S33-001

# Aridland forests

T Lin[1], E, Rotenberg[1], JM Grünzweig[1], D Yakir[1], A Schwartz[2]

[1]*Department of Environmental Sciences and Energy Research, Weizmann Institute of Science, Rehovot 76100, Israel.* dan.yakir@weizmann.ac.il

[2]*Department of Agricultural Botany, Hebrew University of Jerusalem, Rehovot 76100, Israel.* schwartz@agri.huji.ac.il

*Keywords: water stress, aforestation, Aleppo-pine, net primary productivity,* $^{13}C$

## Introduction

Climate models suggest that during the next century the average values of temperature and precipitation are likely to change over large areas of the globe. As a result, widespread adjustments are likely to occur in the distribution of terrestrial vegetation. Tropical forests and Arctic regions have been the focus of much attention, but changes in other areas are expected as well. Possible increase of about 17% in the world desert land during climate change associated with doubling of atmospheric $CO_2$ content was predicted (Emanuele at al., 1985). Ecosystems in the climate transition zones are particularly sensitive to perturbation of the global climate system (Schlesinger et al., 1990). They can provide effective indicators for both the effects of climate perturbations and for the potential forestry and agricultural productivity in these regions.

It is now well established that commercially available sonic anemometers and infrared gas analyzers are sufficiently robust and precise to measure fluxes of $CO_2$ and water vapor over and under forest canopies for long periods (Wofsy et al., 1993; Goulden et al., 1995; Baldocchi et al., 1996). It is also generally recognized that measurements of a suite of climate, soil and biological variables must be made together with canopy flux measurements to enable analysis and interpretation of ecosystem function. These include measurements of soil and water characteristics and their spatial heterogeneity. Frequent studies of leaf physiology are needed to evaluate leaf photosynthesis and stomatal conductance.

We exploit Israel's geographic location in a climate transition zone, and use an aforestation system (the Yatir forest, 31˚20' 49.2" N, 35˚ 03' 07.2 E, 650 m above sea level) as a model for investigating ecosystem functioning. The forest is located in the transition between the extreme arid Negev and Judean deserts and the Mediterranean region. Mean annual precipitation is 259 mm which is usually concentrated in a rainy season between October and April, and followed by a long dry summer. The forest is dominated by *Pinus halepensis*, with small proportion of *Cupressus sempervirens* and other pine trees (mostly *P. brutia*). Density of the forest is about 25 $m^2$ per tree, with little understory vegetation of local annuals. The forest is about 6 km long in the west--east direction, and about 2.5 km wide in the north--south direction. We present here the first data obtained in the forest on leaf photosynthesis, soil respiration and net ecosystem $CO_2$ exchange (NEE), and provide first estimates of annual scale productivity.

**Methods**

Yatir forest is located at the northern part of the Negev desert, in a hilly area north-east of Beer Sheva, at an elevation of 600 to 800 m a.s.l. The forest (mainly *Pinus halepensis*, *P. brutia*, *P. canariensis* and *Cupressus sempervirens*) was planted 35 years ago on 0.20 to 1 m deep Rendzina soil above chalk and limestone, with a water table at a few hundreds meters depth. The tower station (31° 20' 49.2'' N, 35° 3' 7.2'' E) is located at 650 m a.s.l. in the center of more than 800 m radius of mainly *P. halepensis* trees (95%). Plant area index (PAI) around the tower is 1.9 ± 0.4 (2000), with mean tree height of 10 m, mean DBH of 18 cm and a density of 450 trees/ha.

Mean precipitation (P) for 1964-2001 was 259 mm (mid October to mid April). Measurements started after five successive years of drought (mean P= 195 mm). Long-term mean daily temperature is 18.2°C, with midday temperature averaging 31°C in the summer and 13°C in the winter. The long-term mean daily relative humidity (RH) is 54% and midday (14:00) RH averages 40% (lowest RH measured in Yatir was 5% in May 2001).

