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Regeneration of Mamane: Effects of Seedcoat Treatment and Sowing Depth

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ABSTRACT. Emergence of mamane (*Sophora chrysophylla*) was best when seeds were sanded or soaked in sulfuric acid and then sown at 3.8 or 6.4 cm. Soil moisture content and soil temperature were among the factors governing emergence from different sowing depths. End-of-test seedling survival was low—16 percent during a spring test and 2 percent during a summer test; it was significantly affected by type of seedcoat treatment, but not by sowing depth. Low rainfall and extreme soil surface temperatures appeared to account for most seedling mortality. In both tests, some seedlings which had died back to the ground sprouted, one 20 weeks later. FOREST SCI. 27:771–779.

ADDITIONAL KEY WORDS. Hawaii, direct sowing.

MAMANE (*Sophora chrysophylla*), an endemic Hawaiian leguminous tree, is a major constituent of the xeric forest ecosystem which occupies about 21,900 hectares of Mauna Kea, island of Hawaii, above 2,100 m elevation. These forests constitute critical habitat of the Palila (*Psittirostra bailleui*), an endangered endemic Hawaiian bird.[1] The upper forest of Mauna Kea is also thought to harbor fifteen rare and endangered native plant species (Ripley 1975).

These species are endangered partly because of the damage done by feral sheep (*Ovis aries*) over the past 200 years. They suppressed mamane and other tree reproduction, stripped bark from tree stems, and consumed herbaceous vegetation leaving the soil exposed to accelerated erosion.

Because of continued habitat degradation and the attendant threat to the Palila, the State of Hawaii began eradicating feral sheep from the mamane forests of Mauna Kea in 1980. But even when the last feral animal is gone, reestablishment of mamane in some areas will probably take a long time; growing conditions are harsh and the mamane soil-seed bank may have been depleted. Regenerating mamane by planting nursery-grown seedlings or by direct sowing of seeds may hasten recovery.

The objective of this study was to determine the effect of seedcoat treatment and sowing depth on mamane seedling emergence and initial survival under field conditions.

[1] Berger, A. J., and others. 1977. Palila recovery plan. US Department of the Interior, Fish and Wildlife Serv, Honolulu, Hawaii. 35 p.

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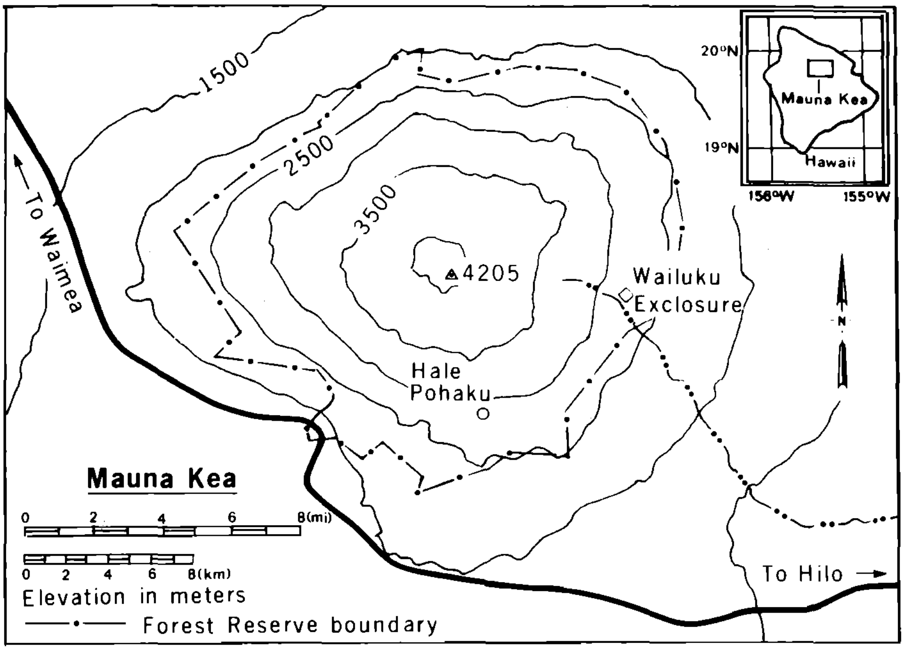

FIGURE 1. The Wailuku sheep exclosure, located on the east flank of Mauna Kea, island of Hawaii, at 2,750 m elevation (tree line), was the site for this study.

