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TIME LAGS BETWEEN RAINFALL AND GROUNDWATER LEVELS IN A FOREST AND CATTLE PASTURE OF AN AMAZON WATERSHED

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Time lags between rainfall and groundwater level response are quantified by cross-correlation analysis comparing transitional forest and cattle pasture (Amazonia and Savanna) ecosystems in the north of Mato Grosso State, Brazil. Groundwater levels were measured monthly from January 2005 to December 2006 in six monitoring wells. Micrometeorological data (air temperature, relative humidity and rainfall) were collected for the same period. Groundwater level increased in the wet season and decreased in the dry season in both ecosystems. The maximum correlation coefficient between rainfall and water level for the forest occurred after a time lag of 2 months in the forest and 1 month in the pasture. The conclusion is that the forest had larger time lag (and smaller amplitude) than the pasture due to the forest having greater evapotranspiration, less average soil moisture, and consequently, lower average level of water table compared to pasture if the soil conditions are similar.

INTRODUCTION

Land use change with accompanying major modifications to the vegetation cover is widespread in the tropics, due to increasing demands for agricultural land. For the Amazon region in particular, this deforestation is tightly coupled with increased probability of drought and fire occurrences driven by both local deforestation and global climate change. Reduction in forest cover leads to changes in evaporation and the surface energy balance, which further reduces precipitation, especially further inland (Betts et al., 2008). Increases in the lifting condensation level due to climate change may be enhanced further by loss of the forest and reductions in evapotranspiration (Cowling et al., 2008).

Over the last 25 yrs more than 70 million ha of the native vegetation in Brazil have been replaced by pastures for beef production. The substitution of native vegetation on such a large scale with African grasses (often from the genus *Brachiaria*) is likely to have an impact on nutrient and organic matter composition, as well as a regional impact on hydrology and water quality (Cerri et al., 2003).

Land-cover change studies have focused on a number of "susceptible" regions where past or current land-cover change has been observed (Osborne et al., 2004). The Amazonian basin, for example, is an area where the tropical rainforest is rapidly diminishing as forests are cleared for forestry and agricultural purposes. The Amazon Basin covers an area of some 7 million km^2 and the central part is almost entirely located within Brazilian territory. This region has the highest rates of deforestation in the world (INPE, 1998).

The fast rate of Amazonian deforestation has motivated numerous modeling and observational studies to study the influence of tropical rainforests on climate.

Amazonian forests play a self-sustaining role in their local climate system (Osborne et al., 2004). It is therefore best understood as a coupled system, where vegetation affects the patterns of precipitation (Rocha et al., 1999) and precipitation affects the distribution and activity of vegetation (Rocha et al., 2004). For example, conversion to pasture can cause a 1.5 – 2.0 kPa increase in vapor pressure deficit and a 5-10°C increase in soil surface temperature relative to intact forest (Culf et al., 1996). Land cover change causes more rainfall to be partitioned into runoff, alters seasonal variations in incoming solar radiation, net radiation, and evaporation, and affects the development of the nocturnal and convective boundary layer (Nobre et al., 1996; Culf et al., 1996). The conversion of vegetation such as tropical forest or savanna to grassland disrupts the hydrological cycle of a drainage basin by altering the balance between rainfall and evaporation and, consequently, the runoff response of the area (Costa et al., 2003).

Groundwater recharge studies are basic in hydrogeology to estimate the volume of groundwater resources annually renewed, which has direct implications in the planning and integrated management of the regional water resources. Groundwaters are recharged by precipitation at the land surface, where part infiltrates, is stored in aquifers, and contributes to stream base flows.

The recharge which reaches groundwater is dependent on various conditions (e.g., ecosystem features, climatic conditions), causing it to vary with time. The present work aims to evaluate the water table response to rainfall and the recharge time, quantifying time lags between rainfall and groundwater levels in the transitional forest (Amazonia and Savanna) and cattle pasture areas in the North of Mato Grosso State, Brazil.