Flux measurement site was established in April 2000 with continuous measurements of $CO_2$ and latent and sensible heat fluxes using an eddy-covariance system centered on sonic anemometer (R3, Gill Instruments, Lymington UK) installed at 19 m a.g.l. (9 m above the canopy) and a $CO_2$/$H_2O$ analyzer (LI –6262, LI-COR Inc., Lincoln, Nebraska, USA). Conventional meteorological equipment (15 m a.g.l.) was used to calculate continuous half-hour mean values of net radiation, incoming photosynthetically-active radiation, air temperature and relative humidity, air pressure, horizontal wind speed and direction and precipitation. Soil temperature was continuously measured at 2 and 6 cm depth with thermocouples and soil heat fluxes were determined at 8 cm depth. Stable isotopes ($^{13}C$) were periodically measured on leaf and soil organics and in air $CO_2$ with continuous flow isotope ratio mass spectrometers (Micromass, Optima for organics; Europa 20-20 for air).

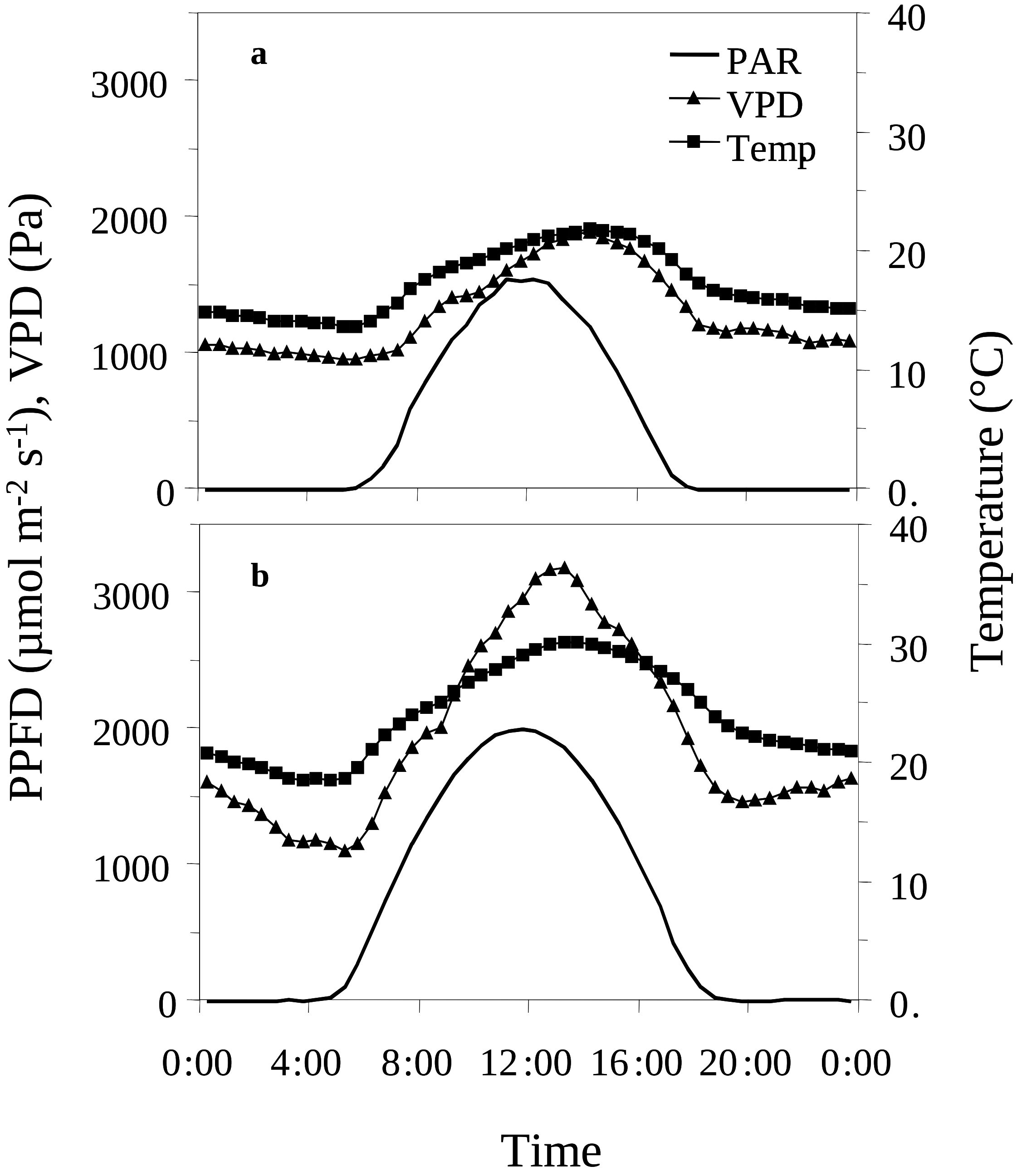


**Fig. 1.** Monthly mean of diurnal course of photosynthetic photon flux density (PPFD), air temperature and vapor pressure deficit (VPD) in (a) March 2001 and (b) June 2001.