STUDY SITE

The experiment was conducted within the 1-ha Wailuku River sheep exclosure located at 2,750 m elevation on the windward side of Mauna Kea (Fig. 1). The only tree species on the site was mamane with an average height of less than 5 m and a density of 24 per hectare. Vegetative cover on experimental blocks was less than 1 percent.

The climate is dry subalpine. Rainfall averages 500 to 750 mm per year, much of it during winter months (State of Hawaii 1970). Air temperatures rarely exceed 21°C or fall below −3°C.

The soil which formed in volcanic ash, cinders, and pumice is Typic Vitrandept, medial over cindery, isomesic (Soil Conservation Service 1973). The loamy sand—85 percent sand, 10 percent silt, and 5 percent clay—is about 1 m deep over olivine basaltic lava. Permeability is very rapid (>20 cm/hr) and the runoff slow. The soil moisture-holding capacity of the upper 15 cm of soil is 18 and 10 percent by volume at ⅓ and 15 bars tension, respectively (pressure plate determination).

METHODS

Old mamane pods were collected from Hale Pohaku, 2,750 m elevation (Fig. 1), and the extracted seeds were stored in sealed plastic bags at 20°C until sowing. About 98 percent of the seeds were "full." Tetrazolium tests indicated that about 85 percent were viable with 74 percent germination ($S_{\bar{x}}$ = 5 percent) obtained in laboratory germination tests.

The spring test was begun in the rain March 7, 1974, when moisture content of the upper 13 cm (5 inches) of soil was about 30 percent by weight. The summer test was begun August 12, 1975, when the soil moisture content was about 5 percent.

The two factors examined were seedcoat treatment and sowing depth. The four seedcoat treatments were

1. Acid soak: Immersed in reagent grade concentrated sulfuric acid for 60 min and then washed in running tapwater. (Seedcoats deeply pitted.)
2. Sanded: Hand abraded between sheets of sandpaper. (Seedcoats scratched only.)
3. Hot water soak: Immersed in water at 100°C and allowed to soak while the water cooled overnight. (Seeds swollen when recovered.)
4. Control: Not treated.

These treatments were chosen because in previous work, acid and sanded treatments had improved seed germination (Scowcroft 1978) and because the Hawaii Division of Forestry and Wildlife had used hot water as a presowing treatment.

Seeds were sown at six depths: broadcast over the surface, and spot-sown at 1.3 cm (0.5 inch), and at every 2.5 cm (1 inch) thereafter to a depth of 11.4 cm (4.5 inches).

The experiment was laid out in a split plot design with seedcoat treatments assigned to main plots and sowing depths to subplots. Three replicates were used. In each subplot, 80 seeds were sown singly, by hand in seed spots spaced 10 cm apart. Surface-sown seeds were hand broadcast. Movement of surface-sown seeds was prevented by a wire screen barrier around the perimeter of the appropriate subplots.

Seedlings were tagged when the first set of leaves were deployed. The condition and height of each seedling were measured periodically for about one year.

Environmental data collected at each measurement included rainfall, max-min air temperatures, and gravimetric water content and temperature of each 2.5 cm layer of soil to 13 cm deep. Surface temperature refers to the soil temperature 1 mm below the surface.

Differences in seedling emergence due to seedcoat treatment and sowing depth were examined by multiway contingency table analysis (Everitt 1977). Pairwise comparisons among treatments and among depths were made using the χ^2 test for two cell tables (Steel and Torrie 1960). The effects of sowing depth, seedcoat treatment, and week of emergence on end-of-test seedling survival for the spring test only were also examined by multiway contingency table analysis. All hypothesis testing was done at the 0.01 level of significance unless otherwise specified.

Results

Seedling Emergence.—The effects of sowing depth on emergence were evaluated for each seedcoat treatment (Table 1). Significant differences in emergence due to sowing depth were largely confined to the acid and sanded treatments. Only for the acid treatment did a single depth stand out as superior to all others—the 3.8 cm depth, with 53 and 21 percent emergence for spring and summer tests, respectively. Except for the spring-sanded treatment, emergence from the shallowest sowing depth was no different than from the deepest depth.

