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Role of Boreal Vegetation in Controlling Ecosystem Processes and Feedbacks to Climate

1997 Final Report

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I. Summary

In the field, dark respiration rates are greatest in cores from more northerly locations. This is due in part to greater amounts of dwarf shrub biomass in the more northerly cores, but also to differences in soil organic matter quality. Laboratory incubations of these soils under common conditions show some evidence for greater pools of available carbon in soils from more northerly tundra sites, although the most northerly site does not fit this pattern for reasons which are unclear at this time. While field measurements of cores transplanted among different vegetation types at the same location (Toolik Lake) show relatively small differences in whole ecosystem carbon flux, laboratory incubation of these same soils shows that there are large differences in soil respiration rates under common conditions. This is presumably due to differences in organic matter quality. Microenvironmental site factors (temperature, soil moisture, degree of anaerobiosis, etc.) may be responsible for evening out these differences in the field. These site factors, which differ with slope, aspect, and drainage within a given location along the latitudinal gradient, appear to exert at least as strong a control over carbon fluxes as do macroclimatic factors among sites across the latitudinal gradient. While our field measurements indicate that, in the short term, warming will tend to increase ecosystem losses of CO_2 via respiration more than they will increase plant gross assimilation, the degree to which different topographically-defined plant communities will respond is likely to vary.

II. Overview

During 1996 and the no-cost extension into 1997, we finished sample and data analyses from the originally proposed field measurements and undertook additional measurements and experiments to better understand the mechanisms underlying some of the patterns we observed. These activities included

A) Analyzing data from field measurements of whole ecosystem photosynthesis and respiration;

B) Laboratory analysis of samples from a destructive harvest of half of the replicate cores;

C) A long-term laboratory incubation of soils from the remaining cores to estimate available carbon pool sizes.

These are described in more detail below.

A. Field measurements of whole ecosystem carbon flux.

Field photosynthesis measurements and ancillary data indicated that

1) Cores transplanted to a common site. Cores which were transplanted to a common location from the same vegetation type, but from different sites of origin along the latitudinal transect, differed in rates of dark respiration and gross photosynthesis (both higher from the more northerly cores). Because these tended to balance out, however, net assimilation did not differ among sites of origin (Fig. 1). Therefore, quantity of vegetation (within the range observed in the cores) was a good predictor of gross assimilation rates, but not of net assimilation. The

differences in dark respiration could be due to differences in soil organic matter quality or to differences in vegetation biomass (the latter positively covaried with respiration rates; Fig. 2). A laboratory incubation of soils from the different treatments was undertaken to differentiate between these mechanisms (see Section C, below)

2) Cores transplanted along the latitudinal gradient. Cores from a common site of origin (intertussock moss mats and associated vegetation from Toolik Lake) which were transplanted along the entire gradient had the highest rates of dark respiration in the warmer, more southerly sites (Fairbanks and Chandalar). Gross photosynthesis did not increase however, with the result that the more southerly cores lost more CO_2 to the atmosphere (Fig. 3). This indicates that increases in temperature have a greater initial effect on soil and plant respiration rates than on plant production. Therefore we would expect that climatic warming would lead increased losses of carbon from ecosystems to the atmosphere, at least in the short term.

3) Cores transplanted among vegetation types at Toolik. Whole ecosystem dark respiration, gross assimilation and net assimilation rates did not differ greatly among different vegetation types from the same latitudinal location (shrub, tussock and wet sedge tundra at Toolik Lake) (Fig. 4). This was particularly surprising given presumed differences in organic matter quality among these different vegetation types. The laboratory soil incubation experiment sought to shed more light on these results (see Section C, below).

B. Soil harvest lab analyses

To test relationships between ecosystem CO2 flux and nitrogen dynamics, we injected transplant cores with $^{15}NH_4^+$ label in the summer of 1994. The following year, one half (5) of the replicates from each treatment were destructively harvested to measure plant and microbial biomass, aboveground net primary production, and the fate of the ^{15}N label (plant uptake, microbial immobilization, incorporation into soil organic matter, or loss from the system). During 1996 and 1997, the resulting soil and plant samples were analyzed in the lab. This work included analyzing soil extracts for ammonium, nitrate, total nitrogen and ^{15}N, weighing plant and soil samples, and analyzing these plant and soil samples for total C, N, and ^{15}N. This data is now being analyzed. The information gained will allow us to construct a total budget of the ^{15}N label that was added to the system, determine how it was partitioned among different ecosystem components, and calculate nitrogen losses from the system. Such a nitrogen budget, combined with the data on productivity and whole system carbon flux, will help to resolve questions about relationships between C and N dynamics at the whole ecosystem level and how these might respond to long term warming, short term warming, and different vegetation compositions. For example, it is known that as temperatures increase, decomposition, soil respiration, and nitrogen mineralization all increase. Whether this leads to net ecosystem loss of C to the atmosphere will depend on the fate of the mineralized nitrogen - if plants are able to get it, greater plant growth in the tundra could actually increase total carbon storage since plants have a higher C/N ratio than soils. On the other hand, if any additional N mineralized is lost from the system (leached away and therefore unavailable for plant growth), we would expect total C storage of the ecosystem to decrease.

