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FluxLetter

THE NEWSLETTER OF FLUXNET

In this issue of the FLUXLETTER, we present two historical accounts; one is a history of flux measurements using the eddy covariance method. The second is a history of the development of flux measurements specific to urban ecosystems. We also profile the Yatir Forest in Israel; a pine forest established at the semi-arid dry timberline. Lastly, Dennis Baldocchi offers a tribute to Shashi Verma; a pioneer in the flux community who has recently retired.

In This Issue:

Editors: Laurie Koteen and Dennis Baldocchi,
The FLUXNET Office at the University of California, Berkeley

The Yatir Forest Site: Postcards from the edge

Dan Yakir

At the dawn of the new Millennium, in early 2000, we decided to setup a flux station site that will provide information on forest activities at the semi-arid ‘dry timberline’ (Figure 1), which was not covered by the extensive efforts of the young Fluxnet. The only funding opportunity available was for a regular “large-equipment” grant as done when requesting a new microscope. This was not inappropriate: in adopting the flux tower as our research tool, we essentially ‘inverted the microscope’. We shifted from a reductionist approach of trying to understand an organism by breaking it apart, to a holistic approach trying to understand how the parts integrate to explain the functioning of the Ecosystem. In reality, one cannot put up a flux site for the price of a microscope. And so, to make ends meet, we set out to a large junkyard. A set of sections of an old building construction crane was found that had the potential, with some imagination, to form a tower at the right height and stability and at a bargain price (Figure 2). These were shipped to a friendly machine shop, cleaned up, mended, and painted (green, of course). Within a couple of months a 19m tower was ceremonially set down and leveled at the bottom of a 3x3x3 m hole and fixed, for ever, with the help of 11 tons of concrete, at the center of the largest (~20,000 ha) and driest (290 mm precipitation) 40 year old pine forest in Israel (31^{0}20’N, 35^{0}00’E). Together with Tongbau Lin, a dedicated postdoc from China, and a few part time students, we added the scientific coating onto the tower, and before long a state of the art flux tower began its operation (Figure 3). Being a field research site, not just a monitoring station, students and postdocs were recruited for a range of projects to obtain a comprehensive perspective on questions such as as:

Figures 1&2. Yatir Forest (above) and an old building construction crane converted to a flux tower (below).

How a forest functions where experts predicted a forest should not exist;

What defines the ‘dry timberline’;

What lessons can we learn from Yatir, with respect to the future of forests in wetter areas undergoing warming and drying?

More than ten years down the road, 4 MSc. and 4 Ph.D. theses, and 10 postdoc projects, with team members from China, New Zealand, Nepal, UK, Germany, and Israel, over 30 scientific papers and dozens of proceedings chapters, abstracts and posters, we are still fascinated, and indeed awestruck, by the intricacies of the operation of the dryland forest. Surprisingly the forest turned out to be a carbon sink of ~2.3 t C Ha, not very different from the FLUXNET mean of about 2.6 (Grunzweig et al., 2002, 2007; Maseyk et al., 2008; Rotenberg & Yakir, 2010). Reconstructing the evolution of the carbon stock in the forest,

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from aerial photography (Bar-Masada et al., 2006) showed that the accumulation is nearly linear in time with no signs of decline. The forest productivity is associated with distinct phenology (Maseyk et al., 2007), tight water budget (with over 90% of precipitation measured as ET; Raz Yaseef et al., 2009). It also shows a "closed energy budget", with a counterintuitive cooler canopy surface that emits larger sensible heat fluxes, compared to the non-forested shrubland (Rotenberg & Yakir, 2010, 2011). A detailed nitrogen budget showed that the threefold increase in carbon stock in the forest was associated with a large increase in NUE (nitrogen use efficiency) and N remobilization, but not in N stock as initially expected (Gelfand et al., 2011). Isotopic analysis of tree-rings indicated a ~25% increase in WUE (water use efficiency) over the past 30 years, most likely due increasing atmospheric CO_2 concentrations (Maseyk et al., 2011). Finally, the time has come to extend our measurement range beyond the flux tower anchored in 11 tons of concrete in Yatir. And so, we are off to conduct another ten years of exciting research using a mobile flux system that will allow us to move around the forest and into other forests and ecosystems in different climatic zones (Figure 4). Some highlights of our exciting ten years project are briefly discussed below by their specific authors. Clearly, this short "postcard" is doing an injustice to the enormous efforts under harsh conditions made by the large team of talented and

Figure 3. The instrumented flux tower at Yatir Forest.

Figure 4. The new mobile flux tower.

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dedicated students and scientists, but we hope it will serve as an invitation to read more of the results from one of the most remote and unique Fluxnet sites.

References:

Grünzweig JM, Lin T, Rotenberg E and Yakir D (2002) Carbon sequestration potential in arid-land forest. *Global Global Change Biology*, 9,791-799.

Bar Massada A, Carmel Y., Even Tzur G., Grünzweig JM, and Yakir D (2006) Assessment of temporal changes in above-ground forest tree biomass using aerial photographs and allometric equations. *Canadian J Forest Res.* 10, 2585-2594.

Grunzweig JM, Gelfand I and Yakir D (2007) Biogeochemical factors contributing to enhanced carbon storage following afforestation of semi-arid shrubland. *Biogeochemistry 4*, 891-904.

Maseyk K, Tongbao L, Rotenberg E, Grünzweig J, Schwartz A and Yakir D (2007) Physiology phenology interactions in a productive semi-arid pine forest. *New Phytology*, 178, 603-616.

Maseyk K, Grünzweig J, Rotenberg E and Yakir D (2008) Respiration acclimation contributes to high carbon-use efficiency in a seasonally dry pine forest. *Global Change Biology*, doi: 10.1111/j.1365-2486.2008.01604.x

Rotenberg E and Yakir D (2011) Distinct long- and short-wave radiation regimes in high productivity semi-arid pine forest. *Global Change Biology*. 17, 1536-1548. Doi: 10.1111/j/1365-2486.2010.02320.x

Rotenberg R and Yakir D (2010) Contribution of semi-arid forests to the climate system. *Science*, 327, 451-454 DOI: 10.1126/science.1179998.

Maseyk K, Angert A, Hemming D, Leavitt S and Yakir D (2011) The control of temperature and precipitation and CO_2 on tree growth and water use efficiency in semi-arid woodland. *Oecologia,* 167, 573-585. Doi:10.1007/s00442-011-2010-4.

Gelfand I, Grunzweig JM and Yakir D (2011) Slowing of nitrogen cycling and increasing nitrogen use efficiency following afforestation of semi-arid shrubland. Oecologia, DOI 10.1007/s00442-011-2111-0

Raz-Yaseef N, Yakir D, Rotenberg E, Schiller G, Cohen S (2009) Ecohydrology of a semi-arid forest: partitioning among water balance components. *Ecohydrology*, DOI: 10.1002/eco.65

Contact:

