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Improved Field Facilities to Study Climate Change Impacts and Adaptations in Pasture

Report for contract CC MAFPOL_2008-18 (125-3)

Prepared for the Ministry of Agriculture and Forestry, Wellington N.Z.

June 2008

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Improved Field Facilities to Study Climate Change Impacts and Adaptations in Pasture

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1. Introduction

Climate (or more properly global) change describes a complex of changes in the environment that are currently happening and expected to continue into the future. The most predictable of these is an increasing concentration of CO_2 in the atmosphere (Newton et al 2006). Against this background of higher CO_2 we can also expect to see higher temperatures and changes in patterns of rainfall (Mullan et al 2008). Experimentation is essential to understanding the impacts of climate change as our ecosystems are being exposed to combinations of factors that are beyond our experience.

Experimental studies of climate change impacts are difficult: it is essential to avoid artefacts introduced by the experimental method and to continue the experiment for sufficiently long periods so longer term biogeochemical responses are captured. In New Zealand, it is also essential to study pastoral systems under grazing by animals as the presence of animals markedly modifies ecosystem responses to climate change (Newton et al 2005). To meet these criteria we have constructed a Free Air Carbon Dioxide Enrichment (FACE) facility to enable us to study the effects of future levels of atmospheric CO_2 on grazed pasture ecosystem processes. Ours is one of a number of such experiments internationally but the only one to include grazing animals, making it a unique facility. Our experiment is described as the NZFACE by the international community ((see http://cdiac.esd.ornl.gov/programs/FACE/face.html). The NZFACE has been running for 10 years looking at the impact of the concentration of CO_2 expected in 25-30 years (a selection of publications from this experiment is provided in the Appendix).

In terms of results from the NZFACE, we have found that the initial impact of elevated CO_2 on plant photosynthesis cascades through the ecosystem and ultimately influences the cycling of nutrients in the soil, the amount and quality of herbage available for animals and the soil drainage characteristics among others. Many of these changes occur over a number of years; this makes the NZFACE experiment an extremely valuable resource as it has been running long enough to capture these long term impacts and thus avoids the misleading results that can be produced from short term impact studies.

Our intention now is to extend our understanding of climate change impacts on NZ pastoral systems by introducing a warming treatment into the NZFACE. Worldwide, night time air and soil temperatures have been rising twice as fast as daytime (IPCC, 2007). This greater increase in night time temperatures has led to projections for New Zealand of decreases in the number of frost days (Mullan et al 2008).

MAF funding in 2008 has enabled us to design and test a warming treatment. In this report we discuss some of the issues related to warming large areas of vegetation, describe our method of choice and present the results of a design and testing process leading to installation of this treatment in the NZFACE.

2. Methods of Experimental Warming

Methods to grow vegetation under warmer temperatures include greenhouses, electrical heat-resistance ground cables, overhead infrared lamps and passive night time warming. We evaluated these methods against a set of criteria, namely:

- installation should lead to as little disturbance to other environmental variables as possible
- the warmed areas should be sufficiently large to capture the heterogeneity present in the experimental areas i.e. should contain a range of different plant species and nutrient conditions
- the system should not interfere with grazing
- the warming should represent future changes as faithfully as possible i.e. include warming of both the air and soil

Each system was evaluated through literature review, experimental testing and the advice of expert collaborators who operate warming experiments.

2.1 Greenhouses

We have previously constructed and used portable temperature controlled greenhouses (White et al 2000) and these have been widely used, particularly in studies in the arctic region (e.g. Kennedy 1995). Greenhouses are effective in raising temperatures but introduce artefacts (humidity, exclusion of insects and rainfall) that make them unsuitable for long-term deployment and interpretation of the results. Our previous use of this system was to introduce a one-off extreme temperature event thus avoiding the long-term artefacts (White et al 2000).

Assessment: greenhouses introduce too many artefacts that rather defeat the advantage of working in a 'Free Air' field situation.

2.2 Soil warming cables

This is a well-proven technology for elevating soil temperatures and has been used in long term experiments for example in the well known Harvard Forest study (http://harvardforest.fas.harvard.edu/research/soilwarm.html). Once established, cables provide a robust heating system but they do not warm the air and plant canopy thus excluding a potentially important consequence of climate warming. The cables also need to be close together to avoid large gradients and installation can create significant disturbance to the soil and vegetation.