MATERIALS AND METHODS

Study area

The study areas are located in the ecotone between two major ecosystem types of South America (wet evergreen rainforest and savanna), a region that was one of the fastest to be deforested in the last three decades (Fearnside, 2000). Two sites were selected that represent examples of the dominant regional land cover forms; mature, intact transitional forest and cattle pasture.

The study areas were located approximately 50 km northwest of Sinop, Mato Grosso, Brazil (11°24.75'S:55°19.50'W – coordinates from a micrometeorological tower in transitional forest, Figure 1), 423 m above sea level in a climatic transition between Amazonian rain forest and savanna that spans between 9°S and 14°S in northern Mato Grosso (Ackerly et al., 1989).

Vegetation within this ecotone consists of savanna (Cerrado), transitional vegetation (Cerradão), and Amazonian forest, which on the southern fringes of the Amazon Basin near Sinop is recognized as dry ("mata seca") or semi-deciduous mesophytic forest (Eiten, 1972; Ratter et al., 1978; Ackerly et al., 1989).

Rainfall near Sinop is approximately 2 m y^{-1}, while precipitation for savanna and rain forest is 1.5 and 2.2 m y^{-1}, respectively, and Sinop experiences a 3-5 month dry season, which is longer than rain forest (0-3 months) but comparable to savanna (Vourlitis, 2002; Priante-Filho et al., 2004; Vilani et al., 2006).

The 30-year mean annual temperature is 24°C with little seasonal variation, and rainfall is 2 m y^{-1} with a dry season between May-September, and a wet season between October-April. The sites are located on the Araguaia Formation, with the same soil texture (Oxisol soil) (Marcelino

