Root Growth, Respiration, and Carbon Dioxide Evolution in an Arctic Tundra Soil

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MEASUREMENT OF ROOT GROWTH IN SIMULATED AND NATURAL TEMPERATURE GRADIENTS OVER PERMAFROST

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ABSTRACT

A method is described for measuring root and rhizome growth along temperature gradients in the field and under controlled conditions. Wedge-shaped Plexiglas sod boxes equipped with thermocouples are inserted into tundra soils over permafrost. After thaw has started, root and rhizome increases in length can be measured at intervals through the growing season by marking the positions of their tips on the sloping Plexiglas sides of the box. A similar box is used in a temperature-controlled coolant bath system in a controlled environment chamber. This latter system can simulate field temperature gradients down to and into permafrost. The simulated permafrost level can be raised or lowered by changing the temperature of the circulating ethylene glycol bath.

INTRODUCTION

Soils in the arctic tundra of the Alaskan North Slope are completely frozen for 8 to 9 mo during the year. They thaw gradually to depths of about 20 to 50 cm in late June and July, and begin to refreeze in early September. Permafrost lies beneath the maximum depth of thaw. Soil temperatures in the thawed or active layer are low (generally between 0 and 10°C) except in sands or gravels where temperatures are somewhat higher and depth of thaw may be as much as 1 m.

In the wet coastal tundra, where the upper part of the soil profile is peat, 85 to 98% of the live vascular plant biomass consists of roots and rhizomes (Dennis and Johnson, 1970; J. G. Dennis and L. L. Tieszen, pers. comm., 1972). The importance of measuring growth rates in such a major component of the vegetation is obvious. However, because of the difficulties presented by the shallow depth of thaw in a very wet cold soil, few field measurements of root and rhizome growth have been made until recently (Shaver and Billings, 1975; Billings *et al.*, unpublished). We have developed two complementary methods for measuring such growth in the field and under controlled conditions.

METHODS

The heart of both measurement systems is a wedge-shaped sod box, the sloping sides of which are Plexiglas. In the soil within the box, roots and rhizomes grow laterally or downward until they come in contact with the Plexiglas, become visible, and can be measured through time along the face of the transparent sloping sides. A root box of the field type is diagrammed in Figure 1. It has sloping Plexiglas faces held by screws to wooden sides. A drain is created by leaving a 5-mm gap between the Plexiglas faces at the bottom of the wedge.

The laboratory root boxes differ from those used in the field; they are made entirely of Plexiglas sheets held together by screws. All four corners and bottom are then sealed by melting the seams with diethyl ether. This procedure produces a waterproof box which can be im-

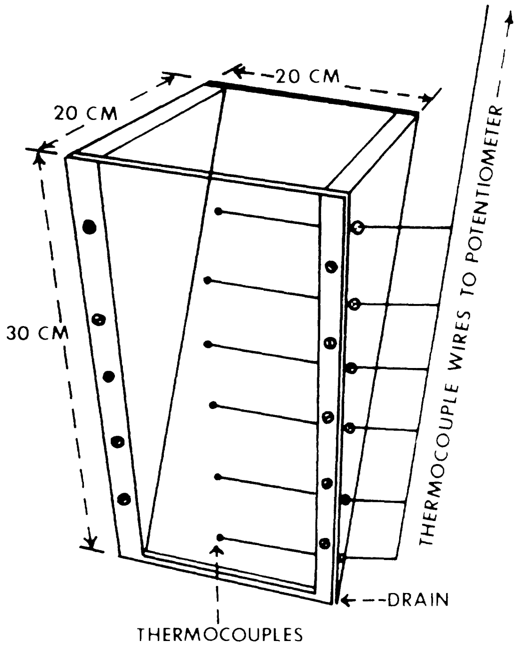

FIGURE 1. Plan of an empty field root box with sloping Plexiglas faces and wooden sides. Thermocouples are attached to the inner face of one Plexiglas face.

mersed in a coolant bath without damage to root systems. Both types of boxes are equipped with thermocouples attached to one Plexiglas face at 5-cm intervals. The thermocouple wire in the field boxes is routed out through holes in one of the wooden sides of the box, as shown in Figure 1, and upward to a potentiometer. In the laboratory boxes, the thermocouple wire is brought to the soil surface inside the box to avoid contact with the coolant.

FIELD METHODS

The first field boxes were installed at time of maximum thaw in the tundra near Barrow, Alaska, in August 1971. Others were put in during August 1973; there is now a total of 36 boxes. All are still in place and usable for measuring growth and soil temperatures.

Installation consisted of cutting out a wedge-shaped sod block from a pure stand of a given graminoid species. The sod block was trimmed to fit into the box. Then, the box was inserted into the hole created by the removal of the sod block so that the soil surface of the block was the same as that of the undisturbed tundra. The boxes can be lifted for first root measurement sometime between July 1 and 15 after thaw has progressed to about 10 to 15 cm.

