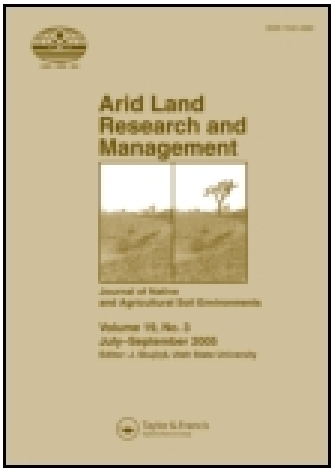

Arid Land Research and Management
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/uasr20

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Published online: 28 Jan 2014.

To cite this article: Hiroshi Yasuda, Mohamed A. M. Abd Elbasit, Kiyotsugu Yoda, Ronny Berndtsson, Takayuki Kawai, Hiroshi Nawata, Asaddig M. Ibrahim, Tomoe Inoue, Wataru Tsuji, Tarig E. A. Gamri & Tadaomi Saito (2014) Diurnal Fluctuation of Groundwater Levels Caused by the Invasive Alien Mesquite Plant, Arid Land Research and Management, 28:2, 242-246, DOI: 10.1080/15324982.2013.819824

To link to this article: http://dx.doi.org/10.1080/15324982.2013.819824

Arid Land Research and Management, 28:242–246, 2014

ISSN: 1532-4982 print/1532-4990 online
DOI: 10.1080/15324982.2013.819824

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RESEARCH NOTE

Diurnal Fluctuation of Groundwater Levels Caused by the Invasive Alien Mesquite Plant

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*Invasive alien plants such as mesquite (*Prosopis juliflora*) alter patterns of groundwater uptake. We measured the groundwater level beneath a mesquite stand in an arid area in Sudan. The changes in groundwater level closely followed plant water uptake. The groundwater level started to decline a few hours before sunrise, recovered around noon, and then continued to decline until a few hours after sunset, before recovering again during the night. Thus, groundwater level showed two peaks: just before sunrise and around midday. The midday recovery was due to the depression of photosynthesis by heat and light.*

Keywords arid land, double peak, groundwater, mesquite, midday depression

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Color versions of one or more of the figures in the article can be found online at www.tandfonline.com/uasr.

The hardy mesquite shrub (*Prosopis juliflora* (Sw.) D. C.), native to Central and South America, was introduced in the 1980s to arid northern Africa to stabilize sand dunes. It has since spread to become an invasive weed in Africa (Pasiecznik et al., 2001; Mwangi and Swallow, 2005; Hoshino et al., 2011) and is listed as one of the world's 100 worst invasive alien species (World Conservation Union, 2004). In addition to destroying ecological systems, mesquite depletes subsurface water resources. Mesquite is a typical phreatophyte and extends its roots rapidly into deep aquifers (Nilsen et al., 1983), which allows this species to survive in arid environments and thus to efficiently compete with many native plant species (Pasiecznik et al., 2001).

Deep-rooted plants show groundwater effects in arid areas. Several studies have shown a decline in groundwater level during the daytime and a diurnal cycle in the water table level (e.g., Cleverly et al., 2006; Yasuda et al., 2013). A decline in photosynthesis associated with decrease in stomatal conductance and transpiration, especially in hot and dry environments, causes a midday depression in water uptake (e.g., Dugas et al., 1992; Pathre et al., 1998; Franco and Lüttge, 2002; Guo et al., 2009). The consequent reduced water uptake may allow the groundwater level beneath the plants to recover briefly. Sap flow of honey mesquite (*Prosopis glandulosa* Torr. *var. glandulosa*) showed a single peak after rainfall and a double peak under dry conditions (Dugas et al., 1992).