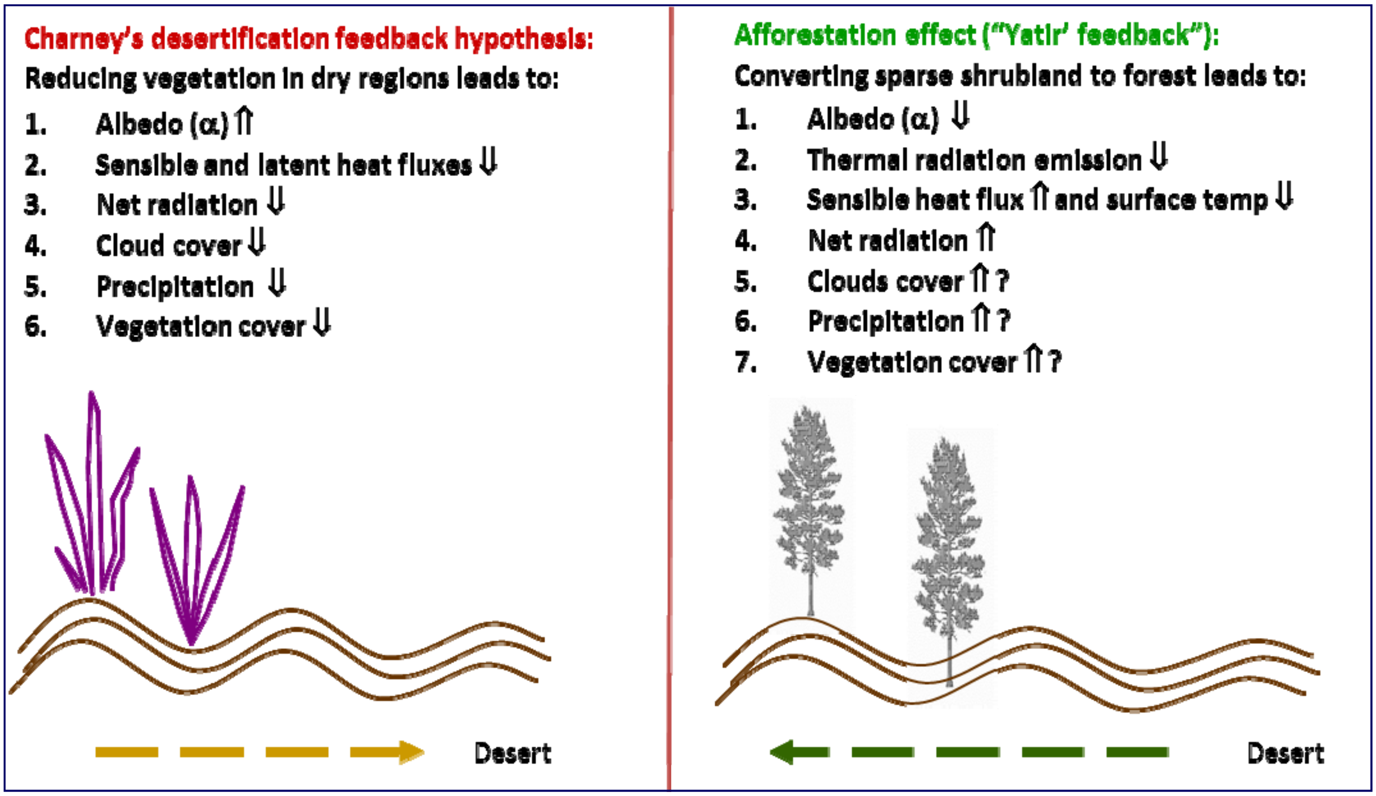
Dan Yakir
Department of Environmental Sciences and Energy Research Weizmann Institute of Science
Rehovot 76100 ISRAEL
Tel: 972-8-934-2549
Dan.Yakir@weizmann.ac.il

The Yatir Forest Site: Solving the energy dissipation riddle in Yatir

Eyal Rotenberg

With annual incoming solar radiation of ~7.5 GJ m^{-2} (~238 W m^{-2}), the Yatir forest is exposed to a radiation load similar to that at the heart of the Sahara desert. Clearly, an evergreen forest needs to develop means to cope with such energy inputs, and with limited water availability this cannot be through the common evapotranspiration route. Furthermore, Charney, who carried out pioneering studies on the surface radiation budget in semiarid regions in the 1970s postulated that "..reduction of vegetation, with consequent increase of albedo in the Sahel region would cause sinking (air) motion, additional drying, and would therefore perpetuate the arid conditions…" (Charney, 1975; 1977 More recently, with greater awareness of the importance of the CO2 rise in the atmosphere, the contrasting effects of vegetation in removing atmospheric carbon reducing its warming effect, while also decreasing surface albedo, enhancing surface warming. But detail studies generally focused on relatively wet regions (temperate, tropical). These aspects motivated us to link geophysical (energy fluxes) and biogeochemical (carbon fluxes) studies in the Yatir forest to explore the potential for and implications of afforestation and desertification in semi-arid regions (Rotenberg & Yakir, 2010, 2011).

Both remote sensing (MODIS) and local measurements indicate that the forest canopy surface temperature in Yatir is lower than the surface temperature in adjacent non-forested areas. While some surface cooling due to added forest cover may sound reasonable, this finding is counter to expectations in Yatir for the following reasons. First, the forest albedo is 0.1 lower than the surrounding, translating



Charney's desertification feedback hypothesis:

Reducing vegetation in dry regions leads to:

1. Albedo (α) ⇑
2. Sensible and latent heat fluxes ⇓
3. Net radiation ⇓
4. Cloud cover ⇓
5. Precipitation ⇓
6. Vegetation cover ⇓

Afforestation effect ("Yatir' feedback"):

Converting sparse shrubland to forest leads to:

1. Albedo (α) ⇓
2. Thermal radiation emission ⇓
3. Sensible heat flux ⇑ and surface temp ⇓
4. Net radiation ⇑
5. Clouds cover ⇑ ?
6. Precipitation ⇑ ?
7. Vegetation cover ⇑ ?

Figure 1. Changes in surface energy fluxes associated with desertification (left; the Charney effect) and afforestation (right, the "Yatir effect). Upward and downward arrows indicate expected enhancement or suppression in flux associated with the land cover change.

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into a 24 W m^{-2} increase in radiation absorption by the forest canopy. Second, the forest “skin” surface (canopy and soil surface) is cooler, by 5°C on annual mean.. Cooler surface emits less long-wave thermal radiation, and additional 25 W m^{-2} are held back by the forest. Combined, the increased absorption and reduced emission, translate tothe nearly 50 W m^{-2} increase in radiation load associated with afforestation in this region. For comparison, this is as large as the difference in net radiation between, the Sahara desert and Denmark, for example. Moreover, latent heat flux, the common cooling and energy dissipation mechanism in temperate forests, is not an option where water is virtually unavailable for some 7 months a year. And so, we are left with sensible heat flux as the only major heat dissipation route. But sensible heat fluxes are normally directly proportional to the surface temperature, and our forest surface is cooler… As it turned out sensible heat flux is indeed the major heat dissipation route. So much so that in summer the Bowen ratio (the ratio of sensible to latent heat fluxes), which is often

Figure 2: The radiation measurement setup over the Yatir forest, included: 2 - Kipp& Zonen CM21 for the solar radiation range, 2 - Eppley PIR for the thermal range,2 - Kipp&Zonen PQS1 for the PAR and 2 - Skye 4 Channel SKR 1850 sensors. A set of sensors is looking upward (to the atmosphere) the other downward.

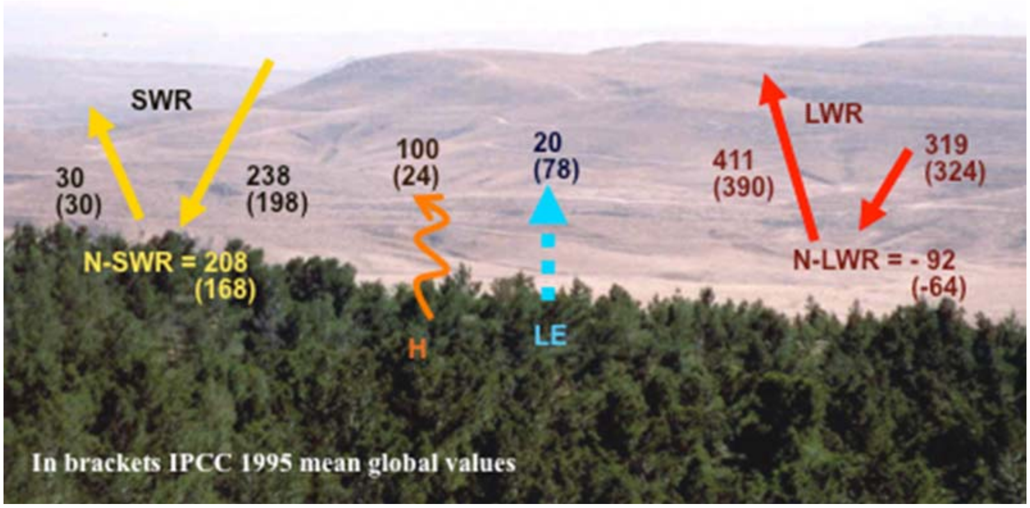

Figure 3. Forest vs background and the characteristic mean annual values of energy fluxes above the semi-arid Yatir forest, compared to global mean values (in brackets). Note the high incoming short wave solar radiations (SWR) and low albedo (ratio of out-going to incoming SWR), the low latent heat (LE) and large sensible heat (H) fluxes.

