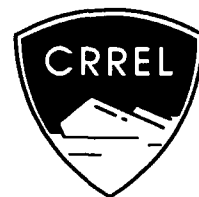AD--A254 303

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Passive Techniques for Manipulating Field Soil Temperatures

Giles M. Marion and Dean E. Pidgeon   June 1992

For conversion of SI metric units to U.S./British customary units of measurement consult ASTM Standard E380, Metric Practice Guide, published by the American Society for Testing and Materials, 1916 Race St., Philadelphia, Pa. 19103.

PREFACE

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Passive Techniques for Manipulating Field Soil Temperatures

GILES M. MARION AND DEAN E. PIDGEON

INTRODUCTION

Recent years have seen an explosion of interest on the potential effects of global climate change on functioning of ecosystems (Houghton et al. 1990). In December of 1990, a workshop was convened at the Kellogg Biological Station (Michigan State University) to develop the International Tundra Experiment (ITEX) (App. A). The principal objective of the ITEX project is to assess the effect of future climate change on tundra plant species. In order to facilitate the circumpolar implementation of this experiment, three constraints are placed on the experimental design. This design must be 1) simple, 2) inexpensive, and 3) ecologically relevant.

Temperature manipulations were selected as a critical component of the ITEX experiments. Keeping these temperature manipulations simple and inexpensive eliminated from consideration active heating manipulations requiring electric power such as buried resistance wires or aboveground infrared lamps. At the ITEX workshop and a subsequent CRREL brainstorming session, several ideas for passive soil heating were suggested. The objective of this report is to document the results of a 30-day field experiment to evaluate several techniques for passive soil heating.

METHODS AND MATERIALS

The site

The experiments began on 29 March 1991 (Julian day = 88) and were terminated on 29 April 1991 (Julian day = 119). The plots, 1×1 m^2, were laid out in a grass field at the CRREL facility in Hanover. Initially the grass was brown and dormant from overwintering but, during the course of the experiments, the grass became green and lush.

Meteorological measurements are routinely made at the CRREL facility. During the course of the experiments, daily rainfall varied from 0 to 34 mm. Incoming daily solar radiation ranged from 1.6 to 24.6 MJ m^{-2} with a mean of 14.5 MJ m^{-2} (standard deviation [SD] = 7.3). Mean daily windspeed ranged from 0.8 to 4.5 m s^{-1} with a mean of 1.8 (SD = 0.9) m s^{-1}.

Experimental design

There were 10 experimental treatments including the control, with no replication of the treatments. The temperature manipulation treatments can be broken into four classes: 1) plastic ground covers, 2) fabric ground covers, 3) fabric greenhouses, and 4) open-top chambers (Fig. 1).

The plastic ground covers had cutout openings (25–50% of the surface area) in the plastic to allow the vegetation in the openings to experience a normal aboveground environment. Both black and clear plastic (0.1 mm thick) were used. The black plastic should principally work by absorbing solar radiation, heating up, and transmitting part of this energy to the ground. The clear plastic should principally work by transmitting the solar energy directly to the ground and trapping part of the re-emitted energy beneath the plastic ground cover. There were two variations of the clear plastic treatment, with either 25 or 50% of the surface area removed. The transmittance of the clear plastic over the visible wavelengths is about 70% (Debevec and MacLean 1991).

The two fabric materials used in these experiments were Agronet and Reemay. Both of these fabric materials allow the transmission of air, water, and solar radiation. Debevec and MacLean (1991) found that the transmittance for the visible wavelengths of Reemay is about 45%. The transmittance of Agronet is unknown but probably considerably higher than Reemay (compare Fig. 1b and 1c). The fabric ground covers were placed
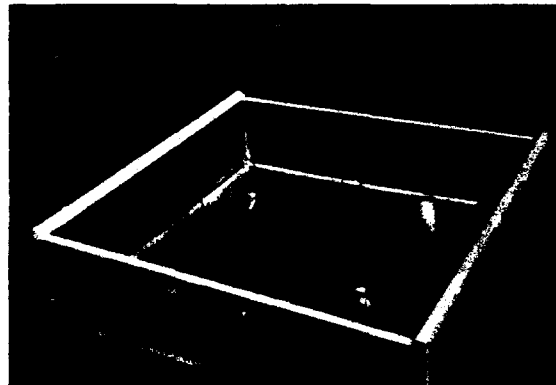
a. *The clear plastic ground cover with 25% surface area removal.*

b. *The Reemay fabric ground cover.*
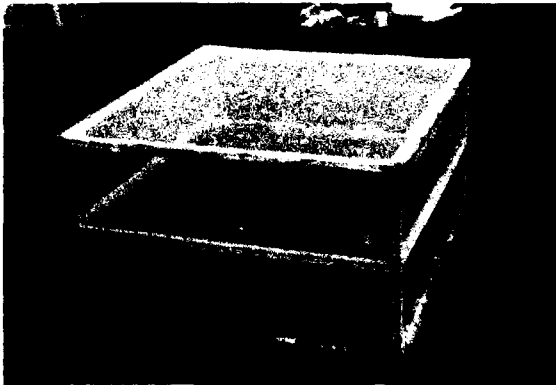
c. *The Agronet greenhouse.*

d. *The 30-cm-tall open-top chamber.*

Figure 1. Examples of the four classes of temperature manipulations.

directly on the vegetation while the fabric greenhouses allow for more air volume between the plant and fabric coverings (Fig. 1). In principle, these fabric materials should act like a greenhouse, trapping energy beneath the fabric covering.

