Subtropical Plant Science, 63:1-6.2011.

Estimating Water Use by Giant Reed Along the Rio Grande Using a Large Aperature Scintillometer

Prasanna H. Gowda[1], John A. Goolsby[2], Chenghai Yang[2], Sukanta Basu[3], Alex Racelis[2], and Terry A. Howell[1]

[1]*USDA-ARS Conservation and Production Research Laboratory, P.O. Drawer 10, Bushland, TX 79012*
Email: Prasanna.Gowda@ars.usda.gov
[2]*USDA-ARS Kika de la Garza Subtropical Agricultural Center, Weslaco, TX 78596*
[3]*Marine, Earth & Atmospheric Sciences, North Carolina State University, Raleigh, NC 27695*

ABSTRACT

Giant reed (*Arundo donax* L.) is a bamboo-like perennial invasive weed from Eurasia presenting a severe threat to agroecosystems and riparian areas in Texas and Mexican portions of the Rio Grande River Basin. It is known to consume excessive amounts of water to support its rapid vegetative growth rate. However, very limited information is available on its water usage in the United States. The objective of this study was to evaluate the use of Large Aperture Scintillometer (LAS) to estimate evapotranspiration (ET) rates by the giant reed in a riparian ecosystem. A 3-day field experiment was conducted for this purpose during March 18-20, 2009 along the Rio Grande near Laredo, Texas. A LAS was deployed at 1-m above the giant reed canopy (5.3 m above the ground level) for estimating sensible heat flux (H). Scintillometer measurements were made at 1-min intervals and averaged to 15-min, synchronized with weather station measurements. In addition, net radiation (R_n) and soil heat fluxes (G) were measured. Latent heat fluxes (LE) and ET rates were derived as a residual, using LAS-estimated H in the energy balance equation ($LE=R_n-G-H$) and hourly ET values, computed from the hourly mean LE values and the latent heat of vaporization, were summed to obtain daily ET values. Analysis of the data for a day with clear skies (March 20, 2009) indicated that the daily water demand for giant reed was 5.2 mm. A long term monitoring of the giant reed canopy is required to accurately quantify the variations in water demand at different growth stages and meteorological conditions. Considering the capability to measure ET over heterogeneous landscape, and relatively easy instrumentation setup, the LAS appears to be an invaluable instrument to estimate ET rates of giant reed in the riparian ecosystem. Scintillometer-based estimated water use data has the potential to be used as a ground truth to validate remote sensing based regional scale daily/monthly/seasonal water use maps covering giant reed areas in the Rio Grande Basin and elsewhere.

Additional Index Words: Invasive species, evapotranspiration, riparian ecosystem, surface energy balance

The mention of trade names of commercial products in this paper is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the U.S. Department of Agriculture.

Giant reed (*Arundo donax L.*) is a bamboo-like perennial invasive C-3 grass species from Eurasia that can grow 3 to 10 m in height with hollow stems of up to 40 mm in diameter. It grows more than 100 mm per day (Dudley 2000). Giant reed was introduced into North America by Spanish colonists and has since become invasive in riparian ecosystems, especially in northern Mexico and the southwestern U.S. (Everitt et al. 2004; Goolsby and Moran 2009; Moran and Goolsby 2009). It is a hydrophyte and is known to consume excessive amount of water to support its high vegetative growth rate compared to most native North American riparian vegetation (Mcgaugh et al. 2006). Under optimal conditions, it is reported to consume more than 1100 mm of water annually (Bell, 1997) which is about 22% more than the crop water demand for irrigated corn from planting to harvest in the Texas High Plains (Gowda et al. 2007). A regional economic model of the Rio Grande Basin by Seawright et al. (2010) estimated that diversion of giant reed water consumption towards agricultural crops may yield farm level benefits ranging from $98 to $160 million annually at a present value.

Giant reed is threatening the viability of watersheds through altering hydrologic and nutrient regimes, wildlife habitats and accelerating fire cycles in the southwestern U.S. (Tillman, 1996; Bell, 1997). In the Rio Grande Basin, where water resources are vital to agricultural and municipal users in the U.S. and Mexico, it competes for this limited water resource (Contreras 2007; Goolsby et al. 2008). Consequently, the giant reed is considered an invasive weed in both the U.S. and Mexico and tens of millions of dollars have been spent to eradicate it (Dudley 2000). The invasion of giant reed in the U.S. and Mexico has been documented using remote sensing (Everitt et al. 2005; Everitt et al. 2008; Yang et al. 2009).

