POTENTIAL USES OF ABANDONED UNDERGROUND MINES

by

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ACKNOWLEDGEMENTS

An operation of this type integrates the efforts of numerous individuals from a variety of disciplines associcated with AMAX and Western State College.

Ed Pommerening of Bunker Hill Mine provided the original reinforcement and helped with the facility siting and throughout the project, provided aid upon request. The Mount Emmons construction crew did well in constructing a structure foreign to them. Ed Perusek and his mining crew regularly trammed materials in and out for us. The miners became custodians in the absence of the regular staff. Thom Coughlin was continuosly supportive. Ken Wikler contributed regularly; Rick Thomas was extremely helpful in monitoring and general troubleshooting. Overall, the AMAX staff was supportive in a manner that it made the operation a true pleasure.

At Western State, Ralph Carter was the person who initiated the operation. A number of students enjoyed the experience of working in a new venture. Sandy Starr was in charge during the past year and put the facility into more productive, routine operation.

Overall, the underground facility was a product of the interaction of many elements, all of whom seemed to derive a sincere pleasure from its success.

FIGURES

Introduction

The need for plant materials for high altitude revegetation poses several distinct problems. Quite often it is difficult to anticipate needs sufficiently far in advance to arrange purchase. Much of the commercially available plant stock is sold out well in advance of the planting season. Most of the plant material is available from lower elevations and acclimating the plants to a high altitude environment is difficult. Plants originating at a lower elevation often have broken dormancy at a time when winter persists at the higher elevation. Handling of such stock until it may be planted causes considerable mortality. Commercial growers often do not raise desirable species. Commercial growers may not have material which is ecotypically desirable. The combination of availability, genetic quality, time and cost prompt a concern for finding more localized material sources.

At the AMAX Mount Emmons Project, an additional incentive was provided. Unusual environments associated with retrofitting previous mining operations suggested unusual plant needs. A serious forest fire of approximately thirty acres in a habitat in which the soil pH ranges from 2.5 to 4.0 underscored the need for developing a supply of plants closer to the point of use and more in keeping with the need of particular species.

In the mid 1970's, Ed Pommerening of Bunker Hill Company, Kellogg, Idaho, began the development of an underground nursery facility. An associate of his, Thom Coughlin, joined the AMAX Mount Emmons Project staff in 1979. In late 1979, after the forest fire, Thom Coughlin suggested the recently modified old Keystone Mine workings had the necessary ingredient to provide an environment for the development of a facility for growing plants. He presented the tentative plan to AMAX higher management who were quick to respond affirmatively, enabling us to pursue a more detailed planning phase.

In an environment with short growing seasons, and extreme winter seasons, where plants are subject to considerable stress and therefore exhibit limited annual growth and where greenhouses are most prohibitive because of heating costs, an underground nursery is potentially extremely desirable. If growing requirements can be met, an underground environment provides constant conditions, nearly equivalent to an elaborate computerized growth chamber. By the same token, if growing conditions are not available, it is very expensive to alter them. For that reason, we feel indeed fortunate the conditions appear to give us the positive environment for plant growth.

Site Location

The underground facility is located two miles west of Crested Butte, Colorado which is 28 miles north of Gunnison and 200 miles west of Denver. The development occurs .75 miles into Mount Emmons and approximately 2,000 feet below the surface. The access adit is located on the south-facing slope of Mount Emmons, at a level above the current temporary office buildings.

Site Preparation

The site was orginally used as a 20' x 20' drilling location (Figures 1 and 2). The following modifications were required:

1. The floor was leveled by overlaying the rock with 12" x 4" pine boards.
2. A wooden framework was constructed to permit the establishment of a system.
3. A chain link barrier was constructed across the cut-out entrance (Figure 3).
4. Overhead fiberglass sheets were placed under the ceiling to intercept rock fall and divert any seep water.
5. A water supply was connected with the existing mine discharge water.
6. A sprinkling system was designed.
7. An air duct, attached to the mine ventilation system, was installed.
8. Pine benches were installed.

Design Specifics

Benches: The benches were construced in 4' x 8' x 3.5' modules (Figure 4). This design permits rearrangements and evacuation, if the drill site is needed once again. There is 384 square feet of growing space available.

Lighting: Six lights are located five feet above the plants. The distance may be changed with utilization of a pulley system. The bulbs are Sylvania BT-56 1000 watt Super Metalarc. Figure 5 shows the location of the lights; the number of foot candles received at various parts of the room, near the tops of the plant containers is indicated in Figure 6. Any interruption