We have evaluated soil warming cables in the Pukepuke soil at the NZFACE Site. Figure 1 shows an increase of 14°C over ambient at a point directly over the cable but this dropped off rapidly to a 2°C increase 20 cm from the cable.

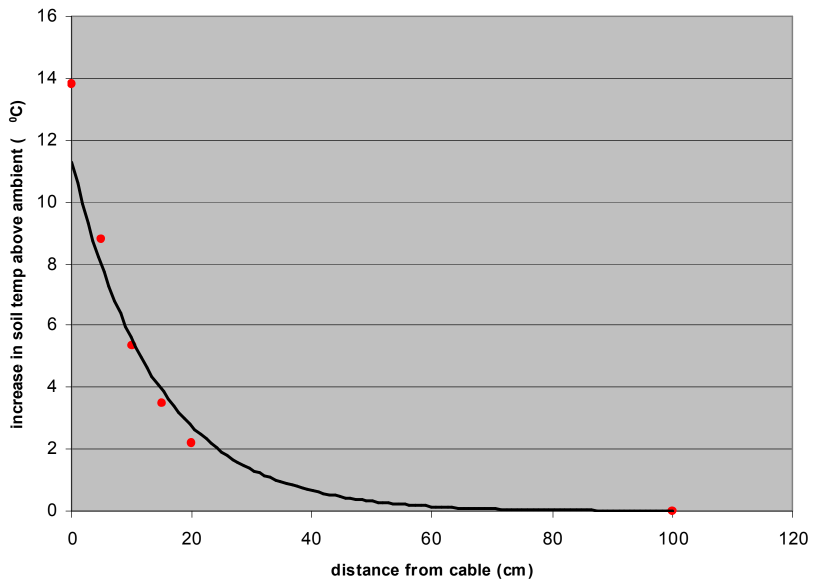

Figure 1 The difference in soil temperature from ambient at 5 cm depth measured at various distances from a soil warming cable buried at 10 cm.

Assessment: The temperature gradients are large and would require cables to be placed close together. This arrangement would increase the disturbance created on installation. There is no warming of air or canopy.

2.3 Infrared lamps/heaters

Infrared lamps or heaters have been widely used in climate change studies to warm areas of vegetation. They are particularly suitable for small plots (circa 1-3 m diameter) but require towers and cables to be suspended above the pasture. Plate 1 below shows examples of this technology used in experiments by two of our collaborators. The cabling and towers would need to be moved at every grazing.

A major artefact when using infrared lamps in warming experiments is the enhanced drying caused by the heaters. The infrared radiation heats the canopy but not the atmosphere, resulting in a greater vapour pressure gradient than would result if all parts of the system (air, soil and canopy) were warmed evenly. Using infrared lamps results in a different relative humidity for the warmed and ambient conditions, which is in contrast to that projected by global change models. Kimball (2005) suggested that when using infrared lamps as a warming treatment, daily water applications to compensate for this drying would correct for this experimental artefact. However the logistics of this solution make it impractical in most situations.

A further drawback to using infrared lamps is that they are expensive to run: for our experiment using the costings of Kimball et al (2008) and current power charges, the electricity alone for an array of six 3 m diameter plots would be nearly $40,000 per year. This compares to a cost of $60,000 per year for CO_2. This power consumption issue is also important for our FACE experiment: we have a limited amount of power available during the photoperiod (day time) when the enrichment system is operating and it is likely that if IR lamps were used they could only be used at night without significant costly upgrades to our power supply infrastructure.

Plate 1 Left: Infra red heater used in the PHACE (Prairie heating and CO_2 enrichment) experiment, Wyoming USA. Two heaters are used for each 3 m diameter plot. Right: Infra red lamp used to warm 1 m diameter plot in the TasFace experiment, Tasmania (Hovenden et al 2006).

Assessment: Installation and management will be difficult with grazing animals present. Warming artefacts need to be accounted for. The running costs are high and all day warming could be problematic for our FACE experiment due to power availability constraints.

2.4 Passive night time warming

The passive night time warming method involves covering the experimental plot with a long wave radiation blocking cover at night to reduce the heat lost by infra red (IR) radiation. Various designs have been used but essentially a frame carries a curtain of IR reflecting material which is extended over the canopy at night and removed during the day and during periods of rainfall. This approach has been successfully used in a pan-European experiment (Beier et al 2004) and is currently being used in a FACE-type experiment with another of our collaborators in Denmark (Plate 2). The warming frame can be used over large areas using single or multiple curtains, is simple to install and can be removed easily during grazing.