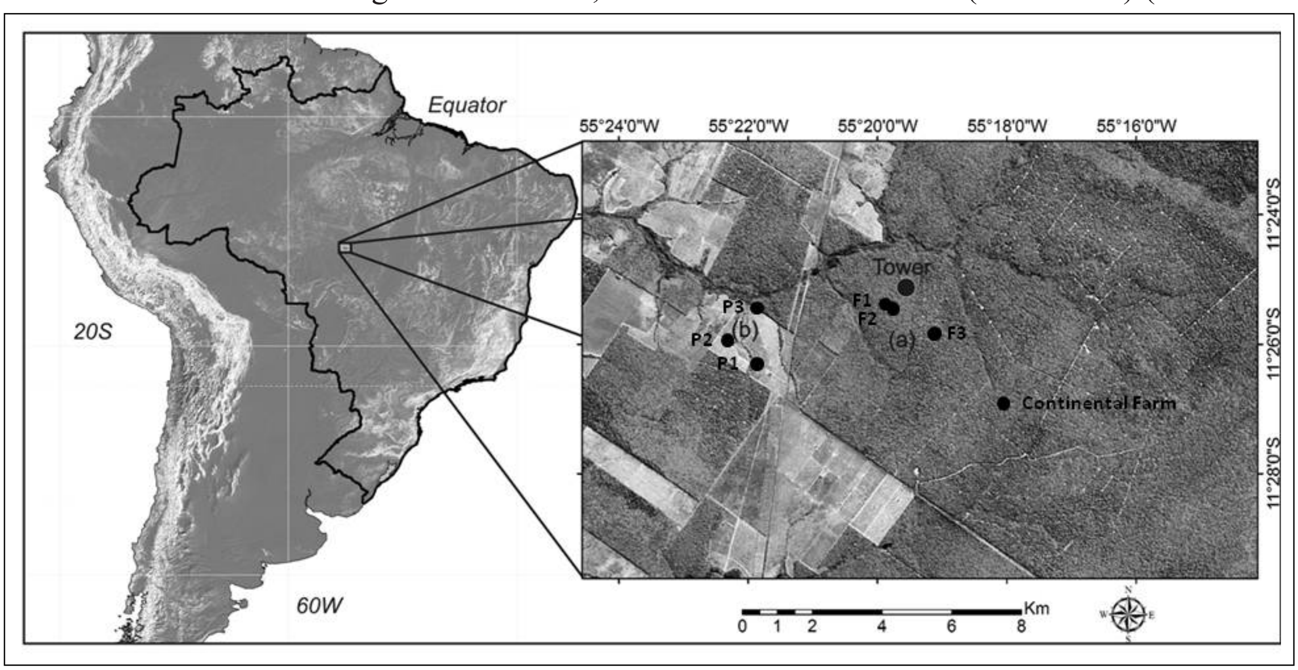

Figure 1. Location of the study area approximately 50 km N from Sinop city, Mato Grosso state, Brazil, South America. Micrometeorological tower was located in transitional forest at 11º24.75'S and 55º19.50'W coordinates. (a) and (b) are related to transitional forest and pasture, respectively in Landsat ETM+ GeoCoverTM 2000 image. F1, F2 and F3 are monitoring wells located in the forest. P1, P2 and P3 are monitoring wells located in the cattle pasture.

et al., 2005). The soil near the forest tower site was a quartzarenic neosol characterized by sandy texture (84% sand, 4% silt, and 12% clay in the upper 50 cm of soil) (Priante-Filho et al., 2004). The soils are quite sandy, poor in nutrients, they have high porosity and drain rapidly following rainfall events (Vourlitis et al., 2002). Figure 2 shows the soil conditions in the forest and pasture.

In the intact transitional forest, the vegetation consists of typical Amazonian arboreal species and over 50% of the stand is dominated by the general *Tovomita schomburgkii*, *Qualea paraensis*, *Protium sagotianum* and *Brosimum lactescens* (Priante-Filho, 2004). In this area the diversity is high, although smaller than the diversity located in Amazonian forest towards the center of the Amazon. The maximum canopy height is 25-28 m and the density and basal area of trees with a diameter > 10 cm is 483 ha^{-1} and 22.5 m^2 ha^{-1}, respectively. Leaf area index varies between 4-5 m^2 m^{-2} in the wet season and 2-3 m^2 m^{-2} in the dry season reflecting the semi-deciduous nature of the forest (Vourlitis et al., 2004; Sanches et al., 2005).

In the pasture area, the original vegetation (transitional forest) was deforested by cutting and burning and planted with fast-growing exotic C4 pasture grass *Brachiaria brizantha*, well adapted to climatic and edaphic conditions found in the region. According to Guenni et al. (2002) about 80% of the roots of this grass are within the top 30 cm of the soil profile.

Management of the water table

Water levels were measured monthly from January 2005 to December 2006 in six monitoring wells using a metric tape equipped with a water sensor at the end. Sites were selected in forest and cattle pasture for the location of the monitoring wells (three in the forest and three in the pasture), based on a previous plan of location, considering common characteristics among them such as: original vegetation, location in relation to the slope, and soil type. Three monitoring wells in the forest and pasture were used to calculate the average water level. Table 1 shows the characteristics of the monitoring wells.