C. Long-term soil incubation

To better understand the degree to which soil organic matter quality differs among different latitudinal locations and different vegetation types and how this might affect ecosystem carbon flux, we started a long-term laboratory incubation with soils from the transplanted cores. At the end of summer 1996, soil was collected from each of the five remaining replicates from each treatment in the field. Soils from all treatments were incubated at 30 °C for 23 weeks to compare quantities of available carbon. We wanted to know if soils from more northerly sites had higher amounts of available carbon (due to lower site temperatures and slower decomposition), if soils from different vegetation types at the same latitude differed in amounts of available carbon (due to differences in litter quality or microenvironment), and how quickly available carbon pools might change under a new temperature regime for the transplanted cores (i.e., have pools changed during the 3 years of the transplant experiment?). In addition, a subset of the soils was incubated at 10 °C to assess whether differences among treatments were affected by temperature of incubation. That is, are available carbon pools the same at 10 and 30 degrees?

Below is a summary of our findings.

1) Soils from intertussock moss mats from different latitudes had different respiration rates. While the pattern generally was that more northerly soils had higher fluxes, the most northerly site, Sagwon, had much lower fluxes than expected based on its latitude (Fig. 5). The patterns were similar at both low and high temperatures, though fluxes from soils at 30 °C were 3-4 times higher than at 10 °C (Fig. 5, Fig. 6). In addition, while soil respiration rates slowed substantially by Day 165 at the higher temperature, indicating consumption of most of the available pool of carbon, rates at the lower temperature continued unabated (though at a lower initial rate).

2) Respiration rates differed significantly among vegetation types at both Toolik Lake and Fairbanks. At Toolik, shrub tundra soils had the highest respiration rates, intertussock soils had intermediate rates, and wet sedge soils had substantially lower rates (Fig. 7). At Fairbanks, intertussock soils from the muskeg site had substantially higher rates of respiration than did soils from an upland black spruce stand. These differences among vegetation types at the same latitude were of similar (or greater) magnitude to differences in soils due to latitudinal site of origin.

3) Transplanting across latitude did not change soil respiration rates significantly after 3 years, but transplanting across vegetation types did. For example, intertussock soils from Toolik Lake transplanted at all four sites along the latitudinal gradient still showed similar respiration rates under common conditions. The same was true for transplanted soil from the Fairbanks spruce site. On the other hand, soil transplanted from tussock and shrub tundra into wet sedge tundra at Toolik Lake showed substantially decreased respiration rates compared to controls, and Fairbanks spruce soils transplanted into the Fairbanks tussock site showed increased respiration rates (Fig. 7). Therefore, microenvironmental factors, such as differences in moisture along topographical gradients, appear to have a much stronger effect on soil organic matter quality than do macroenvironmental conditions (e.g., latitudinal differences in climate). We cannot yet assess how long it might take for changes in macroclimate to lead to the differences in soil respiration that we observed in Section C1 above.

III. Publications

Chapin, F. S., III, McFadden, J. P. , and S. E. Hobbie. (in press) The role of arctic vegetation in ecosystem and global processes. In S. J. Woodin and M. Marquiss (Eds.), Ecology of arctic environments. Blackwell Science, Oxford.

Hooper, D.U., S.E. Hobbie, J.H.Verville, and F.S. Chapin III (1996) Temperature and vegetation controls on soil CO_2 flux in Alaskan tundra. *Bulletin of the Ecological Society of America*, Supplement to Vol. 77, No.3: 202.

Verville, J.H., F.S. Chapin III, S.E. Hobbie, and D.U. Hooper (in press) Response of tundra CH_4 and CO_2 flux to manipulation of temperature and vegetation. Biogeochemistry.

Verville, J.H., F.S. Chapin III, S.E. Hobbie, and D.U. Hooper (1995) Plant growth form more important than temperature in controlling CH_4 flux in Alaskan tundra communities, *Bulletin Of The Ecological Society Of America*. Supplement to Vol. 76, No.2: 398.

Manuscripts in preparation:

Hobbie, S.E., D.U. Hooper, and F.S. Chapin III. Climatic and vegetation effects on nitrogen dynamics in Arctic tundra ecosystems.

Hooper, D.U., W. Eugster and F.S. Chapin III. Problems with calculations of whole ecosystem CO_2 flux using the Licor 6200.

Hooper, D.U., S.E. Hobbie, J.H. Verville and F.S. Chapin III. Effects of short-term warming on whole ecosystem CO_2 flux in transplanted Arctic tundra microcosms.

Hooper, D.U., S.E. Hobbie, J.H. Verville and F.S. Chapin III. Differences among Arctic tundra vegetation types in ecosystem CO_2 flux: effects of vegetation, organic matter quality and microenvironment.

Hooper, D.U., and F.S. Chapin III. Latitudinal and vegetation effects on available carbon pools in Arctic tundra soils: results from a long-term incubation.

IV. Figure legends

Figure 1. Cumulative growing season CO_2 fluxes (net assimilation, dark respiration, and gross assimilation) for cores from different sites of origin transplanted to Toolik Lake LTER. From south to north, F = Fairbanks, C = Chandalar, T = Toolik, S = Sagwon.

Figure 2. Median soil temperature (A) and air temperature (B) at the different locations across the transect. Measurements were taken from all cores at the times of CO_2 flux measurments. Median vascular plant leaf area index (C) from cores originating from different locations. Site labels as in Figure 1.