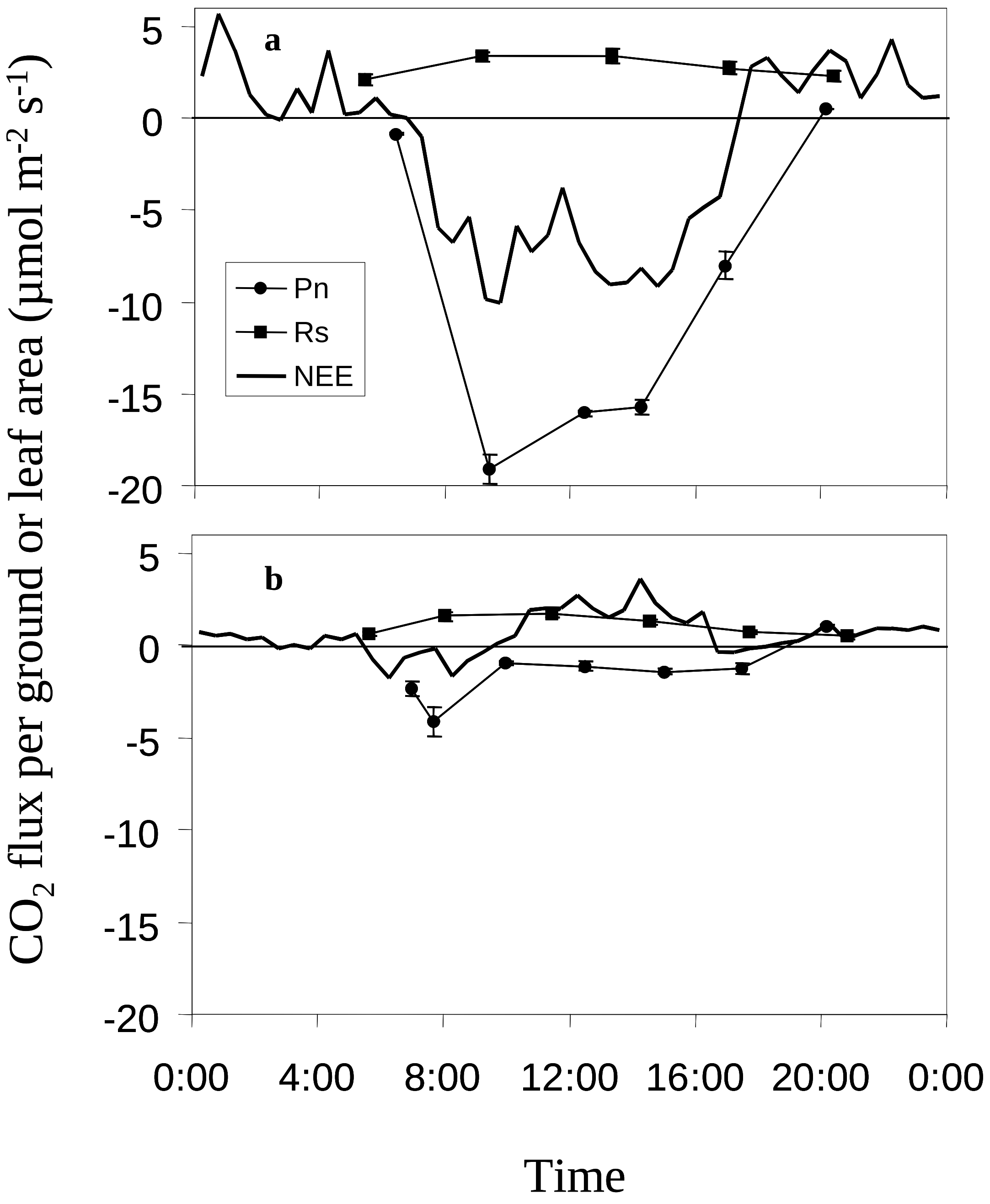


**Fig. 2.** Representative diurnal course of net ecosystem $CO_2$ exchange (NEE) and $CO_2$ fluxes from photosynthesis ($P_n$) and soil respiration ($R_s$) in (a) spring (22/3/01) and (b) summer (12/6/01). Note that NEE and $R_s$ are per ground area, whereas photosynthesis is per leaf area.