Observations of this study were made at Al Kadaru, Khartoum, Sudan. The mean annual rainfall in Khartoum is 132.2 mm (1960–2010). Virtually all rain falls during May to October, thus, natural vegetation is limited. Al Kadaru lies 5 km east of the Nile. The geographical position (latitude and longitude) of the sampling site is Longitude, 32.59; latitude, 15.75. The vegetation characteristics of the mesquite stand was as follows: ten stumps per 100 m^2; each stump has three to seven vigorous sprouts; age of each stump was hard to detect, but that of each sprout was two to three years; maximum height of sprouts was less than 3 m; mean basal diameter of sprouts comprising stand canopy was 3.6 cm. Canopy covered 60% of the ground surface. Leakage from a tap allowed this stand to establish and to develop its roots down to the groundwater table (~23 m below soil surface). To measure the groundwater level, a 5-cm diameter observation well was drilled to 25 m beneath the soil surface and the mesquite stand and a water level gauge (S&DL mini 4800, *Oyo*) was installed. The gauge consisted of a water level pressure sensor and a barometer for atmospheric pressure compensation. Automatic observation gauges for rainfall (S-RGB-M002, *Onset*), temperature (S-TMB-M002, *Onset*), and solar radiation (S-LIA-M003, *Onset*) were installed beside the stand. Observation interval was set to 1 hour for all the gauges. Except for limited rain during the rainy season, the groundwater was the only water source for the stand.

Results showed that groundwater depth (GWD) showed an increasing trend from 4 August to mid-October (Figure 1C) due to recharge during the rainy season. The GWD showed a diurnal fluctuation. Fluctuations of several centimeters in GWD corresponded to fluctuations in photosynthetically active radiation (PAR) and temperature (Temp) (Figure 1B). The average, maximum, and minimum of fluctuations were 0.057, 0.093 (23 September), and 0.032 m (27 August), respectively. A diurnal double peak of GWD was evident. The Mesquite stand at the study site drew water from the aquifer at 23 m depth, equivalent to about 10 times the plant height. During 20–27 August, GWD started to decline 1–2 h before sunrise, recovered around noon, and continued to decline until 1–2 h after sunset. It then recovered