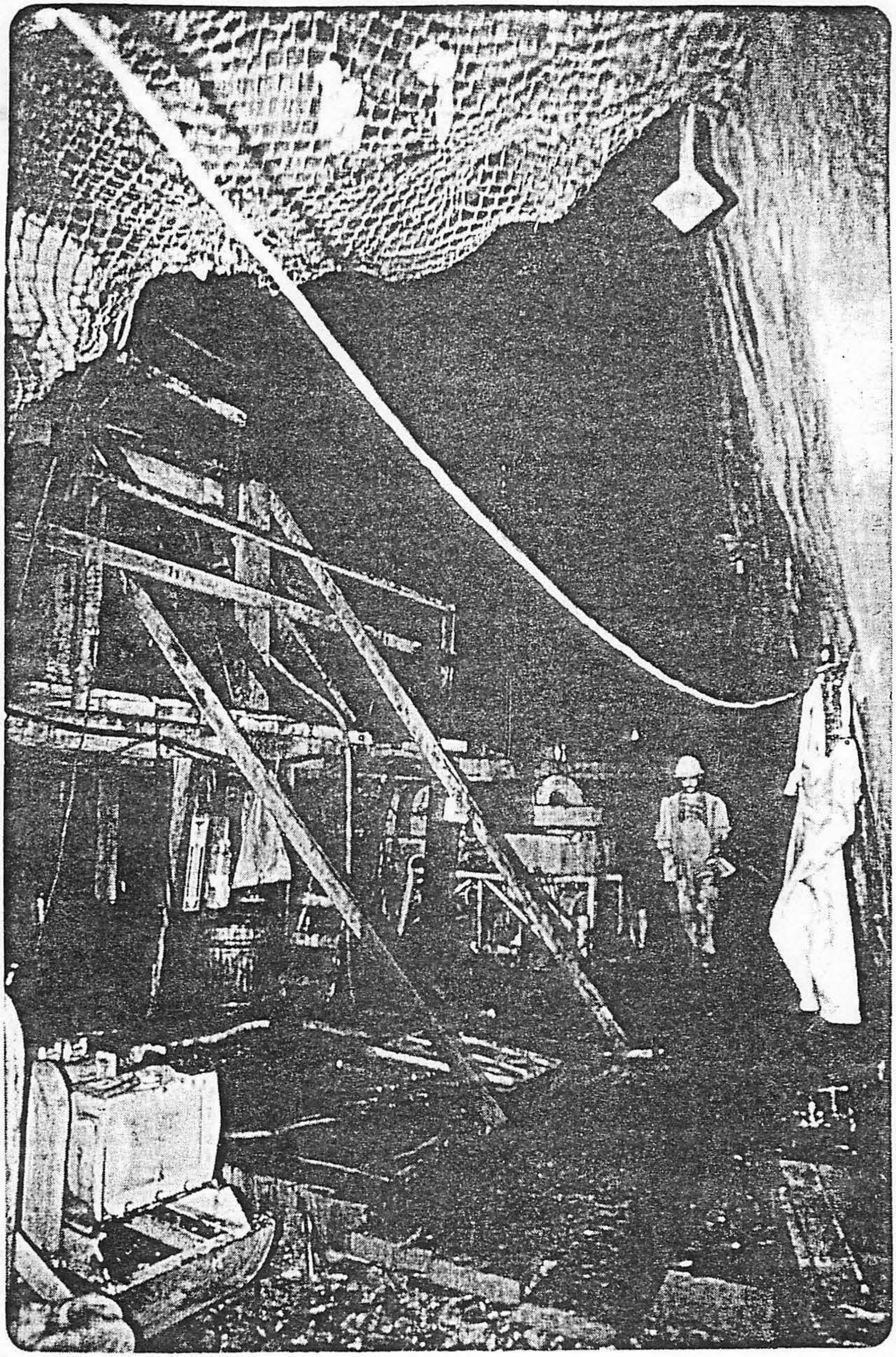


Figure 1

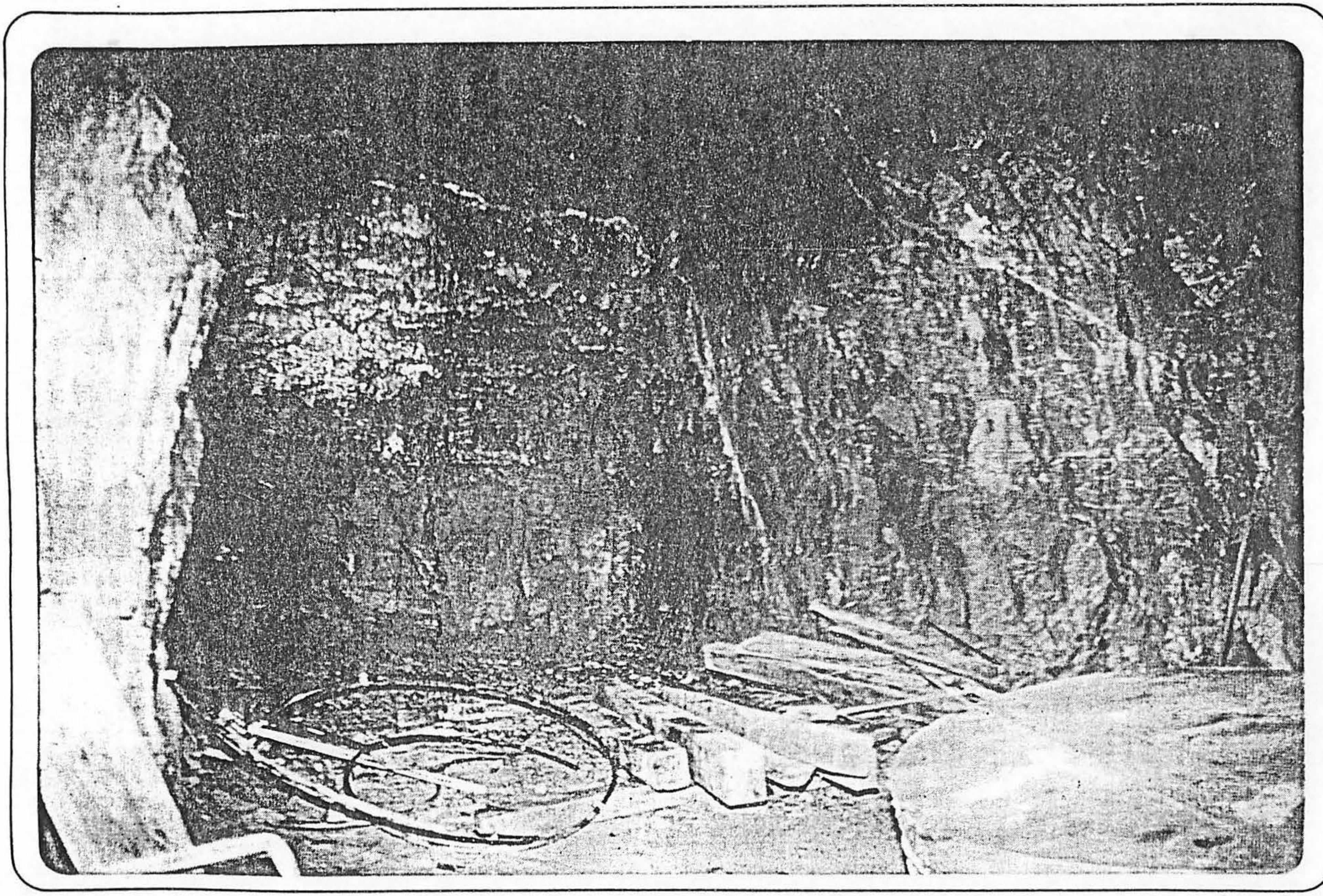


Figure 2

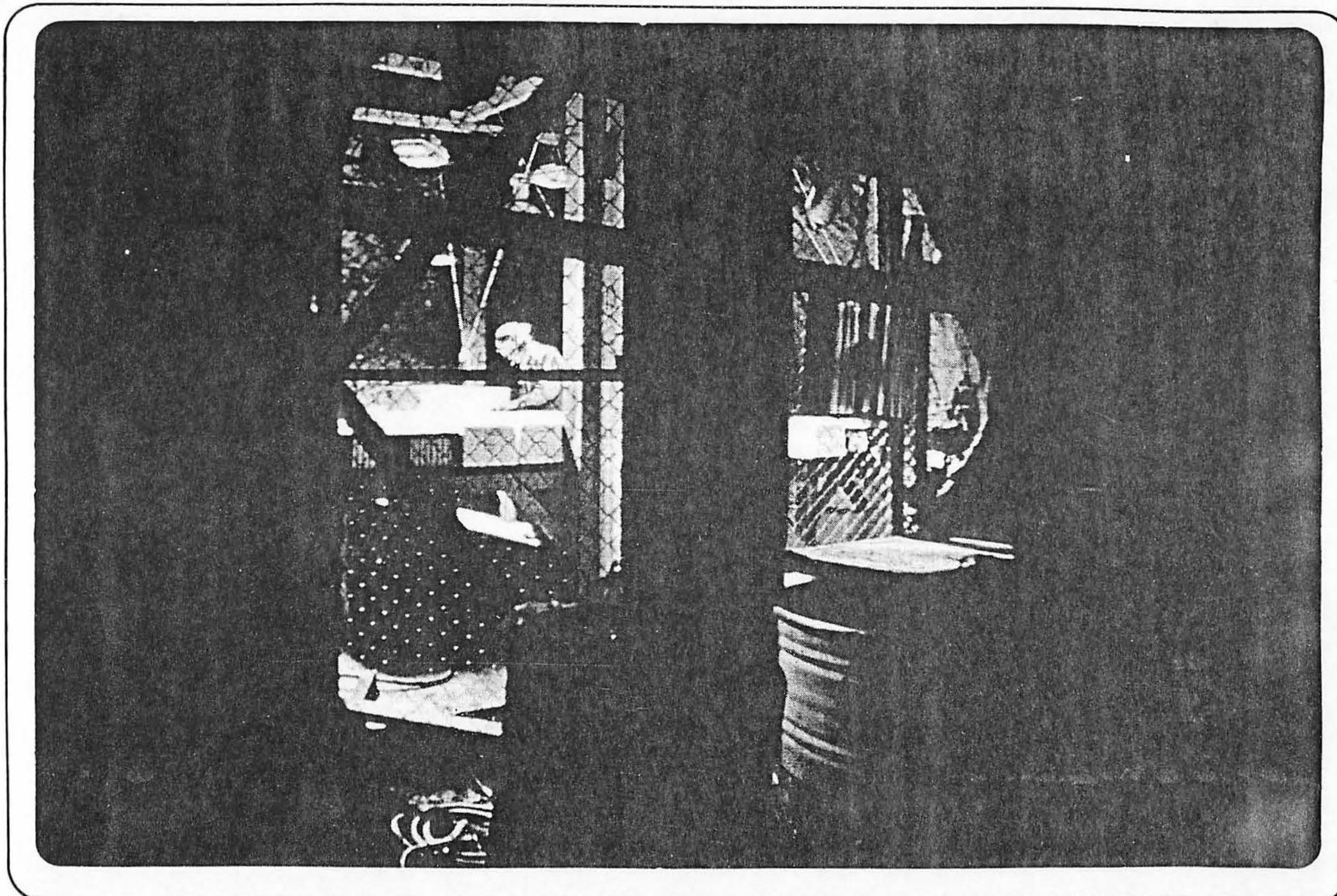


Figure 3

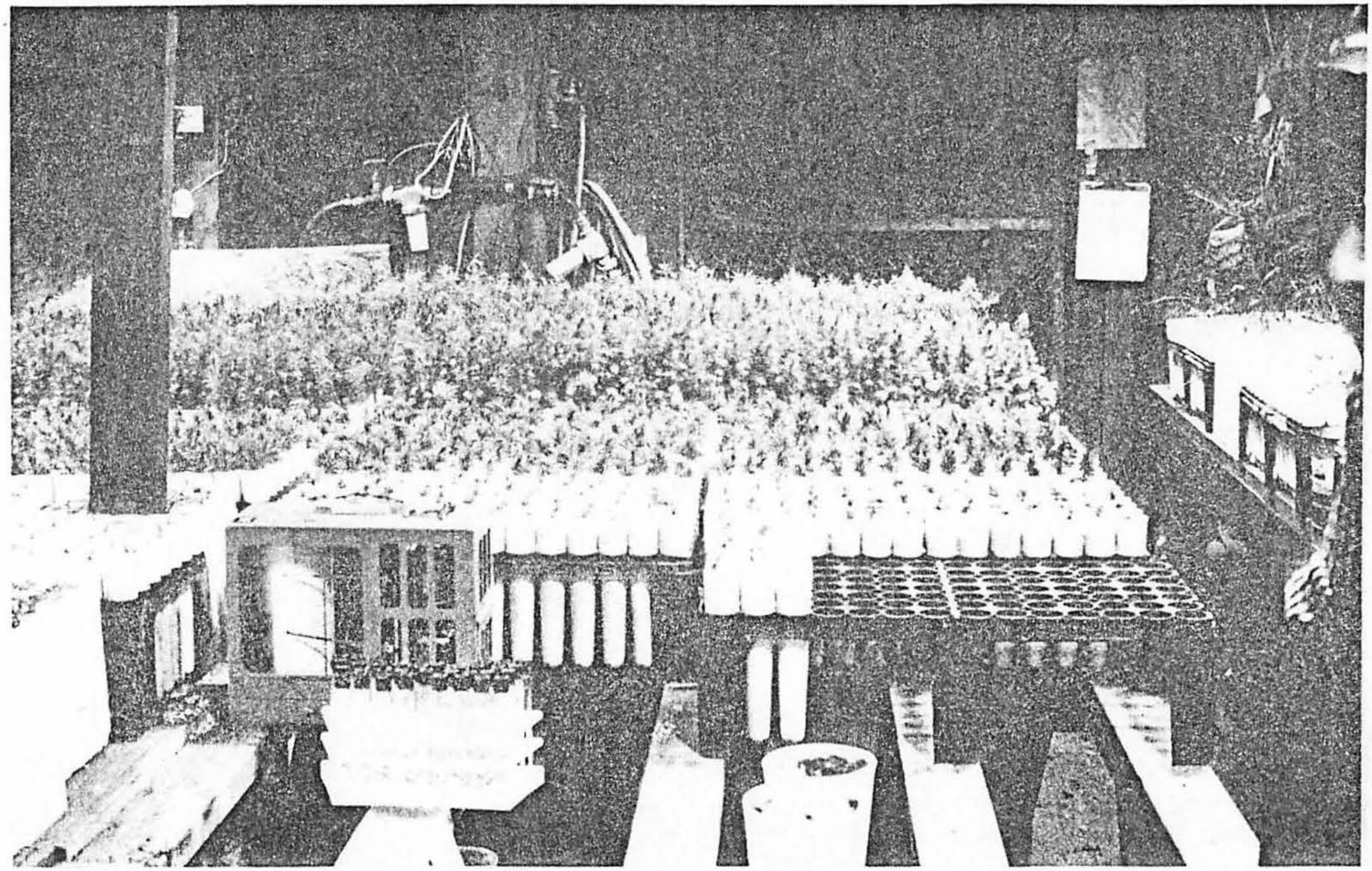
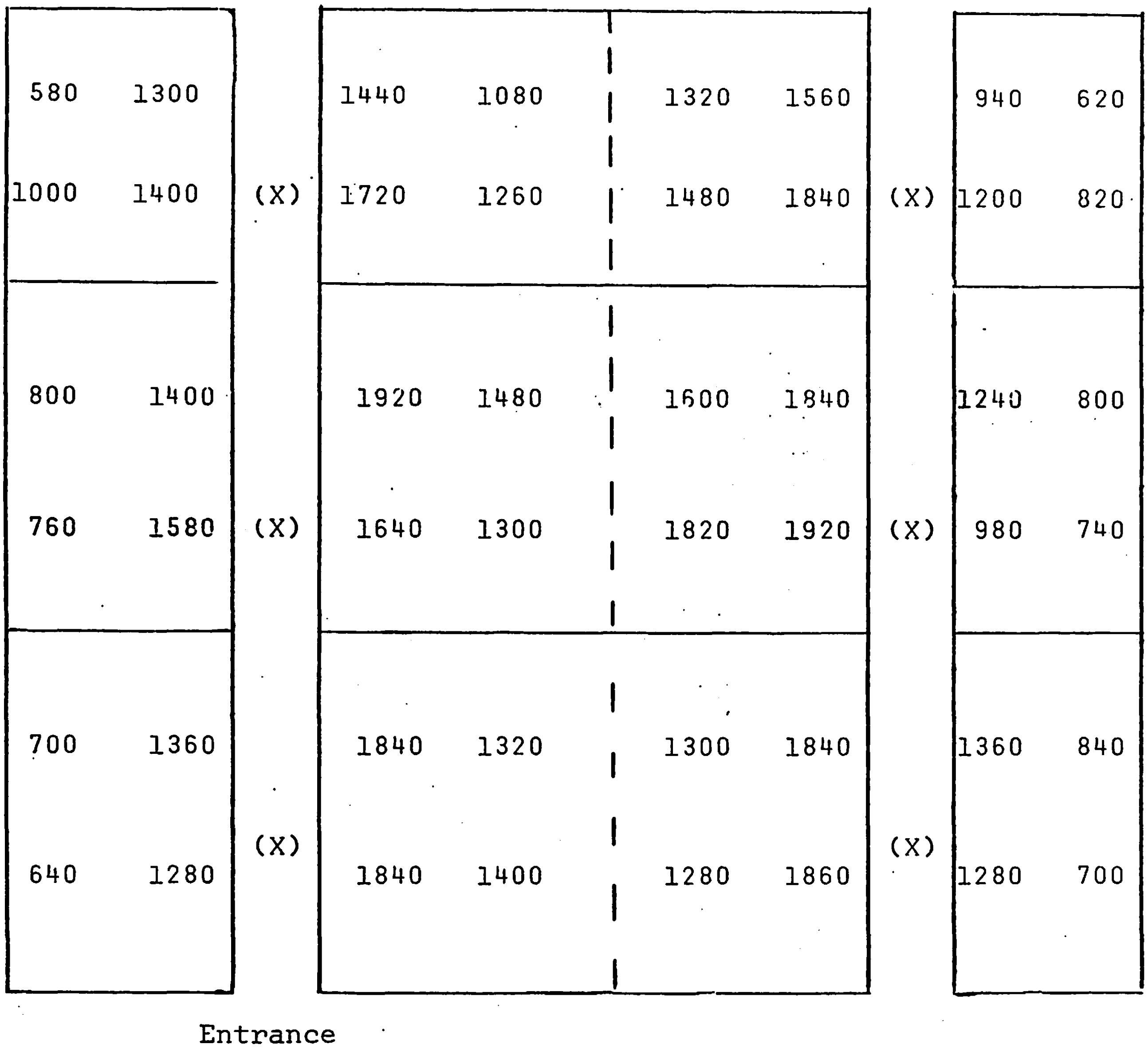


