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Forest adaptation to arid-land climate conditions

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Introduction.

Dry shrubland and grassland covers about 20% of the Earth land surface, with carbon storage being relatively low. For the last three years we studied the functioning of the Yatir *Pinus halepensis* afforestation, at the desert edge (aridity factor <0.15), and identified several unique characteristics, including carbon sequestration rates (NEE; eddy covariance technique) similar to European forests.

The productive period is off-phase to other Northern Hemisphere temperate and boreal forests, thus enjoying an enriched atmospheric CO2 concentration of around 10 ppm. While stem growth is concurrent with the productive wet season, leaf elongation occurs through the mainly rainless period (April to October).

Despite extreme drought, the forest showed some CO_2 uptake throughout the whole summer, mainly in early morning and at late afternoon.

Monthly NEE and ET fluxes were strongly correlated, with high water use efficiency during the productive period and no correlation in the summer.

Daily NEE increased rapidly in response to water input.

Weather conditions at Yatir.

Long periods of dry and hot conditions are characterizing the climate at Yatir, where:

- Long-term precipitation average of 278 mm (1964-2002); 200 mm for the five years prior to station establishment and 298 and 313 mm for the growing years 00/01 and 01/02 respectively.
- The dry season lasts for six to seven and a half months. Rain is the only water source to the forest as the water table is a few hundred meters below.
- 13 ^{0}C winter midday average temperature, 31 ^{0}C summer midday average temperature.
- Average midday relative humidity (RH) of 35% during peak activity, 5% was the lowest RH measured during this period.
- Leaf to atmosphere water gradients are high most of the year round; daytime vapor pressure deficit (VPD) being above 3000 Pa 10% of the time during 01/02 season.
- Soil water content at 0 to 20 cm depth ranged from 0.23 to 0.32 cm^3/cm^3 in winter to 0.06 to 0.09 cm^3/cm^3 in summer.

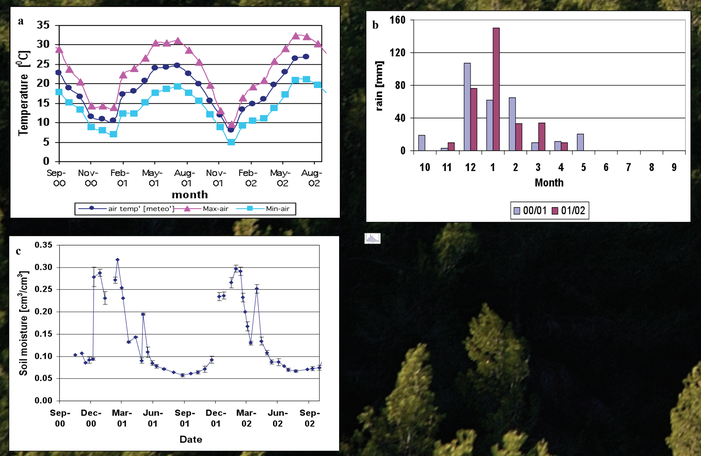

Figure 1. Monthly values for the growing years (Oct. to Sep., 00/01 & 01/02) of: a. average, maximum and minimum (daily range) values of air temperature, b. precipitation amount c. monthly average soil water contain at 0-40 cm, and d. Histogram of 01/02 daytime VPD.

Ecosystem to atmosphere CO_2 and water fluxes:

- Net carbon sequestration by the forest ecosystem, corrected for nighttime flux losses were -140 g C m^{-2} for the year October 2000 to September 2001 and -190 g C m^{-2} at the following year.
- Although the ½ an hour forest assimilation rates are low compared to colder wetter sites, partially due to a low LAI (~1.5), the overall carbon sequestration is similar to the European average as a result of low decomposition rate.
- Yearly evapotranspiration accounts for ~70% of the annual precipitation .

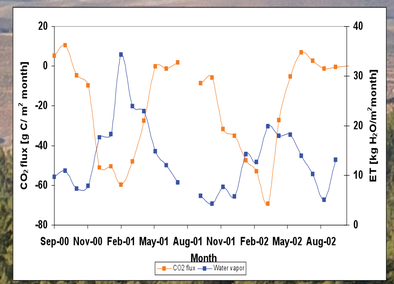

Figure 2. Monthly sum of net ecosystem carbon flux (corrected for nighttime losses) and the water vapor flux of the two growing years (00/01 & 01/02).