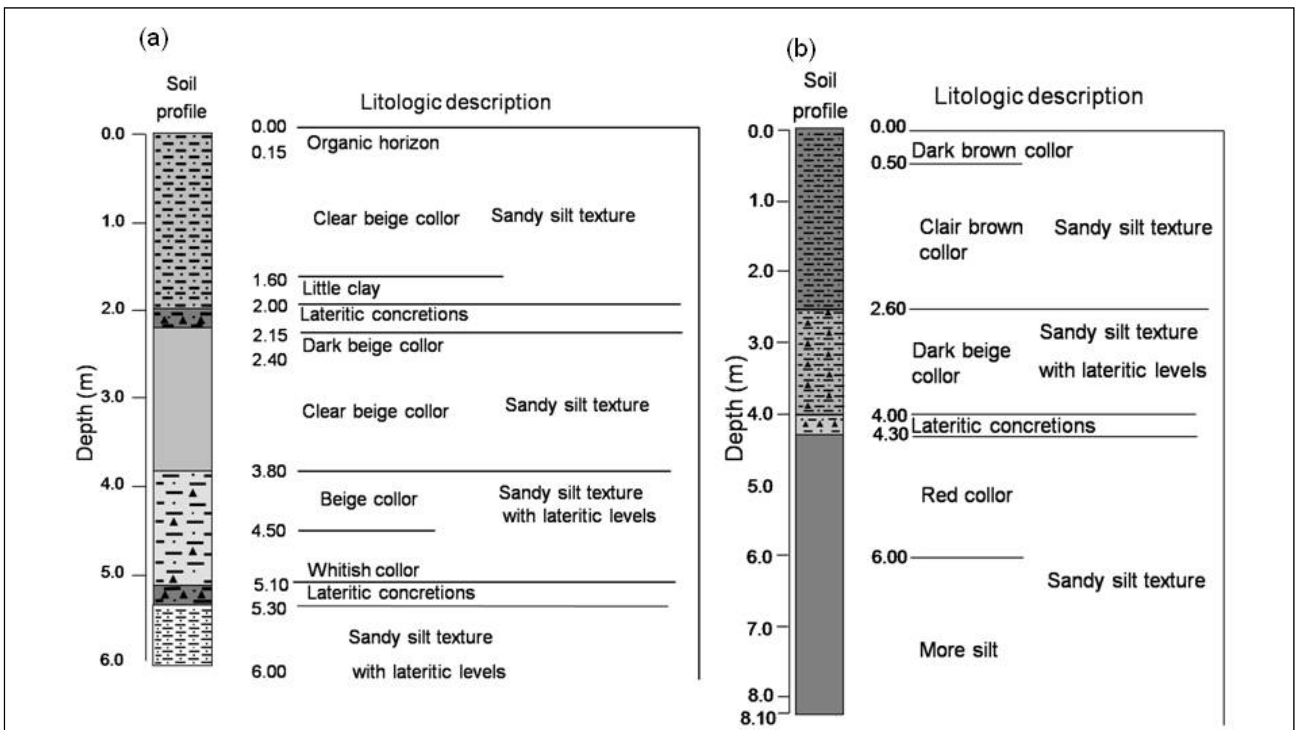

Figure 2. Profile of soil in the (a) transitional forest and (b) in the cattle pasture. Source: Marcelino et al. (2005).

Micrometeorological data collection

Average monthly measurements of air temperature were made at the top of a 40 m tall tower (12-14 m above the forest canopy) using a shielded relative humidity sensor (HMP-35, Vaisala, Inc., Helsinki, Finland). Precipitation was measured every 30 minutes at the top of the eddy flux tower using a tipping-bucket rainfall gauge (TE-525; Texas Electronics, Inc., Dallas, TX, USA). However, gaps in data collection precluded use of the rainfall data measured on site, and data obtained from a manual rain gauge that was read daily at the Continental Farm located 5 km E of the study site was used instead. Rainfall data collected by the manual rainfall gauge was highly correlated to data collected on-site (Vourlitis et al., 2008).

Method of analysis

To assess the time lags between monthly rainfall and water levels, a cross-correlation analysis was performed using monthly intervals. Time lags were calculated for all water levels with respect to rainfall. The lag for each pair of time series, which led to a maximum correlation coefficient, was obtained by use of the cross-correlation function (e.g., Phillips et al., 1999) therefore identifying the recharge time.

RESULTS AND DISCUSSION

Climatic conditions

Average annual rainfall was 2013 mm y^{-1} during the January 2005-06 study period (Figure 3c), and approximately 95% of it was precipitated during the wet period (Figure 3a). Defining the dry season as the number of consecutive months with rainfall < 50 mm (Shuttleworth, 1988), the dry season extended over 4 months in 2005 and 2006, from May to August, and wet season was defined from September to April. Rainfall was consistently < 50 mm in May-August with a longer dry season. Peak rainfall generally occurred in the months of December-February, but there were large monthly variations in rainfall (Figure 3a). For example, rainfall in March 2005 exceeded 500 mm, while rainfall in March and December 2005 combined exceeded 1000 mm, accounting for 50% of the total rainfall for 2005 (Figure 3a).

The air temperature and relative humidity present a well-defined seasonal behavior (Figure 3b and 3c). Maximum air temperature was observed in October 2005 (27.8°C) while minimum air

Table 1. Characteristics of monitoring wells in forest and cattle pasture.

