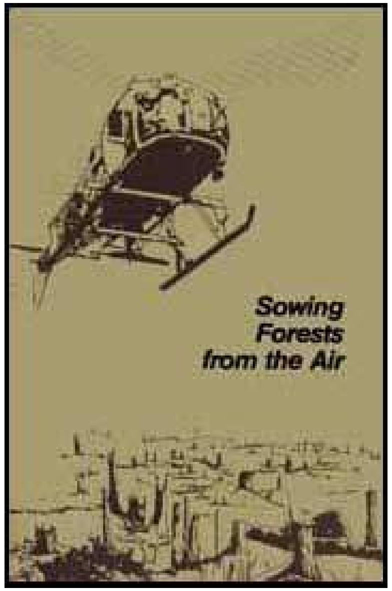


7 Recommendations and Research Needs

Aerial seeding presents many challenges for researchers, especially those in

developing countries. While technology and techniques are developed and available, they are yet to be tested and adapted for use in those Third World areas now suffering devastating deforestation. Because experience with aerial seeding of forests in the humid tropics is limited, little is known about predators and the best species to sow.

The panel recommends that reforestation efforts include an evaluation of the potential of aerial seeding. Researchers are encouraged to consider the more desirable timber and pioneer species growing naturally in their area, along with suitable species such as those listed in Table 2. Aerial seeding could be an expensive failure unless small-scale trials show that direct seeding can be successful for the given species and sites.

Initially, these trials do not require use of aircraft. It is necessary only to broadcast a small amount of seed (pretreated, if necessary) on a small patch of the area being tested with conventional tree-planting methods. However, to evaluate fully the promise of aerial seeding in a given area, researchers must consider:

· The characteristics of species, especially the ability of its seed to germinate without being covered;
· The choice of site and site preparation;
· Effect of season and weather on best time for sowing;
· Seed acquisition;
· Seed handling (storage, transport, care in the field);
. Seed preparation (stratification, coating with animal repellents, inoculation, testing the

coatings for toxicity to seeds or seedlings); and
· Major predators.

Existing plantations and natural stands can sometimes demonstrate how successful direct seeding is likely to be. They indicate the best season to sow the seeds and can generally foretell the seed predation and the success of natural germination (care must be taken that the natural germination being observed is occurring in conditions that approximate those on sites to be sown). The silvics of the species in question should be studied to determine its suitability for direct seeding.

Direct-seeding trials should first be implemented at sites favorable for seeding, and then, with experience, should move to the more difficult sites.

Along with all direct-seeding trials should be some seedling-planting trials. The relative costs and successes of the two techniques can be better judged when they are done in tandem.

Before aerial seeding, sites should be chosen and inspected, if possible, at least 8 months in advance. Factors to be considered include:

. Extent of grazing by livestock and wildlife;
· Infestations of ants, rodents, and seed-eating birds;
· Areas where kees are adequately reproducing naturally;
· Conditions of seedbed and need for burning the site; and
· Advantageous ridges from which aircraft can be guided.

With this information plans can be made for site preparation, seed procurement,

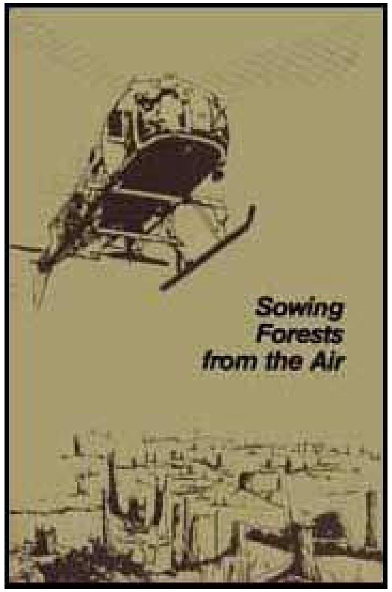
and any seed coatings.

Researchers wishing to improve the technology and techniques of aerial seeding might pursue the following challenging research projects:

. Aerial reforestation of regions covered with Imperata and other vigorous tropical grass species;
· Development of seed coatings for use in dry sites that absorb and hold water and yet do not disintegrate rapidly;
· Improvement of seeding equipment to provide greater control over seedling density and spacing;
. Development of less hazardous chemicals for protecting seeds from rodents, insects, and birds (some examples worth considering are methiocarb -registered in the United States as a bird repellent for use on corn- tannins, lithium chloride, extract of red squill (Urginea maritima), copper sulfate, and cyclophosphamide. Information supplied by Glenn A. Hood, U.S. Fish and Wildlife Service, Building 16, Denver Federal Center, Denver, Colorado 80225, USA.) and
. Development of seed coatings containing spores of mycorrhizal fungi.

The existing knowledge on seed coating and pelleting should be reviewed. Successes and failures are reported in different situations.

Seed can be targeted accurately (often within a meter or two). Thus aerial seeding might prove feasible for filling in the widely scattered breaks in the forest left by slash-and-burn farmers with useful species that best protect the vulnerable soil.



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Appendixes

Appendix A

Direct Seeding from the Ground

In addition to sowing by airplane or helicopter, tree seeds can be broadcast by hand, hand-operated "cyclone" seeders, or tractor-drawn machines. A few examples are shown below. These systems have been made practical for use by the seed coatings developed for aerial seeding use. (U.S. Forest Service photos).

Appendix B

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W. F. MANN, JR. (deceased) was chief silviculturist with the U.S. Forest Service, working for the Southern Forest Experiment Station at Alexandria, Louisiana. He received a B.S. in forest management from Pennsylvania State University in 1937 and an M.F. in silviculture at Louisiana State University in 1964. He headed a nine-man multidisciplinary team of scientists studying methods of artificial regeneration, vegetation control, growth and yield of southern pines, and site preparation and amelioration. He wrote more than 150 papers on a broad array of subjects, but was best known for his work on direct seeding and growth and yield

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FRANOIS MERGEN, Pinchot Professor of Forestry, Yale University, was Dean of the School of Forestry and Environmental Studies at Yale during 1965-1975. He received a B.A. from Luxembourg College, a B.Sc.F. from the University of New Brunswick (Canada) in 1950, an M.F. in ecology from Yale in 1951, and a Ph.D. (forest genetics) in 1954 from Yale. He is especially knowledgeable about Francophone Africa and is currently chairman of the BOSTID Sahel program and a member of BOSTID'S Advisory Committee on Technology Innovation. He was research collaborator at the Brookhaven National Laboratory, 1960-65. In 1966, he received the Award for Outstanding Achievement in Biological Research by the Society of American Foresters. He was Distinguished Professor (Fulbright-Hays Program) in Yugoslavia, 1975. Prior to joining the Yale faculty, he served as project leader in forest genetics for the U.S. Forest Service in Florida. Dr. Mergen has also sened at various times as a consultant to FAO, foreign governments, and private

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FRANCIS R. MOULDS, head of his own forestry consultancy service in Australia, received his M.F. in 1946 and Ph.D. in 1951 from Yale University. He was former Principal, Victorian School of Forestry, and lecturer in forest economics at the University of Melbourne, Australia. For several years he was chief of the Division of Forest Education and Research and of the Division of Forest Management with

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ALAN H. NORDMEYER, a research scientist with the Protection Forestry Division of the Forest Research Institute, New Zealand Forest Service, Christchurch, New Zealand, received a master's degree in agricultural sciences in the area of agricultural microbiology, Lincoln College, University of Canterbury, 1966. His present work concerns the use of plants for erosion control in New Zealand.

JAMES D. SCOTT, a silviculturist with the Ontario Ministry of Natural Resources, Canada, received his B.Sc.F. in 1948 from the University of New Brunswick. He signed as forest management supervisor in three districts of the Ministry (formerly Department of Lands and Forests) before being transferred to the head office of the Ministry, Toronto, in 1960. Since then, he has been engaged in several silvicultural fields including aerial seeding programs, planting machine development, and research on other silviculture equipment. More recently, he became silviculturist for that part of Ontario specializing in hardwoods and pine.

NOEL D. VIETMEYER, staff director for this study, is a Professional Associate of the National Academy of Sciences. Recipient of a PhD. in organic chemistry from the University of California, Berkeley, he has been staff officer for a number of NAS studies that have drawn attention to unconventional aspects of science that could be helpful to developing counkies.

