Impact of rooting depth on transpiration over a hill evergreen forest in northern Thailand

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Abstract

Possible impacts of rooting depth on vegetative processes have also been discussed because rooting depth limits soilwater use. Previous research showed that transpiration in an evergreen broad-leaved forest in northern Thailand (18^{o}48' N, 98^{o}54' E) peaked at the end of the dry season. However, rooting-depth limitations on soilwater use were not investigated. This study examined the impact of rooting depth and soil hydraulic properties on transpiration using a soil plant air continuum (SPAC) model. The soil texture at the site was classified as silty sand from the measured relationship between the volumetric soilwater content and soilwater potential at 0.1-m depths. To effectively simulate heat-pulse velocity variation corresponding to dry-season transpiration and annual discharge, a rooting depth of 4-5 m was needed, assuming a silty sand soil texture under unsaturated conditions. This value is less than the reported maximum rooting depth of evergreen trees and is considered reasonable. A penetration test showed that soil became harder at depths of 4-5 m.

Keyword: rooting depth, transpiration, hill evergreen forest.

1. Introduction

Tanaka et al. [2003] concluded that transpiration in an evergreen forest in northern Thailand peaked in the late dry season. They suggested that reduced canopy wetness lowered evaporation; however, stomatal conductance declined only slightly, even under the driest conditions and highest net radiation. These results counter previous reports of an evapotranspiration decline in Thailand's dry season for evergreen forests [*Pinker et al*., 1980] and other vegetation [*Toda et al*., 2002]. The transpiration peak suggests that sufficient water transpires between the surface and base rock; this trend was found every year. Observations of the heat pulse velocity near a ridge, where no water table seemed to form, also showed that the water use of individual trees was largest at the end of the dry season. This indicates that soilwater is likely to maintain the transpiration peak even in an unsaturated area. However, research on this subject is lacking.

This study used a soil plant air continuum (SPAC) numerical model to investigate how rooting depth affects evapotranspiration in an evergreen forest under unsaturated conditions. Seasonal variations in the heat pulse velocity corresponding to transpiration and annual discharge were compared with simulated results to determine the optimum rooting depth. A penetration test was also carried out in the forest to estimate the strength of the soil.

2. Method

2.1. Site

Since February 1997, the hydrological and meteorological parameters of a sub-watershed of the Kog-Ma Experimental Watershed have been measured. The sub-watershed is situated 1265-1420 m above mean sea level on Mount Pui (18°48' N, 98°54' E) near Chiang Mai in northern Thailand. A 50-m meteorological tower has been built, and instruments for measuring meteorological parameters, such as radiation, wind velocity, and air temperature, have been installed on the tower. Evergreen forest covers the hills of the experimental watershed. Fagaceae dominate, and the species include Lithocarpus, Quercus, and Castanopsis [*Bhumibhamon and Wasuwanich*, 1970]. The LAI is approximately 4.5, with a seasonal range from 3.5 to 5.5 [*Tanaka et al*., 2003]. Forest floor soils derive from granitic materials and are classified as Reddish Brown Lateritic [*Tangtham*, 1974].

To estimate the strength of the soil, a penetration test was carried out with a simplified dynamic cone penetrometer (S06-M, Tsukuba Maruto Co.) at a point near the tower in the sub-watershed. The equipment used consisted of a pair of rods (external diameter: 16 mm) coupled vertically using a knocking head. Using this method, the strength (or compaction) was expressed as N_c, which was defined as the number of times a 5-kg slide hammer had to be dropped from a height of 0.5 m above the knocking head for the tip of the cone to penetrate a depth of 0.1 m vertically.