Description	Vegetation type	Geographic coordinates	Depth of well (m)
F1	Forest	55°19’ W, 11°24’S	6.00
F2	Forest	55°19’ W, 11°24’S	3.42
F3	Forest	55°19’ W, 11°14’S	3.69
P1	Cattle pasture	55°21’ W, 11°25’S	8.10
P2	Cattle pasture	55°21’ W, 11°26’S	2.16
P3	Cattle pasture	55°21’ W, 11°26’S	4.15

temperature was observed in July 2006 (24.0°C, Figure 3b). There was an increase in air temperature of 2.9% in the dry season.

May to September demonstrates a lower monthly average of relative air humidity (minimum of ~62% in May), while the maximum average monthly relative air humidity occurs between September to January (maximum of 84.8% in September 2006) (Figure 3c). There was a decrease in relative humidity of 7.5% during the dry season.

Seasonality of water level

The average water level in the forest reached a minimum value of -4.26 m in September-October during the onset of the wet season and a maximum value of -2.54 m in March at the end of the wet season (Figure 4a). Averaged over seasonal periods, the mean (±95% CI) was -3.08 m during the wet season and -3.35 m during the dry season. There was an increase in the water level of 8.5% in the wet season.

In the pasture, the average water level was lower during the wet season than the dry season, being the same in the forest (Figure 4b), with a seasonal minimum value level in August 2006 (-3.8 m, Figure 4b), and a maximum value level in November 2006 (-2.2 m, Figure 4b). Averaged over seasonal periods, the mean (±95% CI) was -2.67 m during the wet season and -3.26 m during the dry season. There was an increase in the water level of 22.4% in the wet season.