The method raises both day and night soil temperatures, but air temperatures are raised only at night and for a period during the early part of the photoperiod (day time) at canopy height (Fig. 2)

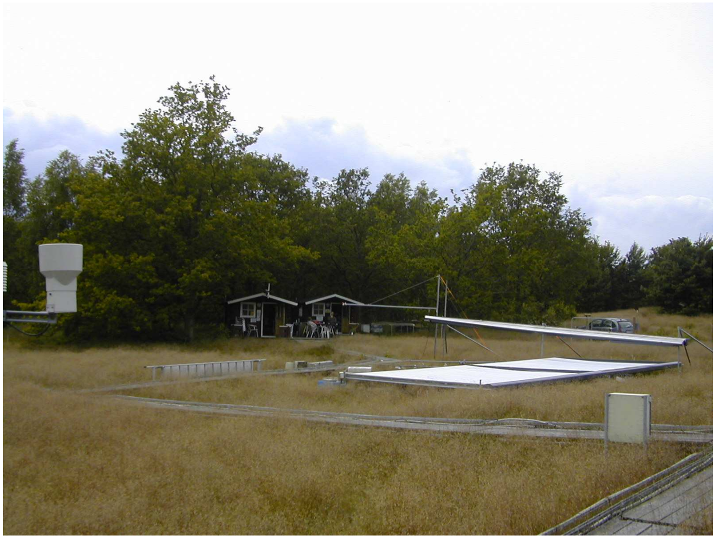

Plate 2 Passive warming screen extended above heathland in the CLIMAITE experiment, Denmark (Mikkelesen et al 2008).

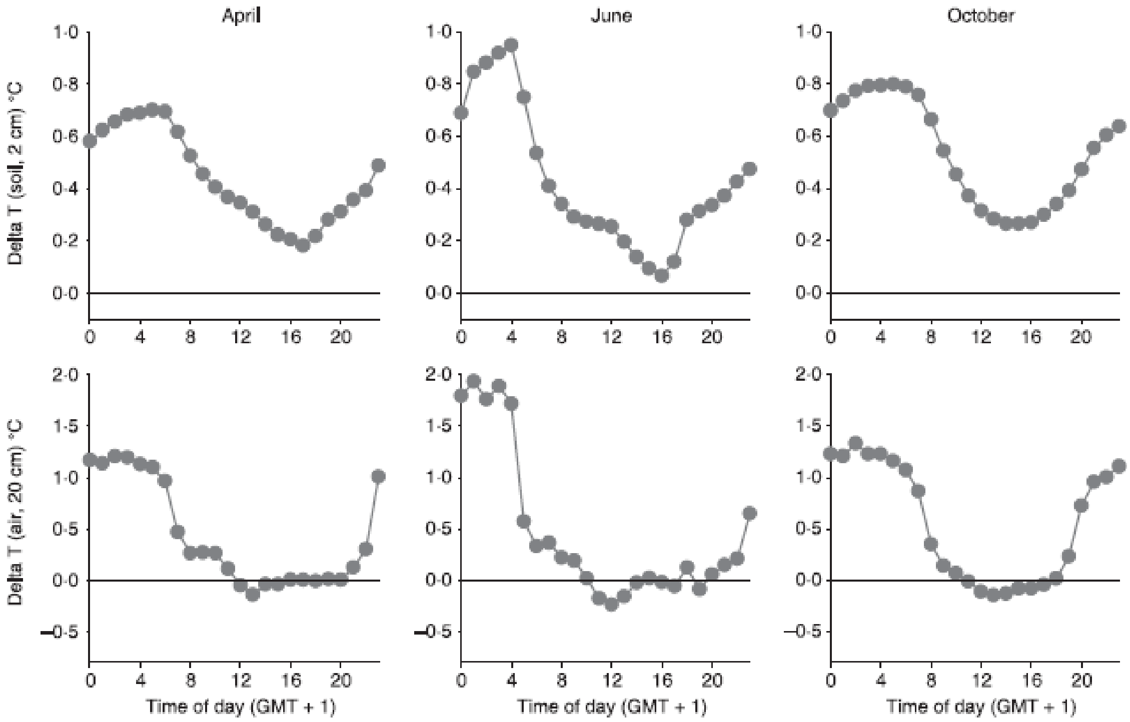

Figure 2 Diurnal warming of the soil (top graphs) and air (bottom) as represented by average hourly temperature differences in the CLIMAITE experiment during April, June and October 2006 (copied from Mikkelesen et al 2008).