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around 1 in temperate forests, goes beyond 20 in Yatir, when the entire net solar radiation flux of ~800 W m^{-2} is dissipated as large sensible heat flux of the same magnitude. The solution to this apparent “riddle” is simple when we recall that while sensible heat flux is indeed directly proportional to the surface temperature, but inversely proportional to the aerodynamic resistance of the surface layer. And a semi-arid forest with its low tree density and large surface area becomes an efficient low resistance “convector” well coupled to the surrounding atmosphere. In Yatir, the ‘canopy convector effect’ is so efficient that the sensible heat flux is even greater than in the Sahara desert. It of course remains to be tested what are the consequences of the massive sensible heat fluxes above a sufficiently large forest area for the local circulation and synoptic systems. The Yatir forest is too small for that, but a modeling exercise is under way to address such questions now that we have quantified the surface behavior.

References

Charney, J. (1975). "Dynamics of deserts and drought in the Sahel." Quarterly journal of the Royal Meteorological Society **101**(428): 193-202.

Charney, J., W. J. Quirk, et al. (1977). "Comparative-Study of Effects of Albedo Change on Drought in Semi-Arid Regions." Journal of the Atmospheric Sciences **34** (9): 1366-1385.

Rotenberg, E. and D. Yakir (2010). "Contribution of Semi-Arid Forests to the Climate System." Science **327**(5964): 451-454.

Contact:

Eyal Rotenberg
Department of Environmental Sciences and Energy Research Weizmann Institute of Science
Rehovot 76100 ISRAEL
Tel: 972-8-934-2549
eyal.rotenberg@weizmann ac.il

The Yatir Forest Site: "Decoupling" phenology to maximize carbon uptake

Kadmiel Maseyk

Pushing a forest to the edge, like the case for the Yatir Forest, can provide insights into the responses and strategies that can be produced in response to climate change. This includes changes in the timing of individual life-cycle events (phenophases), which represent adaptations to maximise fitness in a particular environment.

Vegetative growth goes for the comfort zone: Vegetative growth in forests normally peaks during periods that provides near optimal combinations of soil moisture, temperature and solar radiation. This occurs in late summer in high latitude forests and in spring in dry Mediterranean forests (Figure 1). In the latter case, little physiological activity can be expected during the long, hot, and dry summer period. However, leaf and shoot growth can be observed in some species during summer. This is the case with pine trees, whose origins predate the Mediterranean climate that developed about 3.2 million years ago. In the pine trees in Yatir, this gives rise to a remarkable separation of needle growth from other physiological processes.

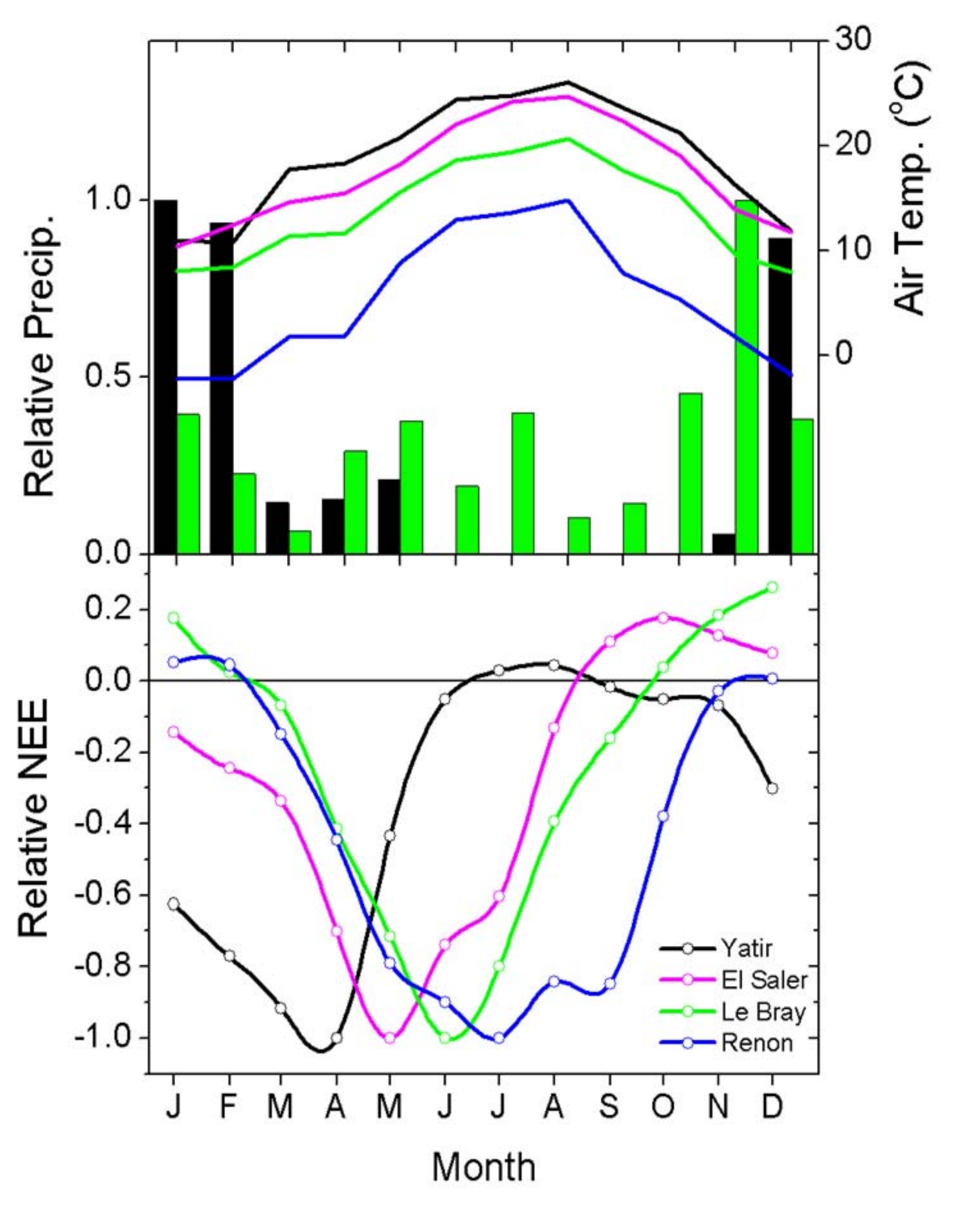

Figure 1: Temporal shift in ecosystem activity across a climatic gradient in different FluxNet stations (Renon, northern Italy, Lat. 46.6; Le Bray, France, Lat. 44.7; El Saler, Spain, Lat. 39.3; Yatir, Israel, Lat. 31.3). All sites show the typical northern hemisphere temperature seasonality, with warm summer and cold winters. Water limitation is evident only in the southern sites with dry summers. This is reflected in a marked shift in peak CO_2 uptake (NEE) from later summer to early spring.