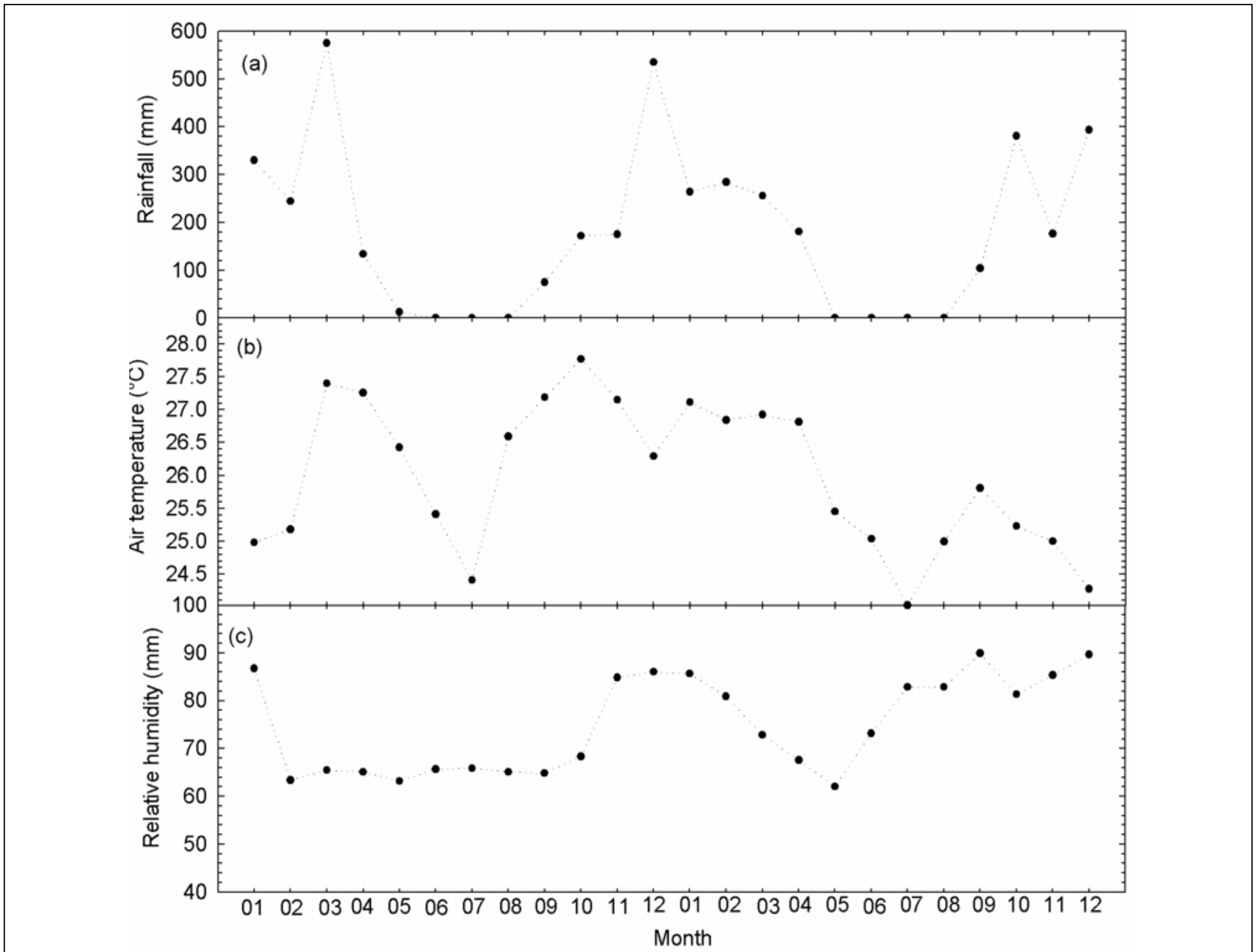

Figure 3. Rainfall (a), average monthly of air temperature (b) and relative humidity (c). (from January 2005 to December 2006).

There was a significant correlation between the water level in the forest ($r=0.52$, $p>0.05$) and seasonal trends in air temperature, relative humidity and rainfall; however correlations between water levels and meteorological variables were not significant.

The relationship between rainfall and water level

Monthly variations in rainfall corresponded well with water levels in the forest and maximum correlation was at a time lag of 2 months. The maximum coefficient of correlation was $r_{max} = 0.66$ (Figure 5).

In the pasture, the cross-correlation analysis for water level and rainfall showed maximum correlation at a time lag of 1 month and maximum coefficient of correlation was $r_{max} = 0.70$ (Figure 5).

Discussion

The seasonality of rainfall influences vegetation dynamics. It can influence the soil water availability and the variation in the water level and recharge time of groundwater aquifers. The variation in groundwater levels due to recharge is the result of a lot of factors, such as land cover, canopy structure, litter production, energy balance and others, and each of these processes can influence either individually or collectively. However this study discusses in particular the biosphere-atmosphere interaction under two sites located in the same watershed, with similar soil conditions (Figure 2a and Figure 2b). This study discusses (a) why the correlation between water level and rainfall had a time lag of 2 months in the forest and 1 month in the pasture, and (b) why the pasture showed the largest amplitude between minimum and maximum water levels.

In response to the first question, it is necessary to understand that the tropical transitional forest of northern Mato Grosso exhibits large seasonal and intra-seasonal fluctuations in evapotranspiration (Vourlitis et al., 2002). During the dry season, the transitional forest showed