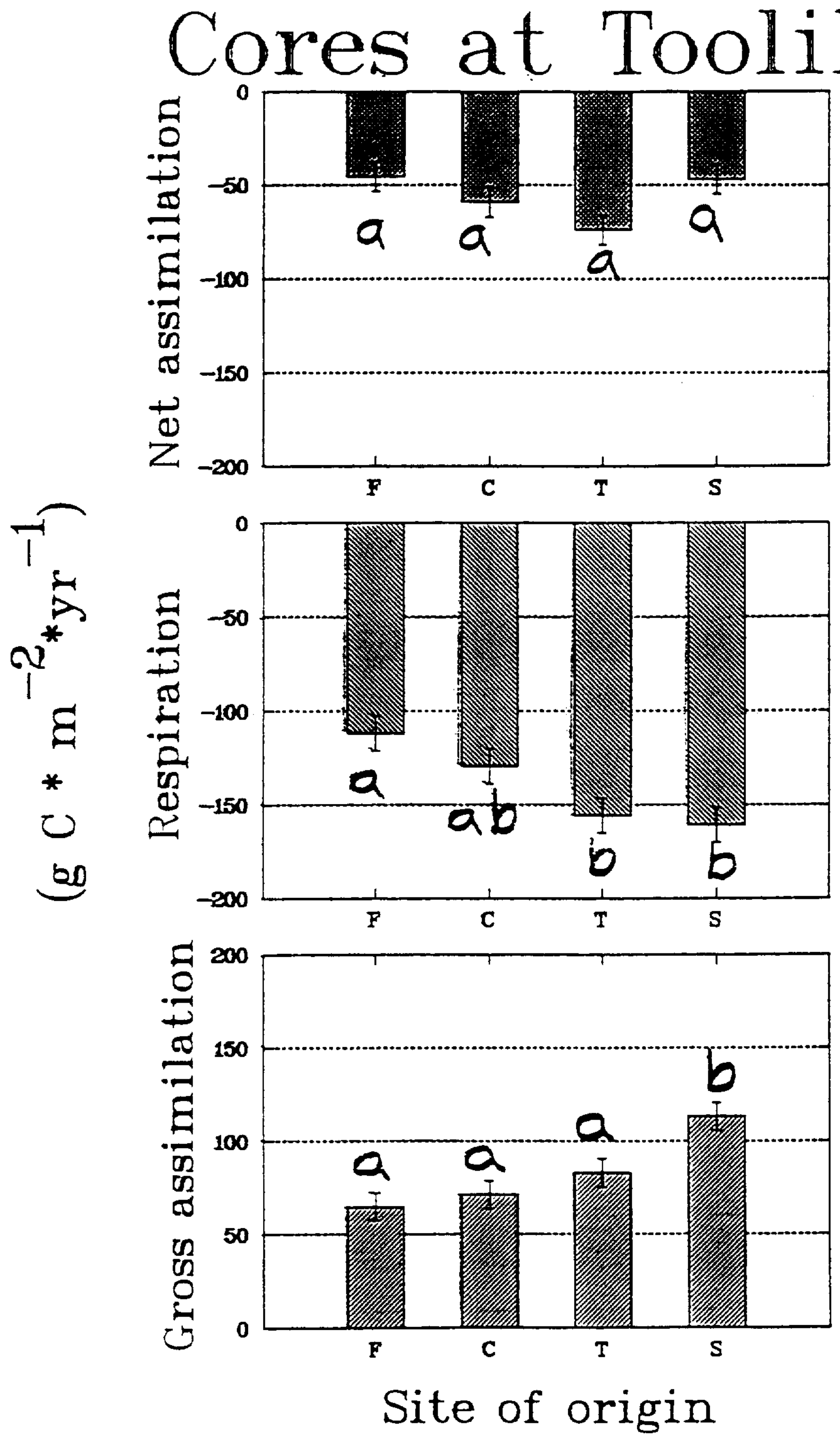
Figure 3. Cumulative growing season CO_2 fluxes (net assimilation, dark respiration, and gross assimilation) for cores originating from Toolik Lake and transplanted across the latitudinal gradient. Site labels as in Figure 1.

Figure 4. Seasonal CO_2 fluxes from reciprocal transplant cores across vegetation types at Toolik Lake LTER. Each box represents one site of transplant for cores from all different vegetation types (S = shrub tundra, T = tussock tundra, W = wet sedge tundra).

Figure 5. Cumulative soil respiration after 23 weeks (A) and soil respiration rates (B) at high (30 °C) temperatures for soils from cores originating from different locations across the latitudinal gradient. From south to north, FTF = Fairbanks core at Fairbanks; CTC = Chandalar core at Chandalar; TTT = Toolik core at Toolik; PTP = Sagwon core at Sagwon. X-axis for B is a log scale.

Figure 6. Cumulative soil respiration after 23 weeks (A) and soil respiration rates (B) at low (10 °C) temperatures for soils from cores originating from different locations across the latitudinal gradient. Site labels are the same as in Figure 5, but note difference in scale.