Acid-soaked and sanded seeds produced significantly more seedlings than hot-water-soaked or control seeds at all sowing depths during the spring test. The only difference between acid and sanded treatments was at the 3.8 cm depth—acid-soaked seeds produced more seedlings. For the summer test, significant treatment differences showed up only at the 3.8 and 6.4 cm depths. At these depths, acid-soaked and sanded seeds both produced more seedlings than hot-water-soaked or control seeds.

Seedling emergence began 1 to 1.5 months earlier and proceeded twice as

TABLE 1. Percent seedling emergence[1] for each combination of seedcoat treatment and sowing depth during the spring and summer tests.

Test and seedcoat treatment	Emergence by sowing depth (cm)—				
	1.3	3.8	6.4	8.9	11.4
Spring test:			*Percent*		
Acid	7.1 a	53.3 b	33.8 c	14.6 a	15.0 a
Sanded	5.0 a	32.9 b	33.8 b	22.1 bc	15.0 c
Hot water	0.4 a	1.7 a	1.3 a	0.4 a	0.4 a
Control	0.0 a	5.4 b	5.4 b	2.9 b	0.8 ab
Summer test:					
Acid	0.4 a	20.8 b	5.0 c	0.4 a	0.4 a
Sanded	0.8 a	13.3 b	5.8 bc	2.1 ac	0.4 a
Hot water	0.0 a	0.0 a	0.4 a	0.0 a	0.0 a
Control	0.0 a	0.4 a	0.4 a	0.4 a	0.0 a

[1] Within row values followed by the same letter are not significantly different ($P = 0.01$).

rapidly during the spring test as during the summer test (Fig. 2). Depth of burial significantly ($P \leq 0.05$) affected week of seedling emergence during the spring test—the deeper the burial, the greater the elapsed time between sowing and emergence. Week of emergence was also affected by seedcoat treatment: seedlings emerged sooner for acid and sanded treatments than for control and hot water treatments. The latter treatments also differed in their effect on week of emergence with almost 50 percent of the hot water seedlings emerging after the 18-week measurement compared to 9 percent of the control seedlings. Too few seedlings emerged during the summer test to be statistically analyzed.

Seedling Survival.—Seedling survival was low for both test periods. Of the 602 seedlings that emerged from spring-sown seeds, only 99 (16 percent) were still alive 54 weeks after sowing. Survival was even poorer for the summer test; only 2 out of 123 seedlings (2 percent) were alive 55 weeks after sowing.

For the spring test, sowing depth did not significantly affect end-of-test seedling survival, but type of seedcoat treatment did. Seedling survival for the acid treatment (10 percent) was significantly less than that for the sanded (23 percent), hot water (20 percent), and control (20 percent) treatments. Too few seedlings survived during the summer test for similar analysis.

Survival was not dependent on week of emergence for the spring test. Seedlings that emerged relatively early had just as good a chance of surviving as those that emerged later. Data for the summer test was insufficient for similar analysis.

Relatively little rain fell during the months of May through September for both tests. During the spring test, the proportion of seedlings that died during these months was high—77 percent (Table 2). Even at the 11.4 cm depth, more than 72 percent of the mortality occurred during that period. In contrast, very little of the mortality occurred during the dry months of the summer test. Instead, most of the mortality (84 percent) took place during the wet winter and early spring months (Jan.–Apr.).

One unexpected discovery was that some seedlings tallied as dead (i.e., no visible aboveground evidence of a plant save the numbered marker) sprouted; one after 20 weeks. Of the 602 seedlings that emerged following the spring sowing, 56 sprouted. At the end of the test, 14 of these were still alive accounting for about 14 percent of the surviving seedlings. Of the 123 seedlings that emerged