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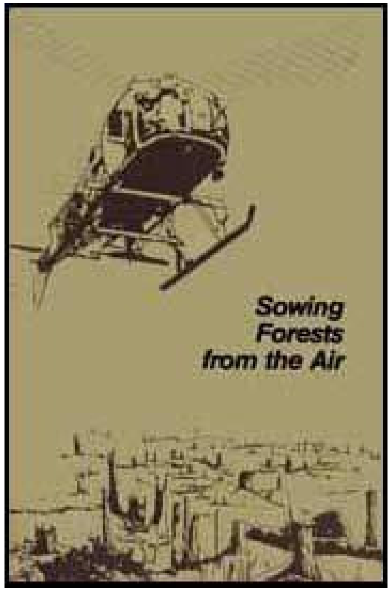

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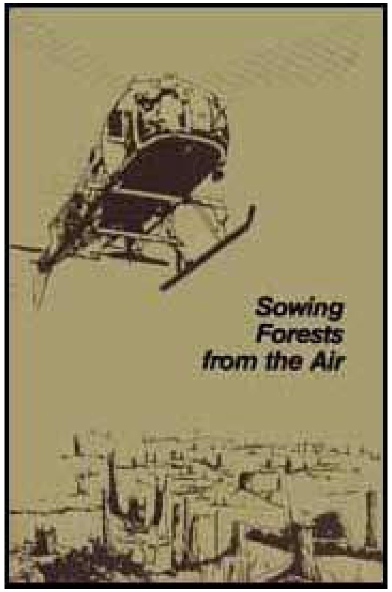

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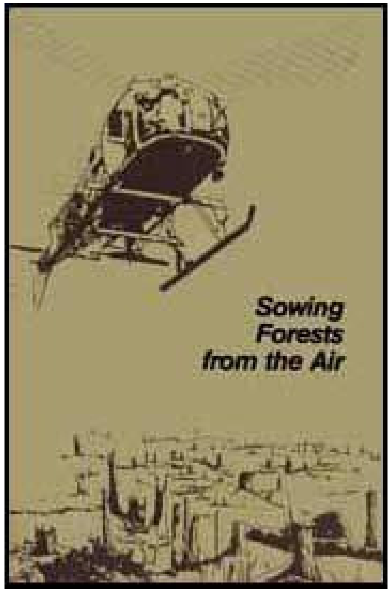

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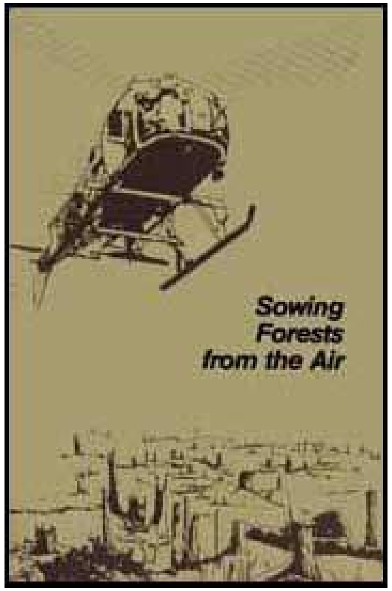

Preface

When people first cultivated trees, they walked the land, sowing seed the way they sowed crops. Later, as foresky became more sophisticated, seeds were germinated in nursery beds and seedlings transplanted to the field. This method required less seed, enhanced seedling survival rates, made tree growing more reliable, and gave trees a healthier start. Moreover, because the seedlings could be properly spaced, transplanted seedlings produced more-uniform forests and an increased growth rate.

Today, however, this planting technique seems not to fulfill all the demands for reforestation, especially in the poorer nations of the tropics and dry areas. In those regions, forests are being destroyed on an unprecedented scale. In 1973, for example, the annual rate of forest destruction in the Philippines was conservatively placed at 172,000 hectares, while reforestation was a mere 16,300 hectares. It was estimated that more than 5 million hectares of deforested land were then awaiting planting, of which 1.4 million were located on critical watersheds subject to serious erosion, and that reforesting just these denuded watersheds would take more than 60 years at the existing rate (Glory, A., cited in Dalmacio, M. V., and Barangan, F. 1976. Direct-seeding of Pinus kesiya. Philippine Forest Research Journal 1 (3): 215-222).

If even a fraction of such forest areas is to be restored, existing planting techniques should be supplemented with methods that require less organization, less infrastructure, less capital investment, and that enable rapid reforestation over vast areas.

One possibility may be the "primitive" practice of sowing seed directly on the site to be forested. This method is known to foresters as direct seeding, broadcast

seeding, or broadcast sowing. The availability of chemicals for coating seeds to repel birds, rodents, and insects has made this a practical and more reliable method of reforestation.

This report discusses reforestation in which the seed is broadcast from a plane or helicopter. It relies mainly on experiences in Australia, New Zealand, Canada, and the United States. It is not a textbook nor a practical guide to aerial seeding: details of the operations and techniques can be found in the selected readings, Appendix B. Our purpose here is to show administrators and foresters that this fast and often economical technique can be successful on appropriate sites, at least in temperate climates. The panel hopes that the report will stimulate trials with, and research into, direct seeding (with or without the use of aircraft). In particular, trials are neededin the tropics where deforestation is most severe, to see if it can become a successful weapon in the war on tropical deforestation-a war now being lost.

Aerial seeding is unproven in the tropics. The panel's purpose is not to recommend it over conventional reforestation techniques but to suggest trials of aerial seeding as a possible supplementary tool.

The panel that produced this report met from November 7 to 9,1979, in Birmingham, Alabama, and Pineville, Louisiana, to examine pine forests that had been aerially seeded 20 years before. In Alabama, they toured mine-spoil banks once devoid of all vegetation but now densely forested as a result of aerial seeding. In Louisiana, they toured direct-seeded pine forests occupying former grasslands and cutover pine lands.

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The final draft was edited and prepared for publication by F. R. Ruskin.

The Advisory Committee on Technology Innovation of the Board on Science and Technology for International Development, National Research Council , is assessing scientific and technologIcal advances that might prove especially applicable to problems of developing countries. This report is one of a series that explores promising areas of plant science that heretofore have been unknown, neglected, or overlooked. Other titles include:

· Underexploited Tropical Plants with Promising Economic Value (1975)
· Products from Jojoba: A Promising New Crop for Arid Lands (1975)
· The Winged Bean: A High-Protein Crop for the Tropics (1975)
· Making Aquatic Weeds Useful: Some Perspectives for Developing Countries (1976)
· Guayule: An Altemative Source of Natural Rubber (1977)
. Tropical Legumes: Resources for the Future (1979)
. Firewood Crops: Shrub and Tree Species for Energy Production (1980)
. The Potential for Alcohol Fuels in Developing Countries (in preparation)
· Producer Gas: A Little-Known Fuel for Motor Transport (in preparation)

- **Vegetable Oils as Diesel Fuel (in preparation)**

For information on obtaining copies.

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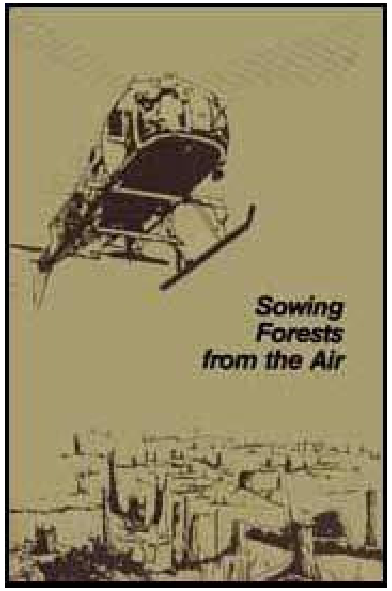

Advisory Committee on Technology Innovation
Board on Science and Technology for International Development

1 Introduction

In many parts of the world, deforestation has reached critical proportions. Africa, Asia, and Latin America have vast areas of once-forested land that is now denuded. Many have been left largely unplanted. Removal of tree cover threatens to destroy already fragile environments. Without trees and their root systems, heavy rains on the hillslopes cause rushing water that erodes the land and produces devastating floods that despoil highways, dams, bridges, towns, villages, and farm lands.

There is no end in sight to the destruction caused by unregulated deforestation: ever-swelling numbers of local farmers cut and burn the forest for land to grow crops; more and more villagers and entrepreneurs harvest trees for fuelwood and charcoal as escalating prices preclude the use of kerosene for cooking and heating; increasingly, pastoralists clear forests and shrubland for grazing; and timber remains the fourth- or fifth-largest export from the Third World to industrialized countries.

Some countries-Haiti, for instance-have essentially eliminated their forests, while many others could reach total deforestation before 1990 (see Table 1). The deforested land is often lost to coarse, almost useless grasses (such as Imperata cylindrica) or to a wilderness of shrubs and scrubby trees with little or no value to commerce or to villagers. Some 25 million hectares of such marginal land already exist in Thailand, the Philippines, and Indonesia alone.