Figure 4

Figure 5



Sample Date - April 8, 1981 (X) Location of lights

Figure 6. Location of lights in the room and number of foot candles at various parts of the room.

in lighting is not recorded, but the total amount of darkness is notable.

<u>Temperature</u>: The ambient room temperature is between 72°F and 78°F. A hygrothermograph (Figures 4 and 7) provides a continuous recording. Rarely is there a fluctuation from whatever pattern has been established. Watering, temporary shutoff of ventilation, and lighting represent the primary cause of temperature change. Four Taylor Sixes maximum-minimum recording thermometers (Figure 8) are distributed throughout the room and they indicate the temperature is not uniform throughout. Table 1 provides data from the hygrothermograph and maximum-minimum thermometers.

<u>Relative Humidity</u>: A hygrothermograph monitors the relative humidity, which is calibrated with a psychrometer. Except after watering, the air is maintained at above 70% (Table 1).

<u>Air</u>: Air can move freely from the mine tunnel through the chain link divider. Air is brought in from the mine circulation system through perforated plastic ducts. Tunnel air is forced into the room by two fans (Figure 9). Room temperature can easily exit through the chain link divider. Air movement is monitored monthly. Carbon dioxide levels are periodically evaluated. If plant growth is at maximum, it is considered carbon dioxide may become limiting, but this condition has not been evident thus far.

<u>Biological</u>: Outside air is being introduced to the underground nursery, and therefore one would suspect a non-sterile