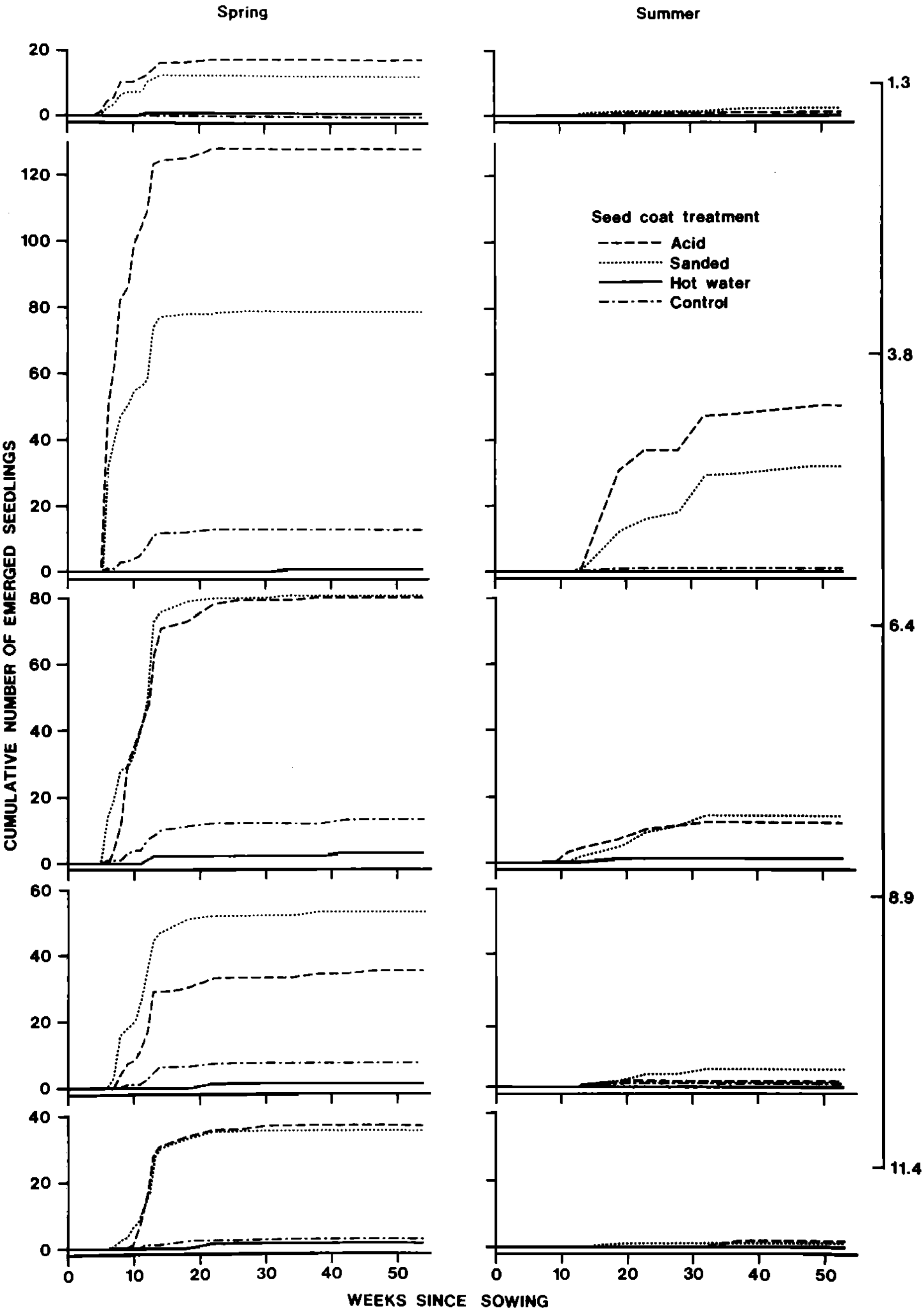

FIGURE 2. Cumulative number of emerged mamane seedlings over time for each sowing depth and seedcoat treatment for spring and summer tests, March 1974 to March 1975 and August 1975 to September 1976, respectively. Both control and hot water data for the summer test are represented by the solid line in the 1.3-, 6.4-, and 11.4-cm sowing depth plots.

TABLE 2. Percent of seedling mortality occurring during periods when rainfall was less than 50 mm and/or soil moisture was less than 12 percent, by treatment and sowing depth for both test periods.