These enormous areas of virtually unproductive land are increasing. Traditional revegetation methods should be applied more extensively, but the time also seems right for examining alternative methods.

Dropping seed from planes or helicopters is a well-known and well-established technique for sowing pastures as well as agricultural crops such as soybeans, wheat, and rice. Forests have also been established in this way. However, aerial seeding of forests is largely unappreciated, even by most foresters; it now seems worthy of increased testing and research.

When conditions and species are right, and seed supplies sufficient, aerial seeding could be an important technique for reforesting large areas. It is easy to organize and seems well suited for reforesting sites that have rough terrain, debris, or difficult access. If it can be developed for sites and objectives in developing countries, aerial seeding could offer opportunities for vastly accelerating their reforestation programs.

TABLE 1. Areas of Rapid and Widespread Deforestation (In these areas, the present rate of deforestation is so great that within about 10 years most virgin forests will be extinct. Source: Myers, 1980, pp. 169-170)

Region	Environment
Australia	lowland tropical forests in the north
Bangladesh	lowland and upland rainforests
India	predominantly seasonal forests, mainly upland
Indonesia	Sumatra and Sulawesi lowland, predominantly rainforests

Malaysia	lowland, mainly rainforests
Melanesia	mainly rainforests
Philippines	lowland, mainly rainforests
Sri Lanka	rainforests, mainly upland
Thailand	seasonal forests, both upland and lowland
Vietnam	seasonal forests, both upland and lowland
Brazil	eastern and southern Amazonia, Atlantic coast
Central America	rainforests, both upland and lowland
Colombia	lowland rainforests, Caqueta and Putumayo regions
Ecuador	Pacific coast forests, lowland and upland
Madagascar	rainforests, lowland and upland
East Africa	relict montane forests, especially in northern Tanzania
West Africa	seasonal forests

Aerial reforestation is not a replacement for planting seedlings by traditional methods. It is best considered as a potential complement to conventional planting and to natural seeding, an additional tool for foresters to use when the needs, sites, and species are appropriate.

Sowing tree seed directly in the field is an old technique but it was little used until the development of repellents to protect seed from insects, rodents, and birds. In the United States, the initial breakthrough came in 1953 when several chemical seed coatings proved effective in repelling birds. Then in 1956 it was learned that

an additional coating of commercial insecticide would guard the seed against insects and rodents. These findings signalled the beginning of large-scale aerial seeding of forests, especially in Louisiana.

Today aerial seeding is already regarded as a practical reforestation technique in a few countries. There it is fully operational. More than a million hectares of well-stocked forests in the United States, Canada, Australia, and New Zealand demonstrate its success. Some of these forests have been established despite seemingly adverse conditions-for example, on steep slopes and on overburden from strip mines.

Although aerial seeding technology has been used mainly in industrialized countries in temperate areas, it would seem the techniques could be modified for use elsewhere. Whether it will prove widely applicable in the arid tropics is still unknown. The uncertainties regarding its application in new regions lie mostly in whether the native animals and plants, as well as local climatic conditions, will permit its success. Nonetheless, sufficient knowledge has been accumulated in large-scale operations in North America and Australasia to justify wide-ranging trials in developing countries.

When sites and species are right, aerial seeding can be as successful as the more conventional process of planting seedlings. For example, pine forests have been well established in over 90 percent of the attempts in the southern United States.

Some species successfully sown from the air in various parts of the world are listed in Table 2.

TABLE 2. Some Species Succesfully Sown from the Air

Species	Common	NameLocation
Acacia auriculiformis		Indonesia
Betula allegheniensis	yellow birch	Canada
Calliandra calothyrsus	calliandra	Indonesia
Cecropia obtusifolia	trumpet tree	Hawii
Eucalyptus camaldulensis	river red gum	Australia
E. delegatensis	alpine ash	Australia
E. globulus	blue gum	Australia
E. grandis	flooded gum	Australia
E. nitens	shining gum	Australia
E. obliqua	messmate stringybark	Australia
E. regnans	mountain ash	Australia
E. viminalis	manna gum	Australia
Leucaena leucocephala	leucaena	Pacific Islands
Liquidambar styraciflua	sweet gum	Honduras
Liriodendron tulipifera	tulip poplar	United States
Melochia indica	melochia	Hawaii
Picea glauca	white spruce	United States
P. mariana	black spruce	Canada
Pinus banksiana	jack pine	Canada

P. contorta	lodgepole pine	United States, New Zealand
P. elliottii	slash pine	United States
P. nigra	black pine	New Zealand
P. mugo	Swiss mountain pine	New Zealand
P. palustris	longleaf pine	United States
P. ponderosa	ponderosa pine	United States, New Zealand
P. radiata	Monterey pine	New Zealand
P. resinosa	red pine	United States
P. rigida	pitch pine	United States
P. taeda	loblolly pine	United States
P. virginiana	Virginia pine	United States
Populus spp.	Cottonwood	United States
Pseudotsuga menziesii	Douglas fir	United States
Robinia pseudoacacia	black locust	United States
Sesbania grandiflora	turi	Indonesia
Spathodea campanulata	African tulin tree	Hawaii

Direct Seeding

Aerial seeding is just one example of the more general process of broadcast seeding by which the seed may also be sown from the ground using mechanical spreaders or by hand. Ground-seeding methods will be preferable to aerial seeding in many situations in developing countries. In such cases, the principles and

requirements are similar to those discussed here.

Ground seeding is not the focus of this report, but some of its techniques are depicted in Appendix A. The advantage of the airplane is its ability to quickly seed large areas, even remote areas, when conditions for prompt germination and survival are best.

Aerial Seeding Sites

Aerial seeding is best suited to sites whose remoteness, ruggedness, inaccessibility, or sparse population make seedling planting difficult. It is particularly appropriate for "protection forests" because helicopters or planes can easily spread seed over steep slopes or remote watersheds and isolated upland areas. It seems well suited for use in areas where there may be a dearth of skilled laborers, supervisors, and funds for reforestation (Large tracts can be seeded so rapidly that supervising personnel are freed for other duties in a relatively short time. A ground crew of only three flagmen and two men to weigh and load seed are usually required). It has the potential to help increase production of tree crops for forage, food, and honey as well as wood for fuel, posts, lumber, and pulp.

Aerial seeding can often be quickly deployed because there is no wait for seedlings to grow in a nursery (which may take 3 months to 3 years). It may be used on areas denuded by clear cutting or shifting cultivation. Also, sites of catastrophes such as forest fires, hurricanes, insect devastation, battles, volcanic eruption, or landslides can be promptly reseeded with useful tree species if seed is available (sometimes a deliberate burn or other technique may be needed to

remove weeds and complete preparation of the seedbed). For example, if a wildfire bares the soil on a remote watershed and makes it vulnerable to erosion, aerial seeding can be used on the ash-strewn seedbed before weedy species overrun the site. In some cases, a mixture of seed can be applied so that herbaceous plants such as mustard, grasses, or herbaceous legumes provide a quick ground cover that protects and "nurses" the young tree seedlings and suppresses undesirable weeds.

On the other hand, rapid deployment may not be practical in some cases because the site may require preparation or the season may be wrong.

To germinate successfully, seeds usually must fall directly onto mineral soil rather than onto established vegetation or undecomposed organic matter. Where organic matter has accumulated thickly, the site must normally be burned, furrowed, or disked. The soil disturbance left after logging is often sufficient. Rough terrain is especially amenable to broadcast seeding.

On certain sites ground preparation may be necessary. Site preparation and the seeding operation must be well coordinated to meet the biological requirements for prompt seed germination and seedling survival. Dry sites may have to be specially ridged or disked so as to optimize the rainfall that reaches the seed. Excessively wet sites may need to be ridged or drained.

The degree of slope is not critical as long as seeds find a receptive seedbed. Steep watersheds, eroding mountain slopes, bare hillsides, and spoil-banks where vegetation is sparse are often suitable for aerial seeding (however, on some steep slopes with smooth, bare soil, rain may wash the seeds away too easily for

successful seeding). On steep strip-mine spoils in West Virginia and in Indonesia slopes of more than 30° (about 70 percent slope) have been successfully revegetated from the air.

Arid and savanna lands (for example, those where annual rainfall is under 500 mm) are most in need of reforestation. These are regions where aerial seeding in principle has exceptional potential. They include vast tracts of unused or poorly used land that has sparse tree cover and that is not confined to private land holdings, so it is generally accessible to aircraft. The native trees (such as species of Acacia, Prosopis, and other genera) in these areas are generally well adapted for survival under difficult field conditions. These are not species for timber as much as for firewood, forage, fruit, gum, erosion control, and other such uses. On dry sites, the amount of successful establishment is increased if the seed can be covered with a thin soil layer.