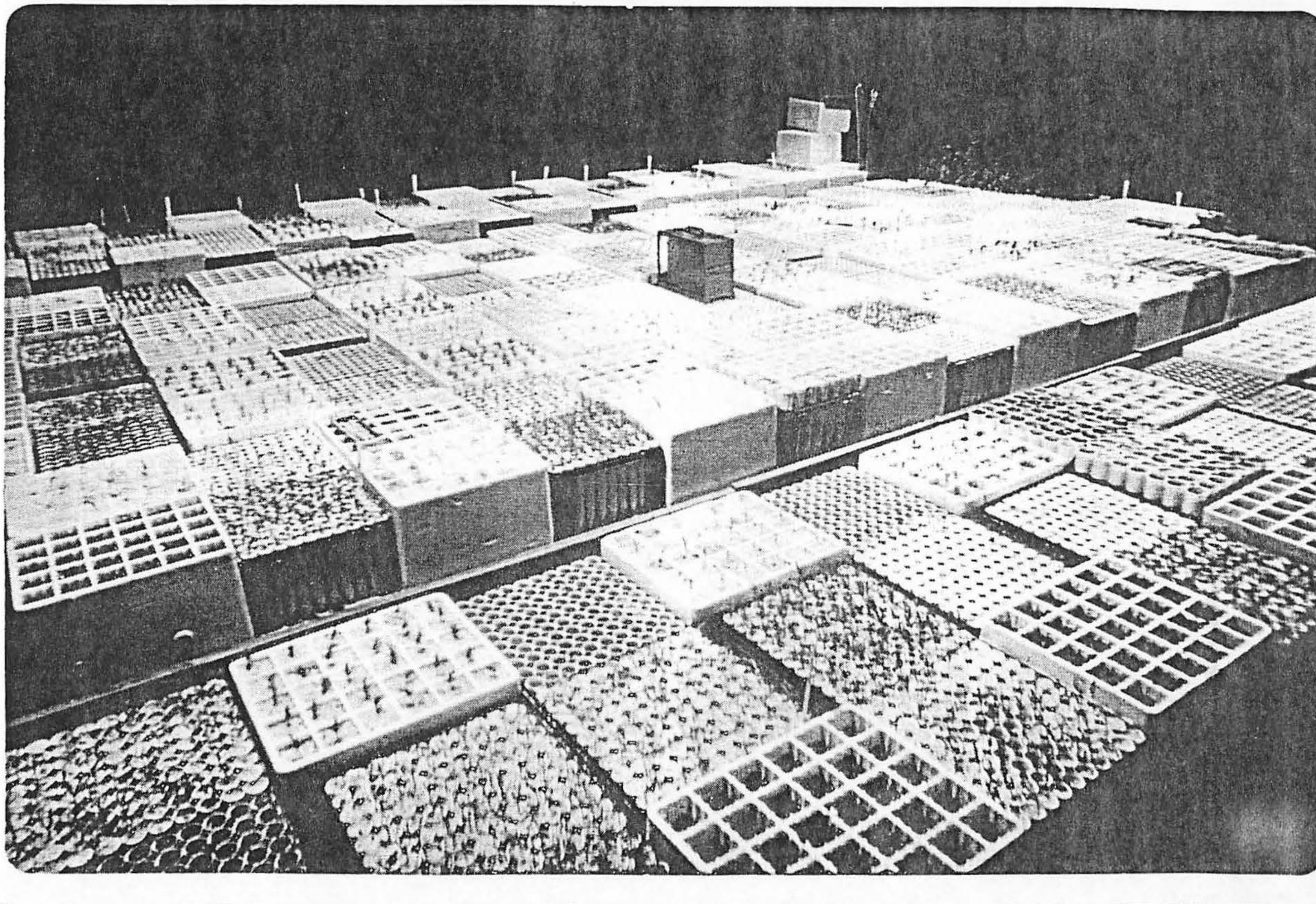


Figure 7

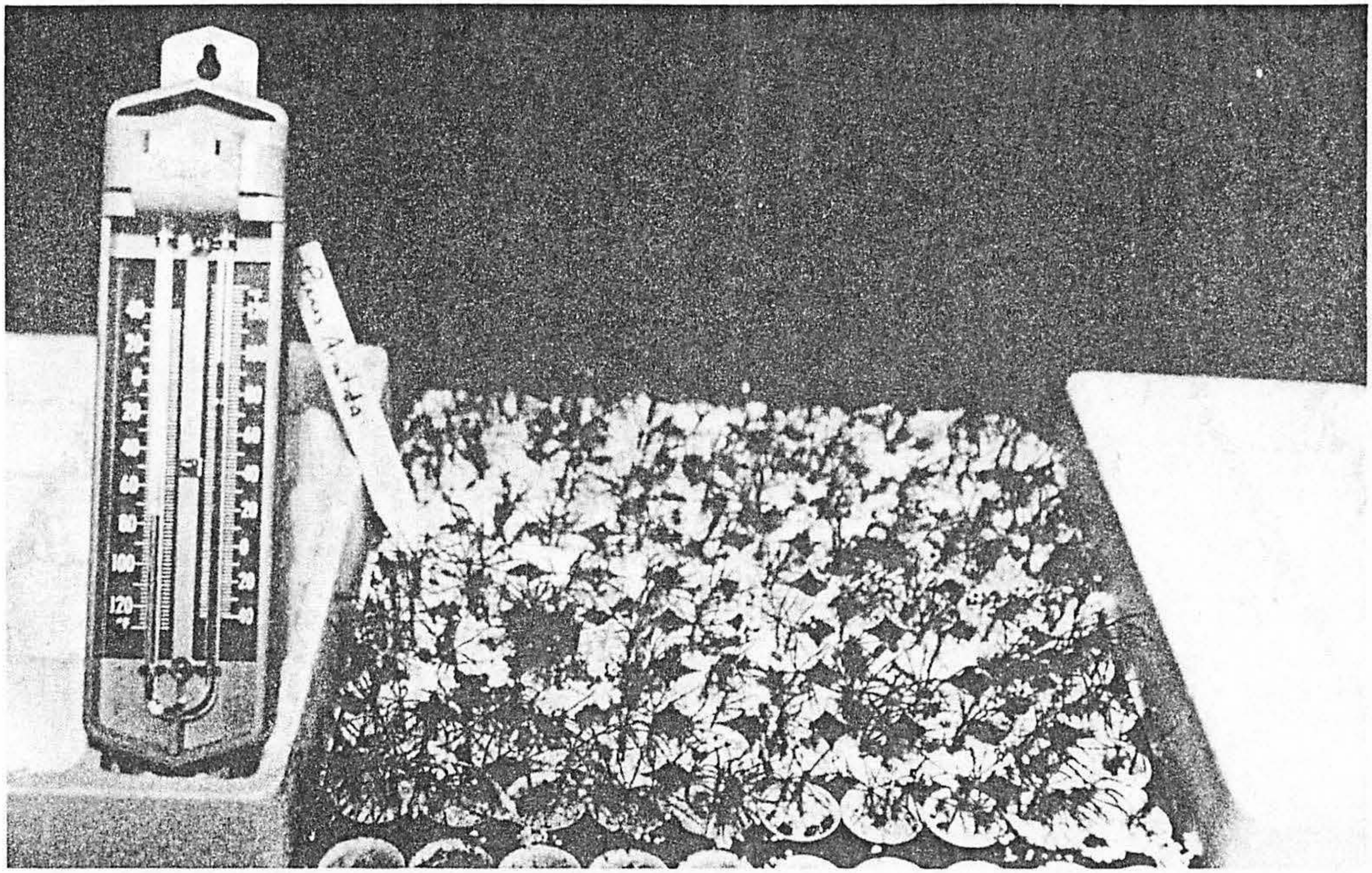


Figure 8

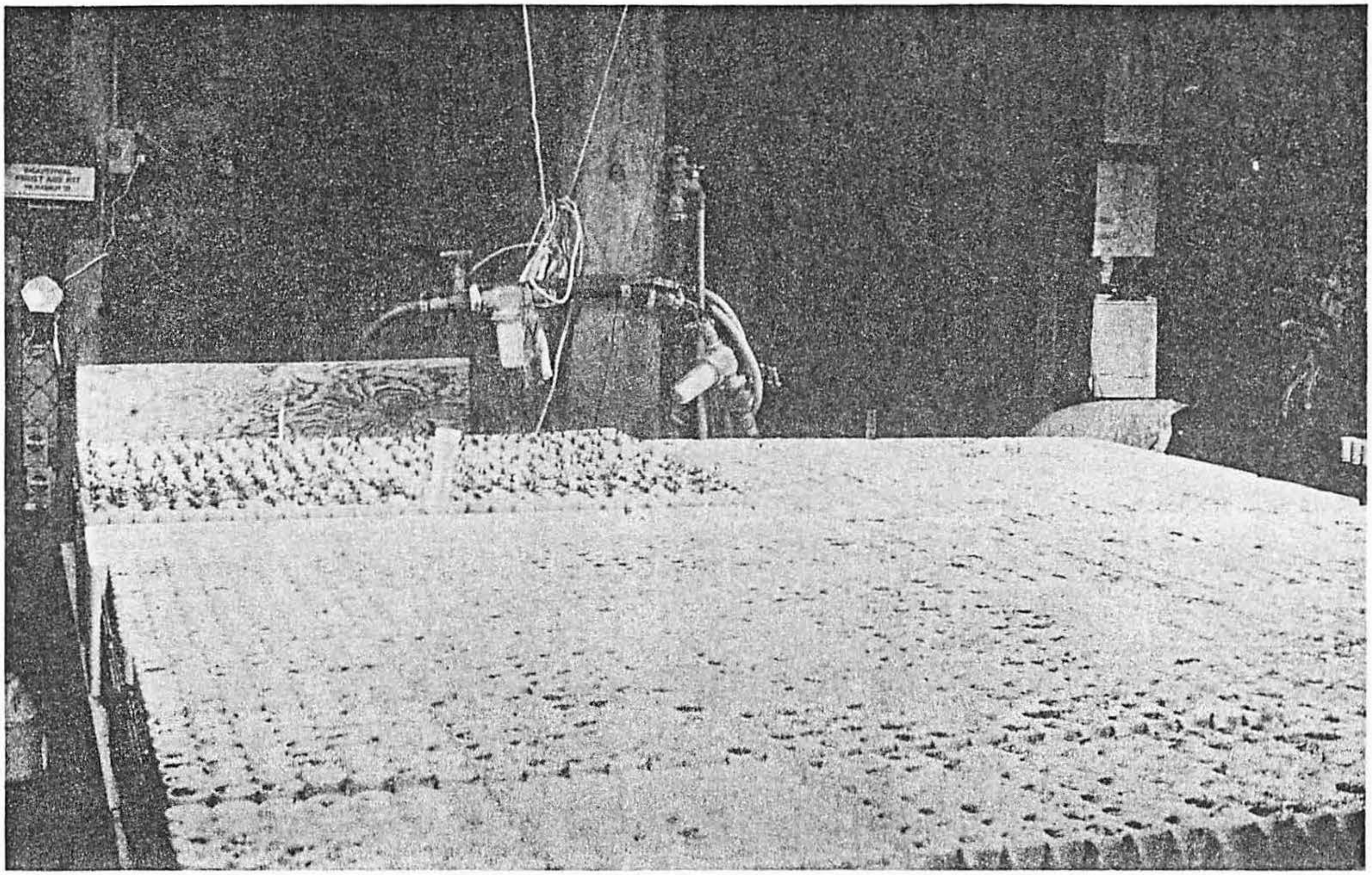


Figure 9

TABLE 1

RELATIVE HUMIDITY AND TEMPERATURE DATA
(March 25 - April 25, 1981)

Date	Hygrothermograph (%) Relative Humidity		Temperature		Thermometer (°F) #1		#2		#3	
	max	min	max	min	max	min	max	min	max	min
3/25	85	72	71	71						
3/26	92	78	71	71	74	74	72	72	70	69
3/27	77	74	71	71						
3/28	75	73	72	72						
3/29	73	72	72	72						
3/30	72	71	72	72						
3/31	72	72	72	72						
4/1	99	70	73	69	75	74	74	72	74	73
4/2	85	72	70	70	74	73	72	72	74	68
4/3	73	70	70	70						
4/4	70	70	71	71						
4/5	69	69	71	71						
4/6	69	69	72	72						
4/7	95	69	72	72	75	74	73	70	71	71
4/8	82	78	71	71						
4/9	82	76	71	71	74	73	73	72	70	70
4/10	81	79	72	70						
4/11	78	77	70	70						
4/12	78	76	70	70						
4/13	76	76	70	70						
4/14	76	76	70	70						
4/15	85	76	71	71	75	74	72	70	74	73
4/16	84	80	71	71	76	74	72	68	70	70
4/17	81	79	72	72						
4/18	79	78	72	72						
4/19	78	77	72	72						
4/20	78	77	72	72						
4/21	77	77	73	72						
4/22	76	76	72	72	76	74	73	70	71	71

environment. Bacteria and fungi proved to be common (Table 2). Algae were virtually undetectable. Other nonvascular plants such as mosses were not monitored, but became evident by growing profusely on the container substrate surface.

Water: Water generated in the mine and being piped out is intercepted at the underground facility and utilized for irrigation. The water is monitored monthly. Thus far, the data has not reflected any conditions which merit concern (Table 3).

Substrate: Considerations for a suitable substrate were received from Ed Pommerening, Marvin Strachan (Colorado State Forest Service Nursery, Fort Collins) and Tinus and McDonald (1979). A general concensus supported the formulation of a 1:1 peat moss-vermiculite mixture, with a Perlite cover to reduce water evaporation. As we consider a greater variety of plants, we recognize aneed to utilize a variety of media.

Containers: The earlier cited consultants made suggestions regarding containers. To resolve the question in our mind, Pine Cells, Super Cells, were obtained from Cone-tainer, Canby, Oregon. The Super Cells have a volume of eleven cubic inches and hold 98 seedlings in a 2 square foot tray. The Pine Cells have a volume of four cubic inches and allow 200 seedlings in the same sized tray. Styrofoam units developed and used by the Colorado State Forest Service Nursery allow thirty seedlings per tray (one square foot) with each subdivision having a volume of 29 cubic inches. All of the containers have openings at the bottom to allow for drainage, to encourage roots to develop

TABLE 2

MICROBIAL MONITORING

Fungi-Potato Dextrose Agar
(10 Minutes)

	Avg. Colonies/Plate 6 Plates	Standard Deviation
Nursery	23.0	4.9
Empty Mine Cut-Out	12.3	2.9
Science Lab	24.0	1.6

Bacteria-Nutrient Agar
(1.5 Minutes)

	Avg. Colonies/Plate 3 plates	Standard Deviation
Nursery:		
Right	34	10.1
Center	27	8.1
Left	29	19.1
Empty Cut-Out:		
Right	66	5.5
Center	25	8.7
Left	38	8.7

TABLE 3

WATER QUALITY STATISTICS FOR MOUNT EMMONS PROJECT

2000 Level Drill Water at Greenhouse

Starting Date 12-7-79/Ending Date 3-10-81

	MEAN	S.D.	S.E.M	MAX.	MIN.	SAMPLE SIZE
FIELD DATA						
PH	5.71634	0.23876	0.06622	6.30000	5.40000	13
SPECIFIC CONDUCTANCE	514.53846	42.32536	11.73894	620.00000	462.00000	13
TURBIDITY	25.87692	24.06184	6.67355	88.00000	2.00000	13
PHYSICAL PROPERTIES						
PH	5.84667	0.64682	0.16701	6.40000	4.00000	15
TURBIDITY	41.87500	26.64252	7.69103	96.00000	2.00000	12
SPECIFIC CONDUCTANCE	442.66667	88.11248	22.75055	510.00000	140.00000	15
SUSPENDED SOLIDS	20.83333	14.00468	3.61599	60.00000	< 5.00000	15
DISSOLVED SOLIDS	320.00000	34.04542	10.26508	375.00000	260.00000	11
INORGANIC CHEMICALS						
CALCIUM TOTAL	54.66667	13.12504	5.35827	65.00000	34.00000	6
MAGNESIUM TOTAL	8.91667	1.02062	0.41667	10.00000	7.00000	6
SODIUM TOTAL	10.30000	1.40570	0.57388	12.00000	7.90000	6
POTASSIUM TOTAL	2.91667	0.54924	0.22423	4.00000	2.50000	6
SULFATE	187.66667	20.16598	5.20683	250.00000	160.00000	15
CHLORIDE	2.16667	0.75277	0.30732	3.00000	1.00000	6
FLUORIDE	12.58667	9.11936	2.35461	45.00000	8.30000	15
METALS						
ALUMINUM TOTAL	1.04583	0.52892	0.15269	1.70000	0.10000	12
ARSENIC TOTAL	0.01700	0.00557	0.00186	0.02000	< 0.01000	9
CADMIUM TOTAL	0.01033	0.01217	0.00314	0.05000	< 0.01000	15
COPPER TOTAL	< 0.05000	--	--	0.05000	< 0.05000	15
IRON TOTAL	26.16667	12.04407	3.10976	53.00000	13.00000	15
LEAD TOTAL	< 0.01000	--	--	0.03000	< 0.01000	15
MANGANESE TOTAL	2.96667	0.72276	0.18662	4.20000	2.00000	15
MOLYBDENUM TOTAL	< 0.10000	--	--	0.10000	< 0.10000	15
SILVER TOTAL	< 0.05000	--	--	< 0.05000	< 0.05000	6
ZINC TOTAL	2.14000	1.08252	0.27951	3.60000	0.15000	15

downward, and to allow for root emergence and self-pruning. Figures 7 and 10 indicate how the containers were tested. Table 4 provides some of the results.