Recently, another group of collaborators have set up a passive heating system to warm rice paddies in Japan. This system, named PROPHET (Paddy Rice Overnight Passive Heating Experiment in Tsukuba; Fukuoka et al., 2007), is made from readily available horticultural materials and achieves a good level of warming of the soil during winter, spring and autumn. During summer, when it tends to be rainy and overcast in Japan, warming by passive heating relative to the control is restricted and buried soil cables are used for warming at this time.

Experiments using passive night time heating have found significant impacts of warming (of approximately 0.8 - 1.2°C) on both soil (e.g. Estiarte et al 2008; Sardans et al 2008; van Meeteren et al 2008) and plant community processes (e.g. Jump et al 2008; Llorens and Peňuelas 2008).

Assessment: Passive warming is an inexpensive, non-intrusive system that can be used to treat large areas. Though soil temperatures are increased through the whole diurnal cycle, the lack of warming of the air and canopy during the latter part of the photoperiod (day time) is a drawback.

2.5 Conclusion

Of the three potential methods to warm large areas of soil/vegetation, passive warming appeals as the most cost effective and robust technique to apply warming. Soil cables are too destructive and provide localised warming with large gradients. Infrared lamps, though providing good control of temperatures, are expensive to run and also have the problem of artificial drying of the canopy. In addition, our existing electrical infrastructure would need an expensive upgrade in order to deal with the required extra loading for all day use of the lamps. The following sections detail the construction and testing of a passive warming system for our grassland system.

3. Design and Testing of our Passive Warming System

3.1 Materials and Methods

Our passive warming system consists of a 3 x 3 m frame made from 10 x 5 cm galvanised tubular steel. (Plate 3) The frame is raised 50 cm above the soil surface by the same sized tubular steel. The covering material is Svensson XLS Firebreak 17F which consists of a high-density polyethylene mesh supporting a pattern of 12 mm wide aluminium strips separated by 4 mm of clear mesh. The curtains reflect 25% of the direct and 24% of the diffuse radiation and allow transfer of water vapour through the mesh. For the prototype used in the testing phase described here (Plate 3), the covering material was coiled on a beam which was manually opened and shut when required. For the warming frames that will be used in the experiment, the beam carrying the covering material will be connected to a motor. The motor will be activated automatically by a controller and the cover retracted based on the following conditions:

a) photoperiod - at sunset the covering will be automatically drawn over the pasture to reduce the loss of infrared radiation; at sunrise the cover will be retracted to leave the plots open during the day.

b) rainfall – to ensure soil moisture levels are not affected by the covering, when it rains at night (as detected by a sensor) the covering will be retracted; when the rain stops the cover will be drawn back across the frame.

c) wind - to reduce potential damage to the cover and increase its lifespan, the cover will be retracted when wind speeds exceed a threshold at night.

In the version of the warming frames that will be installed in the FACE experiment, all frames will be activated by a central controller using data from a centrally located weather station. Communication between the units will be by radio link while system status and environmental data will be automatically downloaded to Palmerston North over the cell phone network.

Plate 3 Prototype passive warming screen open (left) and closed (right). Solar powered data logger and sensor cables also visible. Test location: Agresearch Grasslands, Palmerston North.