The open-top chambers had a wood frame with a clear plastic covering around the sides (Fig. 1). These chambers are designed to block convective (wind) heat flow, which should, in principle, provide a day-time heating effect. Two variations of this treatment were evaluated with chamber heights of 30 and 60 cm on a 1- × 1-m^2 base.

Experimental measurements

Temperatures were measured with thermocouples (accuracy = ±0.2°C; Omnidata 1987) placed under the covers at the soil surface beneath the grass vegetation. Initially, there were two thermocouples/treatment connected to two separate data recorders. Unfortunately, one of the two data recorders malfunctioned during the first week of the experiments. To standardize the data analysis, only data from the thermocouples connected to

the continuously functioning data recorder were used. The temperatures were recorded hourly on an Omnidata Easy Logger 824 data recorder. Every six hours, the hourly measurements were averaged and recorded. The mean daily temperatures are the average of the four 6-hr averages. The daily minimum and maximum temperatures are the minimum and maximum 6-hr averages. In general, the minimums occurred during the 6-hr recording period from 2240–0340, and the maximums occurred during the 6-hr recording period from 1040–1540.

In addition to temperature measurements, we also evaluated two passive heat integrators. The objective was to develop a simple technique that could be calibrated to temperature (heat load) for use at remote sites. The first heat integrator consisted of a 125-mL polyethylene bottle with a rubber stopper through which passed a right-angle glass tube; this bottle was open to the atmosphere and was half-filled with water. The principle is that loss of water vapor from the bottle over time should be proportional to heat load. The second

a.Maximum daily temperature.

a. Daily temperature difference.
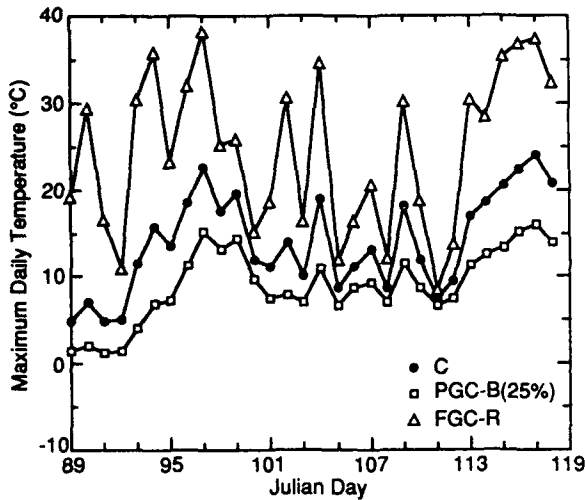
b. Minimum daily temperature.
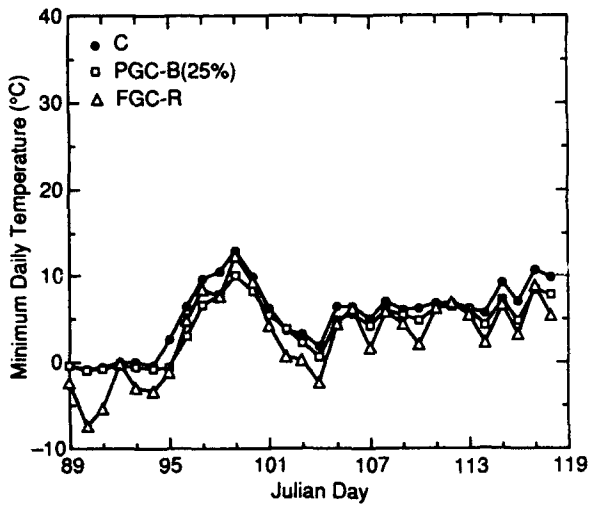
b. Mean daily temperature.

Figure 2. The maximum and minimum daily temperatures for the control (C), black plastic ground cover (PGC-B[25%]), and Reemay fabric ground cover (FGC-R).

Figure 3. The daily temperature differences and mean daily temperatures for the control (C), black plastic ground cover (PGC-B[25%]), and Reemay fabric ground cover (FGC-R).

heat integrator was a closed 125-mL polyethylene bottle, half-filled with water, with an internal test tube containing a desiccant (Drierite). The principle behind this technique is that movement of water vapor into the desiccant should be proportional to heat load. There were two replicates of each heat integrator per treatment.

RESULTS

Daily temperature fluctuations

To simplify the presentation of results, only daily values for three treatments, which span the range of responses, will be presented (Fig. 2 and 3).

The maximum temperature increase occurred with the Reemay fabric ground cover (FGC-R); the black plastic ground cover (PGC-B[25%]) actually decreased soil surface temperatures; all other treatment temperature responses fell between the latter extremes.