Species

As a prerequisite to any method of reforestation, the species selected must be adapted to the temperature, length of growing season, rainfall, humidity, photoperiod, and other environmental features of the area. Ideally, before aerial seeding takes place trial plots should be established to test those species most likely to germinate and grow successfully on the chosen sites. Even when one species has the right characteristics, it may be prudent to test seed of different provenances to fnd those best suited to the site.

Aerial seeding has been used mostly with conifers and eucalypts (see Table 2), although other species that reseed themselves successfully in a given region could

also be aerially seeded with reasonable probability of success. However, in nature seed germinates over a relatively long period, and though environmental factors may be hostile at one time, they usually prove favorable at another. With broadcast seeding, only one or two applications are made, the seeds germinate together, and if timing is off, the results will be poor.

Characteristics that make a particular species appropriate for aerial seeding include:

. Small or medium-sized seed,
· Frequent and prolific seed availability;
· Ability of the seed to germinate on the soil surface;
· Fast germination and rapid seedling growth,
· Ability to withstand temperature extremes and prolonged dry periods,
· Ability to tolerate a wide range of soil conditions;
· High light tolerance;
· Seed that is easy to collect in large quantities and to store for long periods;
· Suitability of seed for handling with mechanical seeding devices; and
· Rapid development of a deep taproot by seedlings to enable them to withstand adverse
climatic conditions in the period following germination.

Species with highly palatable seeds have little prospect of success because wildlife eat the seed before it has a chance to germinate. Also, small seeds and lightweight, chaffy seeds are more likely to drift in the wind, so they are harder to target during the drop. (This can be compensated for by adding a thick coating to the seed.) Small seeds, however, fall into crevices and are then more likely to get

covered with soil, thereby enhancing their chances of survival.

Aerial seeding may prove to work best with "pioneer" species, which germinate rapidly on open sites, are adapted for growth on bare or disturbed areas, and grow well in direct sunlight.

A list of species that may prove amenable to aerial seeding is given in Table 3.

Equipment

Aerial seeding is done by fixed-wing aircraft or helicopters, usually flying at 15-25 m altitude.

Airplanes already in use in pest control or aerial surveying can easily be adapted for use in aerial seeding by slightly modifying the hopper gate to control the flow of seed into the seed-distributing device (see below). Further, they can be used in association with their normal agricultural program, provided they can be utilized at short notice when the conditions for aerial seeding become suitable. Such aircraft are highly maneuverable and can operate from simple, improvised airstrips such as logging roads. Appropriate types are already available in most, perhaps all, developing countries (for a detailed study of the use of aircraft in agriculture see Akesson and Yates, 1974).

For over 20 years in the southern United States, helicopters have been employed to seed forests. Generally, they are more maneuverable than fixedwing aircraft and give better placement of seed; for example, along the edges and in the corners of irregular tracts of land, on steep mountainsides, and in areas as small as 0.5

hectares. Moreover, helicopters can land on site and reload more quickly than fixed-wing planes and the helicopter pilot can check results and discuss plans more readily with ground staff.

Fixed-wing aircraft, on the other hand, are less expensive to operate, and at least in Ontario, Canada, are considered as efficient as helicopters.

TABLE 3 Possible Candidates for Aerial Seeding in Developing Countries (for information on many of these species see companion reports Tropical Legumes Resources for the Future ans Firewood Crops: Shrub and Tree species for Energy Production)

Humid Tropics	Semiarid Areas	Tropical Highlands
Acacia auriculiformis	Acacia albida	Acacia mearnsii
Other Acacia spp.	Acacia nilotica	Alnus acuminata
Albizia falcataria	Acacia saligna	Alnus nepalensis
Albizia lebbek	Acacia senegal	Alnus rubra
OtherAlbizia spp.	Anacardium occidentale	Callitris spp.
Anthocephalus chinensis	Azadirachta indica	Eucalyptus globulus
Avicennia spp. and some	Colophospermum mopane	Grevillea robusta
other mangroves	Eucalyptus citriodora	Inga spp.
Calliandra calothyrsus	Eucalyptus tereticornis	Mimosa scabrella
Cassia siamea	Haloxylon aphyllum	Pinus oocarpa
Other Cassia spp.	Haloxylon persicum	Robinia pseudoacacia

Casuarina spp.	Pinus halepensis	
Cecropia spp.	Prosopis spp.	
Croton spp.	Zizyphus mauritiana	
Derris indica (Pongamia	Zizyphus spina-christi	
glabra)		
Eucalyptus deglupta		
Other Eucalyptus spp.		
Ficus spp.		
Flindersia brayleyana		
Gliricidia sepium		
Gmelina arborea		
Leucaena leucocephala		
Macaranga spp.		
Maesopsis eminii		
Melaleuca spp.		
Melia azedarach		
Melochia indica		
Muntingia calabura		
Musanga spp.		
Neoboutnoia spp.		
Pinus caribaea		

Pinus kesiya		
Sesbania grandiflora		
Spathodea campanulata		
Syzygium cumini		
Tenninalia catappa		
Trema spp.		

Seed containers (hoppers) and distributors that attach to aircraft are commercially available, well developed, and reliable. Most commercially available seeding devices have power-driven augurs to control the rate of seed flow and either venturi or powered slinger-type applicators for spreading the seed (fixed-wing aircraft usually use gravity flow of seed and an unpowered venturi-type distributor. Helicopters must use a power-driven slinger because their speed is inadequate for venturi action). Most units are also capable of sowing seeds in a range of sizes.

At normal altitudes and flying speeds the distributors on ftxed-wing aircraft throw seed over a swath about 20 m wide. The power slingers attached to helicopters throw seed over a swath about 30 m wide. In good weather an aircraft in the United States routinely sows 1,200-1,500 hectares daily. Under favorable conditions (e.g., with landing sites close by) as much as 3,000 hectares have been seeded in a day.

Ideally, before aerially seeding 10 hectares or more, the prospective site is delineated on the ground and the pilot is provided with maps or aerial photos. Arrangements are made for radio communication between the aircraft and ground

crew (although desirable, this is not essential). A system for measuring the seed distribution on the site is worked out in advance and, if possible, flagmen are positioned to guide the aircraft so as to avoid overlapping runs (techniques newly developed in the United States include the use of aluminum flags (dropped from the plane) as well as electronic field triangulation, both of which guide the planes without using flagmen).

Pest Control

The major problem in aerial seeding is not one of engineering or plant science per se; it is the problem of seed predators. Almost any small animal (bird, insect, mouse, shrew, chipmunk, squirrel) will eat or remove seeds lying on the soil surface. It is essential to know the composition and population of seed-eating animals before aerially seeding an area. Mice and birds are generally the most destructive.

Normally, the seeds must be coated with chemicals to repel those animals most likely to eat them. Further, seeds should be sown, if possible, at a season when pest populations are low. Site preparation (i.e., burning or scarification mentioned above) not only prepares a good seedbed, but it often reduces predator populations. The likelihood of different predators stealing the seeds can be easily assessed by covering tiny sample areas with cages whose mesh sizes are selected to keep out different predators (mice, rats, birds, and ants, for example).

To avoid predation, the seed must be made to germinate as quickly as possible. Seed of some species, especially those with hard seed coats, must be stratified (subjected to moisture at low temperature to break dormancy) or scarified

(treated with acid, hot or cold water, or mechanical abrasion) to increase seed-coat permeability and ensure rapid germination.

In the United States, the insecticide endrin (Hexachlorooctahydro-endo, endo-dimethanonaphthalene) is used to protect the seed from insects and rodents in the direct seeding of conifers. The chemical is added as a thin coating around each seed. Although it has been restricted for other uses, endrin is still allowed for direct seeding in most states because the amounts applied are small (about 5 grams per hectare), the chemical is bound to the seed with latex, and the treated seeds become so widely scattered that little lasting environmental hazard is likely (endrin is a toxic material that must be applied carefully, at low dosage, and always in combination with a bird repellent (to avoid harming birds). Seeding projects proposing to use endrin must be reviewed with health and wildlife officials to avoid affecting the nontargeted animals).

The common fungicide thiram (Tetramethylthiuramdisulphide) is generally applied as a seed coating to repel birds. It forms a hard coating, very effective in rendering seed unpalatable to birds. There are few restrictions on its use; however, if improperly used, it can be toxic to some plant species.

Latex is used as a binder to attach the coating to the seed. Aluminum powder is used as a lubricant to prevent the seeds from sticking as they pass through the machines. (It also indicates a warning to personnel handling them and helps repel some birds.)