2.2. Model

A one-dimensional SPAC model was used to investigate the impact of rooting depth on transpiration [*Tanaka et al*., 2004]. The model combines a soil multilayer model for thermal heat and soilwater transfer [*Kondo and Xu*, 1997] and a canopy multilayer model for the heat and water budget [*Tanaka et al*., 2003]. The soil multilayer model considers the change of albedo and evaporation efficiency with the soil moisture at the top of the soil column [*Kondo and Xu*, 1997]. The canopy multilayer model consists of a second-order closure model for atmospheric diffusion coupled with a radiation transfer model, a rainfall interception model, a Farquhar-type photosynthesis model [*Farquhar et al*., 1980], and Ball's stomatal conductance model [*Ball*, 1988]. Combined, the two models consider the loss of soil moisture by water uptake (or transpiration) and the impact of soilwater content on stomatal closure.

Tanaka et al. [2004] detail these assumptions.

Transpiration (E_t), canopy interception (E_i), and soil evaporation (E_s) were simulated using hydro-meteorological variables, such as rainfall, downward short-wave and long-wave radiation, air temperature, humidity, and wind velocity observed above the canopy from 1998 to 2000. The simulated discharge (D) was compared with measured value.

3. Result

3.1 Soil conditions

The modeled volumetric soilwater content (θ)-soilwater potential (ψ) relationship for silty sand proposed by *Kondo and Xu* [1997] is very similar to the measured values at a depth of 0.1 m. Of the four soil textures proposed by *Kondo and Xu* [1997], the soil texture at the site is best classified as silty sand. Therefore, numerical simulations were carried out assuming a silty sand soil texture under unsaturated conditions.

Fig.1 shows the values of N_c in the watershed at a point near the tower. The values gradually increased to a depth of ~4.5-m, although there was a peak at a depth of ~2.8 m; N_c exceeded 10 at depths of 4-5 m, and was ~20 at depths exceeding 5 m. The soil layers clearly became harder there.

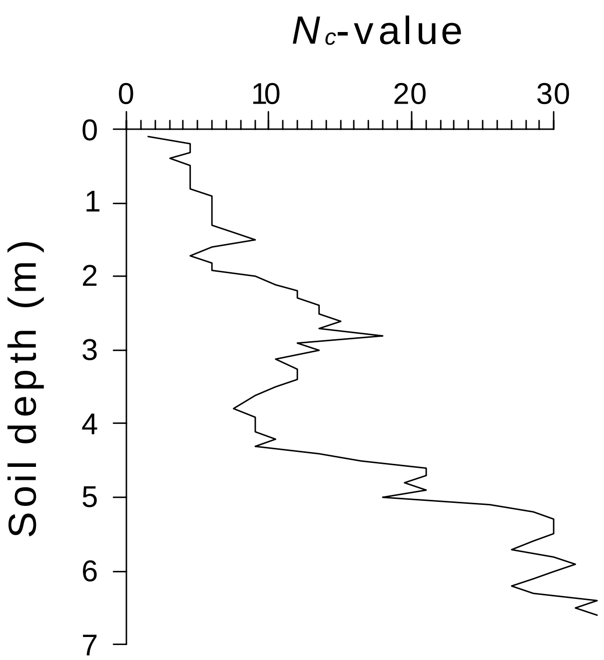

Fig. 1: N_c near the tower. N_c corresponds to the strength of the soil.

3.2 Simulation

The study area has three seasons: a rainy season, and early (cool) and late (hot) dry seasons. Fig. 2 shows the relationship between rooting depth and transpiration in March (late dry season), May (early rainy season), and September (late rainy season). These values are the average values for each month in the years 1998-2000. The simulated transpiration increased with rooting depth in the late dry season. On the other hand, transpiration values changed only slightly with rooting depth in the rainy season (Fig. 2) as compared to the late dry season. At a rooting depth of 4 m, transpiration increased more in the late dry season than in the rainy season (the monthly values of the rainy season transpiration for June to August were 41-49 mm mh-1 at rooting depths of 1-12 m), and the transpiration clearly peaked at the end of the dry season at rooting depths of 4-5 m.