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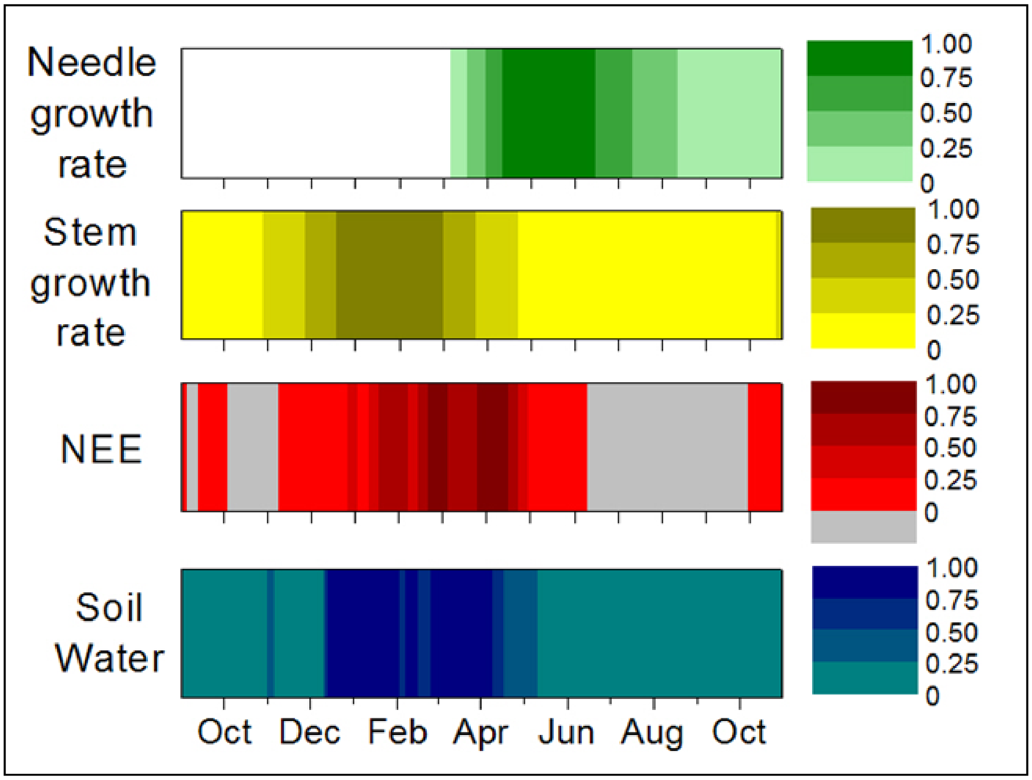

Figure 2. Normalised (relative to seasonal maximum) phenograms of needle elongation, stem increment, net ecosystem exchange (grey periods indicate when respiration exceeds gross photosynthesis) and soil water content. The phasing of needle development is separated from that of the stem growth, occurring through the summer when soil water contents and photosynthesis approach their minimum values.

Needle growth stands it's ground: Needle growth in Yatir occurs throughout the long stressful summer period (March to October), decoupled from the main period of photosynthetic activity (December to May, see Fig. 2)[2]. Photosynthesis continues during the summer, albeit at very low rates for limited times, mostly in early morning, supporting the developing leaves that do not seem to rely on storage. The timing of needle growth is highly conservative and was found to be insensitive to inter-annual variations in climate and manipulation treatments. Yet, needle number, length and thickness varied significantly among years, and in response to experimental manipulation (summer-time irrigation or defoliation). We therefore concluded that needle growth is sensitive to carbon supply during the growth period (as opposed to relying on storage), but the seasonal timing of growth is controlled by environmental cues having little or no inter-annual variation.

Stem growth follows the money: Unlike needles, stem growth is a very plastic feature and generally closely follows photosynthesis[3]. This suggests that cambial development is linked more to physiological processes than to a direct climatic cue, and is considered a more Mediterranean-adapted feature.

A winning combination: Species with both concentrated overlapping phenophases (in spring) and sequential phenophases (e.g. spring and summer) can be seen in Mediterranean vegetation. Phenophase separation distributes growth demands over the time period when resource availability is limited by, for example, cold in winter or water stress in summer, which in turn, reduces intra-plant competition for resources. But perhaps the most obvious advantage of dry summer leaf phenology is that it results in little or no lag period to reach maximal leaf and canopy area of functional needles in the following short wet season. When conditions are finally favourable for photosynthesis, high carbon assimilation rates are achieved early in the short season. Indeed, the young fully

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expanded needles show the highest rates of assimilation at that time among the leaf cohorts. Achieving this high early season capacity is also supported by high leaf nitrogen contents at the start of the season due to the completion of growth-related N remobilisation and translocation (see section on Nitrogen in this Letter), and other adjustments to the semi-arid conditions including dynamic pigmentation to protect needles from photo-damage (reduction in chlorophyll and increase xanthophyll cycle pigments). Having canopy development during the hydrological limitation period also helps maintain canopy size at sustainable levels.

These results highlight important features when considering functional responses to environmental change: the response across phenological processes of a species will differ, depending on the nature of the change, the drivers of the phenophases and evolutionary constraints on plasticity. It appears that the separation of wood and foliage phenophases in this dry environment enables more efficient allocation of resources, optimizes canopy development and maximizes carbon gain. Some investment is required, however, in mechanisms preventing photo-oxidative damage and hydrological stress to maintain dry season leaf phenology. Understanding the interactions between climate, physiology and phenology in this system provides insights into features contributing to the success of pines under warm and dry conditions, and may have more general relevance to (warming and drying) temperate regions as well.

References

Orshan, G. Plant Phenomorphological Studies in Mediterranean Type Ecosystems. Vol. 12 (Kluwer Academic Publishers, 1989).

Maseyk, K. S. et al. Physiology-phenology interactions in a productive semi-arid pine forest. New Phytologist **178**, 603-616, doi:10.1111/j.1469-8137.2008.02391.x (2008).

Maseyk, K., Grunzweig, J. M., Rotenberg, E. & Yakir, D. Respiration acclimation contributes to high carbon-use efficiency in a seasonally dry pine forest. Global Change Biology **14**, 1553-1567, doi:10.1111/j.1365-2486.2008.01604.x (2008).

Liphschitz, N. & Lev-Yadun, S. Cambial Activity of Evergreen and Seasonal Dimorphics around the Mediterranean. Iawa Bulletin **7**, 145-153 (1986).

Contact:

Kadmiel Maseyk
Kadmiel.Maseyk@grignon.inra.fr

The Yatir Forest Site: Decoupling of the tree hydraulic components in Yatir Forest

Tamir Klein

Investment in exploration: When water is scarce, more resources need to be devoted towards exploring for it and extracting it from the soil. This is clearly seen in *Pinus halepensis*, the dominant tree species in Yatir. Increasing water stress triggers dramatic shifts in biomass allocation among leaves, stems, and roots. While in the absence of water stress total root growth is only 34% of freshly synthesized biomass, it increases to as high as 87% under severe water stress conditions (Figure 1; see Klein et al., 2011 for details).

The in and the out of tree water use: Tree water use is often estimated by tree-scale stem sap flow, or by short-term leaf-scale gas exchange measurements. We applied both methods simultaneously, and scaled up both measurements to the stand level by relying on extensive estimates of LAI and local, site-specific allometric equations (Gruenzweig et al., 2007; Sprintsin et al., 2011). As expected, on the daily time-scale, water mass balance exists between the trunk and the leaves. On shorter time-scales, however, strong decoupling between stem sap flow and leaf transpiration was observed (Figure 2). Examining the diurnal dynamics showed that changes in sap flow are gradual, while transpiration rates greatly fluctuate, and peak transpiration can be twice that of sap-flow; Moreover, we found that transpiration ceases at night, whereas sap flow continued long after dark.