The daily cycles of CO_2 fluxes

- Following the similarity in the rain amount, the monthly average CO_2 fluxes (NEE) patterns of the two years are almost identically.
- February's bowl shaped NEE reflects little water stress on the trees in the wet season. In other seasons mid day depression are clearly present.
- At the August summer peak, the trees still sustain activity, but is confined to the early morning and late afternoon hours.
- With autumn temperature drop, even before the arrival of the first rain, the activity hours are extended to all the sunny hours.
- Night time respiration reflects the daily activities, highest inthe winter and lowest in Summer, so the winter to summer ratio is much smaller.

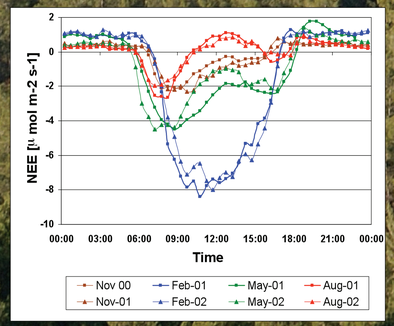

Figure 3. Seasonal pattern of the monthly ½ hours average daily cycle of CO2 fluxes (uncorrected for nighttime loss).

Ecosystem response to rain events and the onset of the winter.

Rain episodes in Yatir are short following by long periods with no rain. Occasionally during these breaks dry and hot conditions occur, even in the coldest months. The forest is adapted to respond fast to rain water input:

- First considerable rain of 38 mm (December 01), came after seven and half months off no rain. Within 4 days after the rain the daily NEE more than tripled from prior days. In the wet season the response to water input after rainless month or is even higher, up to a five fold increase.
- CO_2 flushes in the autumn following rain events are strongly represented in the figure even after a few mm rain.

Sustaining some photosynthetic activity during most of the dry hot periods and various drought-survival strategies (See poster by Lin *et al.*) enable the trees fast response to a n input.

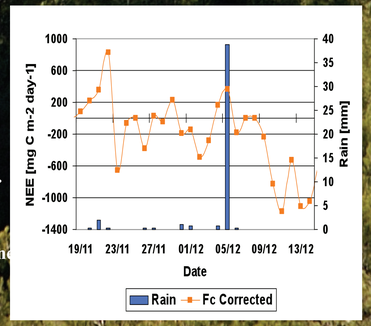

Figure 4. Daily sum of NEE and precipitation at the onset of the winter at the 2001/02 growing season.

Ecosystem water use efficiency (WUE):

In an ecosystem which receives rain in short periods, has a high evaporation demand that rapidly dries the surfaces and with low soil decomposition rate, the ratio of the carbon to the water flux of the ecosystem represents, to the first degree, tree WUE.

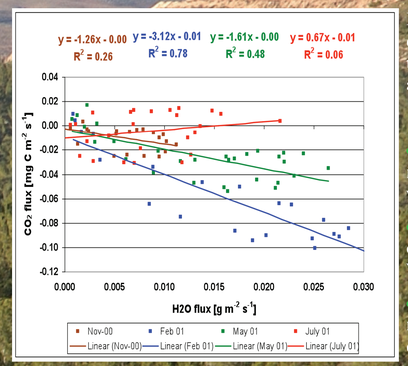

Figure 5. Monthly ½ hours average of the daytime fluxes of CO_2 (NEE) vs. water above the canopy, in November 00, February, May and July 01.

- At Yatir from autumn to spring, which are relatively dry and hot, WUE (=NEE/ET) are within the range found in wetter sites.
- February CO_2 fluxes show relatively high correlation (R^2 = 0.78) to water fluxes with WUE of -3.1 mg C/g H_2O.
- At drier months the correlation breaks, and no correlation is seen in July when the ecosystem becomes a carbon source.
- Although in July VPD could be twice or more the February values the water loss is half.

Conclusions.

- Yatir afforestation carbon sequestration, around 170 g C m^{-2} y^{-1} is within the range found in more forests favorable climates. This shows the possibility of establishing forests on some of the Earth arid-land areas, and they potential to considerably enhance global carbon sequestration.
- Avoiding assimilation in the dry hot hours while sustaining at least some activity all year, a relatively high WUE in mild months and hence conserving water for use in the stress periods and minimizing water losses in this period, combined with the plants strategy for drought survival, are some of the mechanisms that explain the ability of the forest to grow in arid conditions.
- Considering a possible warmer future world, Yatir forest enables studying the influence of dry and hot conditions on canopies and ecosystems most forests currently do not experience.