Thermal remote sensing based energy balance models are better suited for estimating water use by riparian vegetation on uneven landscape with heterogeneous ground cover at a regional scale (Samani et al. 2010). Therefore, numerous remote sensing algorithms have been developed for estimating magnitude and trends in regional land surface energy fluxes and evapotranspiration (ET) rates at a regional scale (Gowda et al. 2008). However, ground-based ET observations are necessary to check the accuracy of resulting ET maps. Conventional techniques for measuring ET on the ground include eddy covariance and Bowen ratio (BR) systems. However, these systems require homogenous surface covers within their flux footprint areas that are difficult to locate along riparian corridors.

Numerous studies have proven the reliability of scintillometers to provide surface energy flux estimated over heterogeneous surfaces (Chehbouni et al. 2000; Meijninger et al. 2002). The spatial scale of the flux data collected from a scintillometer is comparable to spatial resolution of satellite images that are in the order of 100 m (Hemakumara et al. 2003). Therefore, a scintillometer may be a useful tool for measuring ET rates of riparian vegetation with heterogeneous landscapes and ground cover. The objective of this study was to evaluate the use of Large Aperture Scintillometer (LAS; Kipp & Zonen B.V., The Netherlands) to estimate ET (water use) rates by giant reed along the Rio Grande near Laredo, Texas.

MATERIALS AND METHODS

Large Aperture Scintillometer (LAS): A LAS is an optical instrument that consists of a transmitter that emits a beam of light, and a receiver that can measure the amount of scintillations over a horizontal path. The scintillations recorded can be expressed as the structure parameter of the refractive index of air, C_n^2 (Wyngaard et al. 1971). This structure parameter gives the turbulent strength of the atmosphere that in turn describes the ability of the atmosphere to transport sensible heat and water vapor. The relative contribution of the temperature and humidity fluctuations to the C_n^2 fluctuations is wavelength dependent (Andreas 1989). Sensible heat fluxes (H) can be derived from the structure parameter of temperature using the Monin-Obukhov similarity theory (MOST) (Wyngaard et al. 1971). In addition to C_n^2 measurements, net radiation (R_n) and soil heat flux (G) measurements are required to derive latent heat fluxes (LE) as a residual from the energy balance equation ($LE=R_n$-G-H). Latent heat flux is converted to ET (mm h^{-1} or mm day^{-1}) by dividing it by the latent heat of vaporization (λ_v; 2.45 MJ kg^{-1}) and an appropriate time constant while assuming a water density of unity (1 Mg m^{-3}).

The LAS setup in the field consists of transmitter and receiver devices installed at a known distance called path distance (L) and height (z_{LAS}) above the surface, and both units have a Fresnel lens with an aperture diameter (D) of 0.15 m. The electromagnetic radiation emitted (λ = 930 nm) by the transmitter in the direction of the receiver is scattered by the turbulent atmosphere. The observed C_n^2 is recorded at the receiver side. In summary, $C^2{}_n$ measurements together with wind speed and air temperature data and estimates of the surface roughness and zero-plane displacement height, permit one to determine H iteratively. More information on calculating H is presented in Chehbouni et al. (2000).

Study Location: A field experiment was conducted on a giant reed stand (Fig. 1) with a rolling terrain along the Rio Grande near Laredo, Texas (Fig. 2). This location was near the U.S.-Mexico international border delineated by the Rio Grande (Fig. 2). The experiment was conducted during 18-20 March 2009 and the geographic coordinates of the location were [27° 36’ 50” N, 99° 33’ 12” W]. The selection of the location was based on the availability of longest path length with giant reed canopy cover and accessibility to set up two towers for instrumentation.

Experiment Setup: The experiment setup consisted of LAS for measuring C_n^2, a weather station, and net radiometer [Q*7.1, REBS, Seattle, Wash.], and three soil heat flux plates (Campbell Scientific Inc., Logan, Utah), weather parameters, net radiation and soil heat fluxes, respectively. The scintillometer, net radiometer, and weather station were installed at a height of 5.3 m to have measurements at least 1-m above the giant reed canopy. Soil heat flux plates were burried at a depth of 80 mm in the soil below giant reed canopy for measuring G. After aligning the transmitter and receiver, the path length dial knob setting value was calculated using an equation from the LAS manual provided by the manufacturer, and the receiver control panel was set for the path distance.

Fig. 1. A giant reed stand along the Rio Grande River near Laredo, Texas.