The hazards and safeguards of decoupling: The relative magnitude of nocturnal sap flow during summer months surpasses some previously reported values for pine forests. The observations that sap flow occurred at night, temporally decoupled from leaf transpiration, imply that the tree xylem undergoes substantial changes in its water content on a daily basis. Such changes may involve large short-term deficits of up to 15 dm^3 of water per tree, although some of the xylem hydraulic imbalance may be buffered by short-term water storage capacity. Nonetheless, the observed decoupling must also mean the development of embolism in xylem tracheids, as observed in the dynamics of the percent loss of hydraulic conductivity (PLC, up to 40%). This, in turn, would require a capacity to recover hydraulic conductance to maintain the observed hydraulic patterns in a continuous manner. Indeed our latest findings provide evidence on the capacity for rapid recovery from loss of hydraulic conductivity in *Pinus halepensis* (within a few hours and repeating twice in a single daytime cycle).

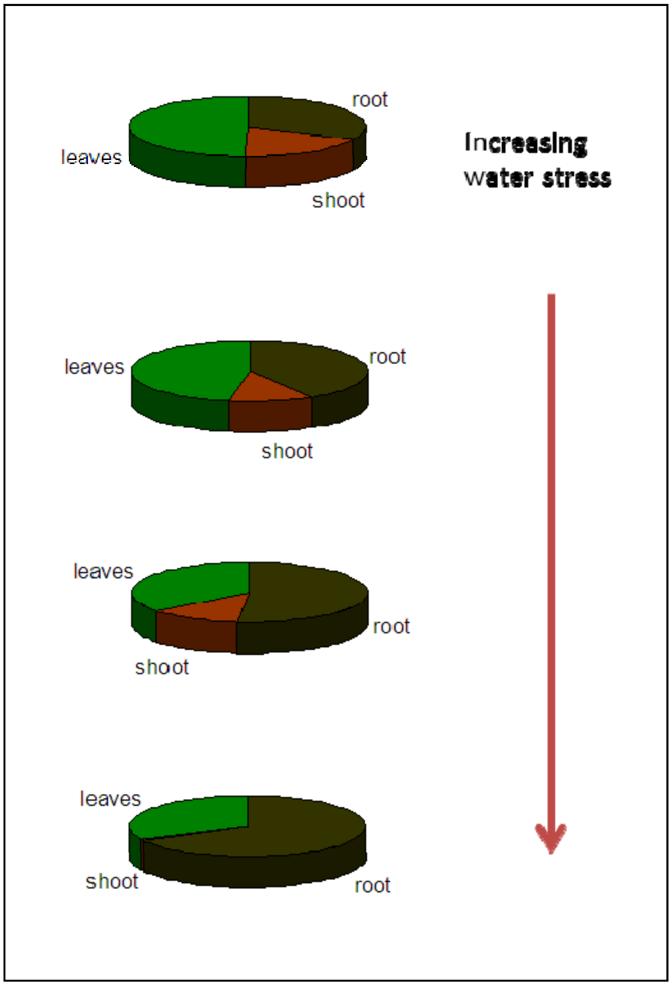

Figure 1. Partitioning of dry biomass accumulation among leaves, stems and roots of *Pinus halepensis* under conditions of increasing water stress.

The Yatir Forest Site: Decoupling of the tree hydraulic components in Yatir Forest

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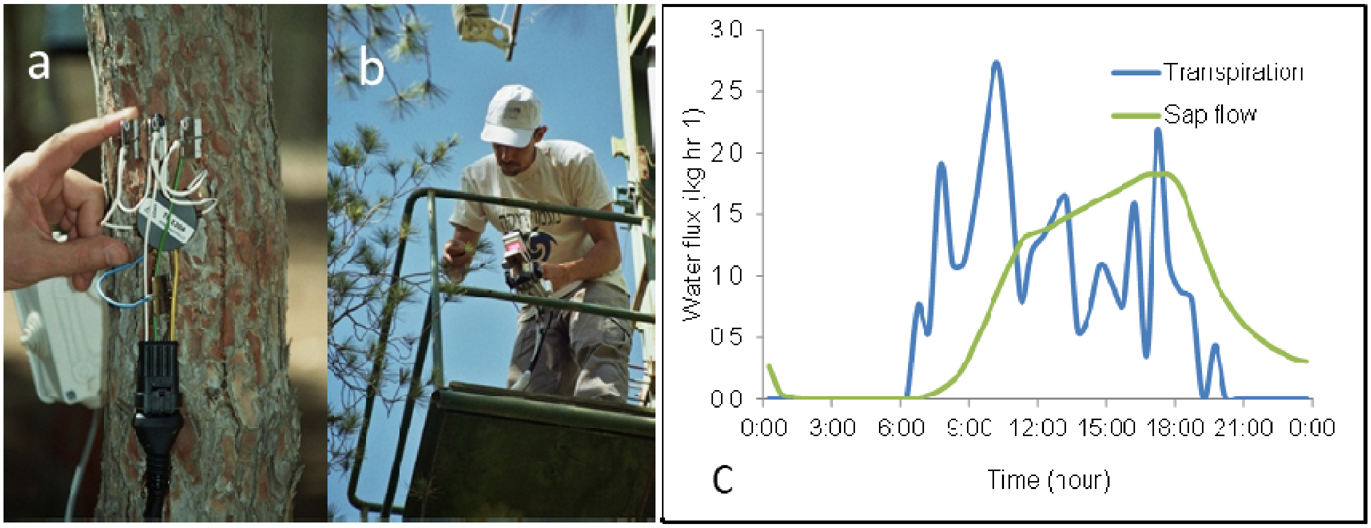

Figure 2. Tree water flux measurements at Yatir, using an installed heat balance sap flow sensor (a) and a LI-6400 leaf gas exchange chamber (b), producing the distinct diurnal curves (c, June 2011).

The results reveal additional insights which help explain the success and relatively high productivity of this Aleppo pine forest at the dry timberline. The trees show a remarkable ability to invest in water exploration, and to decouple and manipulate the tree's hydraulic components (stem and leaves). We believe the results provide an optimistic perspective for pine forests in the Mediterranean region in the face of consistent predictions of warming and drying.

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References

Gruenzweig JM, Gelfand I, Yakir D. 2007. Biogeochemical factors contributing to enhanced carbon storage following afforestation of a semi-arid shrubland. Biogeosciences 4:891–904.

Sprintsin M, Cohen S, Maseyk K, Rotenberg E, Grünsweig J, Karnieli A, Berliner P, and Yakir D. (2011) Long term and seasonal courses of leaf area index in a semi-arid forest plantation. Agri. Forest Meteor. 151, 565-574.

Klein T, Yakir D and Cohen S. (2011) Hydraulic adjustments underlying drought resistance of *Pinus halepensis*. Tree Physiology 31, 637-648.

Contact:

Tamir Klein
tamir.klein@unibas.ch

The Yatir Forest Site: Ecohydrology of Yatir – a forest growing in the desert

Naama Raz-Yaseef

Puzzlement motivated research: The survival and success of the Yatir forest is a puzzle. Average precipitation is 283±88 mm yr^{-1}, but drought years occur regularly, and precipitation as low as 138 mm yr^{-1} has been recorded since the planting of the forest. The rainy season is short, leading to seasonal droughts, with prolonged near-hygroscop-ic surface soil water content levels lasting through the long summer (~5% $m^3\ m^{-3}$ from June to November). Groundwater is deep (~300 m), and because soil water potentials are low, no deep drainage or uptake from depths below 2-3 m can be expected. Yet, a relatively high productivity forest has been growing here over the past 45 years. Understanding the water dynamics within the forest is key to unraveling this puzzle, and helps predict the future of forests across the Mediterranean regions undergoing drying trends. A decade of field measurements and analysis has revealed a range of interesting and unexpected processes.