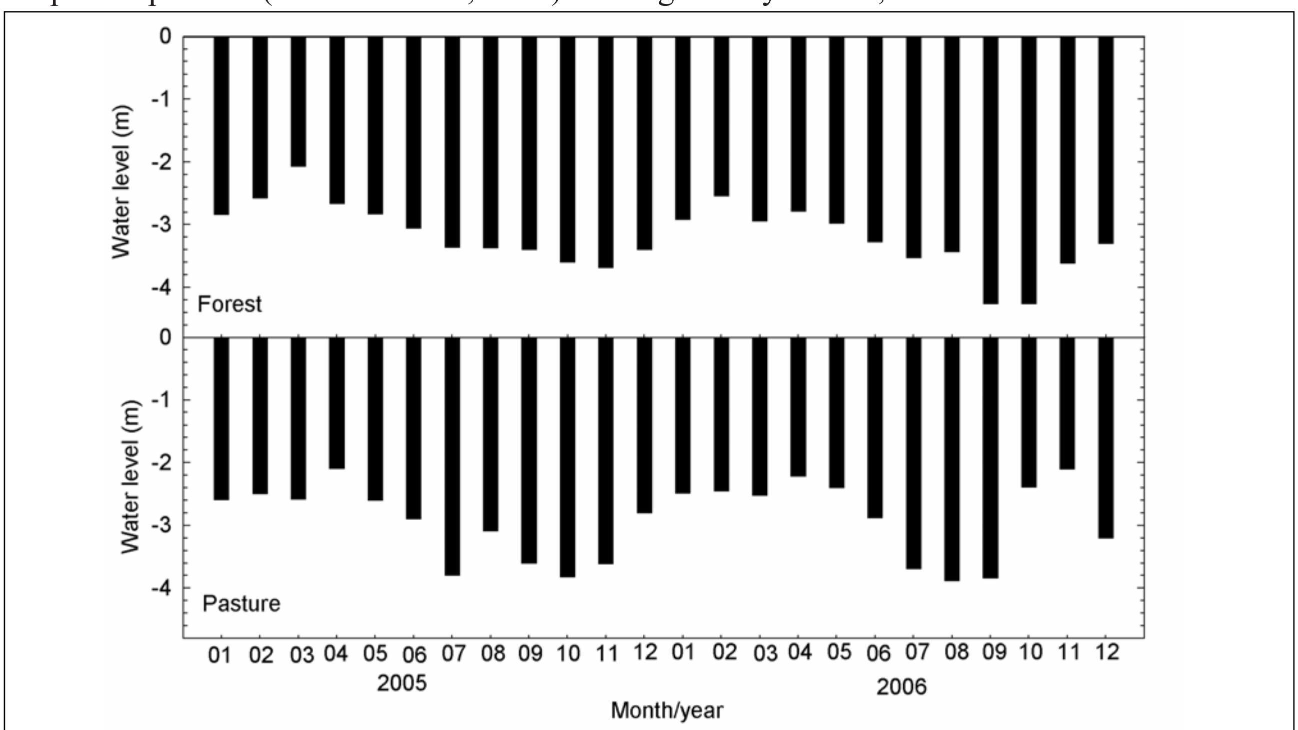

Figure 4. Monthly water level from January 2005 to December 2006 in the transitional forest (a) and pasture (b).

