CO2 Enriched Atmosphere Speeds Growth of Ponderosa Pine and Blue Spruce Seedlings

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Photosynthesis in well-lighted and well-watered plants is frequently limited by atmospheric CO_2 (Bolas and Henderson 1928; Decker 1947; Kramer and Kozlowski 1960; Thomas and Hill 1949). Since CO_2 can be especially limiting in a closed greenhouse, many horticulturists routinely add it to their greenhouse atmospheres. Increases in fresh and dry weight yields of 30 to 100 percent have been reported for a wide variety of vegetable and floral crops (Hardh 1966) in atmospheres ranging from 500 to 3000 ppm CO_2 (Hood 1966; Wittwer and Robb 1964). The optimum concentration, however, varies greatly with the species and the portion of the plant to be harvested (Imazu, Yabuki, and Oda 1967; Lindstrom 1968; Titljanov, Stepanova, and Cesnokov 1967). There are cases where the beneficial effects of CO_2 enrichment were still apparent months after the plants were removed from a high CO_2 atmosphere (Goldsberry 1963).

In northern United States and Canada, it may soon be economical to grow conifer seedlings for forest and shelterbelt planting in greenhouses. It is therefore important to know how much elevated CO_2 levels can speed their growth.

Methods

Equipment

Pour small growth chambers were constructed in a greenhouse (fig. 1). Each consisted of a tar-coated plywood box 44 cm long, 30 cm wide, and 23 cm high, divided into 24 compartments. These 6 x 6 x 23 cm compartments formed individual pots, which were filled with a 2:1 mixture of peat and perlite. The box was sealed under a removable clear cellulose acetate cover 50 cm high.

Air was circulated within each chamber by a blower, and was passed over a cooling coil through which cold tap water could be run. A 250-watt heat lamp placed within the air passage was aimed at the coils. This way more uniform temperatures were maintained than throughout the greenhouse generally. The minimum nighttime temperature was 20°C., and cooling was adequate to prevent daytime temperatures from rising above 27°C. The four chambers were within plus or minus 1°C. of each other at all times.

A pair of chambers were connected so that a single heatercooler-blower unit controlled the air circulation in both. One pair of chambers contained ambient CO_2 , which varied from between 250 to 400 ppm. The other pair was maintained at 1200 ± 100 ppm CO_2 during the day.

Figure 1.—Small growth chamber for elevated CO_2 experiments.

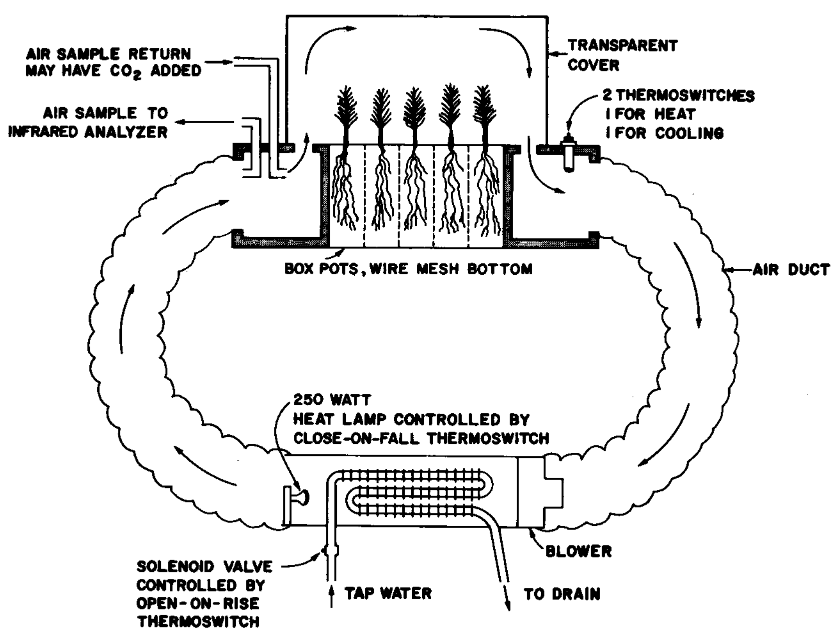

TABLE 1.—*Comparison of* P. ponderosa *Laws. seedlings grown under normal and elevated* CO_2 *levels at 8 and 12 months. Mean values of 12 seedlings per treatment*