The C_n^2 measurements were made during 18-20 March 2009 on a continuous time scale at 1-min intervals and averaged for 15-min intervals, and were synchronized with weather station, R_n and G measurements. Sensible heat fluxes at 15-min intervals were calculated using a step by step methodology provided in the LAS instruction manual. The 15-min ET rates were calculated using estimated H with measured R_n and G fluxes as a residual from the energy balance equation. Hourly average R_n, H, and LE fluxes were calculated for each day and reported for comparison.

RESULTS AND DISCUSSION

More than 90% of the ground cover along the line of sight between transmitter and receiver consisted of giant reed with a small grass patch near the transmitter. The path distance between the transmitter and receiver was found to be about 230 m, which is less than minimum the path length prescribed (250 m) for the LAS to avoid signal saturation. The path length is aperture diameter dependent and therefore, the diameter of the aperture was reduced to 0.1 m using aperture restrictors provided by the LAS manufacturer, on both transmitter and receiver to avoid signal saturation. An average height of giant reed was about 4.3 m during the experiment. Two towers with a 3 x 3 m platform were constructed to deploy the LAS. Due to security issues along the U. S.- Mexico border, efforts were made to collect data only between 8 AM – 6 PM CST during the experiment. All the instruments except the soil heat flux plates were removed from the site at 6 PM every day during the experiment. Instrumentation set up was relatively easy and it took approximately an hour each for two people to set up and align all the instuments in the morning and disassemble them in the evening.

All the intended measurements were successfully made during the experiment. More than 95% of the C_n^2 values observed by the LAS were within the tubulent range of 10^{-12}–10^{-17} $m^{2/3}$, as specified by the manufacturer, indicating no signal saturation. The C_n^2 values beyond the allowed turbulent range were replaced with interpolated values. Measured G values were less than 7 W m^{-2} in all three days of the experiment due to the limited energy penetration through the dense canopy. Occasional cloud conditions occurred during the first two days (18 and 19 March), and clear skies were observed on the third day (20 March; Fig. 3c). However, all three days recorded a maximum R_n close to 700 W m^{-2}. The wind speed varied from 1-1.4 m s^{-1} on 18 March, 1.1-2.9 m s^{-1} on 19 March, and 0.5-

Fig. 2. Location of the experiment site near Laredo, Texas.