In general, the response to temperature manipulation was more significant in changing maximums than in altering minimums (Fig. 2). In some cases, the temperature manipulations actually decreased minimum temperatures below the control.

The greatest temperature differences (maximum-minimum) occurred on sunny days (Fig. 3),

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both because the maximum day temperatures were higher and the associated minimum night temperature were often lower than the controls (Fig. 2). When mean daily temperatures were calculated (Fig. 3), the large temperature fluctuations associated with maximums and differences were considerably dampened. Mean daily temperatures tended to maintain a consistent relationship over time with respect to each other (Fig. 3).

Mean temperature responses

Figure 4 and Table 1 summarize the temperature data averaged over the 30-day experimental period for the 10 treatments. The Reemay ground cover had the greatest effect on increasing the mean daily maximum, while the black plastic actually decreased the mean daily maximum (Fig. 4a). Most treatments decreased mean minimum temperatures (Fig. 4b). The Reemay ground cover increased mean daily temperature by 2.4°C; while the black plastic decreased mean daily temperature by 2.6°C (Fig. 4c). The only other treatments to increase mean daily temperature by 1.0°C were the two clear plastic ground covers and the Reemay greenhouse. The Agronet ground cover had a minimal effect on altering temperature; in all respects, this treatment closely mirrored the control (Fig. 4, Table 1).

Heat integrators

Both the open system heat integrator and the closed system heat integrator were positively correlated to mean daily temperature, as would be expected (Fig. 5). However, the amount of variation explained by the regressions was only 26–30%, and, in both cases, the linear regressions were not statistically significant. Clearly factors other than temperature affected the response of these sensors. The open-to-the-atmosphere sensors will, of course, respond to factors other than temperature, such as wind and external humidity that would affect the suitability of this technique as an integral heat sensor. The closed-to-the-atmosphere sensor suffered from a design flaw. Nighttime condensation formed internally on the bottle cap, below which sat the the opening of the desiccant tube. It was clear that the condensate immediately above the desiccant tube opening was absorbed by the desiccant every day; a dry circle formed in this area later in the morning. As a consequence, there was a daily flux of water into the desiccant that may have had little to do directly with temperature control of the vapor pressure. Another problem with the closed system heat integrator was
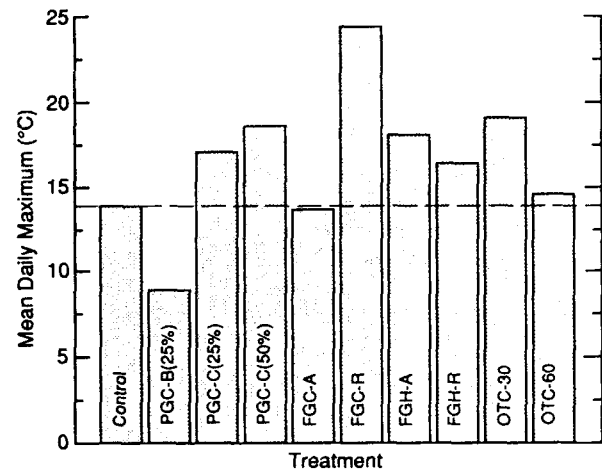
a. Mean daily maximum.
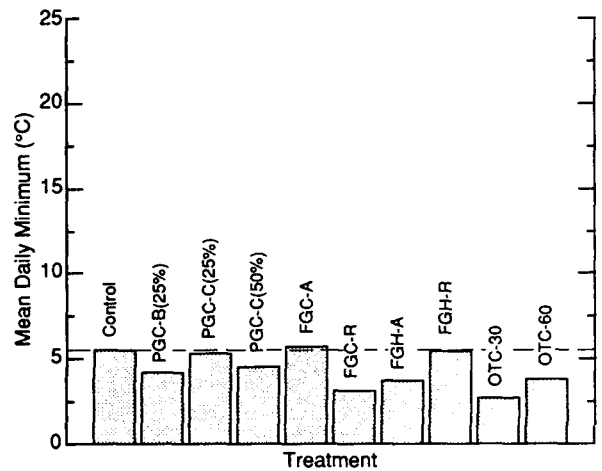
b. Mean daily minimum.
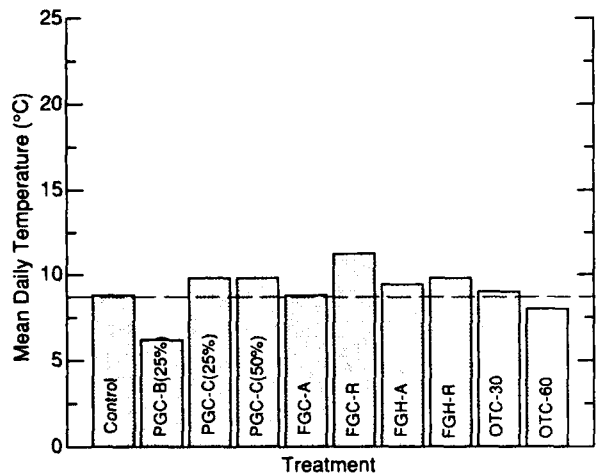
c. Mean daily temperature.