Fertilizer Alternatives: A number of alternatives for fertilization were available for consideration:

1. Mix a standard fertilizer into the growing medium.
2. Mix a slow release fertilizer such as "Osmocote" in the growing medium.
3. Apply a fertilizer to the substrate after planting.
4. Apply a mixture which supplements the minerals in the irrigation water.
5. Apply a Hoagland's Solution made up with distilled water.

Alternatives 2 through 5 were attempted. Despite the ease of utilization and the favorable comments from various sources supporting the second and third alternatives, they proved to be undesirable because they either left out critical elements or provided excesses of certain minerals, when considering the mineralization of the irrigation water. The fourth alternative proved to be the most successful. A modified Hoagland's Solution was developed by taking the analysis of the irrigation water (Table 3) and devising a desirable solution by adding the components which were lacking, and providing an ionically balanced medium. A chelating agent (EDTA) was added to assure that some of the iron in the irrigation water would be available for plant growth.

Species

With the ignorance associated with what species might thrive in the underground facility, an attempt was made to

COMMON NAME (*Scientific Name*)	Date Planted
ASIAN SALT TREE ---- A,B,C L,M,N (*Halimondendron halodendron*)	4/25
WOOD ROSE -------- G,H; (*Rosa woodsii*)	4/25
SNOWBERRY -------- D,E,F (*Symphoricarpos melanocarpa*)	4/15
BLUE SPRUCE (*Picea pungens*)	3/20
SIBERIAN PEASHRUB (*Caragana arborescens*)	4/25
SUBALPINE FIR (*Abies lasiocarpa*)	3/18
BOX ELDER (*Acer negundo*)	4/1
DOUGLAS FIR (*Pseudotsuga menziesii*)	3/18
CHOKECHERRY (*Prunus virginiana*)	4/1
LIMBER PINE (*Pinus flexilis*)	3/11
BIG SAGE (*Artemisia tridentata*)	4/1
LODGEPOLE (*Pinus contorta*)	3/11
PINION PINE (*Pinus edulis*)	3/27
PONDEROSA PINE (*Pinus ponderosa*)	3/6
FOUR-WING SALTBRUSH (*Artriplex canescens*)	3/27
BRISTLECONE PINE (*Pinus aristata*)	3/4
WHITE FIR (*Abies concolor*)	3/20
ENGELMANN SPRUCE (*Picea engelmannii*)	3/4

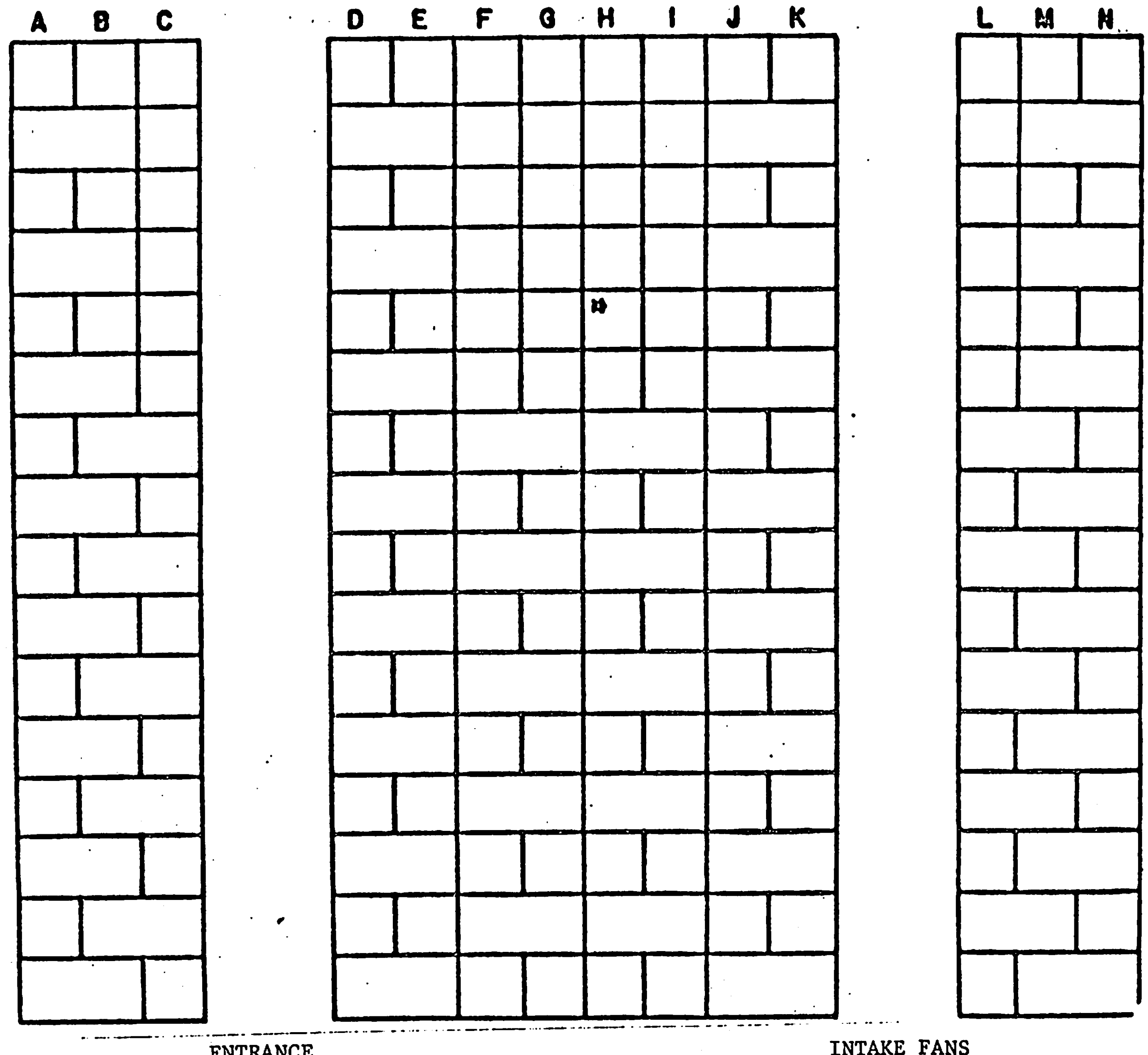


Figure 10. Arrangements of various containers and list of species tested.

TABLE 4

COMPARISON OF HEIGHT MEASUREMENTS
OF CONIFERS IN DIFFERENT CONTAINERS
AFTER 120 DAYS GROWTH
(inches)

	Styrofoam Blocks	Super Cell[R]	Pine Cell[R]
Engelmann Spruce	11.5	8.5	6.5
White Fir	8	---	5.5
Bristlecone Pine	4.5	---	3
Ponderosa Pine	5.5	4	2.5
Pinon Pine	2.5	2.5	3
Lodgepole Pine	4.5	2.25	3
Limber Pine	3.5	---	2.5
Douglas Fir	11	9	8
Subalpine Fir	5.5	5	4.5
Colorado Blue Spruce	11	9	7

examine a variety of plants (Figure 10), and determine which species should be considered desirable in a production schedule, and what that production schedule should be. The species were grown in a variety of containers, each in a row to assure their response to the conditions, as they vary from one side of the room to the other. Table 5 and Figures 11 through 18 reflect some of the success obtained.

<u>Hardening</u>

Because plants will often be removed from the facility during a time when weather will not permit planting in the field, concern was generated relative to where plants might be placed at this time. The problem was resolved when we found the local commercial greenhouse (Alpine Gardens) was putting the entire facility in Aspen production and the facilities would be ideal for putting out plants in a "holding" pattern.

<u>Initial Conclusions</u>

1. All container sizes permit growth. Best growth is associated with containers with maximum volume. Therefore, container size should be selected on the basis of the revegetation environment. Maximum root development is most ideal for a harsh environment.

2. Virtually all species grew well. Primary difficulty was associated germinating shrub species. Some species require being removed after two months; other species can be moved after four months.

3. Fertilizing is best accomplished by utilizing mine water chemical analysis and adding necessary additional chemicals to the mine water. Osmocote and commercial fertilizer application are definite growth supressors.

TABLE 5

GENERAL GROWTH DATA FOR CONIFERS

	Total Days Grown	Germination Days	*Juvenile Growth Stage		**Exponential Growth		Days to Root Egress	Rate of Growth (inches per month)
			Days	%	Days	%		
Engelmann Spruce (*Picea engelmannii*)	153	9	107	70	35	23	49	2.1
White Fir (*Abies concolor*)	138	11	91	66	35	25	33	1.6
Bristlecone Pine (*Pinus aristata*)	153	7	56	36	86	56	49	0.8
Ponderosa Pine (*Pinus ponderosa*)	151	7	109	72	35	23	49	1.0
Pinon Pine (*Pinus edulis*)	131	14	81	61	35	26	28	0.75
Lodgepole Pine (*Pinus contorta*)	147	12	99	67	35	23	42	0.8
Limber Pine (*Pinus flexilis*)	147	12	99	67	35	23	42	0.8
Douglas Fir (*Pseudotsuga mensiesii*)	140	5	104	74	35	25	35	2.2
Subalpine Fir (*Abies lasiocarpa*)	140	7	102	72	35	25	35	0.9
Blue Spruce (*Picea pungens*)	138	7	88	63	25	25	33	2.3

*Juvenile growth stage begins when the seed is exhausted and the tree becomes autotrophic. There frequently appears to be a pause in growth as the seedling forms a rosette above the cotyledons. The first green leaves are frequently different in shape, size, and outgoing from the ones on a mature plant. No buds are visible.

**Exponential growth stage occurs after the seedling has fully taken hold and frequently begins to resemble a mature tree, morphologically. The length of this stage is determined by how close growing conditions are to optimum, how large a tree is desired, and how soon one or more factors become limiting.

