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Ecohydrology of dry regions of the United States: water balance consequences of small precipitation events

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ABSTRACT

Small precipitation events ($\leq$5 mm) are a key component of the precipitation regimes of dry regions in the United States. Understanding their importance is useful, but exploring their significance for water balance processes is of utmost consequence for our knowledge about the functioning of ecosystems and their responses to climate change. Our objective was to evaluate the implications of precipitation event size distributions for the partitioning of water loss between evaporation and transpiration and for the number of days with wet soil. We used sites from the Great Plains of the United States to provide long-term weather data for our simulation analyses. Our simulations varied distributions of precipitation event size and potential evapotranspiration (PET) for two contrasting soils: a sandy loam with low water holding capacity and a silt loam with high water holding capacity. Event size and specifically the numerical importance of the smallest size (0–5 mm) was the most important control on our results. Soil water holding capacity and PET were important modifiers of the responses. The ratio of evaporation to actual evapotranspiration (E/AET) increased as the percentage of small events increased and as PET increased. E/AET was greater for all combinations of event size and PET for the silt loam than for the sandy loam soils. The number of days with wet soil decreased as small events and PET increased. Our results suggest that the number of small events is one of the most important controls on water balance processes in arid and semiarid regions. Copyright © 2011 John Wiley & Sons, Ltd.

KEY WORDS arid; semiarid; precipitation event size; small events; Great Plains; evaporation; transpiration

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INTRODUCTION

Water balance in arid and semiarid regions is determined by interactions between inputs via precipitation (P) and losses via evaporation (E) and transpiration (T). A key influence on losses is the large, omnipresent influence of the blanket of reliably dry air that characterizes arid and semiarid regions. This dry air has high atmospheric evaporative demand, typically creating conditions where the potential amount of water that can be lost via evaporation and transpiration is higher than P inputs. Thus, on upland locations, water received as P is the upper bound on the amount that can be lost back to the atmosphere as evapotranspiration.

A recent analysis has established that in addition to the well-appreciated characteristics of low and variable precipitation amounts, the precipitation regimes of the arid and semiarid portions of the United States are numerically dominated by very small daily amounts (0–5 mm) (Lauenroth and Bradford, 2009). These small events account for 30–80% of total events depending on site location. The percentage of 0–5 mm events is significantly related to the latitude and longitude of the site, suggesting that mean annual temperature and continentality, respectively, are important influences on the size distributions of precipitation events (Lauenroth and Bradford, 2009).

Considerable recent work has focused on the biogeochemical significance of precipitation event size. Sala and Lauenroth (1982) speculated that the smallest precipitation sizes should have a larger effect on microbially controlled biogeochemical processes than on carbon acquisition processes in higher plants. Much of the recent attention to the importance of event size has focused on ecosystem-scale processes (Huxman *et al.*, 2004; Porporato *et al.*, 2006; Kurc and Small, 2007; Sponseller, 2007). Large and small events have been predicted to influence different suites of ecosystem processes (Huxman *et al.*, 2004). North American deserts have been the sites of several recent studies that have indicated that small events tended to favour carbon losses more than acquisition (Kurc and Small, 2007; Sponseller, 2007).

Although primary production and decomposition have received considerable recent attention, much less has been devoted to understanding the impact of precipitation event sizes on the balance between E and T and thus on overall ecosystem-level water balance and water use efficiency. The relative contributions of E and T to AET and the significance of event sizes for the balance between E and T represents an important gap in our understanding of ecosystem water balance in general and for arid and semiarid regions specifically (Lauenroth and Bradford, 2006; Lawrence *et al.*, 2007; Lauenroth and Bradford, 2009).

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Our objective for this article was to use simulation to evaluate the implications of precipitation event size distributions for the partitioning of water loss between evaporation and transpiration and for the number of days with wet soil. We were specifically interested to evaluate the water balance significance of the numerical importance of small events. Our simulation analyses were designed to answer the following specific questions:

1. How does large versus small event size influence the partitioning of water losses among interception, evaporation, and transpiration at a single site. How are these responses altered by soil texture (high vs low water holding capacity)?
2. How do event size, atmospheric evaporative demand, and soil texture influence the partitioning of water loss between evaporation and transpiration?
3. How do event size, atmospheric evaporative demand, and soil texture influence the maximum number of wet days in any single soil layer and the number of wet layer days for all layers?