Figure 7. Cumulative respiration at 30 °C for soils transplanted across vegetation types at the same latitudinal location: A) Fairbanks, B) Toolik. FTFS = Fairbanks tussock in the Fairbanks spruce site; FSFS = Fairbanks spruce in the spruce site; FTF = Fairbanks tussock in the tussock site; FSF = Fairbanks spruce in the tussock site. TSS = Toolik shrub in the shrub site; TTS = Toolik tussock in the shrub site; TWS = Toolik wet sedge in the shrub site; TST = Toolik shrub in the tussock site; TTT = Toolik tussock in the tussock site; TWT = Toolik wet sedge in the tussock site; TSW = Toolik shrub in the wet sedge site; TTW = Toolik tussock in the wet sedge site; TWW = Toolik wet sedge in the wet sedge site.



veg covariate

No Yes

site
$p=0.06$ $p=0.02$

trend NS NS

site
$p=0.002$ $p=0.0$

trend*** **

site
$p=0.000$ $p=0.01$

trend*** *

Fig. 1

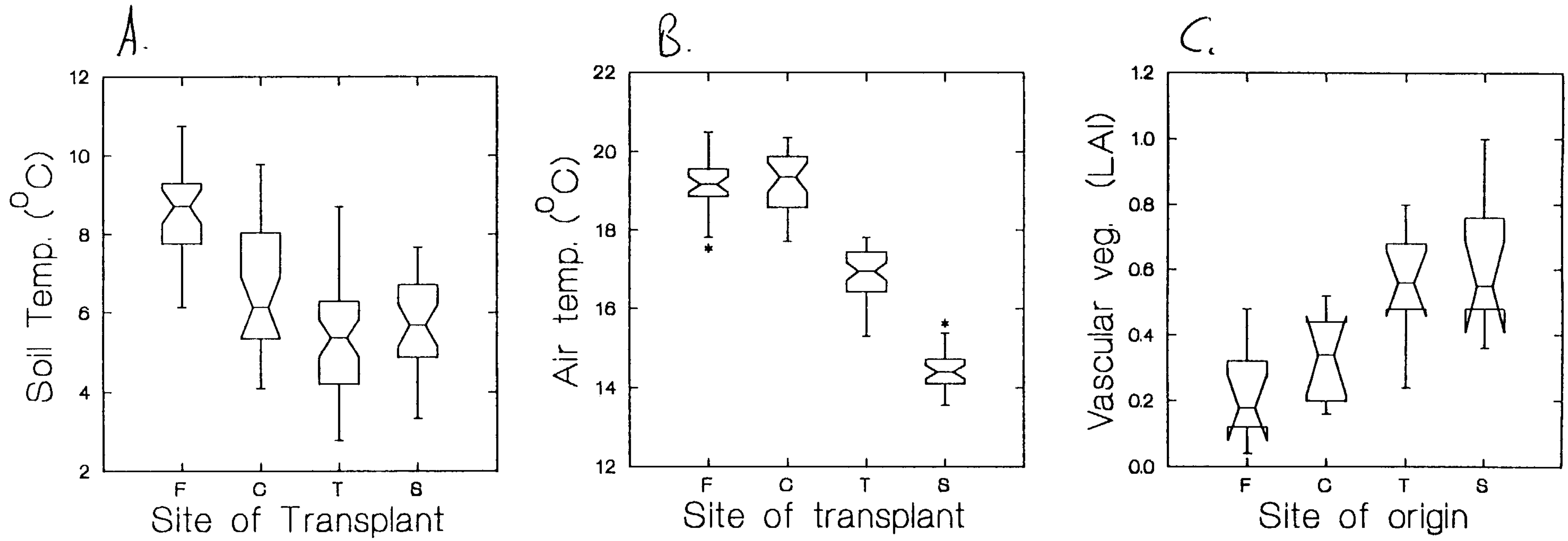
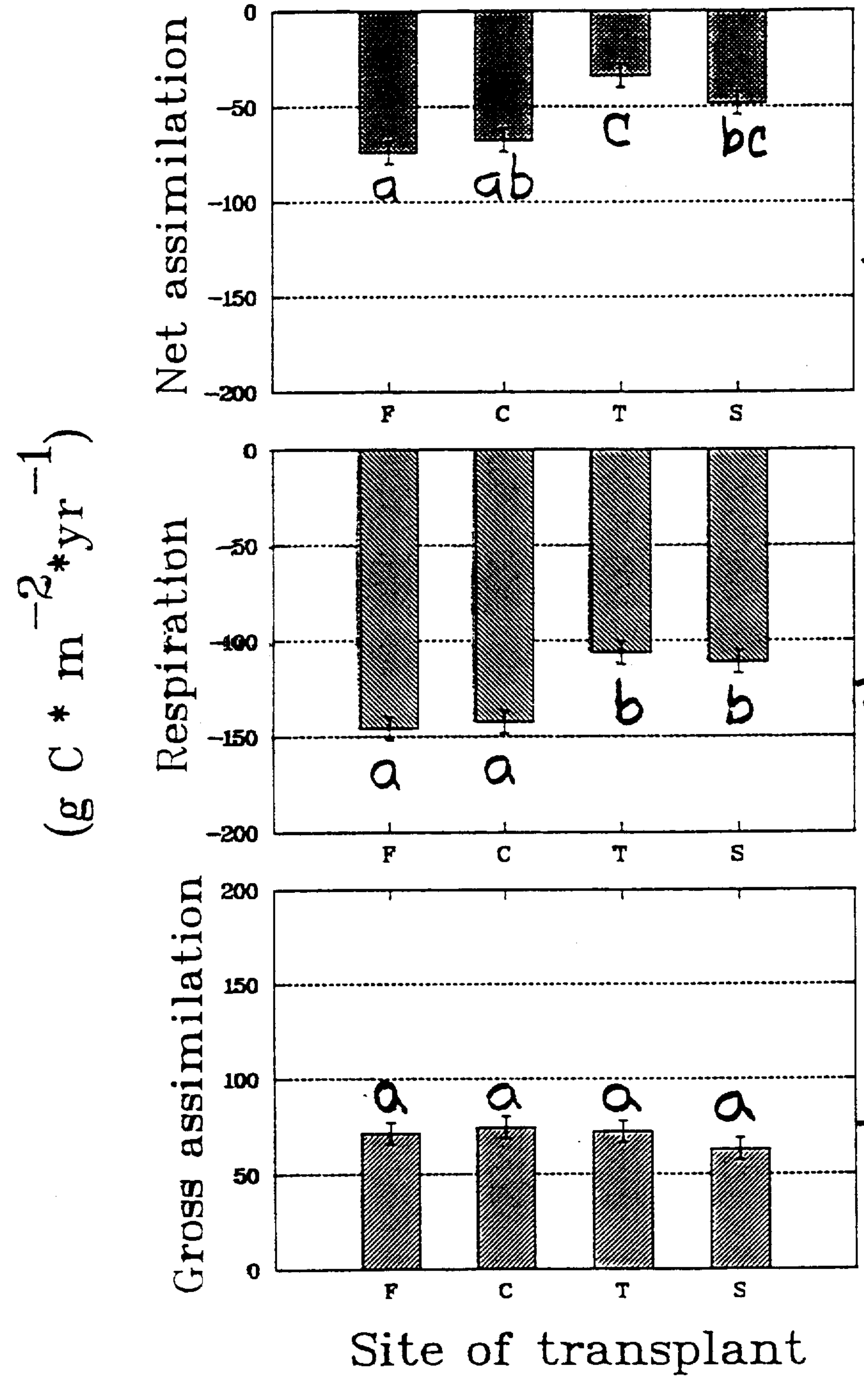