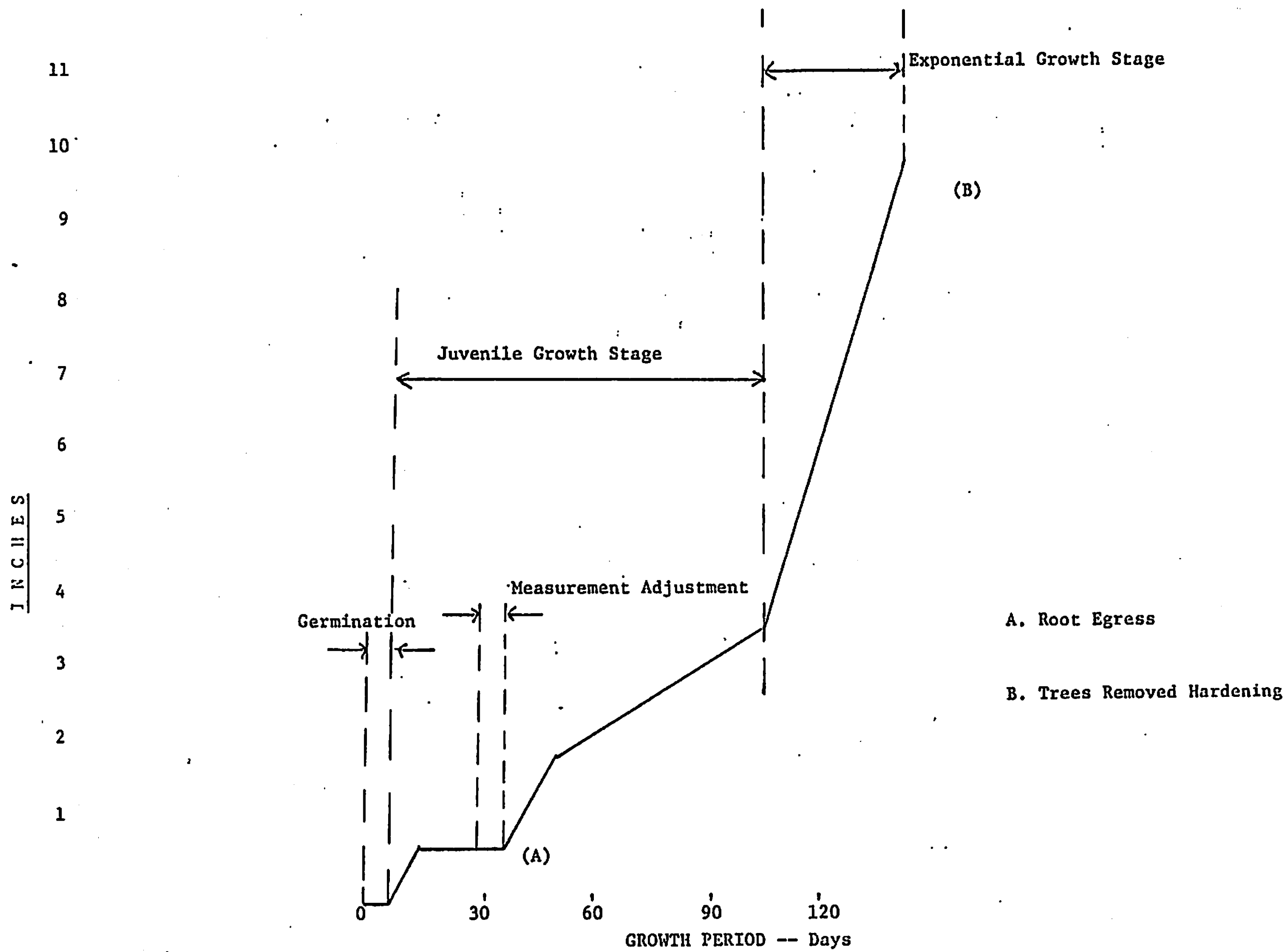


Figure 11. Douglas Fir growth stages, relative to time.

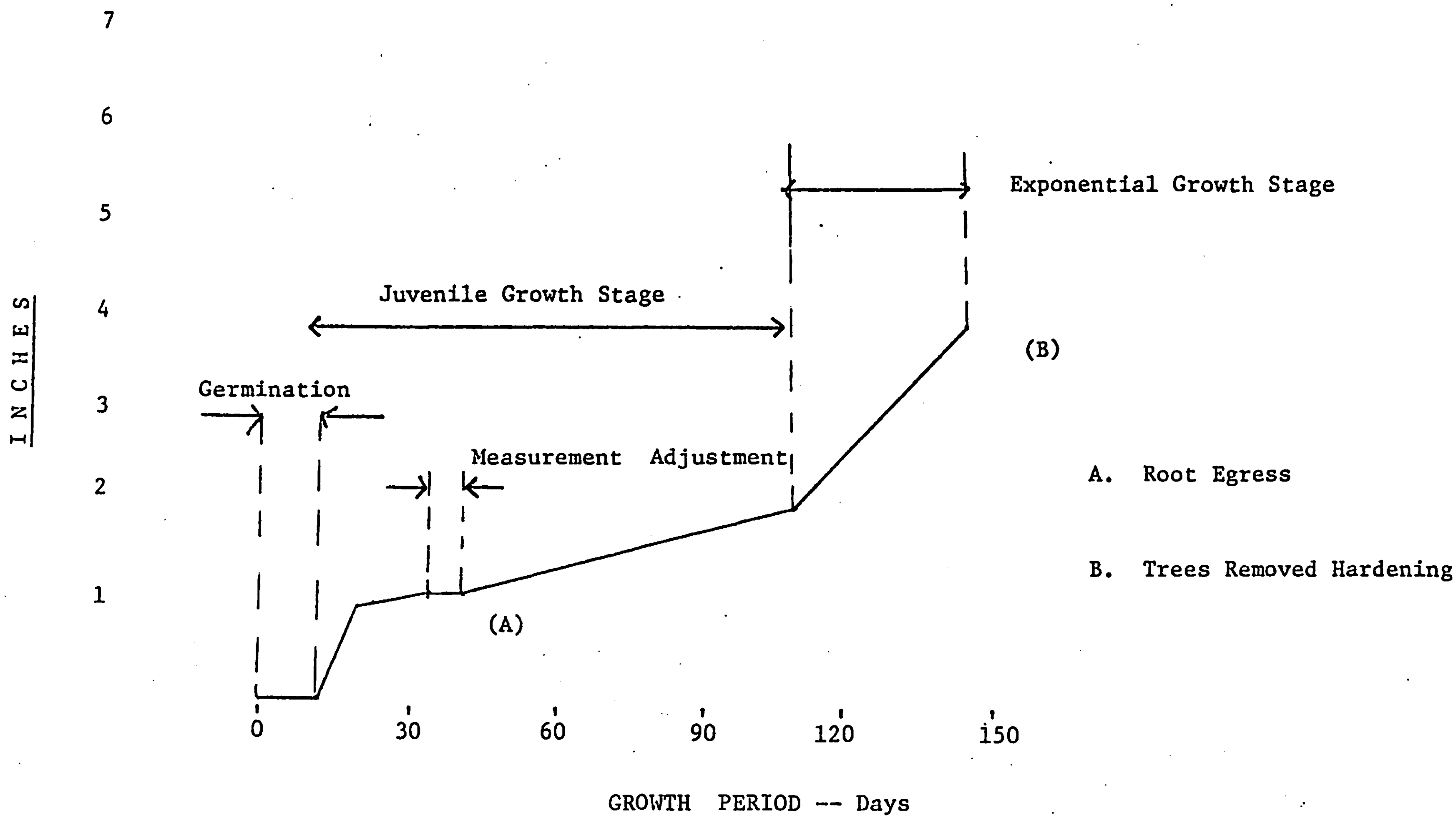


Figure 12. Limber Pine growth stages, relative to time.