Figure 4. The 30-day mean daily maximums, minimums, and temperatures for the 10 treatments. See Table 1 for treatment symbol definitions.

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Table 1. The mean daily temperature, maximum and minimum temperatures, and the temperature difference for the 10 ITEX temperature manipulation experiments (mean ±1 s.e.).

Treatment	Treatment symbol	Mean daily temp (°C)	Mean daily maximum temp (°C)	Mean daily minimum temp (°C)	Mean daily temp difference (°C)
Control	C	8.8±0.8	13.9±1.0	5.5±0.7	8.4±0.8
Plastic Ground Cover					
Clear, 25% Open	PGC-C(25%)	9.8±0.7	17.1±1.1	5.3±0.7	11.8±1.2
Clear, 50% Open	PGC-C(50%)	9.8±0.8	18.6±1.5	4.5±0.7	14.1±1.4
Black, 25% Open	PGC-B(25%)	6.2±0.6	8.9±0.8	4.2±0.6	4.7±0.5
Fabric Ground Cover					
Agronet	FGC-A	8.8±0.7	13.7±0.9	5.7±0.6	8.0±0.7
Reemay	FGC-R	11.2±0.8	24.4±1.7	3.1±0.9	21.4±1.9
Fabric Greenhouses					
Agronet	FGH-A	9.4±0.8	18.1±1.3	3.7±0.7	14.4±1.3
Reemay	FGH-R	9.8±0.7	16.4±1.0	5.4±0.7	11.1±1.0
Open-top Chambers					
30-cm height	OTC-30	9.0±0.8	19.1±1.5	2.7±0.8	16.5±1.6
60-cm height	OTC-60	8.0±0.7	14.6±1.1	3.8±0.6	10.8±1.0

that the movement of water into the desiccant appeared to have exhausted the capability of the desiccant to absorb water. We used an indicating desiccant (Drierite) that switches from blue (dry) to pink (wet). These two problems with the closed system heat integrator could be rectified by a better design.

DISCUSSION

Energy balance

To assist in explaining the experimental results, a simple surface energy balance equation will be used:

$$Q_N + Q_H + Q_G + Q_E = 0 \qquad (1)$$

where Q_N = net radiation at the surface
Q_H = convective component at the surface
Q_G = transfer of heat through the ground
Q_E = latent heat (Lunardini 1981).

Ignored in eq 1 is the contribution of biochemical processes (Q_B) which should be negligible in these experiments. In general, the energy flow attributable to these processes is diametrically different between day and night (Fig. 6).

Q_H and Q_E are often strongly coupled. Barriers such as wind screens (open-top chambers) or fab-

a. Open system.
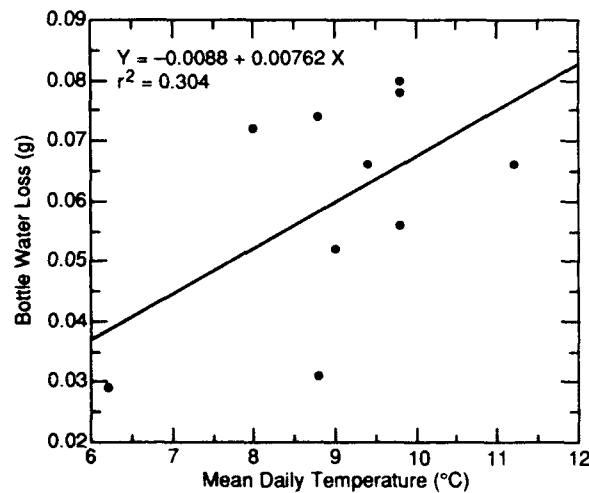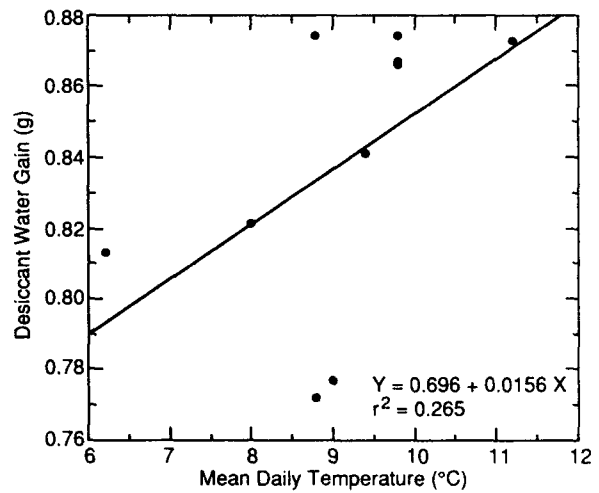
b. Closed system.

Figure 5. The relationship between mean daily temperature and integral water flux (30 days) for open system and closed system heat integrators.