Developments motivated by technological needs: First, we noted that the afforestation essentially totally eliminated runoff. While impressive flash floods were observed at times in the surrounding shrubland, the runoff monitoring station at the exit of the Yatir forest watershed stays dry even during the strongest storms. Indeed, measurements of evapotranspiration (ET) show that, on average, ET accounts for 94% of annual precipitation (Fig. 1; Raz-Yaseef et al., 2010a). Next, our attention was drawn to soil evaporation (Es). In an open-canopy forest, exposed to high radiation load, we expected soil evaporation to be an important component requiring examination. But reliable methods to directly measure soil evaporation at high spatial and temporal resolution were absent. This motivated us to develop our own

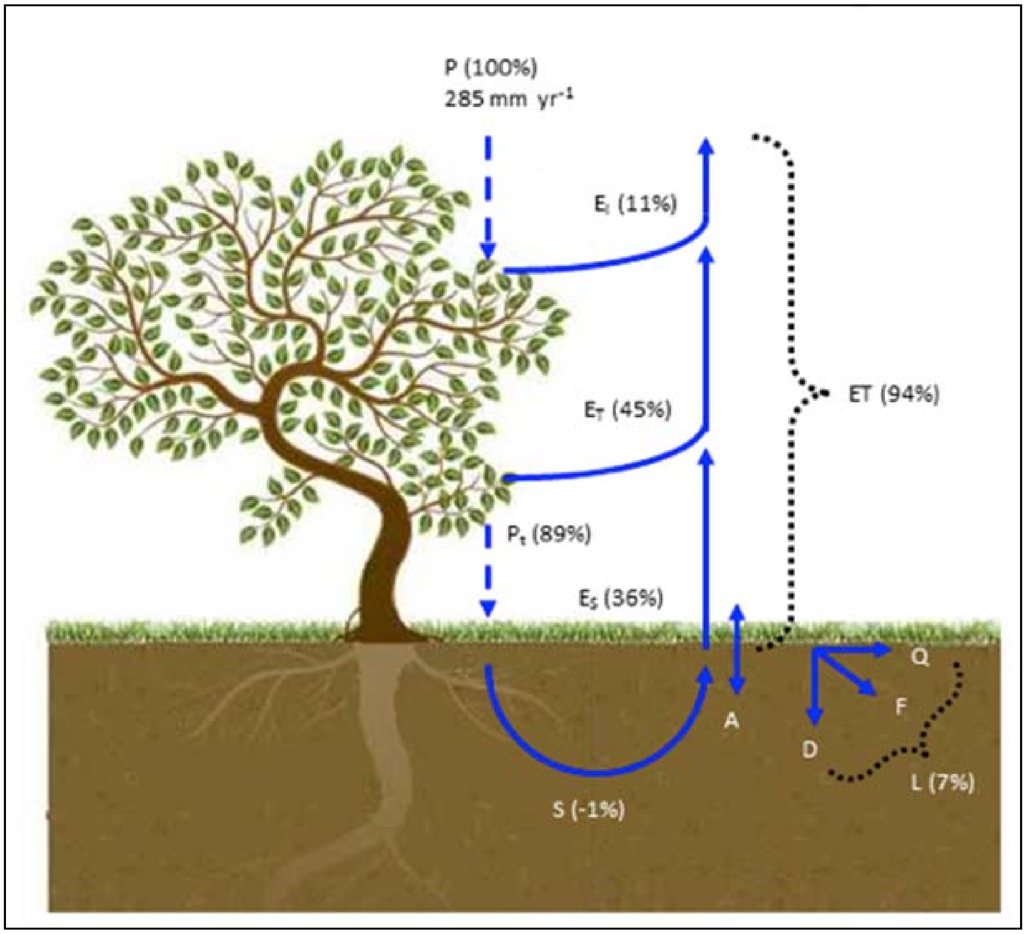

Figure 1. Components of the hydrological cycle in the Yatir forest: Precipitation (P), interception by the canopy (E_I), through-fall (P_t), tree transpiration (E_T), soil evaporation (E_S), soil water adsorption (A), soil water storage (S). Losses (L) out of the system included runoff (Q), subsurface flow (F), deep drainage (D).

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method by modifying our standard soil respiration chambers and the measurement protocol. The effort was worthwhile. Results indicated that soil evaporation accounted for 39% of the total evaporative losses, with large spatial variability. Evaporation fluxes in open gaps were twice as high as those in shaded areas. Simulating tree shading in our forest allowed us, in turn, to predict how the partitioning of ET would vary with changes in the forest tree density. This simple predictive tool indicated that current tree density (300 trees ha^{-1}, canopy cover of 54%), previously arrived at empirically by foresters, is in fact near optimal. Higher tree density at this site would increase ET demands beyond the average precipitation input and could result in tree mortality. Reducing tree density would result in greater losses to soil evaporation (Fig. 2; Raz-Yaseef et al., 2010b).

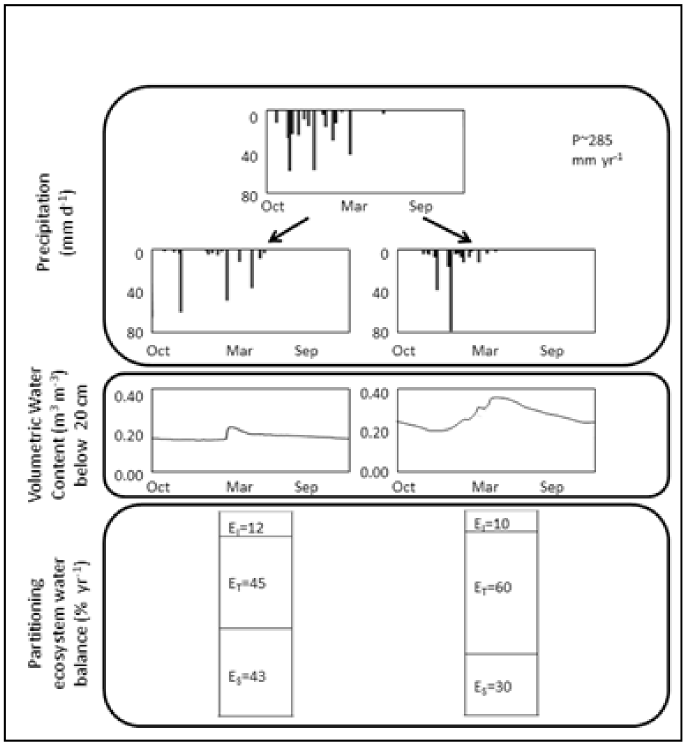

Figure 3. Inter-annual variations: similar annual precipitation but low intensities (2005/6) or high (based 2007/8) years produced significant differences in tree transpiration (Et). Only storms of >30 mm infiltrate below 20 cm soil depth and into the main root zone. Increasing storm intensity can compensate for reduced total precipitation.

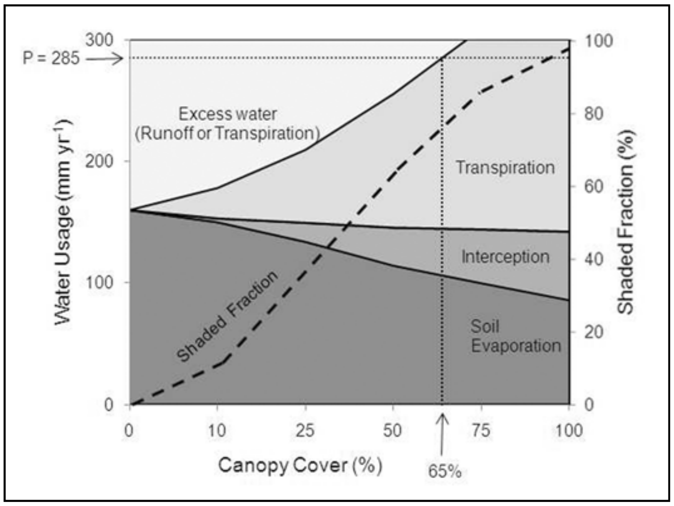

Figure 2. Changes in the proportional contribution to the ecosystem hydrological balance as a function of canopy cover (forest tree density). Shading increases and soil evaporation decreases with increasing canopy cover, but increased interception and tree transpiration reduces residual (excess) water in the system. Excess water is the component available for runoff and recharge to depth or for additional vegetation. Under current precipitation (285 mm yr^{-1}, dotted horizontal line) and tree density (65% cover, 300 tree ha^{-1}) the system is nearly balanced.