Measurement	8 month old seedlings: CO_2 concentration 325 ppm	8 month: CO_2 concentration 1200 ppm	8 month: Difference Percent	8 month: P[1]	12 month old seedlings: CO_2 concentration 325 ppm	12 month: CO_2 concentration 1200 ppm	12 month: Difference Percent	12 month: P[1]
Height (cm)	25.5	27.1	6	NS	25.4	30.6	20	5
Caliper (mm)	4.74	4.98	5	NS	5.46	6.16	13	10
Fresh weight:								
Total (gm)	15.6	19.3	24	10	26.1	44.3	70	1
Stem	3.3	4.4	33	5	5.4	10.3	91	0.1
Needle	9.3	11.1	19	10	15.0	25.0	67	1
Root	2.9	3.8	31	NS	5.7	8.9	58	5
Top/root ratio	4.30	4.07	—5	NS	3.62	3.95	9	NS
Dry weight:								
Total (gm)	5.83	7.05	21	NS	12.35	18.24	48	1
Stem	1.24	1.54	24	NS	2.45	4.16	70	1
Needle	3.68	4.30	17	NS	7.79	10.42	34	5
Root	0.91	1.21	33	5	2.11	3.65	73	1
Top/root ratio	5.41	4.83	—11	NS	4.86	4.00	—18	NS
Total dry/fresh weight ratio	0.37	0.37	0	NS	0.47	0.41	—13	NS
Side branches (No.)	1.42	0.82	—42	NS	3.0	4.6	53	10
Ave. needle length (cm)	—[2]	—	—	—	16.6	18.3	10	5
Needle fascicles (No.)	—	—	—	—	89	141	58	0.1

[1] P is the significance level in percent. NS = P>10.
[2] Not measured.

TABLE 2.—*Comparison of* Picea pungens *Engelmann seedlings grown under normal and elevated* CO_2 *levels at 8 and 12 months. Mean values of 12 seedlings per treatment*

Measurement	8 month old seedlings: CO_2 concentration 325 ppm	8 month: CO_2 concentration 1200 ppm	8 month: Difference Percent	8 month: P[1]	12 month old seedlings: CO_2 concentration 325 ppm	12 month: CO_2 concentration 1200 ppm	12 month: Difference Percent	12 month: P[1]
Height (cm)	27.0	32.3	19	5	29.8	34.2	15	NS
Caliper (mm)	4.71	5.40	15	5	6.65	7.32	10	NS
Fresh weight:								
Total (gm)	16.6	23.4	41	5	24.2	38.9	61	1
Stem	3.8	5.8	53	1	7.4	13.0	76	1
Needle	9.1	12.4	36	5	9.4	15.1	61	1
Root	3.7	5.2	40	10	7.4	10.8	46	1
Top/root ratio	3.46	3.50	1	NS	2.27	2.59	14	NS
Dry weight:								
Total (gm)	4.22	6.50	54	1	10.84	15.85	46	5
Stem	1.01	1.75	73	1	3.85	5.51	43	5
Needle	2.39	3.52	47	1	4.24	5.87	38	10
Root	0.79	1.23	56	1	2.76	4.47	62	1
Top/root ratio	4.30	4.30	0	NS	2.93	2.54	—15	NS
Total dry/fresh weight ratio	0.25	0.28	12	NS	0.45	0.41	—9	NS
Side branches (No.)	16.7	19.7	18	5	17.9	22.2	24	NS

[1] P is the significance level in percent. NS = P>10.

The atmosphere in the CO_2 enriched chambers was monitored continuously by a Beckman Model 215A infrared analyser, and the CO2 concentration was recorded on a strip chart recorder. Limit switches on the recorder operated solenoid valves which added CO_2 from a tank to the chambers on demand. Leaks in the chambers provided for reduction in CO_2 concentration when necessary.

One 150-watt floodlight above each chamber provided approximately 100 ft-c of supplemental light at night to maintain a 20hour photoperiod. This was necessary to insure that the seedlings did not go dormant before the end of the experiment.