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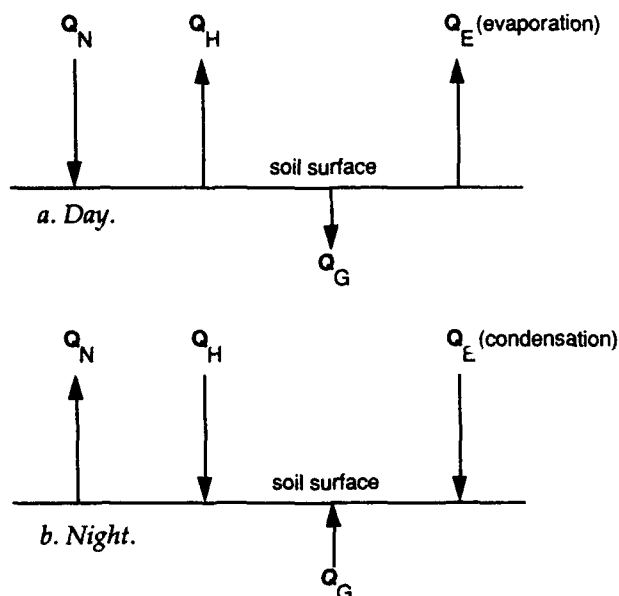
Figure 6. A generalized scheme for day and night energy flows (adapted from Lunardini 1981).

ric coverings that reduce Q_H and Q_E during the day should theoretically result in an increased flow of energy to the ground (Fig. 6). Conversely, the same barriers at night should theoretically result in a net loss of energy from the soil surface by reducing Q_H and Q_E. These simple considerations might account, in part, for the observation that maximum daytime temperatures were generally increased and minimum nighttime temperatures were generally decreased by treatments (Fig. 4,Table 1). Of course, there are variations on this theme among treatments.

Theoretical calculations indicated that altering the surface albedo should affect soil temperatures (Albert, in prep.). This was the reasoning behind the black plastic treatment which was expected to increase soil temperature. Instead, soil temperatures were actually depressed beneath the black plastic (Table 1. Fig. 4). Other theoretical calculations suggested that the problem with the black plastic treatment was that the air layer between the plastic and the ground was an effective barrier to heat flow (App. B). This air-barrier problem was, no doubt, exacerbated by placement of the heat sensors beneath the plastic, which increased air space. Had the energy-absorbing material been placed directly in contact with the ground (e.g., black stones), altering the surface albedo would probably have w .ked better. On the other hand, if one is interested in manipulating soil temperatures over broad ranges, the black plastic is apparently effective in reducing soil surface temperature.

The clear plastic treatments, on the other hand, were more effective in increasing temperature; both clear plastic treatments increased the mean daily temperatures by 1.0°C (Table 1, Fig. 4). Also, the Reemay treatments were effective in increasing the mean daily temperatures by 1.0° and 2.4°C for the greenhouse and ground cover treatments, respectively.

The open-top chambers (OTCs) were selected at the ITEX meetings (App. A) as the most promising technique for manipulating surface temperatures in a simple, inexpensive, ecologically relevant way. Neither of the evaluated OTC treatments was effective in increasing mean daily temperature (Fig. 4, Table 1). Although the 30-cm-tall chamber (OTC-30) increased the daytime maximums, the nighttime minimums were decreased; the net effect was essentially no change in the mean daily temperature. The lesser response of the 60-cm-tall chamber (OTC-60) to maximum daytime temperatures was probably caused by ground shading.

Environmental controls

To ascertain the role environmental factors might play in controlling the treatment temperature response, the data were subjected to a multiple linear regression analysis (Table 2) using the SuperANOVA software program (Gagnon et al. 1989). The dependent variable was the difference in daily maximum temperature between the treatment and control plots (ΔT_{max}), and the independent variables were daily rainfall, daily solar radiation, mean daily windspeed, and Julian day (time). Maximum temperatures were chosen for this analysis because the maximums were most responsive to treatment (Table 1, Fig. 4). Julian day was included in the analysis in order to account for the effect of unspecified factors that might have affected the temperature response with time. Only regression coefficients that were statistically significant at the <5% probability of a Type I error were retained in the regression model (Steel and Torrie 1960).

In all nine cases, solar radiation (X_1)was significantly related to ΔT_{max} (Y in Table 2). In most cases, the regression coefficient for radiation was positive, indicating the ΔT_{max} increased with increasing solar radiation. Differences among treatments were greatest on sunny days, which are reflected in the sharp temperature spikes (Fig. 2). Differences were minimal among treatments on rainy days; note especially Julian day 111, which was overcast and drizzling (34 mm rain) both day and night. The black plastic treatment had a strong

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Table 2. The effect of solar radiation, wind, and time on altering daily maximum temperatures.