METHODS

We utilized SOILWAT, a daily time-step soil water model developed for semiarid grassland (Parton, 1978). SOILWAT requires input information about initial soil water contents, weather, vegetation, and soil properties. Weather inputs include daily precipitation and daily maximum and minimum air temperatures, and mean monthly relative humidity, mean monthly wind speed, and mean monthly cloud cover. Vegetation inputs are mean monthly aboveground biomass, litter, the proportion of aboveground biomass that is green, and the proportion of root biomass in each soil layer. Properties for each soil layer consist of texture (percentage sand, silt, and clay), bulk density, field capacity, and wilting point and the relative proportions (relative to the entire soil profile) of evaporation and transpiration. In this analysis, we simulated soil water in eight layers (0–7·5, 7·5–15, 15–30, 30–45, 45–60, 60–75, 75–90, and 90–120 cm). All the plant parameters remained constant for our simulations. We varied weather inputs and in the simulations to assess the effects of soil texture we varied the percentages of sand, silt, and clay.

SOILWAT simulates interception by and evaporation from the canopy and litter layer, infiltration into the soil, distribution of infiltrated water among layers, and losses by bare-soil evaporation and transpiration from each layer. A description of SOILWAT is presented in Parton (1978) and examples of applications can be found in Lauenroth *et al*. (1993), Lauenroth *et al*. (1994), Coffin and Lauenroth (1993), and Lauenroth and Bradford (2006).

Effects of event size on transpiration and evaporation

We evaluated the effects of event size on the relative importance of water loss by evaporation versus transpiration at a single site in the shortgrass steppe of the Great Plains of North America (40 49′ N,−107 47′ W). We examined two event sizes: small (5 mm) and large (20 mm). Simulations were run for two 10-day periods, one in June and the other in July. Simulations were initiated by a precipitation event and water losses were followed over the subsequent 10 days. We repeated the simulations for the same 10 calendar days in June and July for each of 38 weather years from a shortgrass steppe site (Lauenroth and Bradford, 2006). Evaporation was calculated as the sum of interception and bare-soil losses and transpiration was summed over all layers. We repeated the experiment for each of the two soil textures with contrasting water holding capacities: sandy loam [field capacity = 21% (v/v); wilting point = 9% (v/v)] and silt loam [field capacity = 35% (v/v); wilting point = 16% (v/v)]. We used wilting point water contents as the initial soil water conditions for all layers in all our simulation analyses (Lauenroth and Bradford, 2006).

Effects of event size distributions and potential evapotranspiration on transpiration, evaporation, and wet days

This experiment was designed to evaluate the effects of event size distributions on evaporation, transpiration, and the number of wet days (defined as days when the soil water potential is greater than −1·0 MPa). We varied precipitation event size distributions, PET, and the same two soil textures as in the previous experiment. To represent variations in precipitation event size distributions, we used the results of Lauenroth and Bradford (2009) to identify 12 sites from the North American Great Plains, 4 with few small events (36% of total numbers of events), 4 with the median percentage of small events (58% of total numbers of events), and 4 with the largest percentage of small events (78% of total numbers of events) (Table I). Annual precipitation for the 12 sites was similar, varying from a low of 325 mm to a high of 400 mm. The number of years of daily data for the sites ranged from 28 to 30 years. To assess the effects of PET, we relied on a relationship published by Lauenroth and Burke (1995). SOILWAT calculates PET using the equation of Penman (1948). Lauenroth and Burke (1995) ran SOILWAT for 300 Great Plains sites and found that average annual PET was statistically related to mean annual temperature (MAT) ($r^2 = 0{\cdot}71$). To represent low, medium, and high PET, we modified daily maximum and minimum temperatures such that each of our 12 sites had the same mean annual temperature. Our manipulation preserved the measured seasonal temperature dynamics as well as the relationship between daily precipitation and temperature. We introduced a temperature coefficient to produce low, medium, and high PET. Low PET was represented by a MAT of 4 C, medium PET by a MAT of 12 C, and high PET by a MAT of 20 C. These MATs match up to PETs calculated by SOILWAT of 1140, 1540, and 1940 mm/year, respectively. Geographically, these PETs correspond to the US Great Plains sites in east-central Montana, west-central Kansas, and southern Texas. We counted a wet day when the soil water potential in any

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Table I. Key characteristics for 12 sites from the Great Plains of the United States used in experiment 2.