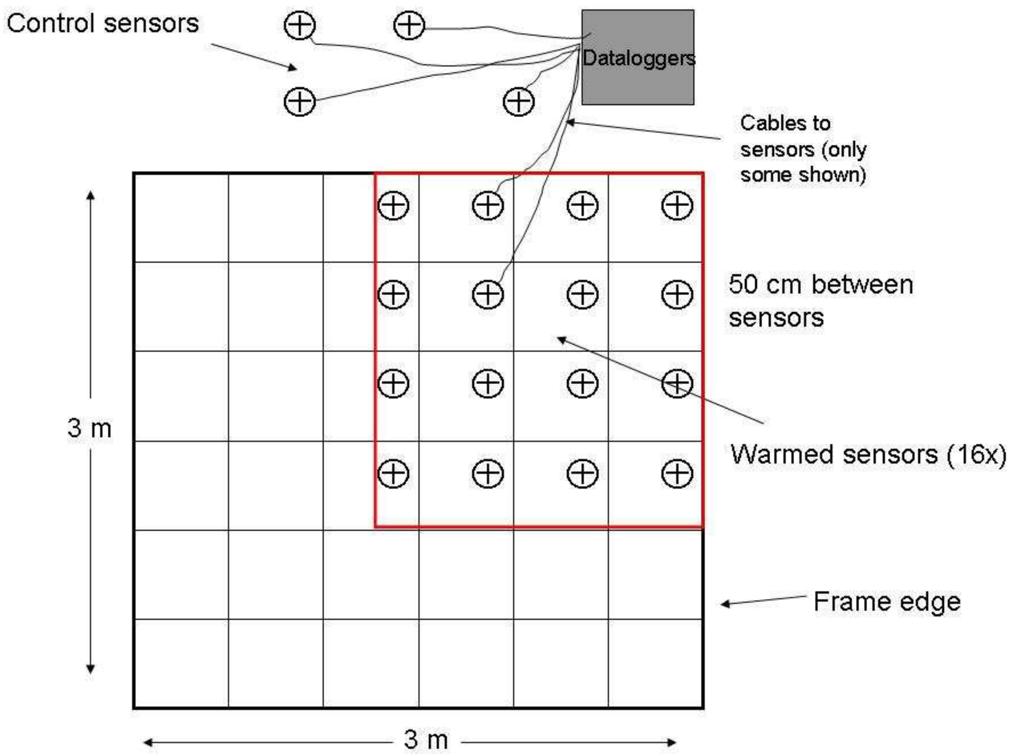

Figure 3 Schematic diagram of the sensors buried in the soil under the frame to determine spatial aspects of the warming treatment. The red outline indicates the extent of Fig. 6 (see below)

The prototype frame was set up in a recently cultivated and sown field of perennial ryegrass. Seedlings had just emerged. To assess the spatial aspects of the warming treatment, temperature sensors were buried at 5 cm depth in a 4 x 4 grid 50 cm apart in one quadrant of the frame (Fig. 3). The outermost sensors were placed on the edge of the frame and the innermost sensor in the centre. Four sensors were buried outside of the frame to measure ambient soil temperatures. A solar powered set of data loggers recorded the temperatures every 10 minutes.

To determine the biological response to warming, two sets of measurements were taken. Firstly, approximately 4 weeks after the frame was installed, resident perennial ryegrass seedlings that were about 5 weeks old were harvested from near the centre of the frame and from outside. Secondly, about 1 week after the frame was put in place, we planted seed of annual ryegrass, timothy and cocksfoot in patches inside and outside the frame. These were harvested 4 weeks after planting, at the end of the testing period. In both cases, plant height, number of leaves and tillers and leaf/sheath and root dry matter of the seedlings were determined.

3.2 Results: physical

Figure 4 shows the temperatures recorded near the centre of the warming frame compared to those outside the frame. Across the whole testing period, including when the cover was not on, the warming treatment generated a difference of nearly 1 °C at 5 cm soil depth. The responsiveness of the treatment can be seen from when the cover was not put on for prolonged periods of time due to rain events: the degree of warming soon declined, though there was still a noticeable thermal lag.