Treatment	Regression equation*	Adjusted R^2	Standard error of estimate (°C)
Plastic ground cover			
Clear, 25% open	$Y = 29.8 + 0.161X_1 - 0.281X_2$	0.744	1.5
Clear, 50% open	$Y = -8.1 + 0.344X_1 + 0.074X_2$	0.772	1.4
Black, 25% open	$Y = -1.6 - 0.283X_1 + 0.43X_3$	0.825	0.9
Fabric ground cover			
Agronet	$Y = 5.6 - 0.061X_1 - 0.060X_2 + 0.74X_3$	0.532	0.9
Reemay	$Y = 23.0 + 0.697X_1 - 0.219X_2$	0.900	1.7
Fabric greenhouses			
Agronet	$Y = 0.284X_1$	0.973	0.8
Reemay	$Y = 15.1 + 0.114X_1 - 0.137X_2$	0.769	0.8
Open-top chambers			
30 cm height	$Y = -1.5 + 0.456X_1$	0.877	1.2
60 cm height	$Y = 7.6 + 0.109X_1 - 0.082X_2$	0.573	0.9

* Y = difference in daily maximum temperature (°C) between the treatment and control plots
X_1 = total daily incoming shortwave radiation (MJ/m²)
X_2 = Julian day
X_3 = mean daily wind speed (m/s).

negative relationship between ΔT_{max} and solar radiation (Table 2). This suggests that the black plastic treatment was especially effective in shielding the ground from temperature increases during sunny days.

In six of nine cases, Julian day (X_2) was significantly related to ΔT_{max} (Table 2). In most cases, this relationship was negative, suggesting that the difference between treatment and control diminished with time. This negative relationship may be due to changing vegetation, which was initially brown and dormant but became green and lush during the course of the experiment. The more luxurious vegetation may have effectively shaded the soil surface, where the thermocouples were located, from direct solar radiation.

In two cases (PGC-B[25%] and FGC-A), wind speed (X_3) was significantly and positively related to ΔT_{max} (Table 2). The two treatments showing a significant relationship were the only two treatments in which mean daily maximums were below the control plot values (Table 1, Fig. 4). Whether this relationship is the direct effect of wind on the treatment per se, or an indirect effect of wind on the control plot is impossible to ascertain at the present time.

Comparisons with previous studies

During the 1991 summer, two research groups field-evaluated the Reemay ground covers. Christina Wegener (Norwegian Polar Research Institute) and Ann Marie Odasz (University of Tromsø) from Norway evaluated Reemay over a 30-day period from mid-July to mid-August on Svalbard;

they found that Reemay increased the mean daily temperature by 1.3°C (Fig. 7). Walter Oechel and Stephen Hastings (San Diego State University) evaluated Reemay at Prudhoe Bay, Alaska, over a 7-day period in early September; they found a 0.9°C increase in mean daily temperature. In contrast to our finding of a decreased minimum under the Reemay ground cover (Fig. 4), the latter two field studies reported that minimums were actually increased by 0.7 to 1.3°C under the Reemay treatments (Fig. 7).

Typar, a denser polyester material than Reemay, has been used at CRREL to assist in the germination and growth of fall grass seedings (Racine et al. 1990). For the fall 1988–spring 1989 and the fall 1989–spring 1990 growing seasons, Typar increased the mean daily temperatures beneath the coverings by 1.1 and 1.7°C, respectively.

In a recent study, Debevec and MacLean (1991) evaluated several plastic and fabric materials as coverings for small field greenhouses. They found that plastic produced the largest temperature effect, with daily maximums and means elevated 7.8 and 2°C, respectively, above the control, and average daily minimums depressed 1.1°C below the control. Average elevation of daily mean temperature was 0.9°C in a mixed plastic-fabric greenhouse and 0.4°C in an all-fabric greenhouse.

One of the "apparent" inconsistencies among studies is the effect of treatments on altering minimum temperatures. However, this inconsistency may not be real, but may simply reflect where temperatures were measured within the treatment space, especially ·r vs soil temperatures. In

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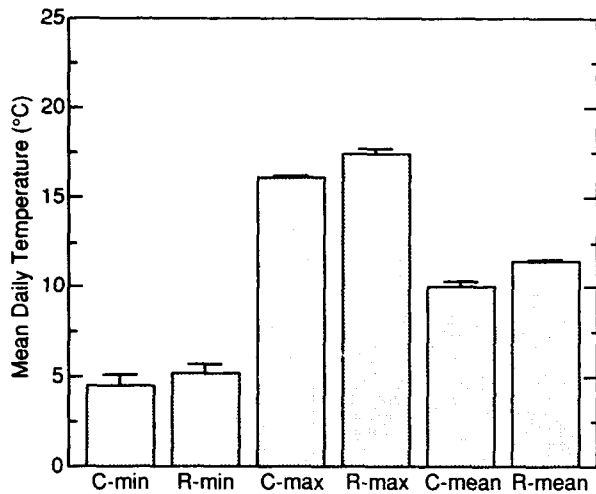
a. *Reemay evaluation–Svalbard.*   b. *Reemay evaluation–Prudhoe Bay.*
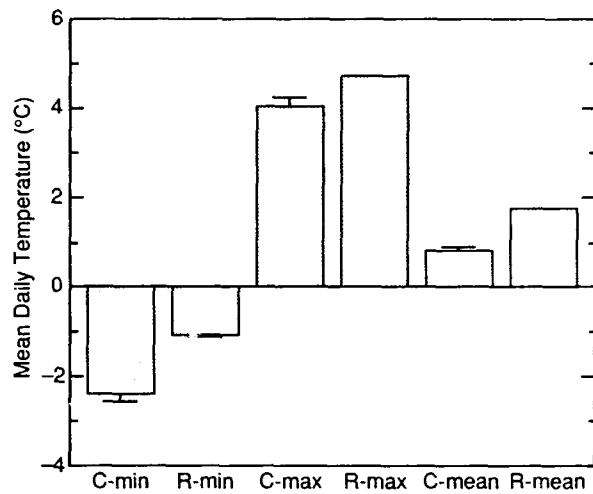
Figure 7. Field evaluations (mean ±1 s.e.) of the Reemay ground covers during the summer of 1991 on Svalbard and at Prudhoe Bay. "C" refers to control and "R" refers to Reemay.