A.
Soil Temp. (°C)
12
10
8
6
4
2
F
C
T
S
Site of Transplant
B.
Air temp. (°C)
22
20
18
16
14
12
F
C
T
S
Site of transplant
C.
Vascular veg. (LAI)
1.2
1.0
0.8
0.6
0.4
0.2
0.0
F
C
T
S
Site of origin

Fig. 2

Cores from Toolik



soilT covariate

NO YES

site
p=0.0003 p=0.1
trend*** NS

site
p=0.000 0.035
trend*** *

site
p=0.54 0.91
trend NS NS

Fig 3

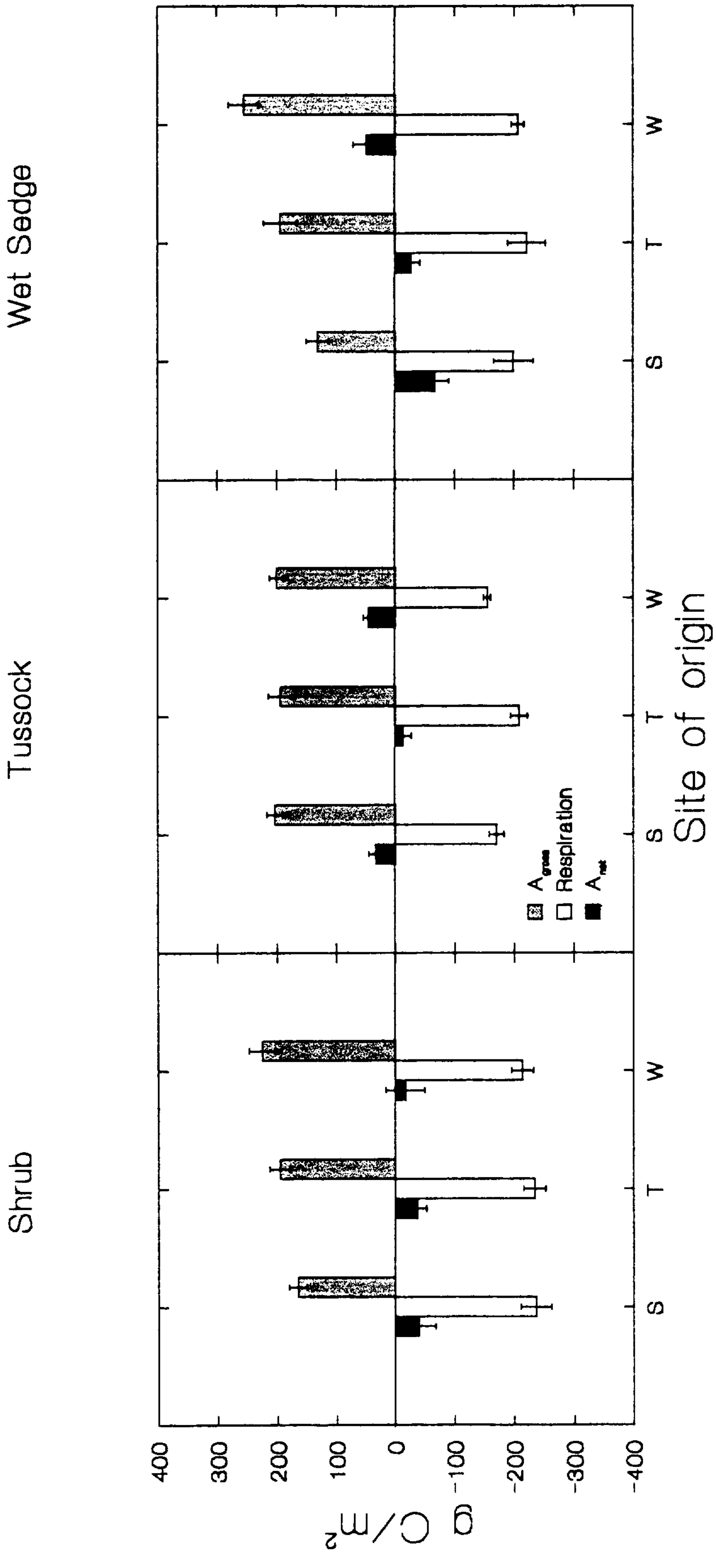
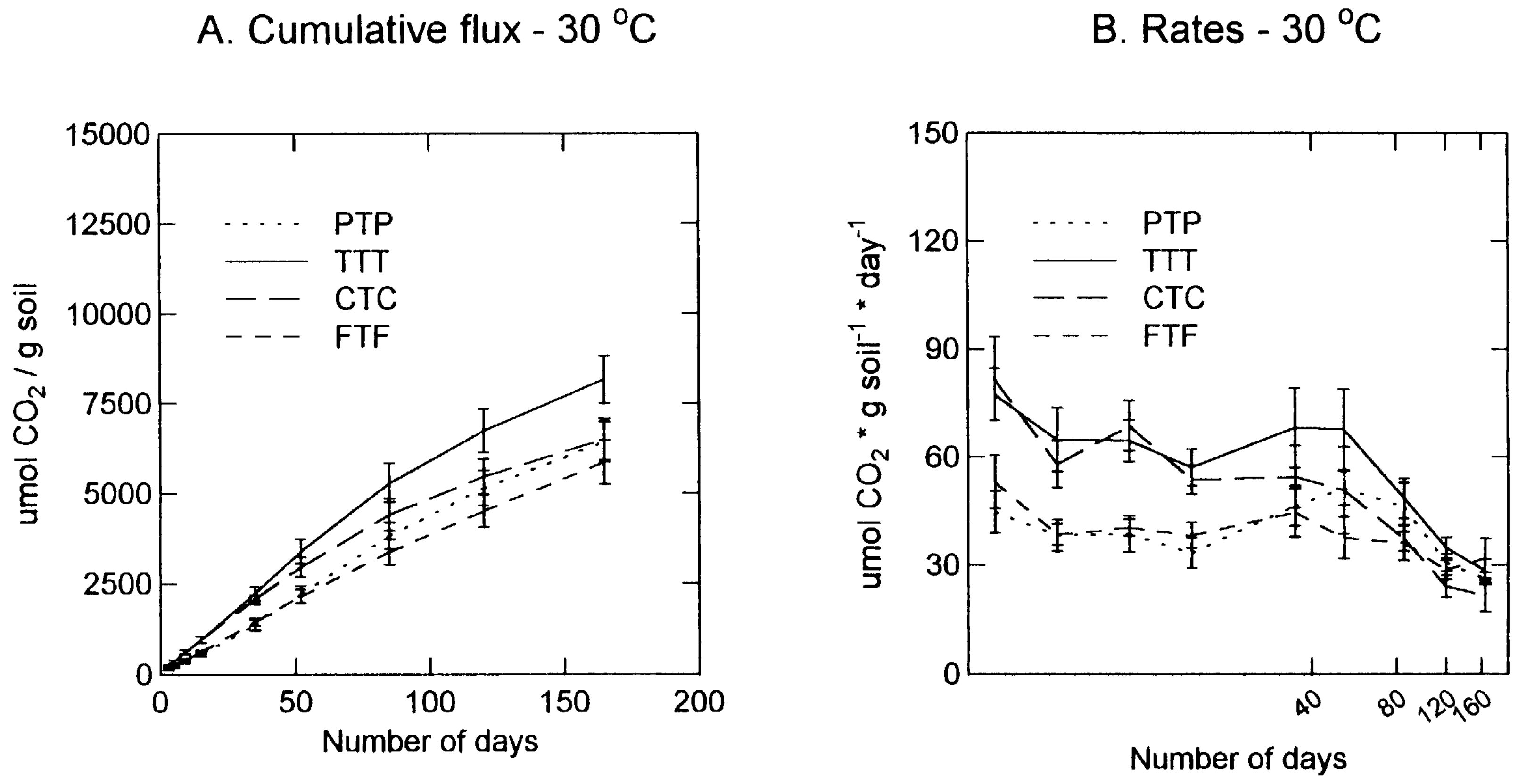