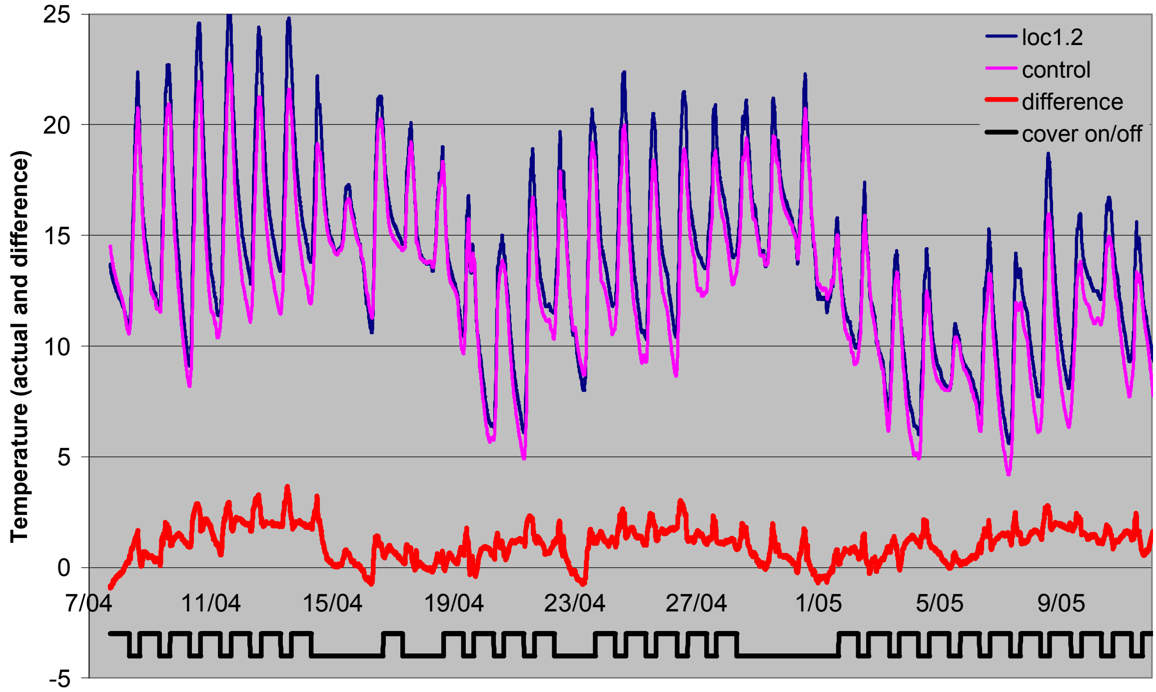

Figure 4 Graph showing the actual soil temperature (5 cm depth) at one location near the centre under the warming cover (blue lines) and the average of four control locations (purple lines). Data were collected every 10 minutes. Red line is the difference between warmed and control. Black line at the bottom indicates the on/off status of the cover with the upper line signifying when the cover was on.

The diurnal nature of the warming was similar to that shown above for the CLIMAITE experiment (Fig. 2): at night a warming of nearly 1.2 °C was achieved (Fig. 5). The cover was usually retracted by 0730h and temperature differences dropped to about 1 °C by lunchtime. The noticeable drop in the early afternoon to about 0.8 °C was likely to be due to an increase in ambient wind speed at this time. The cover was usually drawn over at about 1645h, and warming to over 1 °C was achieved after about 2 hours.

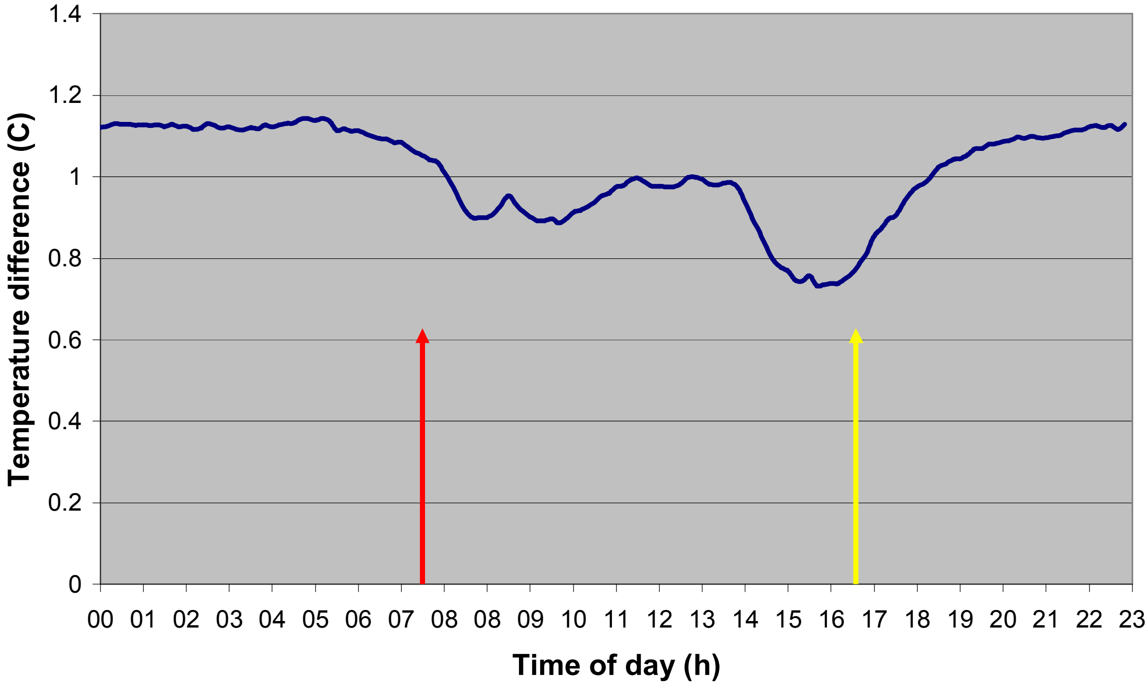

Figure 5 Diurnal change in the difference in soil temperature (5 cm depth) between inside the frame (warmed) and outside (ambient control). Red arrow indicates approximate time of cover retraction; yellow arrow when the cover was put back on.