LABORATORY METHOD

Figure 2 diagrams a longitudinal section through the laboratory control and measurement system. The system contains six all-Plexiglas boxes, as described above, filled with peat. The boxes are planted with vegetative tillers of the species selected for study. These planted boxes are inserted into an insulated container which includes a support for the root boxes and a pan through which a coolant mixture of ethylene glycol and water is circulated. The lower 25% of the root boxes is immersed in the coolant. The support which rests on top of the coolant pan is a Plexiglas sheet with openings having the dimensions of the root boxes at that depth. Fiberglas insulation is packed between the sloping sides of the root boxes above the level of the support. This insulation and the support member keep the boxes in a vertical position.

The coolant enters and leaves the pan through inlet and outlet ports of copper tubing connected to insulated Tygon tubing. The coolant reservoir is in a refrigerated and heated circulating refrigeration unit (Forma Scientific Model 2095) beneath the insulated root growth container. In this system, there is no ice build-up on the tubing or on the outsides of the root boxes. The temperature of the coolant can be raised or lowered by adjusting the controls on the refrigeration unit. In this way, the upper level of frozen soil ("permafrost") in the root boxes can be raised or lowered at will.

The whole system can be placed on benches in a controlled temperature room, or on a movable truck which can be taken from one phytotron chamber to another. The four thermocouple leads from each of the six root boxes were connected to a 24-point recording potentiometer. In our experiments in a phytotron room, ambient air temperature was maintained at 10°C under continuous light to simulate mid-summer tundra conditions.

EXAMPLES OF RESULTS

The kinds of data which can be obtained with this technique in the field and under controlled conditions are shown in Table 1. The field data are from "peak season" in late July 1974 from boxes installed in 1971. The laboratory data are from August 16, 1975, 72 days after planting 10 tillers per box. These merely illustrate a few of the kinds of measurements and manipu-

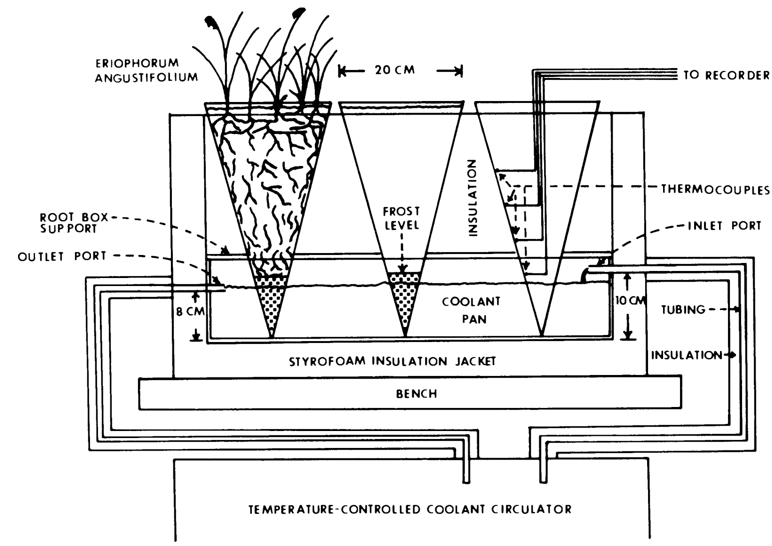

FIGURE 2. Diagram of a longitudinal section through the controlled-temperature laboratory root growth and temperature gradient system with artificial permafrost. For further description, see text.

TABLE 1

Temperatures (T, in °C) and mean number of white live root tips (R) from both sloping faces along a depth gradient in root boxes in the field (F) and in the phytotron (P) for sods of the three principal graminoid species of the coastal tundra

Depth (cm)	*Dupontia fischeri*				*Carex aquatilis*				*Eriophorum angustifolium*			
	F		P		F		P		F		P	
	T	R	T	R	T	R	T	R	T	R	T	R
0	—		14.2		—		14.2		—		14.2	
0-5		3.5		10		0.5		2		3		1
5	7.9		—		7.8		—		10.0		—	
5-10		11.5		20		2		2.5		11.5		3.5
10	6.7		9.1		6.7		9.4		7.1		9.8	
10-15		3		0		2		3.5		21		8
15	5.1		6.7		5.7		7.2		4.5		7.5	
15-20		0		0		0		7		28		8
20	3.6		4.0		3.6		4.1		2.8		4.1	
20-25		0		0		0		0		28		12
25	—		0.5		—		0.2		—		0.0	
25-30		0		0		0		0		2		0

lations possible. They also show how well the experiment can be made to simulate field conditions. Table 1 also illustrates the different root growth modes of the three species from the shallow perennial systems of *Dupontia* to the deep "annual" root systems of *Eriophorum* in which the roots can grow at temperatures as low as 0°C at the upper limit of permafrost. Additional field data appear in Shaver and Billings (1975) and in Billings *et al.* (unpublished). Early results under controlled conditions are reported by Trent (1972) and by Billings *et al.* (1973).

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