Shrub
Tussock
Wet Sedge
g C/m^2
400
300
200
100
0
-100
-200
-300
-400
S
T
W
Site of origin
A_{gross}
Respiration
A_{net}

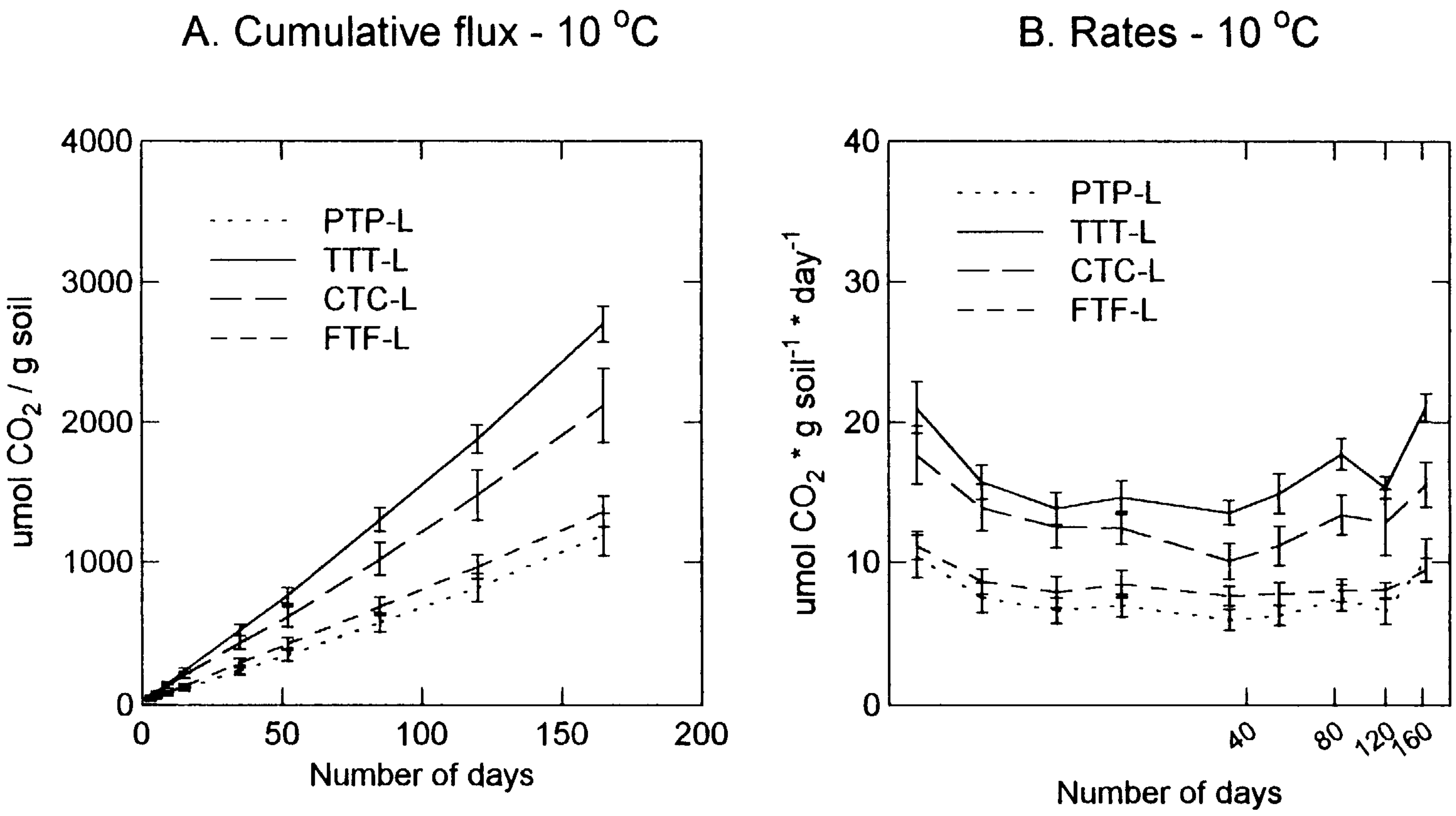
Fig. 4



A. Cumulative flux - 30 °C

B. Rates - 30 °C

Fig. 5


A. Cumulative flux - 10 °C

B. Rates - 10 °C

Fig. 6

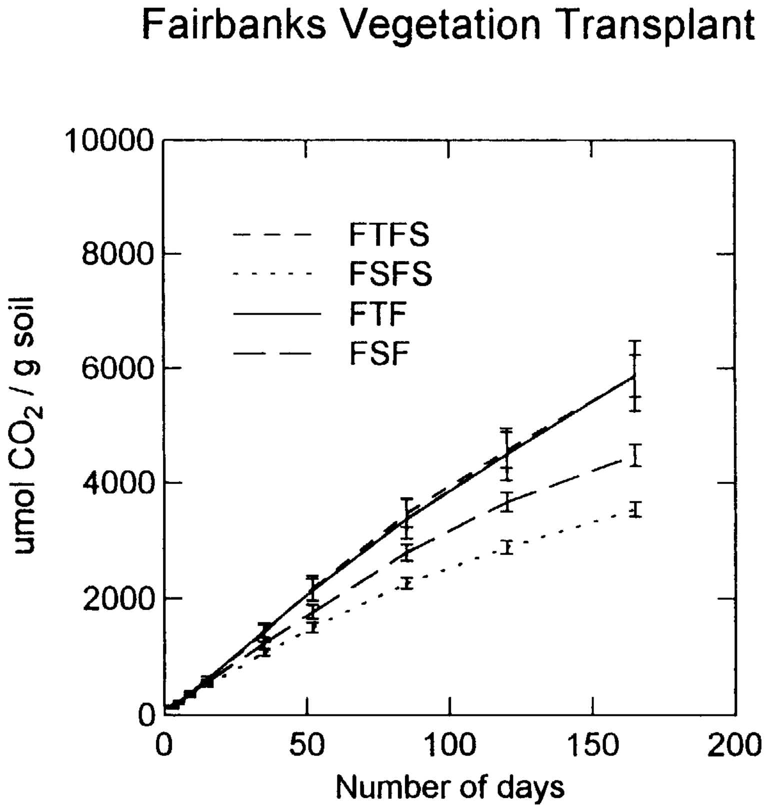