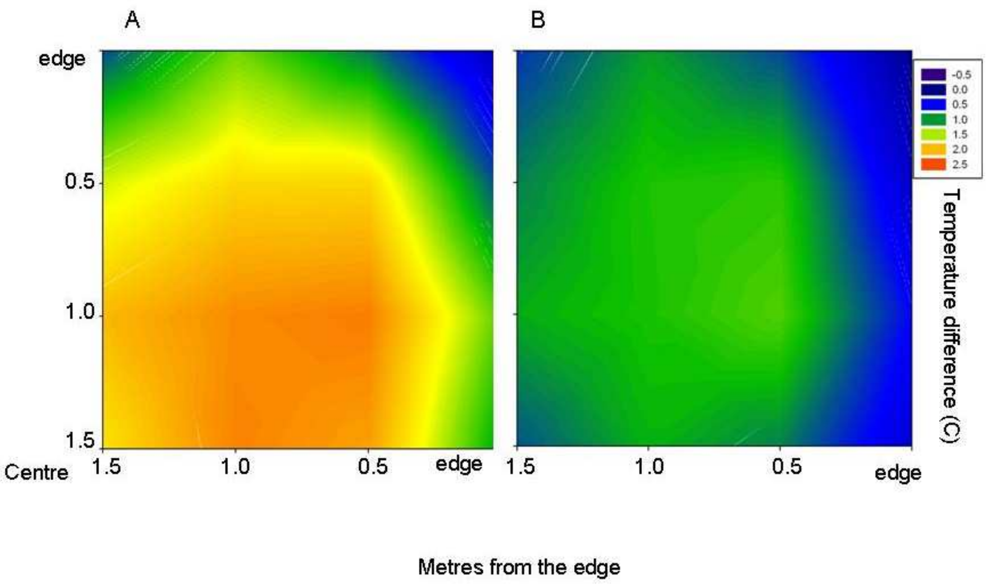

Figure 6 Spatial distribution of the temperature differences between inside and outside the frame for one quadrant of the frame on a typical day (A) and across the whole 35 days and nights of the test period (B; includes nights when cover was not on due to expected rain). In both figures, bottom left is the centre of the frame, top right is the corner (see Fig. 3 for schematic diagram).

The spatial aspects of the warming treatment are shown in Figure 6 for one quadrant of the frame. On a typical day during a period when the cover was put on at night repeatedly, warming of up to 2 °C occurred. This level of warming occurred up to about 30 cm from the edge, giving an effective warmed area of nearly 6 m^2. Averaged across all the days of the testing period (including nights when the cover was not put for multiple days due to rain), the warming was in the order of 1 °C across a similar effective area of 6 m^2.

A number of aspects of this short term testing phase impacted on the physical performance of the warming frame. Most importantly, because the system was manually operated, control over whether the cover was on or off was not as good as it will be when the system is automated. For example, because we wanted soil moisture levels to be similar between control and warmed plots, a decision had to be made by late afternoon (1700 h) whether it would rain or not that night. If rain was predicted then the cover stayed off and a period of potential heating was missed if it did not rain until early the next morning for example (say 0400 h). In contrast, the automatic system would have closed at 1700 h and remained so until 0400 h, warming the soil until the rain started.

The limited time period of this testing phase would also have affected the level and consistency of warming. Wind can markedly affect the level of warming achieved. For example in the CLIMAITE experiment, (Mikkelesen et al 2008), little or no warming was achieved when wind speeds were above 6 ms^{-1}. The experiment reported here was located in a fairly sheltered area and the effect of localised increases in wind speed in the testing phase was noted above. The site of the FACE experiment is windier than the test site and it is likely that warming will be in the range of 0.8 °C rather then the nearly 1.2 °C found here. This is a similar level to that achieved in the CLIMAITE experiment (Mikkelesen et al 2008).