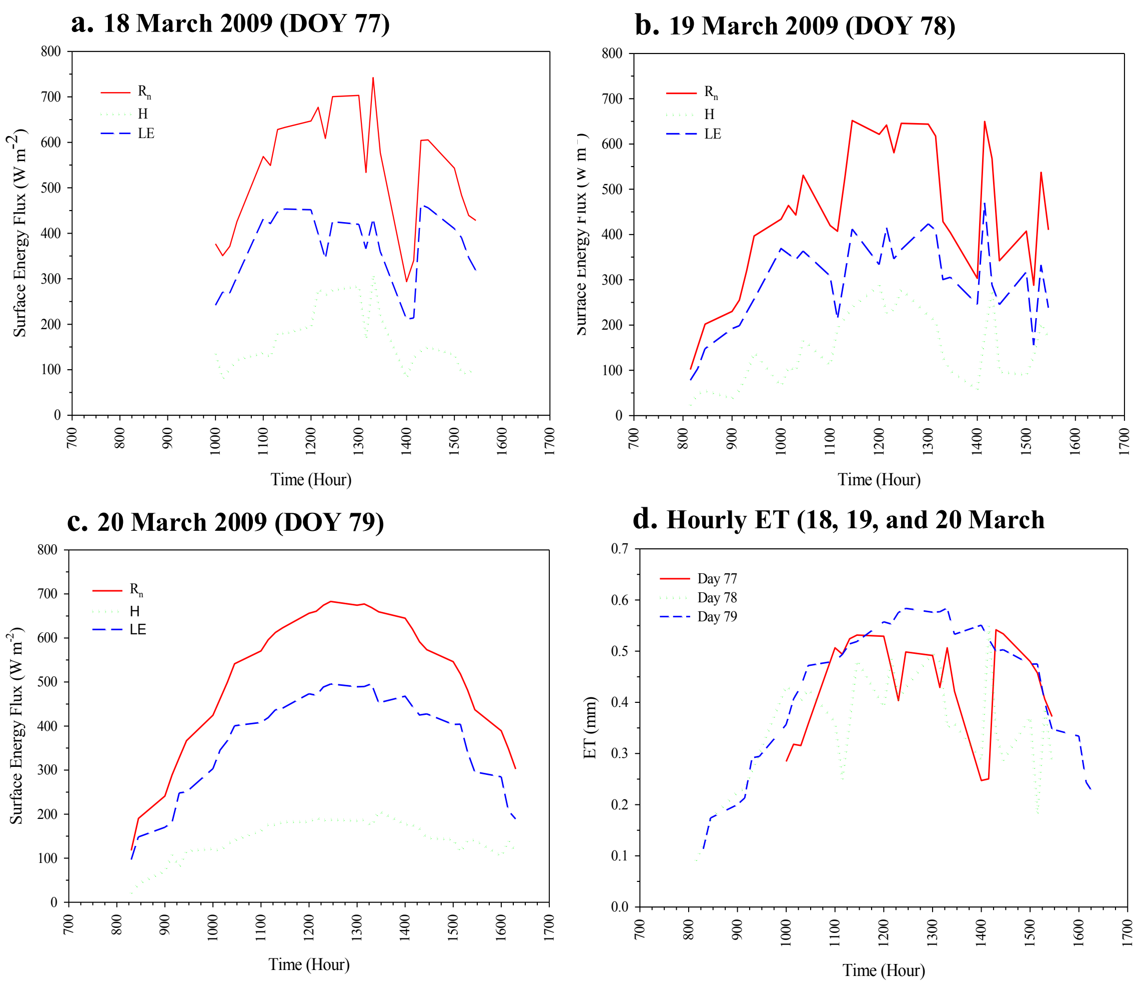

Fig. 3. Hourly land surface energy fluxes observed during the experiment and estimated hourly ET rates.

2.8 m s^{-1} on the 20 March. The air temperature during the experiment varied from 29-35°C, 29-31°C, and 30-38°C on 18, 19, and 20 March, respectively.

Fig. 3(a-c) illustrates measured surface fluxes at 15-min timestep for 18, 19, and 20 March, respectively. Both H and LE fluxes closely followed the trends observed in R_n fluxes as expected. Irregular R_n flux curves on 18 March and 19 March indicated occasional clouds observed over the site during the experiment. The average daytime observed R_n fluxes for 18-20 March were 534, 499, and 587 W m^{-2}, respectively. The average hourly estimated H and LE fluxes were 166 and 368 W m^{-2} for 18 March, 171 and 328 W m^{-2} for 19 March, and 163 and 424 W m^{-2} for 20 March, respectively. Fig. 3(d) illustrates hour ET rates for all three days of the experiment. Estimated average hourly rates for the study location were 0.4, 0.4, and 0.5 mm h^{-1} for 18, 19, and 20 March, respectively. Relatively higher average hourly ET on 20 March was due to clearer sky conditions that existed on that day. On the day with clearer skies (20 March), the estimated daily ET rate was 5.2 mm for the 10 h period from 8 AM to 6 PM.

SUMMARY

A scintillometer is an optical instrument that has the ability to provide surface energy fluxes estimated over heterogeneous surfaces. Scintillometer-based water use (ET) data can be used as a ground truth to validate thermal remote sensing based regional scale daily/monthly/seasonal water use maps. These capabilities make the LAS suitable for monitoring sensible heat fluxes and subsequently estimating crop water use. In this 3-day study, a LAS was used to estimate water use by giant reed along the Rio Grande River near Laredo, Texas. Analysis of the 3-day data indicated that giant reed have an average hourly ET rate of 0.4-0.5 mm h^{-1}. A long term monitoring of the giant reed canopy is required to accurately quantify the variations in water demand at different growth stages and meteorological conditions. Our field experiences indicated that the LAS is easy to setup quickly over heterogeneous riparian vegetation on a rugged terrain. Further, quality of the measured C_n^2 data and estimated magnitude and trends in H an LE fluxes and corresponding ET rates indicate that the LAS might be a potential tool for measuring ET over riparian vegetation such as giant reed along the Rio Grande River for monitoring water use.

LITERATURE CITED

Andreas, E.L. 1989. Two-wavelength method of measuring path-averaged turbulent surface heat fluxes. J. Atmos. Ocean. Tech. 6:280-292.

Bell, G.P. 1997. Ecology and management of *A. donax* and approaches to riparian habitat restoration in southern California. In J.H. Brock, M. Wade P. Pysek, and D. Green (Eds.): *Plant Invasion: Studies from North America and Europe.* Backhuys Publsihers, Liden, The Netherlands, pp. 103-113.

Chehbouni, A., C. Watts, J.P. Lagouarde, Y.H. Kerr, J.C. Rodriguez, J.M. Bonnefond, F. Santiago, G. Dedieu, D.C. Goodrich, and C. Unkrich. 2000. Estimation of momentum fluxes over complex terrain using a Large Aperture Scintillometer. Agric. For. Meteorol. 105:215-226.