Need to scratch the surface: The proportional contribution of different flux component to total ET varied seasonally, due to their differential response to seasonal environmental drivers (Raz-Yaseef et al., 2012). Soil evaporation was correlated to soil moisture at the topsoil (0-10 cm). It peaked twice during the seasonal cycle: Once during the wetting period in the fall, and again during drying season in spring. These periods were characterized by superficial

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soil moisture and high radiation. Summer was too dry and winter was too cold to generate significant evaporation fluxes. Surprisingly, low evaporation fluxes were measured throughout the dry summer period. Perhaps even more surprising was the conclusion that ~50% of the daily flux was due to re-evaporation of moisture condensed onto the soil at night (measured as negative water fluxes from atmosphere to the soil). In contrast to soil evaporation, tree transpiration (Tt) was associated with soil moisture at a 10-20 cm depth layer (the depth of maximum root density), and peaked only in late spring (~1.5 mm d^{-1}), after the accumulation of moisture from the few larger storms that infiltrated below the topsoil layer. Moisture at this depth was maintained for much longer periods than at the surface, often with carry-over between hydrological years. Ultimately, the ratio Tt/ ET, the major link to forest productivity and survival, was more strongly associated with the fraction of precipitation from larger storm (>30 mm), than with total annual precipitation.

These results are significant because climate change scenarios for the Mediterranean often predict drying but also increasing storm intensity. Our findings indicate that the latter effect (intensity) can at least partially compensate for the former (drying) (Fig. 3).

References

Raz-Yaseef, N., Rotenberg, E., Yakir, D., 2010a. Effects of spatial variations in soil evaporation caused by tree shading on water flux partitioning in a semi-arid pine forest. Agricultural and Forest Meteorology 150 (3): 454-462.

Raz-Yaseef, N., Yakir, D., Rotenberg, E., Schiller, G., Cohen, S., 2010b. Ecohydrology of a semi-arid forest: partitioning among water balance components and its implications for predicted precipitation changes. Ecohydrology 3: 143-154.

Raz Yaseef, N., Yakir, D., Schiller, G., Cohen, S., 2012. Dynamics of evapotranspiration partitioning in a semi-arid forest as affected by temporal rainfall patterns. Agricultural and Forest Meteorology 157, 77-85.

Contact:

Naama Raz-Yaseef
Climate and Carbon Sciences Program, Earth Sciences Division, Lawrence Berkeley National Laboratory, Berkeley, CA.
NRYaseef@lbl.gov

The Yatir Forest Site: Backing up the flux measurements in the Yatir Forest

José M. Grünzweig

Ecosystems in dry regions are generally low in productivity and carbon storage, but the Yatir forest seems to defy such assumptions. This was checked quantitatively by eddy covariance measurements over 10 years. But, eddy flux measurements have their own difficulties and uncertainties and must be backed up and constrained by additional measurements, and ultimately by "carbon accounting".

Figure 1. Subsampling stem sections and branches for moisture content during a field campaign aimed at creating site-specific allometric equations for *Pinus halepensis* (picture courtesy: Avi Bar Masada).

Carbon stocks meet carbon fluxes: Much effort was invested in Yatir to add this perspective, by aerial photography (Bar Massada et al., 2006), and by estimating carbon stocks both below and above ground. As it turned out, planting a *Pinus halepensis* forest in an overgrazed, semi-arid shrubland increased the soil organic carbon stock by 75% over a period of 35 years (Grünzweig et al., 2007). Adding the tree and understory carbon inventory (using site-specific allometric equations; See Figure 1) to soil organic carbon, obtained by coring, produced estimates of the ecosystem carbon stock. In total, those in the forest were 2.5 fold the carbon stock in the shrubland. Aerial photography suggests a near linear increase in aboveground tree carbon stock over time (Bar Massada et al., 2006), which allowed us to estimate meaningful average annual increases of 180 g C m^{-2} yr^{-1} over 35 years. These estimates are consistent with the recent NEE measurements of just over 200 g C m^{-2} yr^{-1} with large inter-annual variations (Grünzweig et al., 2003; Rotenberg & Yakir, 2010).

No nutrients to the rescue: Such a large increase in carbon stocks would suggest the need for a similar increase in nutrient stocks, mainly nitrogen. However, nitrogen stocks did not change significantly due to afforestation. Consequently, the ecosystem C/N ratio increased markedly from 7.6 in the native shrubland to 16.6 in the forest, suggesting an increase in nitrogen use efficiency by the ecosystem (Grünzweig et al., 2007).

No water and no decomposition: Biogeochemical mechanisms enabling the rise in carbon storage include low decomposition rates due to recalcitrant pine litter and dry conditions (the volumetric water content of the upper 40 cm of the soil profile is below 20% over 75% of the year and below 12% over 65% of the year). ^{13}C isotopic analyses indicated a small isotopic signal introduced by relatively ^{13}C-rich pine biomass (-23 to -24‰) as compared to ^{13}C-poor

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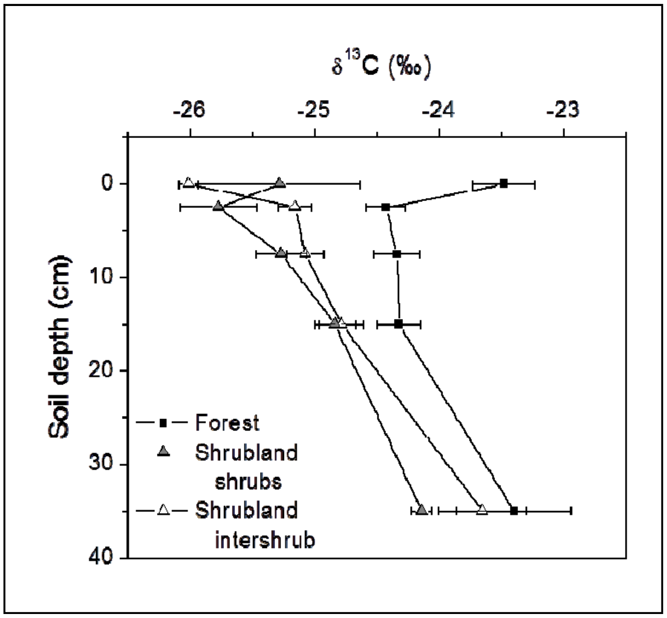

Figure 2. Small isotopic signal of pine biomass recorded throughout the litter layer (0 cm depth) and soil profile (0-50 cm depth). This relatively ^{13}C-rich signal allowed us to calculate the addition of new organic carbon and of decay of old shrubland-derived carbon in the soil (from Grünzweig et al., 2007).

shrubland vegetation (-26 to -29‰), leading to a distinct pine signal especially in the litter and the upper soil layers (Figure 2). This helped us to show that soil organic matter (SOM) derived from pine inputs decays at low rates, likely as a consequence of protection within organo-mineral complexes. Low decay rates of litter and SOM were also confirmed by relatively low soil-respiration rates as determined by measurements of CO_2 efflux from the soil surface (Grünzweig et al., 2009). And, soil respiration rates were low despite high root production (Grünzweig et al., 2007), and relatively high belowground NPP (root production, exudation, micorrhiza etc.; Gelfand et al., 2012) and belowground carbon allocation (~40% of GPP; Grünzweig et al., 2009). Therefore, in the light of the total carbon budget, we concluded that the high carbon sequestration of the Yatir semi-arid pine forest reflects its relatively high productivity, moderate nitrogen requirements and low heterotrophic carbon loss rates.

References

Bar Massada A, Carmel Y., Even Tzur G., Grünzweig JM and Yakir D (2006) Assessment of temporal changes in aboveground forest tree biomass using aerial photographs and allometric equations. Canadian Journal of Forest Research 10, 2585-2594.