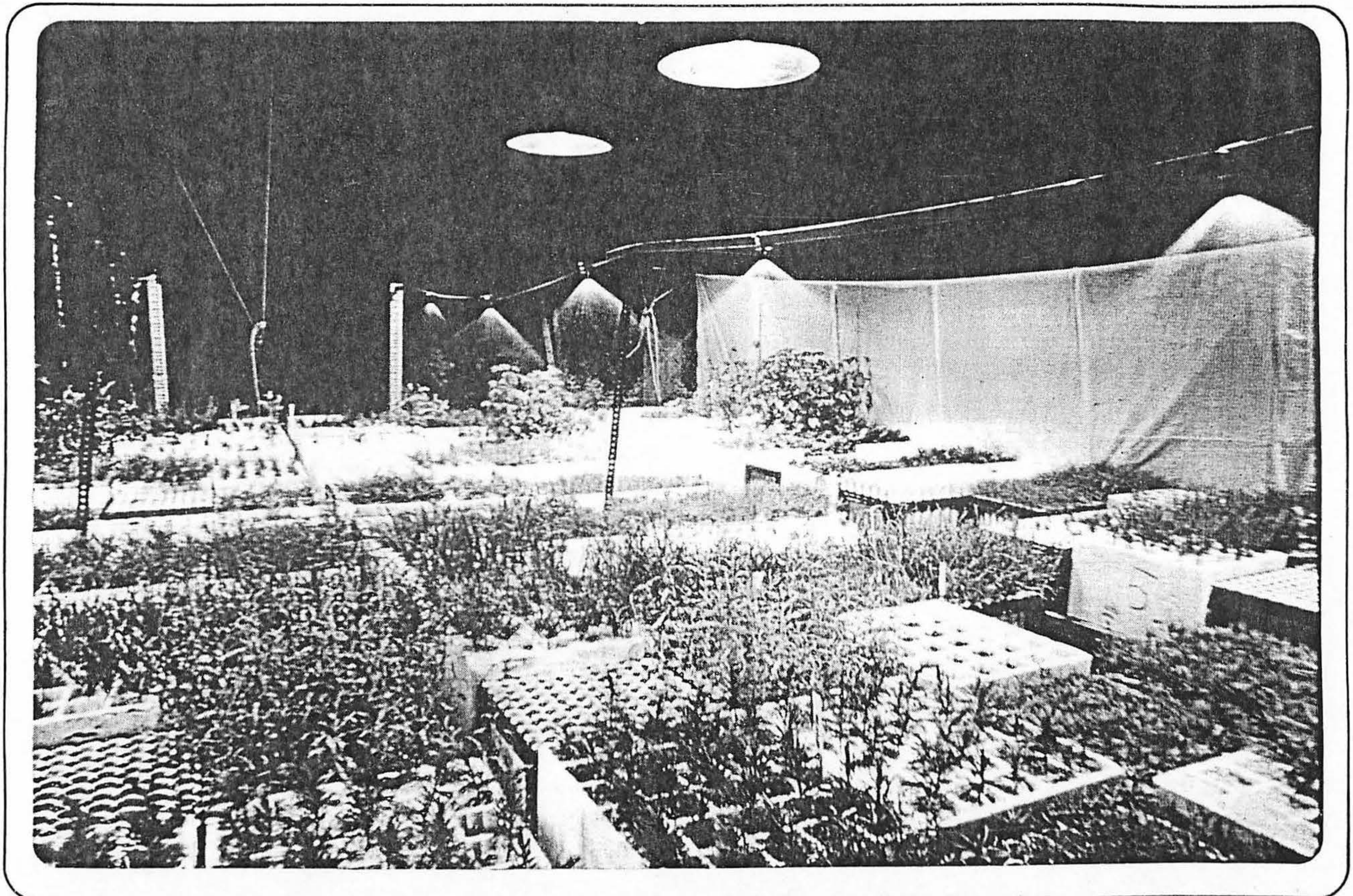


Figure 13

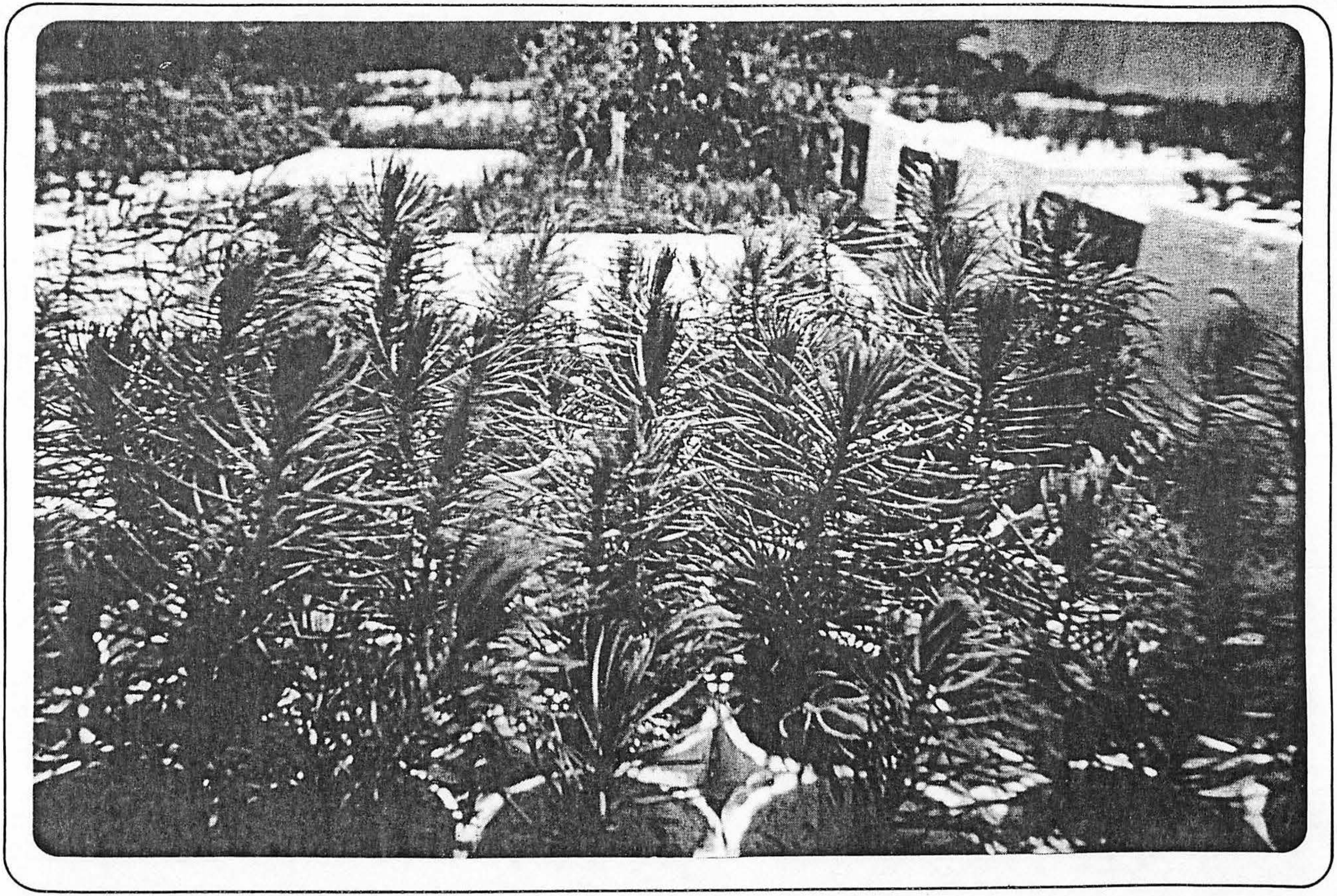


Figure 14

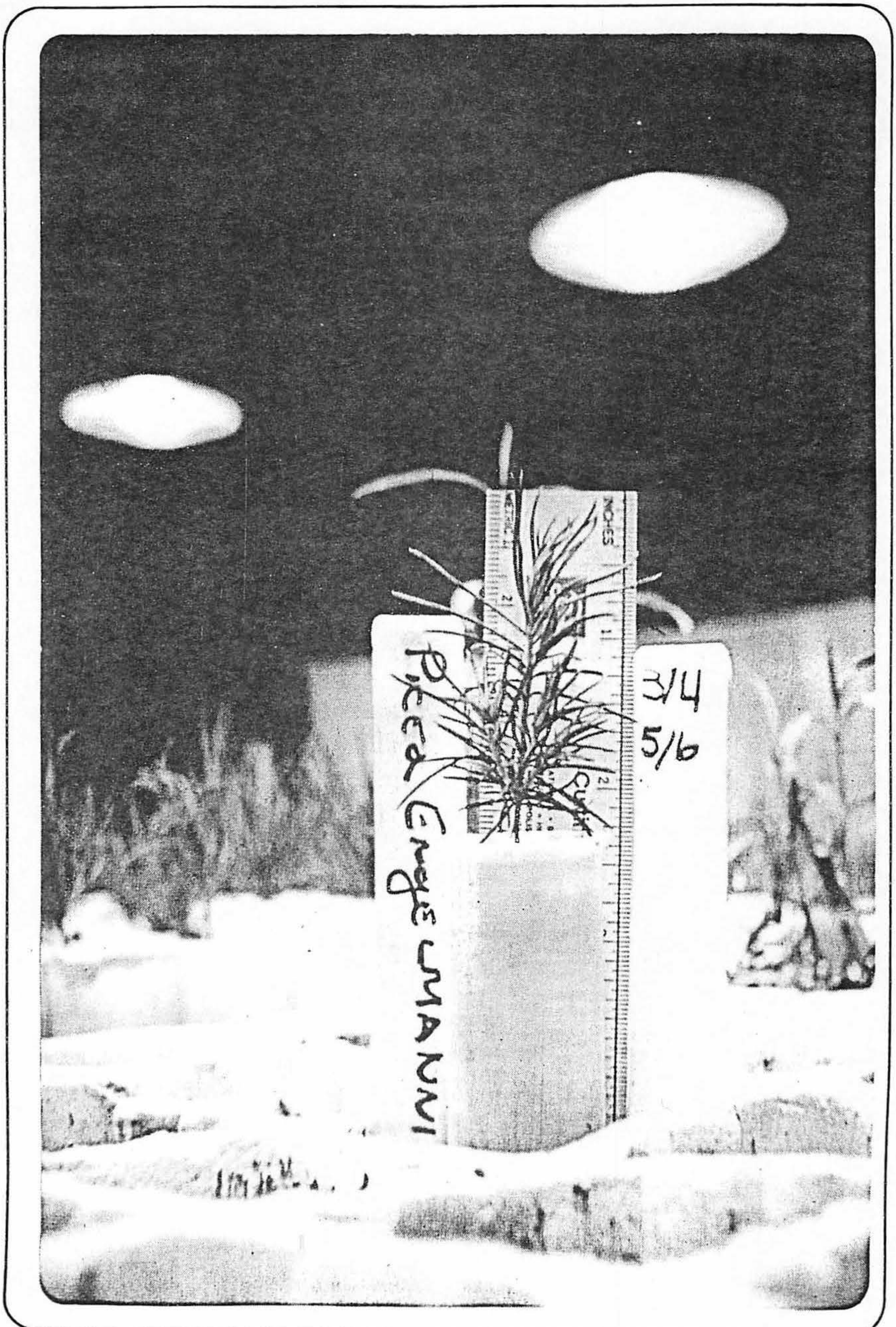


Figure 15

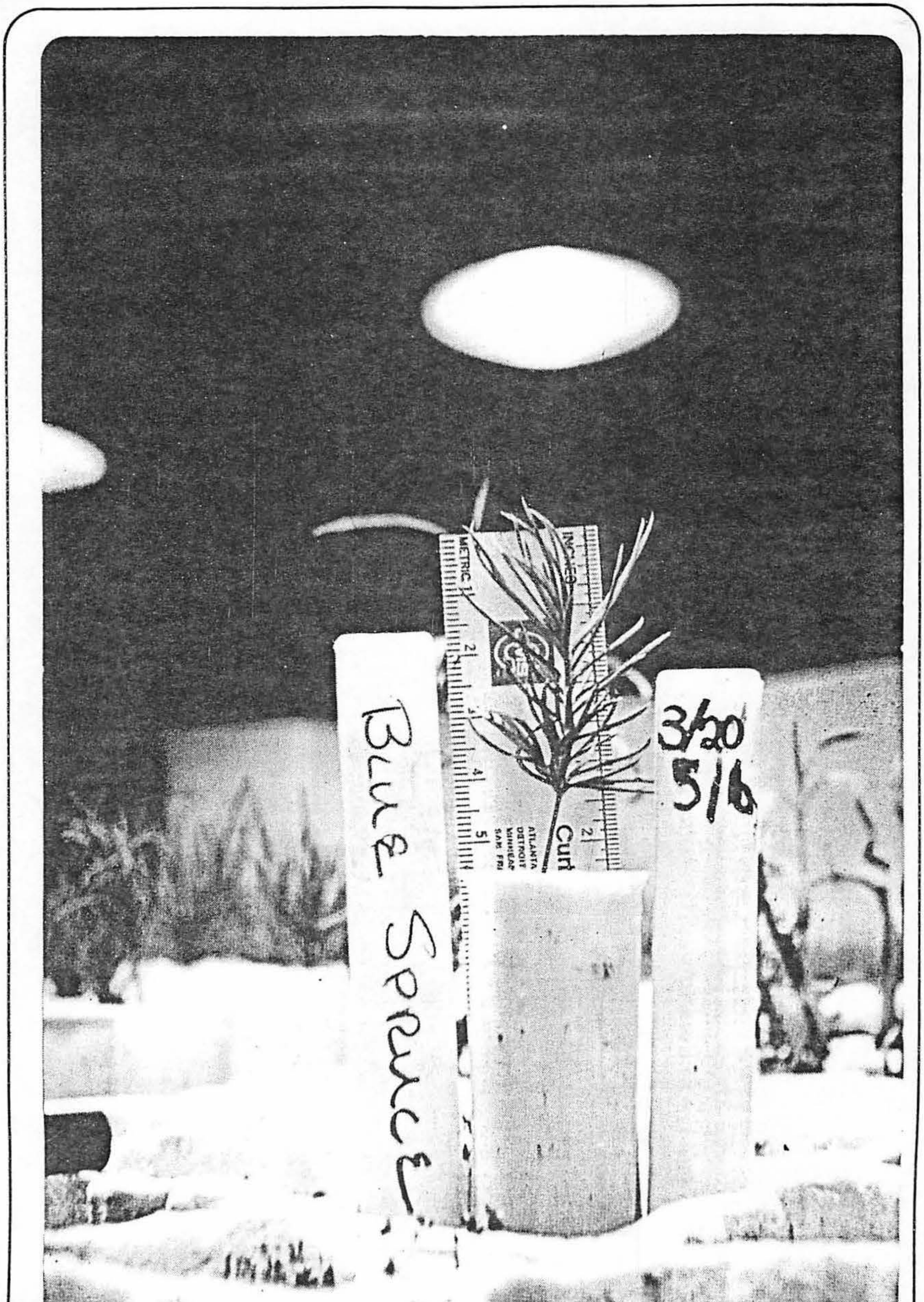


Figure 16

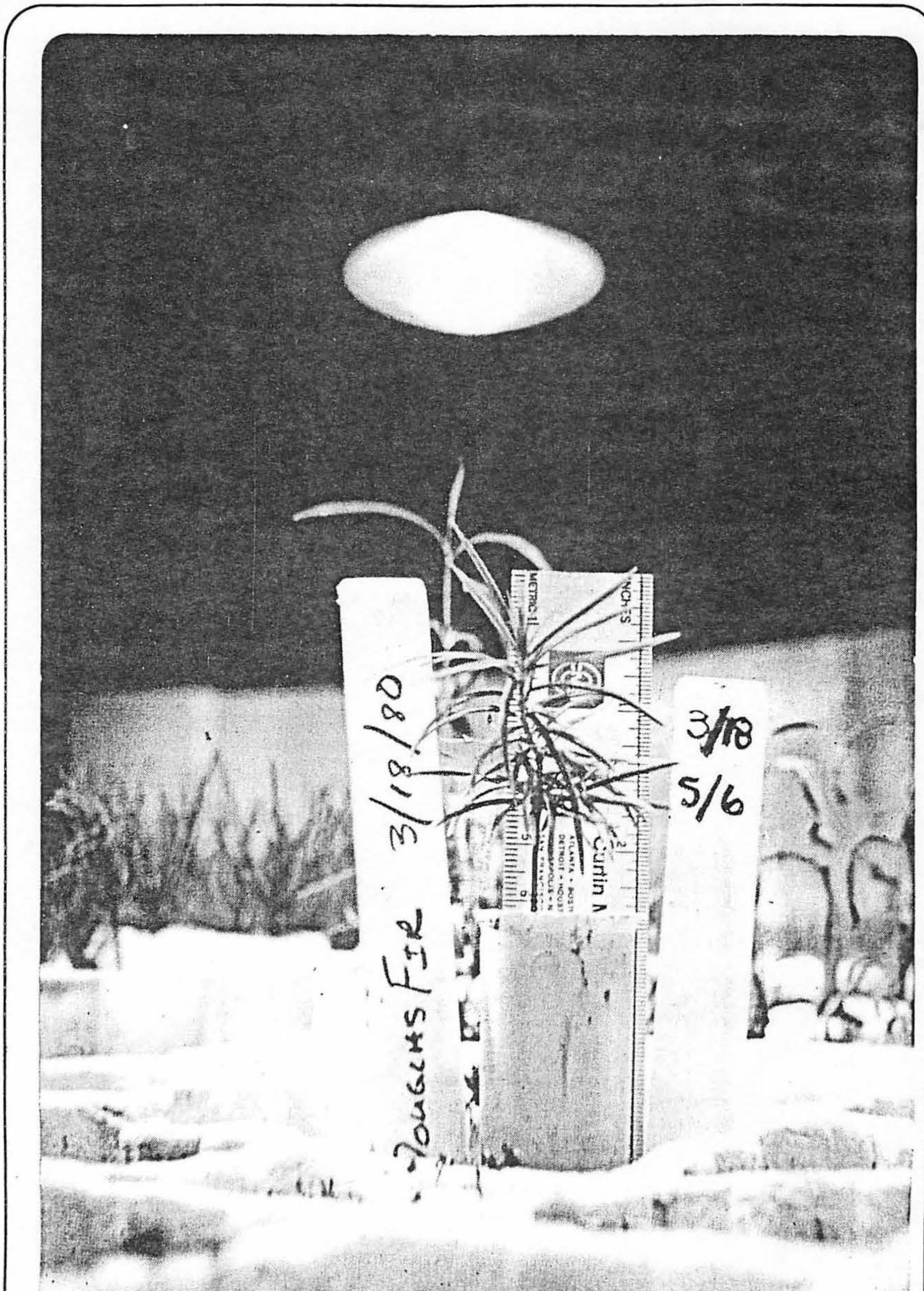


Figure 17

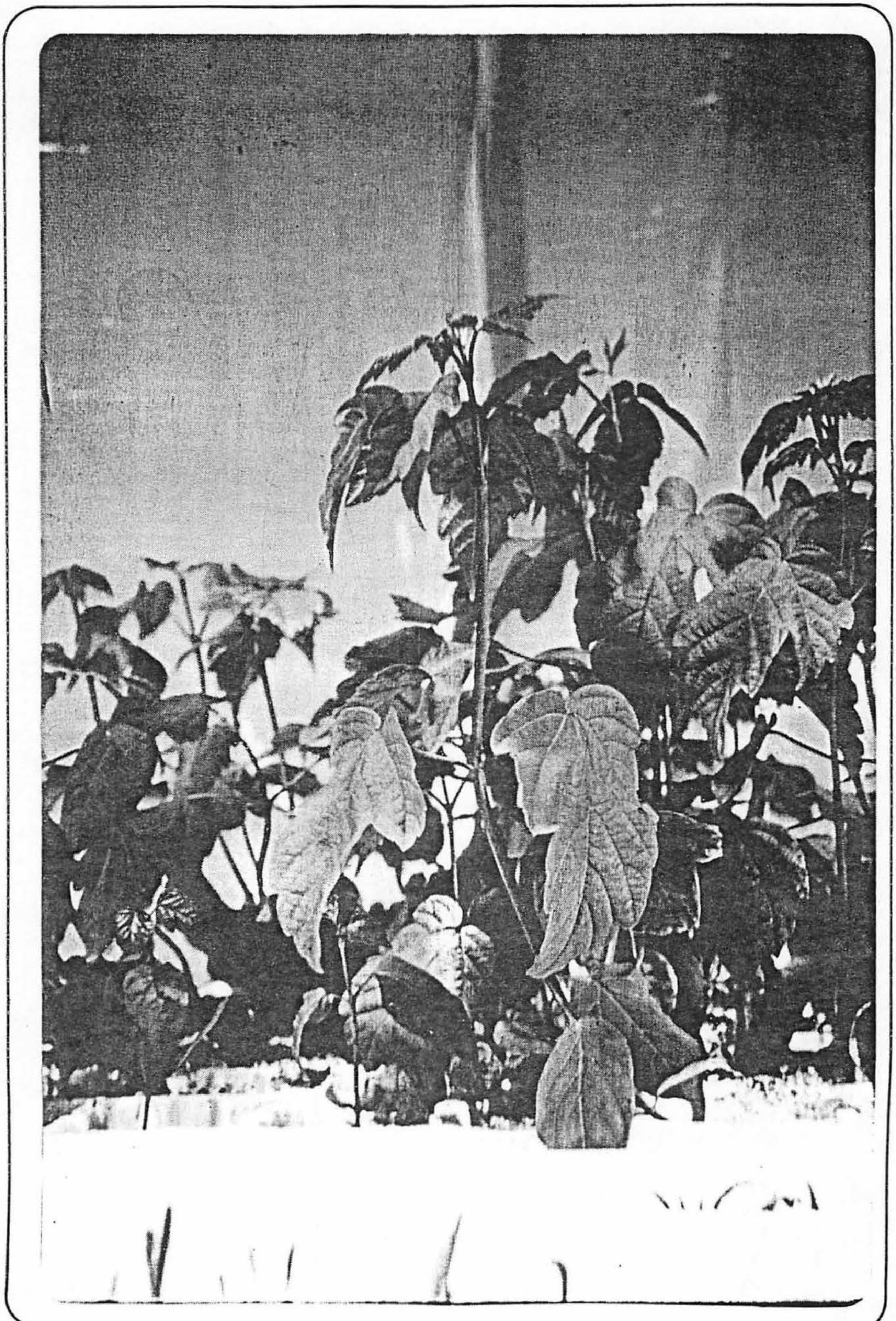


Figure 18

The Second Phase

The first phase of our work demonstrated we had the capability of being a production facility. The number of plants which could be produced, exceed the needs of the Mount Emmons Project. We also grew materials for Henderson and Climax. Inadvertently, we saw additional opportunities. In September, 1980, three Western State College students requested some space to carry out research, because the college does not own a greenhouse. One student worked on a project associated with AMAX; the other two were attempting to resolve questions associated with other mines. Because our underground facility telescopes three growing seasons into one year, it represents an ideal facility in which certain types of research can be conducted. Anticipated problems associated with the development of the Mount Emmons Project may be addressed and hopefully resolved long before they are to be encountered.

The research conducted this past year was directed at how to modify undesirable substrates so that they will support the greatest variety of species. In one case, it was the examination of the material which will be left behind at the completion of an open pit mine (Figure 19); in one case the evaluation of the tailings which will be anticipated with the development of a new Gunnison titanium operation; and in the third case, attempting to modify the Mount Emmons burn area soils to enable a more productive and diverse vegetation.

Success with research will encourage us to couple routine production with:

Figure 19