Contreras, A. 2007. Investigación sobre la distribución de la planta invasora *Arundo donax* (carrizo gigante) en la cuenca del Río Bravo. ProNatura. Proyecto 6204 22000 019105.

Dudley, T.L. 2000. *Arundo donax*. In: Invasive plants of California wildlands, Edited by C.C. Bossard, J.M. Randal, and M.C. Hosovky, University of California Press, Berkeley, pp. 53-58.

Everitt, J.H., C. Yang, M.A. Alaniz, M.R. Davis, F.L. Nibling, and C.J. Deloach. 2004. Canopy spectra of giant reed and associated vegetation. J. Range Manag. 57:561-569.

Everitt, J.H., C. Yang, and C.J. Deloach. 2005. Remote sensing of giant reed with Quick Bird satellite imagery. J. Aquatic Plant Manag. 43 (2):81-84.

Everitt, J.H., C. Yang, C., R.S. Fletcher, and C.J. Deloach, Jr., 2008. Comparison of QuickBird and SPOT 5 satellite imagery for mapping giant reed. J. Aquatic Plant Manag. 46:77-82.

Gowda, P.H., R.L. Baumhardt, A.M. Esparza, T.H. Marek, and T.A. Howell. 2007. Suitability of cotton as an alternative crop in the Ogallala Aquifer Region. Agronomy Journal, 99:1397-1403.

Gowda, P.H., J.L. Chavez, P.D. Colaizzi, S.R. Evett, T.A. Howell, and J.A. Tolk. 2008. ET mapping for agricultural water management: Present status and Challenges. Irrigation Sci. 26(3):223-237.

Goolsby, J.A. and P.J. Moran. 2009. Host range of *Tetramesa romana* Walker (Hymenoptera: Eurytomidae), a potential biological control of giant reed, *Arundo donax* L. in North America. Biological Control 49:160-168.

Goolsby, J.A., P. Moran, A. Kirk, W. Jones, J. Everitt, C. Yang, P. Parker, D. Flores, D. Spencer, A. Pepper, J. Manhart, D. Tarin, G. Moore, D. Watts, and F. Nibling. 2008. *Arundo donax*—giant reed; an invasive weed of the Rio Grande Basin, Western Weed Science Society Annual Meeting, March 12-14, Anaheim, CA.

Hemakumara, H.M., L. Chandrapala, and A. Moene. 2003. Evapotranspiration fluxes over mixed vegetation areas measured from large aperture scintillometer. Agric. Water Manag. 58(2):109-122.

Mcgaugh, S.D., D.A. Hendrickson, G. P. Bell, T.L. Dudley, K. Lyons, V. Souza, and L. Mceachron. 2006. Draft Arundo Eradication Plan: Cuatro Ciénegas, Coahuila, México. (Versión de Septiembre 01, 2005 Versión, http://desertfishes.

Meijninger, W.M.L., O.K. Hartogensis, W. Kohsiek, J.C.B. Hoedjes, R.M. Zuurbier and H.A.R. De Bruin. 2002. Determination of Area-Averaged Sensible Heat Fluxes with a Large Aperture Scintillometer over a Heterogeneous Surface - Flevoland Field Experiment. Boundary-Layer Meteorology**,** 105:37-62.

Moran, P.J., and J.A. Goolsby. 2009. Biology of the galling wasp *Tetramesa romana*, a biological control agent of giant reed. Biological Control 49:169-179.

Samani, Z., A.S. Bawazir, R.K. Skaggs, M.P. Bleweiss, A. Pinon, and V. Tran. 2010. Water use by agricultural crops and riparian vegetation: An application of remote sensing technology. J. Contemporary Water Res. and Educ. 137(1):1-13.

Seawright, E.K., M.E. Rister, R.D. Lacewell, D.A. McCorkle, A.W. Sturdivant, C. Yang, and J.A. Goolsby. 2010. Economic implications for the biological control of *Arundo donax* in the Rio Grande Basin. Southwestern Entomol. 34:377-94.

Tillman. 1996. Biodiversity: Population versus ecosystem stability. Ecology, 77:350-363.

Wyngaard, J.C. Y. Izumi, and S.A. Collins Jr. 1971. Behavior of the refractive index structure parameter near the ground. J. Optical Soc. Amer. B, 61:1646-1650.

Yang, C., J.A. Goolsby, and J.H. Everitt. 2009. Using Quickbird satellite imagery to estimate giant reed infestations in the Rio Grande Basin of Mexico. J. Applied Remote Sensing, 3(033530):1-12.