three greenhouse configurations, Debevec and MacLean (1991) found minimum temperatures depressed by 0.4 to 1.1°C at 40 cm above the soil surface; on the other hand, at 10 cm below the soil surface, minimums were increased by 0.3 to 1.9°C. These results are consistent with the field Reemay evaluations (Fig. 7), which showed higher minimums beneath Reemay based on subsurface soil measurements, and our results, which showed lower minimums beneath treatments based on soil surface (air) measurements (Fig. 4).

CONCLUSIONS

It appears that these simple, passive techniques for manipulating soil surface temperatures can only alter mean daily temperatures by, at most, ±2.5°C. Whether this is an adequate temperature change will, no doubt, depend on the nature of the experiments. Most global climate models predict a 2° to 5°C increase in temperature for a doubling of CO_2 in the atmosphere (Houghton et al. 1990). For a major change such as this, these passive techniques would only be marginally adequate. Active heating by resistance wiring or infrared lamps would be necessary to assure a heat load increase on soil-plant systems of 2–5°C. Nevertheless, the passive heating techniques evaluated in this report may find a niche in evaluating shorter-term (decadal), lesser changes in soil surface energy balances.

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NOTE ADDED IN PROOF

Further testing indicates that the transmission of light through the clear plastic and Reemay may be higher than cited on p. 1 (Debevec and MacLean 1991). Independent tests suggest that clear plastic and Reemay transmit ca. 90% and 75% of visible light, respectively.

ITEX

December 5, 1990

APPENDIX A: RESOLUTION— INTERNATIONAL TUNDRA EXPERIMENT

As a result of deliberations and consensus achieved at a workshop to design an International Tundra Experiment (ITEX) on December 2-5, 1990, at the Kellogg Biological Station, Michigan State University, U.S.A., the participants from nine countries (Canada, Denmark, Finland, Great Britain, Iceland, Norway, Sweden, United States, USSR) have agreed to submit the following findings and recommendations to their respective organizations and scientific colleagues.

Taking into account

1. That the tundra regions represent an important component of the geosphere-biosphere, being a sensitive indicator of global change and contributing actively in the functioning of the global climate system;

2. That the understanding of the geophysical and ecological processes that occur in the tundra is an important objective of the international community concerned with global change, biodiversity, environmental protection, and sustainable development;

3. That recent acceleration of international interest and cooperation in arctic and alpine science has opened new possibilities for coordinated international research and analyses;

And recognizing

1. That carefully organized comparisons within and among tundra sites and over time will greatly increase understanding of the ecology of tundra species;

2. That coordinated observations and measurements of a few carefully selected arctic species populations occurring along circumpolar mega-transects and environmental gradients are achievable;

3. That an experimental approach to a few selected manipulations of the environment is deemed desirable as a cost effective means to compare species responses to variables relevant to global change;

4. That international exchange of scientists, especially students, is highly desirable to enhance communication and training;

The participants therefore agree

That an initial set of selected tundra plant species, measurement protocols and manipulations have been specified for the ITEX experiments starting in 1991 as the result of this international meeting of experts. They, therefore, recommend

1. That the first ITEX experiment focuses on responses of vascular plant species;

2. That a set of abiotic observations and destructive and non-destructive measurements be carefully specified to determine phenological events, reproductive and vegetative effort, physiological responses, and genetic response to the manipulated and predominant environmental variables during the growing season and over a period of years;

3. That explicit protocols be developed for simple and relatively inexpensive manipulations of air temperature (such as by small greenhouses) and snow cover (as by snow fences) at participating sites;

4. That sets of selected individuals in field transplant gardens be subjected to a common garden (environmental) experiment and assessed in terms of genetic variation within each species population and its phenotypic response in order to evaluate probable adaptations to climate change;

5. That more complex or expensive experiments involving manipulations such as atmospheric CO_2, or soil temperature and reciprocal transplant gardens, fertilizer treatments, or even phytotron experiments may be desirable and practical for some sites;

6. That appropriate coordination of research, communication and synthesis of results be achieved by a small set of coordinators, and by convening of participating principal investigators for periodic assessment workshops, exchanges of scientists and students among sites will facilitate ITEX;

7. That development of an appropriate protocol for the exchange of ITEX data among participants is needed;

8. That funding for research is the responsibility of each participating country, and may utilize activities already underway, and including Biosphere Reserves, protected areas, and long-term ecological research areas; and

9. That future experiments focusing on other taxa and ecological parameters, including animals, are desirable, and contacts for ITEX established through the MAB Northern Science Network are encouraged.