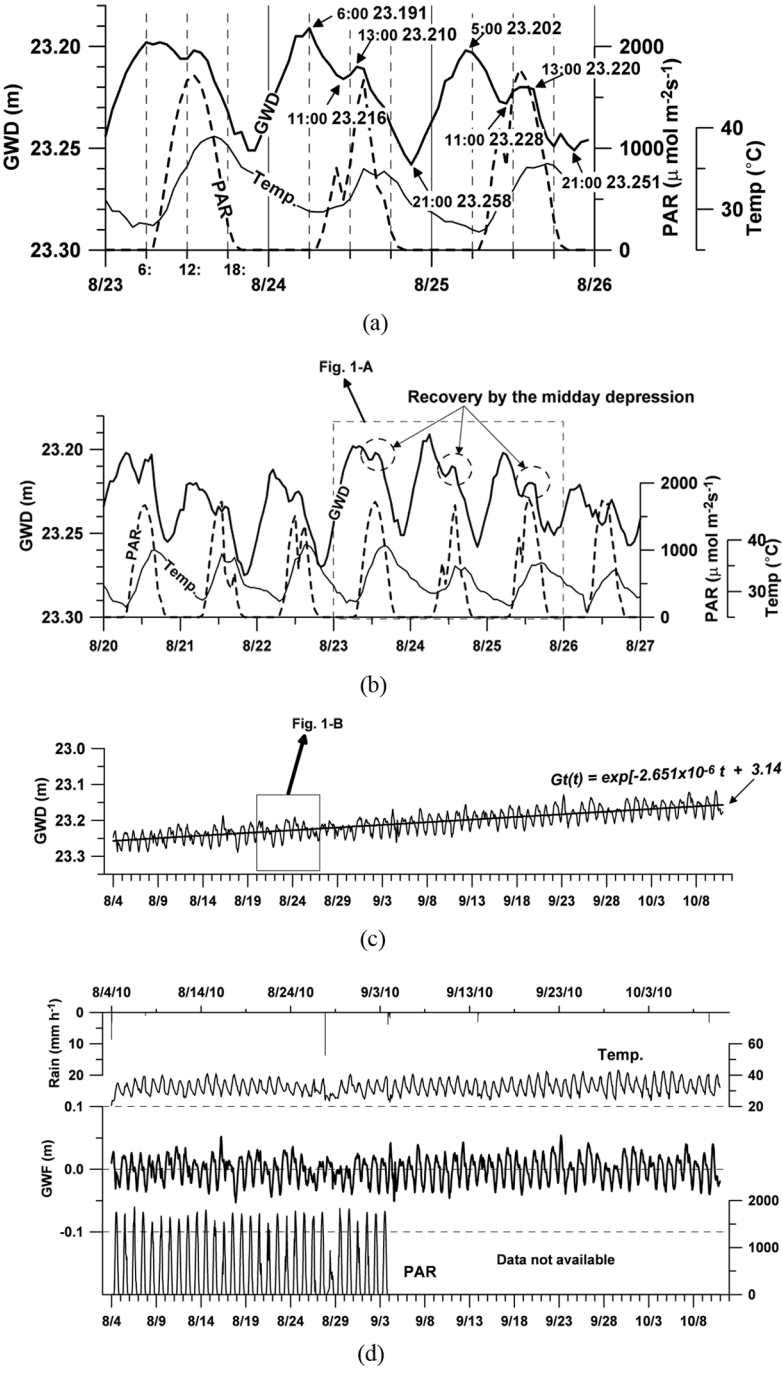

Figure 1. (a) Fluctuation of groundwater depth. GWD, PAR, and Temp from 23–25 August 2010. GWD: Groundwater depth (m), PAR: photosynthetically active radiation (μ mol m^{-2} s^{-1}), Temp: Temperature (°C). (b) Fluctuation of groundwater depth. GWD, PAR, and Temp from 20–25 August 2010. (c) Fluctuation of groundwater depth. GWD and Gt (t) from 4 August–10 October 2010. Gt (t): Fit of exponential function. (d) Fluctuation of groundwater depth. Rain, Temp, GWF, and PAR from 4 August–10 October 2010. GWF: Groundwater fluctuation (m).

during the night. On 24 August, GWD was 23.191 m, the shallowest of the day, at 06:00 (Figure 1A). GWD declined to 23.216 m at 11:00 and then rose again slightly to 23.210 m, the second shallowest peak of the day, at 13:00. This dip indicates that water uptake by the mesquite ceased during about 2 h around noon, allowing GWD to recover. GWD then resumed its decline, reaching 23.258 m, the greatest depth of the day, at 21:00. The net decrease of GWD was 0.067 m. On 25 August, GWD followed the same pattern of diurnal fluctuation, with a midday recovery of 0.018 m and a net change of 0.049 m. The net decrease, several cm every day indicated superior transpiration of the mesquite for its survival in severe arid environment.

Previous research has reported similar diurnal fluctuations of the water table in arid environments, caused by plant water uptake (e.g., Cleverly et al., 2006; Yasuda et al., 2013). Here, we recorded a midday recovery, which caused a clear double peak in sunny day throughout the observation period (Figure 1C). The midday depression of plant activities such as photosynthesis, water uptake, transpiration, and sap flow has been found in many taxonomic groups (Pathre et al., 1998; Franco & Lüttge, 2002). Suppression of transpiration and sap flow with stomatal closure to prevent water loss is commonly observed in plants under severe drought conditions (David et al., 1997). Figure 2 shows observed closing of foliage for the mesquite during the midday depression. The foliage closure corresponds to the observed recovery of the water table during noon. The midday depression is thus a part of the mesquite's survival strategy in extremely arid environments.

To evaluate the overall increase in GWD from 4 August to 10 October, we fitted an exponential function to the data (Figure 1C). The exponential function, $Gt(t)$ stands for the seasonal change (m) and t is the elapsed time from 00:00 on 4 August (h). We extracted the groundwater fluctuation, $GWF(t)$ (Figure 1C), as deducted above $Gt(t)$ from the original groundwater depth, $GWD(t)$.

As groundwater level is subtracted from seasonal change, increase of GWF is corresponding to the rise of groundwater level. The plot of GWF indicates both variable diurnal fluctuations and regular double peaks. Correlation analyses showed that GWF was correlated with both PAR ($r = 0.171$) and Temp ($r = -0.420$, $p < 0.05$). Temperature had a larger effect on groundwater fluctuation than solar radiation. Comparison of the daily highest and lowest values of GWF with daily PAR and daily maximum, minimum, and accumulated Temp showed a significant negative correlation of the daily lowest GWF with the daily maximum and accumulated Temp.

Figure 2. Leaves of mesquite. Left: Leaves were opened for the normal condition. Right: Leaves were closed during the midday depression.

In the arid environment, Sudan, one of the world's 100 worst invasive alien species, mesquite affects subsurface water dynamics. Due to transpiration of mesquite, groundwater level indicated diurnal fluctuations. The midday depression of mesquite was clearly shown on groundwater fluctuations.

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