1. Shrub reproduction. This is anticipated in conjunction with Dr. Arthur Tiedeman and his group at the Shrub Science Laboratory, Provo, Utah. The objective is to determine if the underground facility may best serve as a means of reproducing shrubs.

2. Examination of asexual reproduction of such species as raspberry, rose, aspen, water birch, etc. We wish to examine if reproduction may be successful throughout the year for plants which do not reproduce easily from seeds.

3. Determination of best conditions for root system development.

4. Incorporation of mycorrhizal inoculum to develop the best root system.

5. Substrate evaluation, for the purpose of determining how substrates which currently are not exposed for plant growth may best become revegetated.

6. Screening of species. To determine which combination of species may best constitue a seed mix.

7. Determination of nutrient requirements. Currently, there is virtually nothing known regarding the nutrient requirements of native species. Fertilizer requirements for reclamation are based primarily on crop species, as opposed to the species you are attempting to plant.

Overall Conclusions

The underground environment has proven to have a potential to produce plant materials needed for revegetation. The quantity and quality of plants is sufficient to take care of future AMAX needs.

Secondary, the questions associated with revegetation often necessitate research. The underground facility is in a position to provide quick answers, or preliminary answers which field tests may verify.

It is unfortunate that closure of the underground facilities is imminent. Ongoing research during the quiescent state of mine development could save many dollars.

References

Tinus, Richard W., and Stephen E. McDonald. 1979. How to grow tree seedlings in containers in greenhouses. USDA Forest Service General Technical Report RM-60. 256 p.