3.3 Results: biological

Variate	Species	Control	Warmed	F test
Max. length (mm)	Lol per	11.52	11.95	0.476
	Dac glo	31.74	30.02	0.250
	Phl pra	27.64	28.10	0.749
	Lol mul	73.10	70.72	0.413
Tiller no.	Lol per	4.60	3.25	0.001*
	Dac glo	1.00	1.00	-
	Phl pra	1.00	1.00	-
	Lol mul	1.20	1.20	-
Leaf no.	Lol per	11.03	8.83	0.023*
	Dac glo	1.94	2.12	0.009*
	Phl pra	2.00	2.10	0.022*
	Lol mul	2.96	3.12	0.306
Shoot d.wt (g)	Lol per	1.93	1.22	-
	Dac glo	0.06	0.05	-
	Phl pra	0.05	0.05	-
	Lol mul	0.30	0.28	-
Root d.wt (g)	Lol per	0.46	0.32	-
	Dac glo	0.04	0.03	-
	Phl pra	0.04	0.03	-
	Lol mul	0.10	0.09	-

Table 1 Maximum height, tiller and leaf number and shoot and root dry weight (d.wt) of perennial ryegrass (Lol per), cocksfoot (Dactylis glomerata (Dac glo), timothy (Phl pra) and annual ryegrass (Lol mul) with and without (control) warming. For the height and tiller and leaf number the values are for at least 40 individual seedlings and the F value is for an unpaired t test for each species while for shoot and root d.wt are averages of the individual seedlings combined (hence no statistics).

There was no difference between control and warming for maximum height of the seedlings. However, for perennial ryegrass, cocksfoot and timothy but not annual ryegrass, leaf number was greater under control. Tiller number was 40% greater for the earlier planted perennial ryegrass but due to the short test period the other species all had similar tiller numbers (i.e. 1). Shoot d.wt was about 60% greater for perennial ryegrass but because this value was that of the bulked individual plants, the significance of this could not be tested. Similarly, differences between control and warming for the other species could not be tested and the short duration of the experiment would have made it difficult to detect differences.

The biological results from our very limited initial experiment are inconclusive in terms of the response of plant growth to warming. However, there is a hint that at least under the conditions of the experiment, early growth was adversely affected by the warming. This is most likely due to the interaction between photosynthesis and respiration. Both the rates of photosynthesis and respiration usually increase under warmer temperatures, though responses are very much dependant on species and the magnitude and time of exposure to warming (see review by Luo, 2007). Though we did not measure air temperatures in this testing phase, data from the CLIMAITE experiment show that air temperatures are warmed at night and only in the early part of the morning while soil temperatures are warmed for the whole day (Fig. 2). Our diurnal soil temperatures (Fig. 5) were similar to those found in the CLIMAITE experiment and we are confident that air temperatures acted similarly. Hence it is likely that day time photosynthesis was not stimulated as much as night time respiration and the warmed seedlings had a lower positive carbon balance and therefore lower growth. Additionally, our experiment was carried out in late autumn when day lengths are rapidly decreasing and the available time for photosynthesis was limited. However, there is evidence in the literature that plants can acclimate their responses to warming (Luo, 2007) and that over longer time periods growth is generally enhanced with warming. Finally, other plant processes are also affected by warming (e.g. phenology and length of the growing season), as well as other biological processes that could affect plant growth (e.g. nutrient cycling and N availability), making predictions of pasture responses to warming based on temporally very short experiments difficult.

4. Conclusions

Our report presented a technology that will add the dimension of warming to our existing elevated CO_2 experiment. We examined the various technological options available to add a warming treatment and decided that passive night time warming best suited our situation: it warms to adequate levels in a biologically meaningful way that is cost effective and does not interfere with our grazing protocols. Our testing phase indicates that the levels of warming achieved will be up to 1 °C at 5 cm soil depth: this is in line with the most likely future climate change scenarios. When the warming is installed (mid July) we will have a unique experimental platform for studying the full range of potential climate changes.

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6. Collaborators

We have active research programmes with the following groups that have warming/CO_2 experiments.

6.1 TasFace

http://www.utas.edu.au/docs/plant_science/ps/ps/face.html

Based on natural grassland in Tasmania.

6.2 Climaite

http://www.climaite.dk/

This experiment is on heathland in Denmark. The PI, Claus Beier, leads the experimental research in the NitroEurope programme and we are an associate member of this network.

6.3 PHACE

http://www.phace.us/

The prairie heating and CO_2 enrichment experiment is situated in Wyoming.

6.4 PROPHET

A passive night time warming experiment on rice paddies at NIAES Tsukuba: PROPHET - Paddy Rice Overnight Passive Heating Experiment in Tsukuba

7. Appendix

A selection of publications from the NZFACE experiment

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