Test and sowing depth (cm)	Seedling mortality				
	Acid	Sanded	Hot water	Control	All
Spring test:			*Percent*		
1.3	88.2	75.0	[1]0.0	—	80.8
3.8	80.2	81.4	—	60.0	78.2
6.4	84.5	67.7	[2]50.0	70.0	75.8
8.9	68.8	88.1	[1]100.0	42.9	76.8
11.4	75.0	67.9	[1]100.0	[1]100.0	72.6
All	79.9	76.4	37.5	60.7	76.7
Summer test:					
1.3	[1]0.0	[2]0.0	—	—	0.0
3.8	12.5	31.2	—	[1]0.0	19.8
6.4	8.3	8.3	[1]0.0	0.0	7.7
8.9	[1]0.0	0.0	—	[1]0.0	0.0
11.4	[1]100.0	[1]0.0	—	0.0	50.0
All	12.7	21.2	0.0	0.0	16.0

[1] Based on one seedling.
[2] Based on two seedlings.

following summer sowing, only eight sprouted. Two of the eight were still alive when the test ended—the only two that survived.

Environmental Factors.—Relatively high soil moisture was maintained at each sowing depth during the first 7 weeks after spring sowing (Fig. 3). In contrast, soil moisture was low the first 9 weeks after summer sowing (Fig. 4). Several times during the spring test, soil moisture in the top 2.5 cm layer dropped below 10 percent, once falling to near zero. These dry conditions existed from several days to a week or more each time. They were even more common and extended deeper into the soil during the summer test. Not until about the 23rd week did the water content of all five soil layers exceed 10 percent.

Total rainfall up to the start of emergence was 207 and 105 mm for spring and summer tests, respectively. Through the time when emergence was at least 90 percent complete for all depths and treatments, rainfall totaled 623 and 752 mm for spring and summer tests.

Air temperatures ranged from daytime highs of 21°C to nighttime lows of −1°C during both tests. More important to seed germination and seedling emergence and survival was soil temperature. Daytime highs at the surface consistently exceeded 50°C during summer months, and were commonly maintained for 30 minutes or more. The highest temperature recorded was 71°C. Even at 1.3 cm, temperatures in summer averaged near 50°C. The lack of insulating vegetation or litter, high solar radiation, dark soil color (10YR 3/1, very dark grey on the Munsell color scale), and low water content of the surface layer contributed to these very high temperatures.

Low surface temperatures were common at night. Only during August did the average daily minimum rise above 0°C. At the study site, I saw needle ice on the soil surface throughout the year. The ice never lasted more than a few hours after sunrise, but its formation resulted in frost heaving of plastic seedling markers, a vertical displacement of about 3 cm.