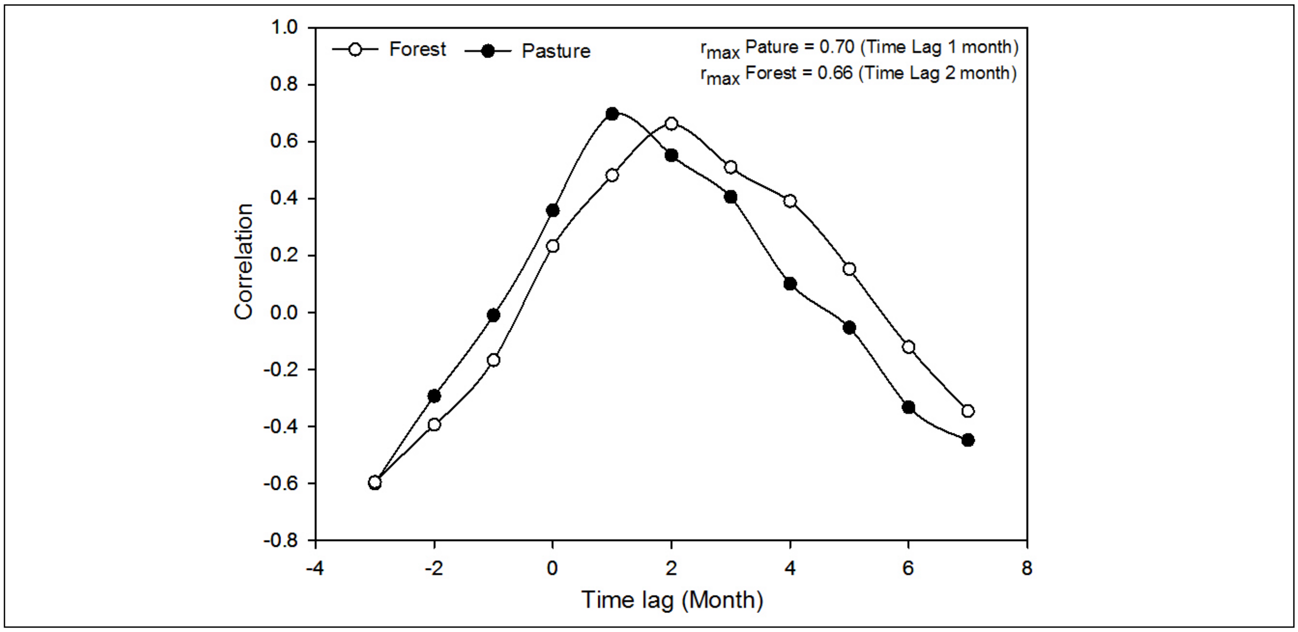

Figure 5. Cross-correlation between rainfall and water level in the forest (a) and pasture (b).

a decline in soil water content (Vilani et al., 2006) with high vapor pressure deficit and low rainfall, causing a decline in evapotranspiration (Vourlitis et al., 2002). Similarly, the increase in evapotranspiration during the wet season presumably reflects an increase in surface and soil water content, water level and/or a decline in evaporative demand. Due to the variation in meteorological variables such as precipitation, air temperature and humidity in the different seasons there was an increase of 8.5% in the water level in the wet season

The variation of water level in the forest was higher than pasture cover mainly due to the influence of the land cover. For example, Priante-Filho et al. (2004) reported that the forest had significantly higher rates of evapotranspiration compared to pasture. The trend that became more extreme during the onset of the dry season. Large differences in pasture and forest mass and energy exchange occurred even though seasonal variations in micrometeorology (air temperature, humidity, and radiation) were relatively similar for both ecosystems. In general, while both the forest and the pasture partitioned more net radiation (Rn) into latent heat flux (Le) than sensible heat flux (H), the forest partitioned substantially more Rn into Le (85%) than the pasture (58%) (Vourlitis et al., 2002).

Morever, Vourlitis et al. (2002) show that the surface soil water content of the pasture site was significantly higher compared to the forest. These differences in soil water content presumably reflect differences in soil textural properties, however, differences in volumetric soil water content may not translate into differences in soil water availability because soil texture influences both soil water storage and water potential.

In response to the second question, the largest amplitude between minimum and maximum groundwater level occurred in the pasture. The pasture lost water in the dry season faster than forest suggesting an important vulnerability of pasture to drought. However, in the period with least water available in the ecosystem, the water level in the pasture stayed higher than in the forest, corroborating studies that indicate that, in spite of the reduction of the infiltration rates in deforested areas, the groundwater recharge can be greater as a consequence of lower transpiration (Bruinjzeel, 1990; Calder, 1998; Bacellar, 2005). In general there is less infiltration of precipitation to groundwater under pasture, and greater losses to runoff and evaporation.

The physiology of plant canopies (i.e. stomata) influences canopy water exchange (Roberts, 2007). The degree to which highly productive rainforests can return water to the atmosphere via transpiration (including the evaporation of water pooling on leaf canopy surfaces) affects the amount of moisture that lowland Amazonia recycles back to the atmosphere via evapotranspiration and the amount of warming that is promoted when decreasing vegetation cover partitions more incoming solar energy into sensible and latent heat flux (Cowling et al., 2008).

SUMMARY AND CONCLUSIONS

This study quantifies time lags between rainfall and water level by cross-correlation analysis in transitional forest (Amazonia and Savanna) and cattle pasture areas in the North of Mato Grosso State, Brazil. In summary, the water level increased in the wet season and decreased in the dry season in both ecosystems. The maximum correlation coefficient between rainfall and water level was found at a time lag of 2 months in the forest and 1 month in the pasture.

From the analyses presented earlier, the conclusion is that the forest has a larger time lag (and smaller amplitude) than the pasture due to the forest having greater evapotranspiration, less average soil moisture, and consequently, a lower average level of the water table than pasture if the soil conditions are similar.

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