Fairbanks Vegetation Transplant

Fig. 7 A

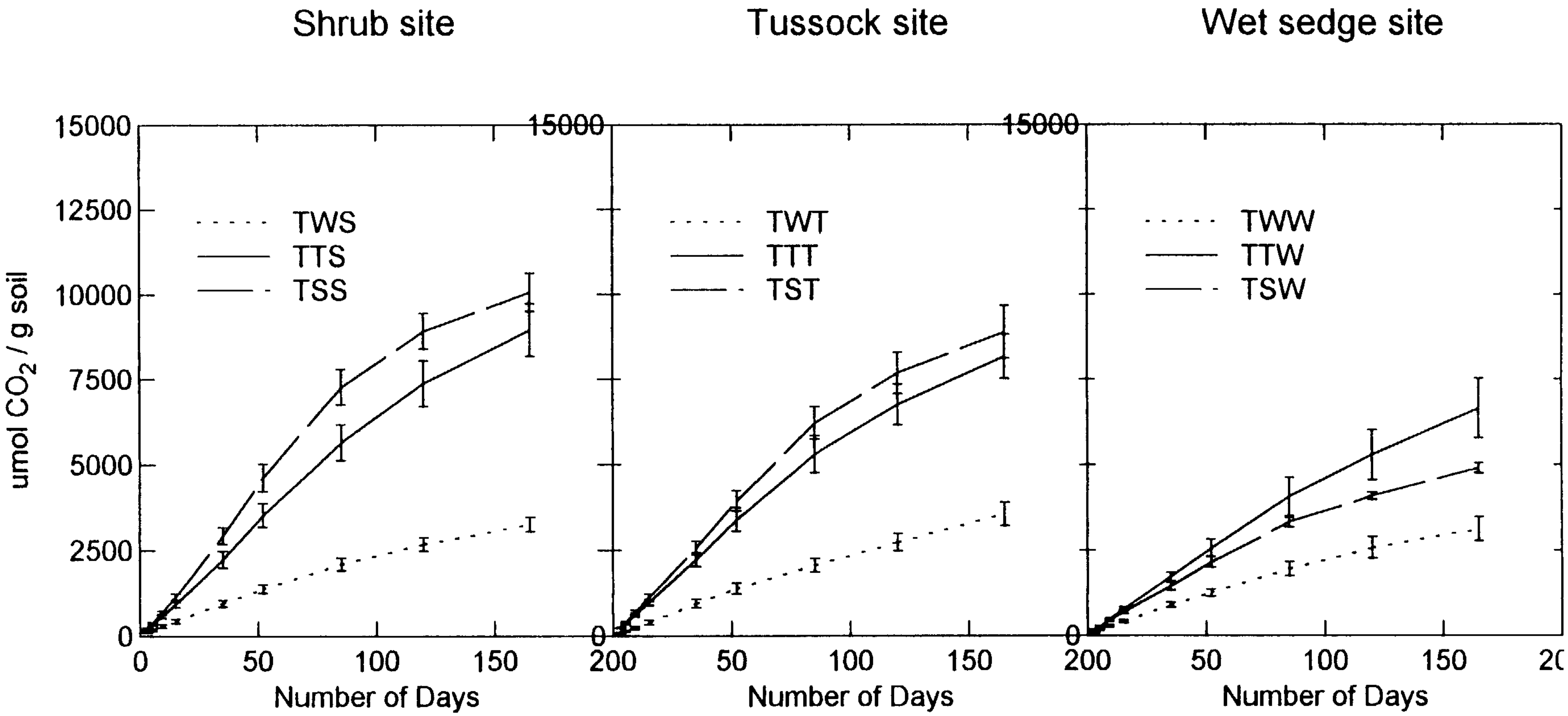
Shrub site
Tussock site
Wet sedge site
umol CO$_2$ / g soil
15000
12500
10000
7500
5000
2500
0
15000
0
15000
0
TWS
TTS
TSS
TWT
TTT
TST
TWW
TTW
TSW
0
50
100
150
200
50
100
150
200
50
100
150
20
Number of Days
Number of Days
Number of Days

Fig. 7B