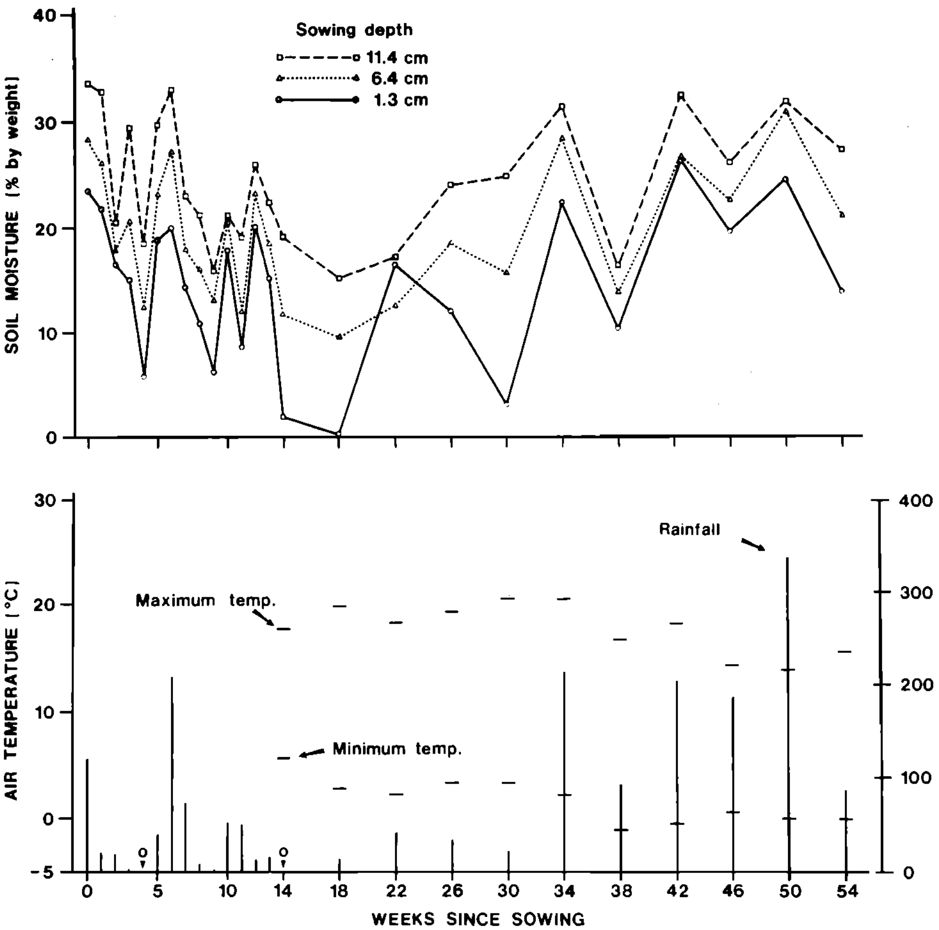

FIGURE 3. Moisture content (by weight) of the 1.3-, 6.4-, and 11.4-cm soil layers at intervals during the spring test period, March 1974 to March 1975, are shown in the upper figure. Maximum and minimum air temperatures and rainfall for the same measurement intervals are shown in the lower figure. Zero rainfall is so identified.

DISCUSSION

Differences in number of emerged seedlings among treatments were due to the relative effectiveness of each in breaking seedcoat dormancy. Acid soaking or abrading with sandpaper were the most effective. The hot water soak, while softening the seedcoat, apparently killed many seeds, thus negating its effectiveness. These results were in keeping with an earlier laboratory study (Scowcroft 1978).

Differences in emergence among the depths were a joint function of soil moisture content and temperature. On and near the soil surface, inadequate moisture was the limiting factor. At the 8.9 and 11.4 cm depths, poorer emergence was probably due more to cooler temperatures than to low soil moisture.

Lack of water appeared to be a major factor contributing to seedling mortality during the spring test. Because the soil moisture-holding capacity was very low, even short periods without rain could create moisture stress in emerging seedlings with their limited root systems.