Simple procedures are available for treating seed prior to aerial seeding. For example, U.S. Forest Service workers in Louisiana use mammal and bird repellents

stirred together in a small pail with the latex binder blended in. The resulting mixture is poured over the seed in a small concrete mixer and tumbled for about 2 minutes. A small amount of aluminum powder is next spooned in and the mixture tumbled 1 minute more. By then, the seed is fully coated and is spread out to dry for several hours or bagged for drying in a low-temperature kiln. Using these simple procedures a three-man crew can treat a ton of pine seed a day (the procedures were worked out for pine seed but should he widely applicable to seed of other species. For detailed description see Derr and Mann, 1971).

Costs

On sites where it succeeds, aerial seeding can be less expensive than conventional methods of reforestation. In 1980 hand planting costs in New Zealand were about $250-300 per hectare; aerial seeding for protection forestry cost about $20-30 per hectare (information supplied by A. Nordmeyer).

With aerial seeding there are no large capital costs for establishing and staffing nurseries, transporting nursery stock, or buildings roads and camps to house the laborers. Further, there are no labor costs to outplant the seedlings.

On the other hand, there are extra capital costs for collecting and storing seed, and there are expenses for aircraft-support facilities, for seed-spreading devices, and for operating the aircraft. In most developing countries, planes are privately owned and it is sometimes difficult for a government to arrange and pay for their hire, relocation, and support. Helicopters are particularly expensive in developing nations.

Gogama District, Ontario. Helicopters require a power-driven centrifugal slinger for distributing the seed. The types in use in North America cover a swath 30 m wide. Flagmen are often used to guide helicopters and ensure that seed is spread evenly. (J. Scott)

Aerial application in the United States costs from $3.75 to $20.00 per hectare, depending on the size of the tract. Except for site preparation, the price of commercial seed is the biggest expense. The cost for pine seed is about $50.00 per hectare (spread at a rate of about 0.85 kilograms per hectare).

Aerial seeding is generally most economical for areas greater than 200 hectares. As a general rule, the most money is saved on sites where planting costs are highest. In the southern United States aerial seeding is reported to save an average of $7 per hectare on well-drained open land to $50 per hectare on rough sites where debris slows down planting crews (information supplied in 1979 by W. F. Mann, Jr.). Thinly stocked forests, or sites dominated by low-quality trees, are costly to plant but are easy and cheap to seed.

In countries with agricultural aviation services there need be no large capital outlays. Aircraft can be obtained under short-term contract when conditions for seeding are right. In some countries contractual services are also available to procure and treat the seed before sowing. Also, aerial seeding might fit developing countries having an air force that can be enlisted into civic-action programs.

Obtaining adequate amounts of seed may prove a major cost because aerial seeding often requires 10 times the amount of seed as reforestation with nursery grown seedlings. Ensuring adequate local seed supplies may require sectioning off

part of a forest as a seed-production area. This is already standard procedure in many countries. Fortunately, if a storage facility is available, seed of many species can be stored for several years so that it is available for use when seasons and conditions are appropriate.

The emphasis on genetically improved trees in recent decades has depressed the amount of aerial seeding in the United States. Seed from hybrids and genetically selected specimens have been too scarce and expensive to allocate to aerial seeding. Today, aerial seeding is mostly done with seeds collected from wild stands and plantations of unimproved genetic strains.

Treatment of seed with endrin, thiram, and a coloring agent is only a minor cost in the operation.

Limitations

Aerial seeding is not a method to be applied casually. It is more subject to environmental uncertainties than is planting of nursery stock. Correctly used, it is cheap, fast, and reliable, but for maximum success with greatest economy the forest manager must learn where this method is better adapted than alternative techniques.

Aerial seeding is unlikely to be successful until a good working knowledge of seed and seedling behavior is obtained and satisfactory techniques of gathering and storing seed are developed.

As previously mentioned, when aerial seeding is used, seed-eating birds, animals,

and insects must be prevented from destroying the seed and the sites must be suitable for promoting germination of the seed and survival of the young seedlings. As with conventional forestry, unchecked fire, grazing, and weeds will cause failures and they may be more troublesome at the remote sites where aerial sowing is likely to be employed.

Although aerial seeding is easier to organize and requires a smaller number of people than the planting of seedlings, it does require technicians trained in the storing, handling, and preparation of seed and it involves aircraft pilots, radio operators, and aircraft maintenance mechanics. Moreover, while aerial seeding appears to run counter to developing-country needs for labor-intensive technologies, it does require a lot of seed, which usually is collected by hand.

Only a few sites and species have been tested so far, and aerial seeding may eventually prove suitable only for certain sites and species. (For a list of species successfully seeded from the air see Table 2). It is already known, however, that not all tree species are suitable for aerial seeding. Infrequent seed production, the difficulty and high cost of collecting seed, and the sensitivity of the seed to long-term storage are all limiting factors.

A further impediment to aerial forestation is that it offers poor control over the density and spacing of the trees produced. It is most useful where the production of regularly spaced trees is of secondary importance. Forests resulting from aerial seeding are much like those produced by natural regeneration; they often become overstocked and require early thinning to promote growth and vigor. With some species (e.g., Pinus taeda) this is not a serious limitation; the stands thin themselves because individual trees dominate and suppress the less-vigorous

ones. In the United States the cost of mechanically thinning the overstocked stands has been a deterrent to aerial seeding. But in those developing countries with serious firewood shortages, the excess of stems could be an advantage because wood removed as thinnings is likely to end up as fuel for family cooking and heating.

Despite the hope that aerial seeding could help reforest arid areas, dry sites represent some of the greatest challenges to the technology and it may prove only infrequently successful there. Nevertheless, several species of Acacia as well as neem and cashew are traditionally direct seeded (from the ground) in the Sudan and in neighboring Sahelian areas. This offers hope that aerial seeding also may prove successful with these species in similar dry areas. However, the only aerial seeding in a dry area that we know of is a trial involving seeding neem (Azadirachta indica) from an airplane in northern Nigeria in the early 1960s. The seeds germinated readily, but because the sowing season was wrong only those shaded by the brush vegetation on the site survived.

Other possible limitations on individual sites include lack of seed, lack of available aircraft, competition from weeds, or the inability to control wildfires. Also, aerial seeding requires relatively sophisticated logistical, administrative, and communications support, which may not be readily available, especially in some remote areas (Akesson and Yates, 1974).

As is true with seedling transplants, dry-season fires in the savanna regions and heavy weed growth in the humid tropics are likely to be major management problems following a successful sowing.

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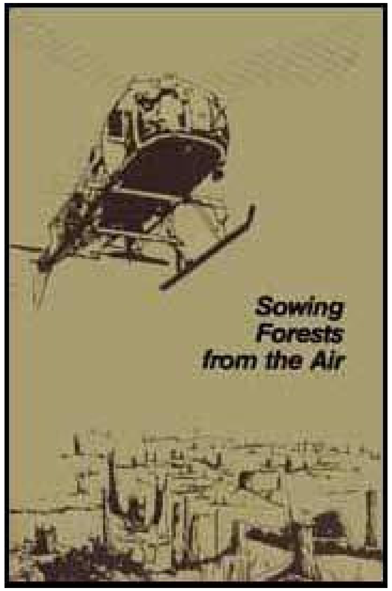


2 American Experience

(This chapter is based largely on information supplied by William F. Mann and Herschel G. Abbott.)

Direct seeding became an operational technique in the United States during the 1950s. Since then, over 1 million hectares have been sown, primarily from aircraft. Initially, most seeding was concentrated in the Northwest, using Douglas fir. Soon thereafter, seeding became widespread throughout the South following development of a repellent seed coating that sharply reduced depredations by birds, rodents, and insects. Pines such as loblolly (Pinus taeda), slash (P. elliottii), shortleaf (P. echinata), Virginia (P. virginiana), longleaf (P. palustris), and jack (P. banksiana) have been the primary species sown. Black locust (Robinia pseudoacacia) has been widely seeded on mine spoils. Numerous other species, mostly conifers, also have been sown successfully, although not on a large scale.

A broad array of sites has been aerially seeded, ranging from open level areas of the Atlantic and Gulf coastal plains to rugged mountainous ranges of the Pacific Coast. Some specific regions where aerial seeding has proved successful include:

· Former forest lands devastated by wildfires, insects, floods, tornadoes, or hurricanes;
· Cutover forests or lands inadequately stocked with commercial tree species;
· Waterlogged sites where planting equipment could not be operated;
· Remote areas, and
· Rocky spoil and steep banks left after strip mining.