APPENDIX B: STEADY-STATE ANALYSIS OF
AIR TEMPERATURES BENEATH PLASTIC

(with V.J. Lunardini)

A simple energy balance model can be used to approximate the effect of a plastic sheet on heating of air beneath the plastic (Fig. B1). If a steady state is assumed, the energy flow in the plastic sheet can be represented by

$$h_\infty(T_s - T_\infty) + \varepsilon \sigma T_{s,K}^4 + h(T_s - T_a) = \alpha\phi \, S \tag{B1}$$

and similarly for the air layer beneath the plastic:

$$\alpha \tau S + h (T_s - T_a) = h_g (T_a - T_g) \tag{B2}$$

where S = solar radiation
   α = fraction of solar radiation entering the plastic surface
   ϕ = fraction absorbed by the plastic
   τ = is the transmitted fraction ($\phi + \tau = 1$)
   h = is the surface coefficient of free convection
   T = is temperature (°C, except for $T_{s,K}$ which is the sheet temperature in kelvins)
   ε = is the emissivity of the surface
   σ = is the Stefan-Boltzmann constant (5.67×10^{-8} W m^{-2} K^{-4}).

Assuming a solar radiation input of 440 J sec^{-1} m^{-2}, $\alpha = 0.9$, $\varepsilon = 0.95$, $h_\infty = h = h_g = 5.65$ J°C^{-1} sec^{-1} m^{-2}, $T_g = 4.4$°C, and $T_\infty = 8.8$°C, then one can solve the two equations (B1 and B2) for the two unknown temperatures, T_s and T_a, given various values of τ (the transmitted fraction). For $\tau = 0$ (black plastic), the calculated T_s and T_a are 12.1 and 8.3°C, respectively. The black plastic warms up but is not effective in transmitting this energy to the air below the plastic. For $\tau = 0.4$ (clear plastic), the calculated T_s and T_a are 6.1 and 19.3°C, respectively. The clear plastic is much more effective in warming the air beneath the plastic than is the black plastic. The measured mean daily maximums for the black plastic (8.9°C) and the clear plastic (17.1°C) (Table 1) compare favorably to the calculated values of 8.3 and 19.3°C, respectively. This analysis neglects the longwave radiation between the sheet and the ground, but this is not too serious unless τ approaches 1.0.
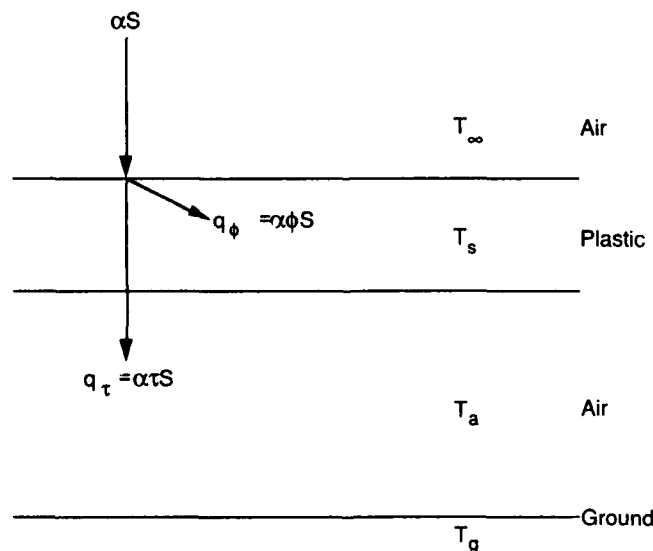

Figure B1. A schematic representation of energy flow through plastic.

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Recent concerns about global climate change have focused attention on the methodology for manipulating field soil temperatures. The objective of this study was to evaluate several simple, inexpensive, passive systems for changing soil surface temperature in the field. Four classes of treatments were evaluated including plastic ground covers, fabric ground covers, fabric greenhouses, and open-top chambers. In general, treatments raised daytime maximums and lowered nighttime minimums. In some cases these opposite effects balanced, and there was no change in mean daily temperature. Five treatments changed mean daily temperature by at least ±1.0°C; these included black plastic (–2.6°C), two clear plastic treatments (+1.0°C), Reemay greenhouses (+1.0°C), and Reemay ground covers (+2.4°C). A multiple linear regression analysis of maximum temperatures indicated that the temperature differential between treatment and control plots was most strongly controlled by solar radiation > time > wind speed. Differences among treatments were greatest on sunny days and minimal on rainy days. Both the present study and previous studies suggest that these passive systems can alter mean daily soil surface temperatures by, at most, ±2.5°C.

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