## Results and discussion

The first annual cycle of measurements has recently been completed and preliminary results showing representative data for winter and summer months are reported here to illustrate peak activity in spring and during lowest activity in summer. In spring, the soil profile and underlying water-absorbing bedrock were moist as a consequence of periodic rains during winter (300 mm in 2000/2001). Mean diurnal temperature was 15°C in late March 2001, mean daytime vapor pressure deficit (VPD) was 1000 Pa (Fig. 1a). For comparison, during the most active period (May-June) in a drought-stressed *Pinus ponderosa* forest (annual precipitation approx. 400 mm), mean daytime VPD was 1000 Pa (Law et al. 2000), and the same parameter measured in a semiarid *Juniperus occidentalis* forest (220 mm) reached 1500-2000 Pa at that time (Miller et al. 1992). During the dry summer, the topsoil dries out rapidly, with mean diurnal temperature and daytime VPD reaching 27°C and 3000 Pa and higher (Fig. 1b). Consistent with the climatic conditions, the main photosynthetic activity of the trees is confined to the cooler, rainy period (January to April). In 2001, the forest was a carbon sink ranging from about –1 to – 5  mol $m^{-2}$ $month^{-1}$during those months. During the most active period in March 2001, photosynthetic rate reached almost - 20 µmol $CO_2$ $m^{-2}$ leaf area $s^{-1}$ and net ecosystem exchange (NEE) reached –10 µmol $CO_2$ $m^{-2}$ ground area $s^{-1}$ (Fig. 2a), with other days during the same month showing a sink as high as –15 mol $m^{-2}$ $s^{-1}$. These photosynthetic rates are close to maximal rates measured in the more humid ponderosa-pine forest during summer and four times higher than maximal rates in the juniper forest (Law et al. 2000, Miller et al. 1992). With the termination of rainfall, photosynthetic and respiratory activity dropped drastically, so that the ecosystem was a $CO_2$ source of around 1.6 mol $m^{-2}$ $month^{-1}$ in June and July 2000. Photosynthesis and NEE typically reached maximal sink values of–4 and –2 mol $CO_2$ $m^{-2}$ $s^{-1}$ during summer (Fig. 2b).

For the year period between June 2000 and May 2001, the semiarid Aleppo-pine forest was a carbon sink of 195 g C $m^{-2}$. This amount of carbon sequestration was within the range reported for much wetter European forests (270 ± 230 g C $m^{-2}$ $y^{-1}$; Valentini et al. 2000, Janssens et al. 2001) and close to the 1996/7 average for the the drought-stressed ponderosa-pine forest (295 ± 29 g C $m^{-2}$ $y^{-1}$; Law et al. 2000). Preliminary results on soil organic carbon were consistent with low rates of decomposition due to the dry conditions (2 kg C $m^{-2}$). Current above-ground biomass is estimated at ~1 kg $m^{-2}$ and combined with information on periodic thinning of about 40% of the trees every 7 years, we estimated a total carbon sink of ~60 t C $ha^{-1}$. This estimate is consistent with current NEE estimates (2 t C $ha^{-1}$) being representative for this 35 years old forest.

As expected for the dry conditions, $^{13}C/^{12}C$ ratios of plant and soil organic material were very high (ca. –23‰). Such values indicate high transpiration efficiency (ratio of mole carbon fixed to mole water lost) for the Aleppo pine trees under these conditions.

The results reported here demonstrate unexpectedly high potential for plant productivity in regions not usually exploited for forestry, agroforestry or agriculture.

## Acknowledgement

The technical help of E Negreanu, H Sagi and A Pelner, and support from KKL is greatly acknowledged.

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