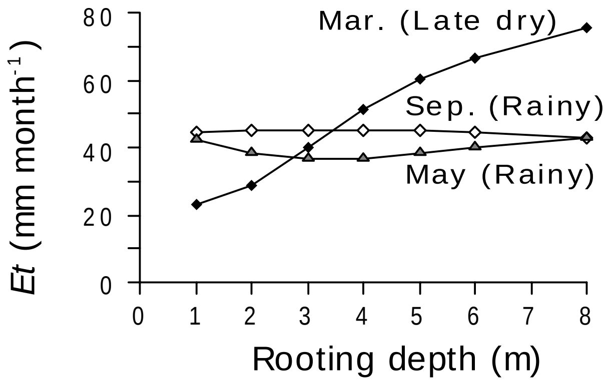

Fig. 2: Relationship between rooting depth and transpiration E_t in the late dry season and rainy season, assuming silty sand as the soil texture. The values are the averages of monthly values for each month in

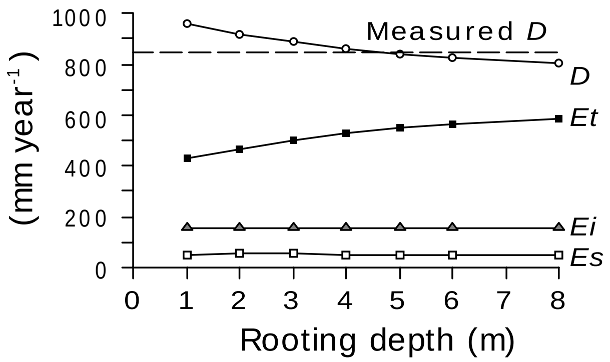

Fig. 3: Relationship between rooting depth and annual water budget component amounts (*i.e.*, discharge D, transpiration E_t, canopy interception E_i, and soil evaporation E_s), assuming silty sand as the soil texture. The values are the annual averages for a 3-year period (1998-2000).

As expected, rooting depth had little influence on the annual amounts of soil evaporation and canopy interception, particularly canopy interception, but it did affect the annual amounts of transpiration and discharge (Fig. 3). Therefore, a rooting depth of 4-5 m should be used to agree with the annual discharge (Fig. 3).

4. Consideration

The N_c profile showed that the strength of the soil clearly changed at depths of 4-5 m. In the study, the soil texture at the site was classified as silty sand [*Kondo and Xu*, 1997]. To effectively simulate transpiration peak in the dry season and annual discharge, a rooting depth of 4-5 m was needed for the silty sand soil texture. This value is lower than the reported maximum rooting depth of evergreen trees [*Canadell et al*., 1996; they reviewed the maximum rooting depth of trees from many references and calculated the average and standard deviation as 7.0 $\pm$ 1.2 m.] and is reasonable. The value also approximates the depth at which N_c clearly changed. These results emphasize that the late-dry-season transpiration peak is theoretically possible based on rooting-depth limitations to soilwater use.

As , The results show that the rooting depth should be set to exceed the tree rooting depths that are often used in land surface models within global circulation models (GCMs) (e.g., 1-2 m) to simulate transpiration peaks over forests in the late dry season using a one-dimensional model.

The finding that a deeper rooting depth is necessary to simulate the transpiration peak over forests in the late dry season is similar to the results for an Amazonian forest under dry conditions [*Arain et al*., 1997, *Sen et al*., 2000]. Generally, evergreen trees can develop roots that penetrate to deeper soil layers so that they can maintain leaves and transpiration under dry conditions. As *Canadell et al*. [1996] showed, tropical evergreen forests likely have deeper rooting depths than do tropical deciduous forests, which have no leaves under dry conditions. *Jackson et al*. [1999] showed that only evergreen species grew roots deeper than 10 m in an ecosystem containing deciduous and evergreen species.