Seedlings

Ponderosa pine seeds were collected in 1962 and 1964 near Ainsworth, Neb. Blue spruce seeds were collected from several good specimen trees at Cheyenne, Wyo., in 1967. Arasantreated seeds were germinated in petri dishes on moist blotting paper in an incubator at 25°C. in November 1968. One germinating seed was then planted per pot, radicle end down and not covered, in a depression in the potting mixture. Within each chamber, pine and spruce were arranged in quadrants of 2 x 3 seedlings. Pine occupied the NE and SW quadrants, while spruce occupied the other two. The cellulose acetate cover was removed three times a week to water and fertilize the trees with halfstrength Hoagland's solution.

Half the trees of each species were removed in a checkerboard pattern after 8 months of treatment. Each tree was carefully washed free of potting mixture, and measured as follows:

1. Height, root collar to bud (cm ± 0.1)
2. Caliper at root collar (mm ± 0.1)
3. Fresh weight (gms ± 0.1) of:
   a. stem
   b. needles
   c. roots
4. Dry weight (gms ± .01) of:
   a. stem
   b. needles
   c. roots
5. Number of side branches
6. Number of needle fascicles (pine only)
7. Average needle length (cm ± 0.5) (pine only)

The remaining trees were harvested in November 1969 when they were 12 months old, and the measurements were repeated. Differences between treatments were tested by analysis of variance.

Results and Discussion

Blue spruce responded to a high CO_2 concentration at an earlier age than pine (tables 1 & 2). Fresh weight of 8-month-old spruce under high CO_2 was greater than that of control trees, and this difference was even greater after 12 months. Dry weight differences, however, tended to decrease between 8 and 12 months. Height and caliper differences also decreased slightly during this time.

In contrast, all differences in ponderosa pine were greater at 12 months than at 8 months of age. Twelve-month-old pines grown under high CO_2 were 70 percent heavier by fresh weight and 48 percent heavier by dry weight than control trees. Height difference was significant only at 12 months. Pines grown under high CO_2 had longer needles and many more needle fascicles than those grown under low CO_2. (These observations were made only at the 12-month harvest.)

High CO_2 concentration did not produce any noticeable morphological changes in either species. Blue spruce appeared to grow continuously without producing noticeable buds, while ponderosa pine grew in-distinct flushes after it was about 4 months old; one flush followed another without an extended rest period. These growth patterns typify blue spruce and ponderosa pine that have been grown from seed under continuous long photoperiod and favorable temperatures.

Top/root ratios of seedlings of both species grown under high CO_2 were not significantly different from control seedlings. Likewise, CO_2 level did not affect, the succulence of either species as measured by the ratio of dry weight to fresh weight. With the exception of dry root weight of spruce, the greatest response to elevated CO_2 was an increase in stem weight. Thus, outplanting success for seedlings grown under high CO_2 should be at least as good for those grown under standard atmosphere, other conditions being equal.

The small response of ponderosa pine to high CO_2 recorded at age 8 months was probably because something other than CO_2 was limiting. Light intensity may have been suboptimum. Pines are generally capable of responding to higher light intensities than spruces (Hodges and Scott 1968; Ronco 1970). Air temperature of 20-27°C should have been close to optimum, but root temperatures may have been 5-7°C above optimum (Larson 1967).

Conclusion

Ponderosa pine and blue spruce grown for 1 year from seeds grew larger under 1200 ppm CO_2 than they did under ambient 300 ppm CO_2. Trees grown under high CO_2 were well balanced; succulence and top/root ratios were not significantly different from those obtained under ambient iC02. Height, caliper, and number of side branches of trees grown under high CO_2 tended to be greater than for those grown under ambient CO_2, while fresh and dry weights were strikingly greater. Thus, tripling or quadrupling the atmospheric concentration of CO_2 would benefit greenhouse production of these two conifers and probably many other species.

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Caution: Pesticides can be injurious to humans, domestic animals, desirable plants, and fish or , other wildlife-if they are not handled or applied properly. Use all pesticides selectively and carefully as prescribed. Follow recommended practices for the disposal of surplus pesticides and pesticide containers.