Some spoil banks where the terrain was too rocky for workers to plant seedlings have shown remarkable tree growth following aerial seeding. The stones formed a protective environment for seed dispersed over the area by helicopters. Weathering processes eventually decomposed this rocky, virtually sterile material and, together with organic matter from the trees, the quality of the "soil" was

improved as the years passed. These spoil banks are among the easiest sites on which to sow forests because the freshly turned spoil harbors few animals to eat the seed and few plants to compete with the seedlings.

The vegetative cover on aerially seeded sites has ranged from dense native grasses to stands of worthless brush. Much of the successful seeding has been done immediately following timber hanesting or wildfires, although large brush-covered areas that had lain idle for up to 4 decades following logging of virgin stands have also been sown successfully.

While industrial landowners were the first to employ direct seeding in contemporary times, small private owners are now also using this method.

Although direct seeding has accounted for only 4-18 percent of the area reforested annually in the United States over the past 2 decades, its contribution ranges to over 50 percent in some states.

In the South, almost 1.2 million hectares have been successfully sown with pines since the mid 1950s. For example, in 1977 and 1978 41,000 and 32,000 hectares respectively were direct seeded, primarily by air, although hand seeders and tractor-drawn row seeders were also used. A sound base of research preceded commercial operations. Endrin has often been used to repel rodents and kill insects, and thiram or anthraquinone to repel birds. Seeds were deposited on various types of soils and sites: thin, rocky soils, silt-loam soils, sandy loam, and strip-mine spoils.

Grassy sites are most difficult to seed because dense grass blocks the seed from

reaching the ground and its roots compete vigorously with tree seedlings for moisture and nutrients. Some hardwood-dominated sites are easy to sow because competing ground vegetation has been shaded out and the hardwoods themselves can be killed with herbicide if the species being sown demand strong light.

Direct seeding of southern pines is impractical in swampy sites where seed would be submerged in water for a week or more. These sites are sown only after they dry out or after they are disked to provide rows of seedbeds raised above the water level before being aerially seeded. Sandy soils are also to be avoided because their surface layers dry out rapidly, leaving too little moisture to support continuous seed germination. However, ground seeding, using equipment to bury the seed about 1 cm deep, usually assures satisfactory germination in both swampy and sandy soils.

Sowing time is important. Usually, seeding is done in the fall (mid November to mid December) or spring (mid February to mid March). The seed is stratified (if necessary) to obtain more rapid and complete germination.

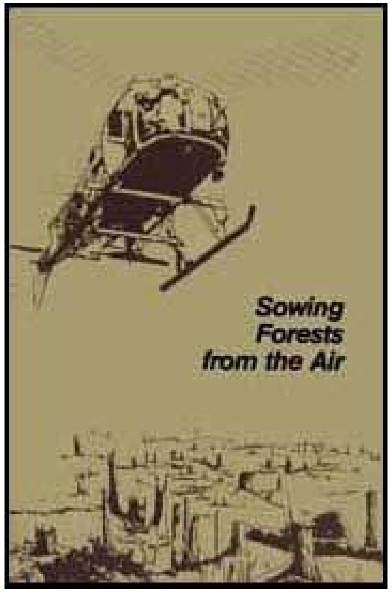
Broadcast-seeding operations have been declining in the South during the past 10 years, mostly because large programs are nearing completion and because the forestry industry is turning to use of seed orchards, which have produced only limited amounts of seed, so far. Because of economic considerations during the past several years, however, small landowners have resumed direct seeding with the encouragement and support of federal agencies and corporate landowners.

Direct seeding in the North Central (lake states) region of the United States has

lagged behind the Northwest and South. But in recent years, various interests have initiated large-scale operations with jack pine and in limited situations with black spruce (Picea manana). Overall success with other spruces and firs (Abies species) has been discouraging because their seedlings grow too slowly. Red pine (Pinus resinosa) has not been tested adequately, but it seems to show promise for direct seeding.

Soils in the North Central and Pacific Northwest regions usually contain a thick layer of partially decomposed organic material that poses a special problem in seeding operations. This layer dries out rapidly, and germinating, seeds often desiccate and die before the seedling root can penetrate to the moist soil below. To achieve consistent success, the organic material must be burned or mechanically scarified to expose the mineral soil beneath.

In western Oregon, summer soil temperatures (60° C) on newly burned sites proved too high for successful broadcast seeding. But by sowing mustard seed (Brassica juncea) at a low rate with the tree seed, success was achieved. The quick-sprouting mustard reduced both erosion and soil temperature and, in its cool shade, Douglas fir (Pseudotsuga menziesii) seedlings germinated and survived. The low density of seedlings that this allowed reduced the competition for moisture (information provided by C. M. McKell. see McKell and Finnis, 1957).



3 Canadian Experience

(This chapter is based largely on information supplied by James D. Scott)

Aerial seeding has become an increasingly popular form of artificial regeneration in the provinces of Ontario and Quebec in central Canada. This is due to the success in seeding jack pine, the steadily rising cost of growing and planting nursery stock, and the relative ease of regenerating areas where rough terrain and difficult access all but preclude other procedures for reforestation.

In the northern regions of both Ontario and Quebec, aerial seeding has become a

completely acceptable method of reforesting cutover areas.

The area of forest land aerially seeded in Ontario increased from 560 hectares in 1962 to 20,000 in 1978; in this same period, aerial seeding in Quebec rose to 7,000 hectares. Direct-seeding programs in the other provinces are less advanced, although Alberta, Saskatchewan, Manitoba, and Newfoundland all plan operational trials in the near future. Whereas Ontario and Quebec sow mainly jack pine, the western provinces of Alberta, Saskatchewan, and Manitoba have concentrated on white spruce (Picea glauca). Alberta seeds lodgepole pine (Pinus contorta) as well. Experiments in Newfoundland have shown some success with the seeding of black spruce. Overall, the best results have been with jack pine, with lesser success in white and black spruce and lodgepole pine.

Ontario initiated a few experimental aerial seeding projects as early as the 1930s, but not until the invention of the Brohm Aerial Seeding Unit (by the Ontario Forest Research Branch at Maple, Ontario) in 1962 did the first fully operational trials in that province take place. This device, designed specifically to distribute tree seed from both fixed-wing aircraft and helicopters, is the most commonly used seeding mechanism in the province.

Over the years aerial seeding has been a contentious issue among foresters in Ontario. Jack pine seeding is now, however, generally regarded as a viable and highly successful regeneration technique, particularly in the northeastern part of the province. This acceptance has been enhanced by research relating to seedbed receptivity as well as to rates and methods of seed application. Current research holds promise for the aerial seeding of black spruce as well.

Fixed-wing aircraft are preferred in Ontario for applying seed, whereas Quebec is partial to helicopters. Preferences seem to be determined by the individual pilot's experience rather than any inherent technical advantage of the type of aircraft.

Aerial seeding in Canada was originally used to regenerate sites that were inaccessible or difficult to plant because of topography. Now, however, it is also used to regenerate sites where the soil is too thin to plant by hand, such as the shallow rock-strewn soils in northern Ontario and Quebec. It is also used on boulder-skewn sites in Newfoundland and has become an inexpensive alternative to planting jack pine seedlings on sandy outwash plains where vegetative competition after the site has been prepared is relatively weak.

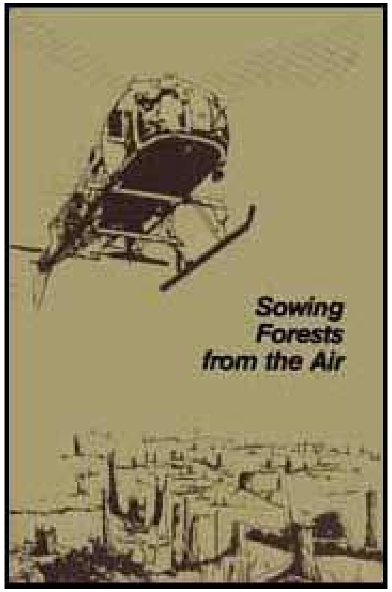
Most aerial seeding in Canada is preceded by some form of mechanical site preparation to break up the accumulated layers of undecomposed organic matter and create a suitable seedbed. This is done by scarification, using shark-finned barrels, spiked ship's anchor chains, or teeth mounted on bulldozer blades.

Most seeding takes place in late winter or early spring so that the seed will germinate as soon as possible after the snow melts. Seeding in the fall can be advantageous because it provides natural stratification, important with some tree species. Some seeding is also carried out after wildfires and after prescribed burns. Fires must be hot enough to burn away the organic surface material and expose enough mineral soil to provide a good seedbed. The thin soil of the Laurentian Shield, left after Ice Age glaciers scraped off the topsoil, has proved suitable for aerial seeding, as have the coarse sands of outwash plains.