5. Summary

Numerical simulations were carried out using a SPAC model to investigate the impact of rooting depth and soil texture, which limit soilwater use, on transpiration. The model assumed that unsaturated soil conditions were dictated by the boundary conditions. The soil texture at the site was classified as silty sand by *Kondo and Xu* [1997], based on comparisons of modeled and measured θ -ψ relationships. The results showed that a rooting depth of 4-5 m effectively simulated transpiration variation during the dry season and the annual discharge, assuming silty sand. The value of 4-5 m is within the reported maximum rooting depths of trees, and approximates the depth of 4-5 m at which the N_c-value corresponding to the strength of soil clearly changed and the soil became harder. Therefore, the late-dry-season transpiration peak is theoretically possible based on rooting-depth limitations to soilwater use.

References

Arain, A. M., W. J. Shuttleworth, Z.-L. Yang, J. Micheaud, and J. Dolman, Mapping surface-cover parameters using aggregation rules and remotely sensed cover classes, *Q. J. R. Meteorol. Soc*., 123, 2325-2348, 1997.

Ball, J. T., An analysis of stomatal conductance, Ph.D. thesis, 89 pp., Stanford Univ., Stanford, CA, 1988.

Bhumibhamon, S., and P. Wasuwanich, The structural characteristics of Huay Kog-Ma forest (in Thai with English abstract), Kog-Ma Watershed Res. Bull., 20 pp., Dept. of Conserv., Fac. of For., Kasetsart Univ., Bangkok, Thailand, 1970.

Canadell, J., R. B. Jackson, J. R. Ehleringer, H. A. Mooney, O. E. Sala, and E.-D. Schulze, Maximum rooting depth for vegetation types at the global scale, *Oecologia*, 108, 583-595, 1996.

Farquhar, G. D., S. von Caemmerer, and J. A. Berry, A biochemical model of photosynthetic CO2 assimilation in leaves of C3 species, *Planta*, 149, 78-90, 1980.

Jackson, R. B., L. A. Moore, W. A. Hoffmann, W. T. Pockman, and C. R. Linder, Ecosystem rooting depth determined with caves and DNA, *Proc. Natl. Acad. Sci. USA*, 96, 11387-11392, 1999.

Kondo, J., and J. Xu, Seasonal variations in the heat and water balances for nonvegetated surfaces, *J. Appl. Meteor*., 36, 1676-1695, 1997.

Pinker, R. T., O. E. Thompson, and T. F. Eck, The energy balance of a tropical evergreen forest, *J. Appl. Meteorol.*, 19, 1341-1350, 1980.

Sen, O. L., W. J. Shuttleworth, and Z.-L. Yang, Comparative evaluation of BATS2, BATS, and SiB2 with Amazon data, *J. Hydrometeorol*., 1, 135-153, 2000.

Tanaka, K., H. Takizawa, N. Tanaka, I. Kosaka, N. Yoshifuji, C. Tantasirin, S. Piman, M. Suzuki, and N. Tangtham, Transpiration peak over a hill evergreen forest in northern Thailand in the late dry season: Assessing the seasonal changes in evapotranspiration using a multilayer model, *J. Geophys. Res*., 108 (D17), 4533, doi:10.1029/2002JD003028, 2003.

Tanaka, K., H. Takizawa, T. Kume, J. Xu, C. Tantasirin, and M. Suzuki, The impact of rooting depth and soil hydraulic properties on the transpiration peak of an evergreen forest in northern Thailand in the late dry season, *J. Geophy.Res.*, 109, doi:10.1029/2004JD004865, 2004. (in Press)

Tangtham, N., Preliminary study of the ecosystem of hill evergreen forest in northern Thailand, Ph.D. thesis, 65 pp., Pennsylvania State Univ., University Park, PA, 1974.

Toda, M., K. Nishida, N. Ohte, M. Tani, and K. Musiake, Observations of energy fluxes and evapotranspiration over complex terrestrial land covers in the tropical monsoon environment, *J. Meteorol. Soc. of Jpn*., 80, 465-484, 2002.