Gelfand I, Grünzweig JM and Yakir D (2012) Slowing of nitrogen cycling and increasing nitrogen use efficiency following afforestation of semi-arid shrubland. Oecologia, 168, 563-575. doi: 10.1007/s00442-011-2111-0

Grünzweig JM, Lin T, Rotenberg E, Schwartz A and Yakir D (2003) Carbon sequestration in arid-land forest. Global Change Biology 9,791-799.

Grünzweig JM, Gelfand I, Fried Y and Yakir D (2007) Biogeochemical factors contributing to enhanced carbon storage following afforestation of a semi-arid shrubland. Biogeosciences 4,891-904. doi:10.5194/bg-4-891-2007

Grünzweig JM, Maseyk K, Hemming D, Lin T, Rotenberg E, Faloon and Yakir D (2009) Water limitation to soil CO_2 efflux in a pine forest at the semi-arid ‘timberline’. Journal of Geophysical Research 114, G03008, doi: 10.1029/2008JG000874.

Rotenberg E and Yakir D (2010) Contribution of semi-arid forests to the climate system. Science 327, 451-454 doi: 10.1126/science.1179998.

Contact:

José M. Grünzweig
jose.gruenzweig@mail.huji.ac.il

The Yatir Forest Site: The nitrogen perspective

Ilya Gelfand

Obvious expectations, not so obvious observations: Observing large increases in C storage, (see 'Backing up the flux measurements in the Yatir Forest, this newsletter), in the forest, compared to the background shrubland, got us thinking that there must also be significant changes in the ecosystem nitrogen budget. We therefore embarked on an attempt to construct the complete N budgets of both the forest and shrubland ecosystems (Fig. 1). Combining field (Fig. 2) and laboratory measurements and incubations, we estimated the size of the major N pools, the flux rates between these pools, and ultimately, the nitrogen use efficiencies of the systems (Gelfand et al., 2012). In contrast to our initial hypothesis, we found little differences in the overall, ecosystem N budget between the Yatir forest and the surrounding shrubland. Yet, we also observed a range of internal adjustments in the forest N cycle (specific fluxes, pool, retention time) that clearly supported the increase in C sequestration potential, even without a net change in total input/output.

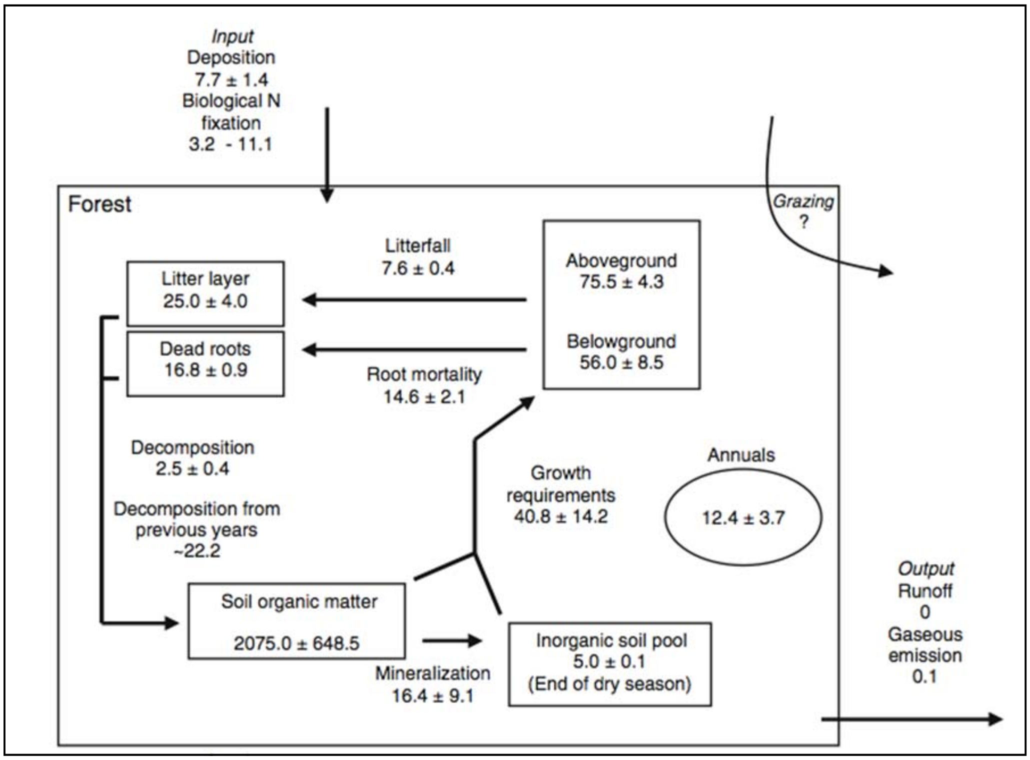

Figure 1. The Yatir forest nitrogen budget with pools in Kg N ha^{-1} and fluxes in Kg N ha^{-1} y^{-1}.

Delay with an advantage: The larger canopy surface area in the forest vs. the shrubland enhanced, slightly, the capture of ammonium, seen first in dry deposition, and later when rain arrives in wet deposition. Ammonium accumulated in the soil was further enhanced because of the long seasonal drought, which slows microbial activity, and thus nitrification. When the first rains of the wet season arrive, the microbial communities recover. But, apparently, the microbes that oxidize ammonium to nitrite (NO_2^-) recover faster than the microbial community that oxidizes nitrite to nitrate, an uncharacteristic (i.e. rare) accumulation of nitrite is observed. The slower microbes soon catch up and nitrite gives way to the more typical nitrate (NO_3^-) peak (Gelfand et al., 2008). Interestingly, the delayed appearance of nitrate, the main plant nutrient, improved the synchronization between the time of peak availability of this major nutrient and the time of maximum plant photosynthetic activity in the developing active season.

Quality vs. quantity: With a large increase in carbon accumulation but no change in the nitrogen budget, the forest must have changed its nitrogen use efficiency (NUE), as well as its C/N ratio, compared to the shrubland. Indeed, above ground NUE almost tripled (235 vs. 83 kg dry mass kg^{-1} N), and the forest C/N ratio doubled (16 for the forest vs. 8 for the shrubland). Furthermore, the entire ecosystem nitrogen cycling rate markedly slowed down in the forest compared to the shrubland: net

The Yatir Forest Site: The nitrogen perspective

Ilya Gelfand

N mineralization rates in the soil decreased by approximately 50%, decomposition rates decreased by approximately 20%, and a decrease of approximately 64% in NOx loss in volatilazation was estimated (Glefand et al., 2009). While our investigation was by no means exhaustive, the first insights into the N cycle of a pine forest at the dry timberline provide another piece of the puzzle that help explain the observed 2.5-fold increase in the C stock of this ecosystem without the need to invoke any significant changes in the N stocks.

Figure 2. Ilya Gelfand and assistant coring soil in Yatir for nitrogen analyses and for seasonal incubations

References

Gelfand I and Yakir D (2008) Influence of nitrite accumulation in association with seasonal patterns and mineralization of soil nitrogen in a semi-arid pine forest. ***Soil Biology Biochemi***, **40, 415-424**.

Gelfand, I, Feig, G, Meixner FX, Yakir D (2008) Effects of semi-arid shrubland afforestation on biogenic NO emission from soil. ***Soil Biology Biochemi***, 41, 1561-1570.

Gelfand I, Grunzweig JM and Yakir D (2012) Slowing of nitrogen cycling and increasing nitrogen use efficiency following afforestation of semi-arid shrubland. Oecologia, 168, 563-575. DOI 10.1007/s00442-011-2111-0

Contact

Ilya Gelfand
W.K. Kellogg Biological Station,
Michigan State University
3700 E Gull Lake Dr
Hickory Corners, Mi 49060
igelfand@kbs.msu.edu