The need to treat seed for rodent, bird, and insect control is not as well

understood as it should be and seems to vary from province to province. With concern over toxic chemicals increasing, the use of endrin to control rodents has been discontinued in Ontario. There is a general impression that the smaller the seed size, the fewer the losses to predators.

In Ontario, where most aerial seeding is preceded by mechanical site preparation, it has been found that considerable control over stocking can be achieved by maintaining a balance between the amount of mineral soil exposed and the rate of seed applied. Overstocking is not considered a serious problem.



4 Australian Experience

(This chapter is based largely on information supplied by Francis R. Moulds)

Aerial seeding of forest trees commenced in Australia on a trial basis some 20 years ago with a small number of eucalypts (Eucalyptus regnans, E. delegatensis, E. nitens, E. globulus, E. viminalis, and E. obliqua) and with Monterey pine (Pinus radiata). Before that, the technique of direct seeding (using hand broadcasting or hand-held spreaders such as the "pepperpot") had been used for spot sowing onto prepared seedbeds, normally following a hot burn of the slash left after logging the site. The direct hand-sowing method also had been used widely to establish windbreaks and shelterbelts (using, for example, E. cladocalyx, E. cornuta, and E. gamphocephala) on agricultural and pastoral land.

Today, foresters understand the behavior of the seed of Eucalyptus species in direct sowing. Details of stratification; prime planting time; controlling grasses and other competition; protecting the seed from insects, birds, and animals; and fencing the young seedlings, if necessary, against browsing or grazing animals are all well documented.

An important impetus for aerial seeding in Australia has been the movement of the timber industry into mountain forests, particularly in Victoria, New South Wales,

and Tasmania. The valuable species in these forests, especially E. regnans and E. delegatensis, occur as pure stands. These species regenerate only in open sunlight; thus the forests are clear-cut.

Large areas must be regenerated each year. Hand methods are difficult or impossible to use, particularly because only a few days each year exhibit the combination of weather conditions in which it is both safe to burn the slash and satisfactory to sow the seed onto the ashes produced. Once these days are missed, a year is lost and the resultant growth of scrub species and the loss of slash by decay make it difficult to get the hot burn needed to provide a good seedbed. Aerial seeding provides the needed flexibility to take advantage of the few burning and sowing days, particularly when large areas are involved.

Each year in Australia, aerial seeding regenerates 8,000-12,000 hectares of cutover mountain eucalypt forests. The process is well established and faces little risk of failure, provided the standard operating instructions are followed. Lowland eucalypt species are largely managed on a group selection or shelterwood system with natural regeneration.

Monterey pine (Pinus radiata) and other exotic softwoods in Australia have been direct seeded experimentally to establish new stands or second rotation crops. But softwoods are not normally established by sowing because rodents eat the seed, seed-orchard stock is expensive, and row plantings enable thinning to be done more cheaply. Also, the sites chosen for softwoods are generally much easier to plant than the steep and remote mountain eucalypt sites.

Regenerating the mountain eucalypts is a relatively simple and straightforward

procedure. It simulates natural processes that regenerate and perpetuate these high-quality timber species. For instance, periodic wildfires (caused by man or by lightning) are part of the natural environment, and such eucalypts regenerate themselves naturally in ash-strewn sites after a hot fire has caused the capsule (fruit) to open and release the seed.

The procedure involves:

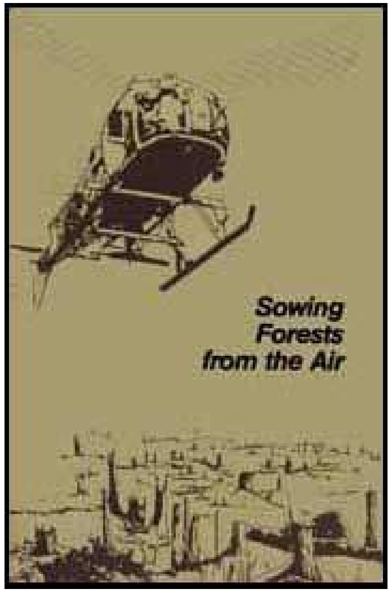
· Removing the overhead canopy so that maximum light reaches the ground;

· Providing a favorable seedbed by burning the groundcover and the slash left after logging so as to expose the mineral soil; and

· Distributing an adequate quantity of viable seed onto this seedbed.

The seed is first tested for viability and coated with kaolin, insecticide, fungicide, and coloring matter (to make it easier for the pilot and ground crew to see how well the seed is being distributed).

The Forests Commission of Victoria publishes details of all operations, including recommended sowing rates and instructions governing aircraft calibration. (See Selected Readings) Great care is exercised at every step to ensure that the properly treated seed is sown on the properly prepared seedbed at the most appropriate time for germination and subsequent seedling development.



5 New Zealand Experience

(This chapter is based largely on information supplied by Alan H. Nordmeyer)

Aerial seeding of pasture grasses was developed in New Zealand in the mid 1940s, and today New Zealand farmers use aircraft extensively to seed crops and spread fertilizer, especially on hill-country farms. Indeed, this "aerial agriculture" has become a major industry and applies, for example, over 2 million tons of fertilizer

each year. However, little has been done to apply the technique to sowing forests. It was not until the late 1 960s that the New Zealand Forest Service began testing the suitability of different aircraft for reforestation in remote areas. Nevertheless, aerial seeding has now developed to the stage where several types of fixed-wing aircraft and helicopters are used in reforestation, using various attachments for spreading tree seed or forest fertilizer.

Aerial seeding is not widely used in lowland forestry in New Zealand. It is used primarily in high-altitude protection forests that stabilize eroding mountain land. New Zealand's mountains are young, steep, and easily eroded. Much of their vegetative cover has been burned or severely browsed by large numbers of introduced animals, resulting in enormous losses of topsoil. Aerial seeding has been an effective tool for reestablishing vegetation in inaccessible, high-country sites.

Following initial trials, it was clear that of all the species tested, lodgepole pine was the most successful at altitudes up to 1,500 m elevation. But in the most eroded sites, the initial attempt failed because of extreme infertility and exceptionally harsh conditions. Few seedlings survived their first winter, all though good germination and reasonable establishment were achieved. In the cold, clear, mountain atmosphere, needles of ice as long as 25 cm formed in the soil and "heaved" the seedlings into the air, leaving them, with roots exposed, to die of desiccation in the spring. New Zealand foresters observed, however, that this did not occur when the soil was covered by a mulch of stones, litter, grass, or low-growing plants. Guided by this observation, they now spread a mixture of the seed of trees, grasses, and herbaceous legumes (legumes used successfully include trefoil (Lotus pedunculatus), white clover (Trifolium repens), and

“perennial lupin (Lupinus polyphyllus).

Grasses include Yorkshire fog Holcus lanatus), browntop (Agrostic tenuis), and fescue (Festuca rubra).

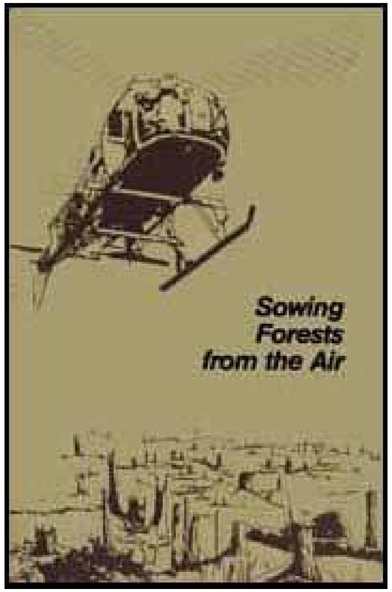
The "carpet" of vegetation that forms during the first season protects the young and vulnerable lodgepole pine seedlings by reducing the threat of frost-heaving from ice needles. Eventually, the kees appear through the "carpet" and benefit from the nitrogen fixed by the legumes, from the more equable ground temperatures that the mulch of vegetation provides, and from the erosion control induced by the grasses and legumes.

As a result, seedling survival is markedly increased by sowing tree seed simultaneously with legumes, grasses, and added fertilizer. The fertilizer (superphosphate) must be carefully regulated, because too little gives poor legume growth and the tree seedlings die from frost-heave; too much gives dense legume growth that suppresses small tree seedlings (the quantities of superphosphate applied vary with site but are in the range of 200600 kg per hectare. The legume fixes each year approximately 50-100 kg of nitrogen per hectare, which continuously increases soil fertility).