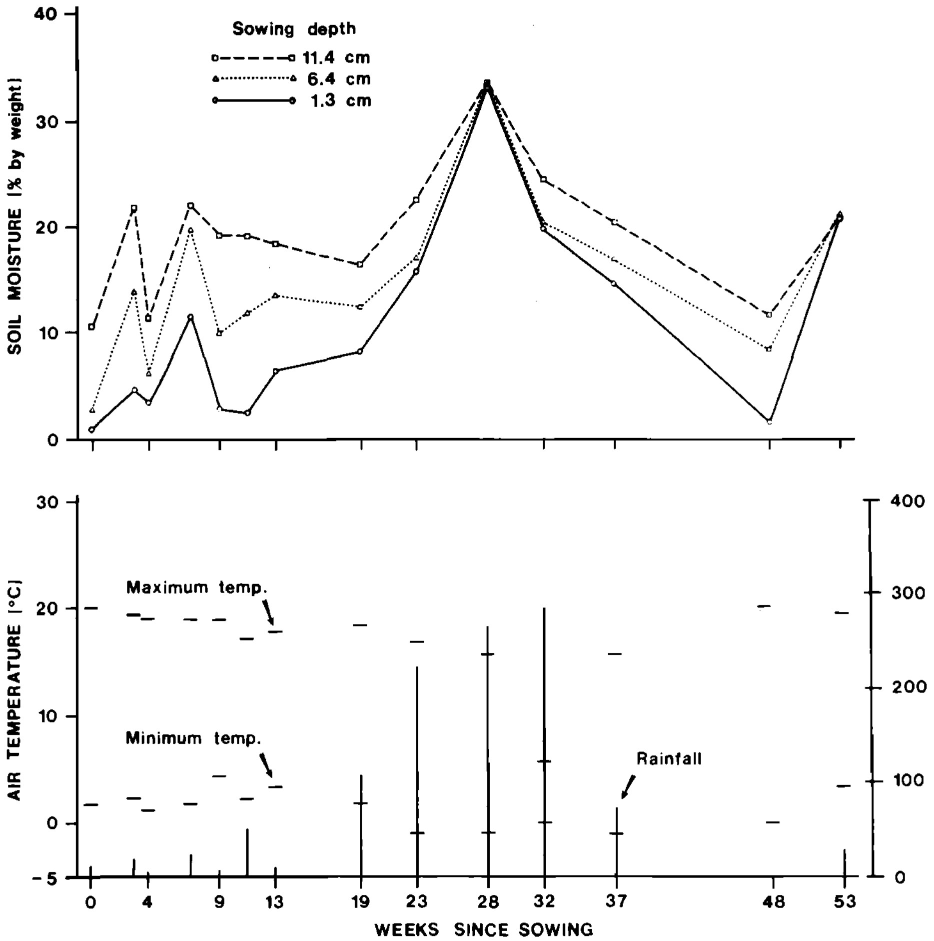

FIGURE 4. Moisture content (by weight) of the 1.3-, 6.4-, and 11.4-cm soil layers at intervals during the summer test period. Maximum and minimum air temperatures and rainfall for the same measurement intervals are shown in the lower figure.

Another factor that probably contributed to seedling mortality during the spring test was extreme soil surface temperatures. Surface temperature commonly exceeded the thermal death point (50–60°C) of most active plant cells. Damage to the relatively unprotected live tissue of the emerging seedlings at the ground-air boundary probably occurred (Spurr and Barnes 1980).

Unlike the spring test, lack of water did not appear to be a significant factor affecting summer test mortality. During the 4-month period when most seedlings died, rainfall totaled 860 mm. It was well distributed—never more than a week between rains. High soil temperature was probably not a significant factor either; the average maximum for the period was 30.4°C. However, low surface temperature could have been a factor. During the months of greatest mortality, surface minimums averaged −2.1°C. Freezing of succulent stem tissue at the soil-air boundary could have occurred. Frost was common during the period and many seedlings appeared frost damaged.

The lack of significance of sowing depth on end-of-test seedling survival for the spring test was surprising. Ordinarily, I would have expected better survival with greater depth due to more favorable soil moisture. Possibly, the differences in moisture that I observed were too small or of too short duration to favor seedlings originating deeper in the soil. Or perhaps the true effects of depth were masked by extreme soil surface temperatures which affected all seedlings equally without respect to depth of origin.

The results of this study suggest that three conditions must exist before natural regeneration from seed can take place. First, seeds must be buried. Surface-sown seed failed to germinate. Second, seedcoats must be broken down by natural scarification if germination is to exceed about 1 percent. In this study, scratching the seedcoat with sandpaper or eroding it with acid resulted in an average increase in seedling emergence of 700 to 800 percent over untreated seeds. Third, soil moisture must be adequate. Not only was seedling emergence delayed during the summer test when soil moisture was low, but total emergence was only one-fifth of that observed during the spring test when soil moistures were greater.

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Control of Shoot Growth in Trees

Compiled and edited by C. H. A. Little. 1980. Proceedings of the Joint Workshop of IUFRO Working Parties on Xylem and Shoot Growth Physiology. Obtainable from Centre Editor, Maritimes Forest Research Centre, PO Box 4000, Fredericton, N.B. E3B 5P7 Canada. 360 pages. $10.00 (Can.).

Reviewed by David A. Rook, Forest Research Institute, New Zealand Forest Service, Rotorua, N.Z.

This volume comprises photoreproduced copies, bound in a soft cover, of sixteen invited papers and abstracts of nineteen volunteer papers presented at an IUFRO workshop, hosted by the Canadian Forestry Service, in Fredericton in July 1980. The organisers are to be congratulated on attracting a high calibre group of scientists with interests well distributed over the subject matter, although perhaps more attention could have been paid to photosynthetic controls on shoot growth. The invited papers are reproduced as they were received without any editing, but some minor editing and retyping was carried out on the abstracts of the volunteer papers. The latter complement well the invited papers. None of the discussion is recorded.

While some authors produced manuscripts which are difficult to fault on their scientific content or presentation, too many of the manuscripts are marred by careless spelling