This interesting aerial seeding technique is probably applicable to problem sites elsewhere in the world (it is used, for example, for revegetating strip-mine spoils in much of the Appalachian region of the United States. There, black locust (Robinia pseudoacacia) is aerially seeded along with grasses and herbaceous legumes). However, it works particularly well where (as in New Zealand) precipitation is well distributed year-round. In areas with long dry seasons,

grasses and legumes can prevent tree establishment by competing for the scarce soil moisture during dry periods.

In New Zealand high-altitude forest establishment using aerial seeding is best on a thin herbaceous turf where some topsoil is present; moderate on sites with a mulch of surface stones; and poorest on compact, eroded subsoils prone to frost-heave.



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6 Tropical Experience

As already noted, there is almost no experience with aerial seeding in developing countries. But in such countries the everincreasing gap between forest destruction and forest planting demands that consideration be given to any reforestation methods that might be undertaken on a wide scale with less effort than the conventional methods.

Direct (i.e., broadcast) seeding is already used with some species in some developing nations. In parts of East and West Africa and the Sudan, for example, Acacia nilotica, Acacia senegal, Cassia siamea, neem (Azadirachta indica), Gmelina arborea, and cashew (Anacardium occidentale) are all routinely established by direct sowing of the seed. In the Philippines it has been found that direct sowing of cashew is a promising reforestation technique for areas covered with Imperata cylindrica. (No site preparation was used, but the seeds were buried 1-5 cm deep - Cadiz and Dalmacio 1978). It is reported that in Zambia at one time Eucalyptus citriodora, Eucalyptus camaldulensis, and Eucalyptus tereticornis were all direct sown "with considerable success," although they are now almost entirely planted as tubed stock (Laurie, 1974). In Guatemala the direct seeding of a watershed using repellent-treated seed of Pinus caribaea and Pinus oocarpa has proved quite satisfactory (reported by J. A. Lewald., see Research Contacts). Aerial seeding of Prosopis juliflora was successfully carried out to stabilize sand dunes in Gujarat, India, in the 1950s (information reported by M. N. Vaishnav, Conservator of

Forests, Gujarat State, India).

However, out of the handful of trials with aerial seeding in the tropics, only those of Indonesian foresters carried out in the early 1970s seem to have been well documented.

Indonesia

(The text of this section is based on a translation from the Indonesian provided by K. Freerk Wiersum)

In 1972 trials were established to test the possible use of aerial sowing in the forestry districts of Balapulang (Central Java) and Lawu (East Java-results of trials at Balapulang and Lawu have been reported by Sumarna and Sudiono, 1974a and 1974b, and Hadipoernomo, 1979).

The Balapulang trial took place in an area with average rainfall of 2,500 mm (3 dry months with less than 60 mm rain and 8 wet months with over 100 mm rainfall). The soils were a complex of heavily eroded grumusols (vertisols), regosols, and Red Mediterranean soils (alfisols) on a substrate of marl and limestone. The vegetation consisted of Imperata cylindrica mixed with some shrubs and herbs such as Mimosa spp. Terrain was prepared by tractor plowing or cutting and burning or was left untreated. In December 1972, 370 hectares were aerially seeded. On average, 24.8 kg seed were sown per hectare. The seed was a mixture of Sesbania grandiflora, Leucaena leucocephala, Calliandra calothyrsus, Acacia

auriculiformis, and a species of Dalbergia(The germimabilitv of the different species is given as Sesbania, 42 percent; Leucaena, 70 percent; Calliandra, 37 percent; and Dalbergia, 70 percent; other species, no data. No information on seed preparation is reported.).

The results are given in Table 4. After 10 months the stocking percentage In plowed fields was 89.4 percent and in burned fields 73.8 percent. After 7 years the land was covered by trees, erosion had stopped, and a humus layer had been formed on the prepared terrain. No success had been obtained on fields without terrain preparation (Sumarna and Sudiono, 1974b; Hadipoernomo, 1979.).

The Lawu trial took place in an area with average rainfall of 1,800 mrn and 4-5 dry months each year. The area is situated at 800 m altitude on intermediate and basic volcanic deposits on which a complex of lithosols and redbrown latosols occurs. It was a difficult site for forestry, with slopes averaging 35 degrees and shallow, nonporous soils with only a thin humus layer. Vegetation consistmg of Imperata cylindrica mixed with Lantana camara, Eupatorium pallescens (E. inulifolium), and grasses covered the area. Terrain was prepared by hoeing or cutting and burning or was left untreated. Sixty-five hectares were seeded In November 1972. A mixture of Acacia auriculiformis and Calliandra spp. was used at about 53,000 seeds per hectare.

(Germinability of each species was about 50 percent). The results in October 1973 are given in Table 5. The untreated sites have the highest establishment (Soemarna and Sudiono, 1974a).

TABLE 4 Development of Aerial-Sown Plants at Balapulang, Indonesia

	Seeds sown/ha	Percent success after 1 year (Dec.'73)	Percent success after 2 years (Dec.'74)	Percent success after 3 years (Oct.'75)	Percent success after 7 years (Jan.'79)	Trees present after 7 years (per ha)
Sesbania grandiflora	101,200	14.0	0.8	0.7	0.25	272
Leucaena leucocephala	117,300	15.7	14.0	13.5	8.25	9,964
Calliandra calothyrsus	15,400	16.6	18.5	18.5	10.4	1,742
Acacia auriculiformis	8,500	26.0	13.5	13.4	2.6	248

Source: Hadipoernomo, 1979.

Aerial seeding of areas dominated by Imperata cylindrica was successful in Java. The average stocking after 10 months was about 75-90 percent by the use of 24.8 kg seed per hectare (which is a large amount of seed). In preparing the terrain, plowing with a tractor gave better results than burning, while hoeing demonstrated the worst results. The results on untreated plots were variable. Of the species used, the most promising were Leucaena leucocephala and Calliandra calothyrsus. Sesbania grandiflora and Acacia aurieuliformis showed high early success, but later mortality was high. A species of Dalbergia failed and Pinus

merkusii was used in quantities too small to give results.

TABLE 5 . Results of Aerial Sowing in Lawu District. Indonesia, After 1 Year

		Hoed fields	Bumed fields	No treatment
Acacia auriculiformis	Percent success	23.9	46.7	50.0
	Mean maximum height (m)	0.89	0.9	51.02
Calliandra calothyrsus	Percent success	13.4	18.4	28.5
	Mean maximum height (m)	1.29	1.69	1.34

Source: Soemarna and Sudiono, 1974a.

Pacific Islands

World War II left many Pacific Islands bomb pocked and denuded of vegetation. To restore a plant cover the U.S. Navy seeded Guam, Saipan, Tinian, Corregidor, and other islands with leucaena dropped from bomber aircraft. Today these islands are densely covered with the plant (unfortunately a seedy, bushy variety was used and it has since become a rampant weed. The arboreal types were not then available. -For more information see National Academy of sciences. 1977 .Leucaena Promising Forage and Tree Crop for the Tropics.)

The technique had been pioneered in Hawaii as far back as 1926 when a large burned section of forest in the Panaewa Forest Reserve near Hilo was sown from the air.

Many of today's dense stands of leucaena on low-elevation, dry slopes on Oahu may result from aerial sowing in the 1930s sponsored jointly by the U.S. Army Air Corps and the Territorial Division of Forestry. In 1936, for example, 11 tons of leucaena seed were dropped over denuded areas on Oahu.

Hawaiian foresters also used other species in addition to leucaena. For example, in July 1926, 250 kg of mixed seed of 35 tree species were dropped from a Loening aircraft over a burned area of the Panaewa Forest Reserve on the island of Hawaii; 20 species were established, resulting in a forest containing many Melochia indica, Cecropia obtusifolia, and Spathodea campanulata. Further, aerial seeding was carried out in 1929 and 1932 on the West Maui mountains and parts of the Pupukea, Ewa, and Kawailoa Forest Reserves by an employee of the Hawaiian Sugar Planters Association in cooperation with the Army Air Corps. Some of the species that may have become established as a result of this work include: Acacia confusa, Cecropia obtusifolia, Spathodea campanulata, Albizia falcataria, and Psidium guajava. In 1937 the Army Air Corps helped the Hawaii Forestry Division aerially seed 7 tons of seed of trees, shrubs, and grasses on Kauai and Oahu (Information supplied by R. Skolmen).

Nigeria

In the early 1960s an aerial seeding trial was conducted in northern Nigeria using neem. A strip 30 m wide and 5 km long was sown from the air at an average density of 12 seeds per m2. The seeding produced profuse germination, but all seedlings in direct sunlight died of sunscorch; only those shaded by natural scrub survived the dry season. It was concluded that "the method would succeed if

sufficient ground cover could be assured (Forestry Abstracts 1964 Volume 25: Abstract No. 574).