Station name[a]	Latitude (N)	Longitude (W)	Number of years	MAP (mm)	MAT (C)	% Small events
Sheffield, Texas, USA	30·68	−101·82	30	367	19·0	37
Midland 4 ENE, Texas, USA	32·02	−102·02	30	363	18·0	41
Crossroads 2, New Mexico, USA	33·50	−103·33	29	368	14·1	37
Plainview, Texas, USA	34·18	−101·70	30	372	14·9	58
Bell Ranch, New Mexico, USA	35·52	−104·08	30	375	13·9	30
Sheridan AP, Wyoming, USA	44·77	−106·97	30	370	7·4	79
Usta 8 WNW Kelly Ranch, South Dakota, USA	45·25	−102·30	28	325	7·1	58
Linton, North Dakota, USA	46·27	−100·22	29	344	6·0	58
Breien, North Dakota, USA	46·37	−100·93	30	406	6·4	58
Miles City, Montana, USA	46·42	−105·87	30	338	8·0	78
Trotters 3 SSE, North Dakota, USA	47·28	−109·90	30	373	6·2	79
Williston Sloulin Fld, North Dakota, USA	48·17	−103·63	30	356	5·5	79

[a] Weather station name from the National Climatic Data Center.

layer was greater than or equal to −1·0 MPa. We also tallied wet layer days, which was a day when a particular layer had a soil water potential greater than or equal to −1·0 MPa.

RESULTS

Event size on evaporation and transpiration

The balance between evaporation and transpiration following a precipitation event was more dependent upon event size than on soil type (Table II). Water loss was dominated by evaporation regardless of event size or soil type. Bare-soil evaporation accounted for an average of 61% of water loss and 28% of transpiration. The largest total percentage losses to evaporation (E/AET) were from the 5 mm simulations, which averaged 77% compared to 66% for the 20-mm simulations. Much of the difference between event sizes was accounted for by interception losses, which were 15% for the 5 mm simulations and 7% for the 20 mm simulations.

Event size and PET on transpiration and evaporation

The ratio of E to AET was significantly related to the percentage of small events and PET for sandy soils (Figure 1a)

$$E/AET = 0{\cdot}55 + 0{\cdot}00217 \times \text{Small events } (\%) + 0{\cdot}00012 \text{ PET (cm)}$$

Table II. Thirty-eight-year average percentages of total water loss for interception, evaporation and transpiration.

Soil type	Event size (mm)	Interception (%)	Bare soil evaporation (%)	Transpiration (%)
Silt loam	5	15	59	26
	20	7	60	33
Sandy loam	5	15	65	20
	20	7	59	34

These are results from soil water simulations. See the text for a description of the experimental design.

($P \leq 0{\cdot}001$; $R^2 = 0{\cdot}72$) and silt loams (Figure 1b)

$$E/AET = 0{\cdot}61 + 0{\cdot}00164 \times \text{Small events } (\%) + 0{\cdot}00018 \times \text{PET (cm)}$$

($P \leq 0{\cdot}001$; $R^2 = 0{\cdot}66$). The greatest proportion of total water loss was from evaporation regardless of event size or PET. E/AET was smallest when the precipitation regime consisted of few small events and PET was low. For both soils, E/AET increased slowly as PET increased, but rapidly as the percentage of small events increased. E/AET on a sandy soil increased from less than 0·65 when the precipitation regime consisted of 30% small events to approximately 0·75 at 80% small events. On the silt loam, E/AET increased from 0·68 with few small events to greater than 0·75 with 80% small events. The greatest proportional losses to bare-soil evaporation occurred at the greatest percentage of small events and the highest PET. Transpiration losses were the opposite of evaporation, greatest at small percentages of 5 mm events and lowest values of PET. Maximum proportional losses to transpiration were less than 0·40 for both soil types. Minimal transpiration losses were between 0·20 and 0·25 and occurred under high PET and many small events.

Event size and PET on wet days

The maximum number of wet days in a single layer was significantly related to the percentage of small events and PET for sandy soils (Figure 2a)

$$\text{Wet days} = 293 - 1{\cdot}35 \times \text{Small events } (\%) - 0{\cdot}576 \text{ PET (cm)}$$

($P \leq 0{\cdot}001$; $R^2 = 0{\cdot}85$) and silt loams (Figure 2b)

$$\text{Wet days} = 239 - 0{\cdot}706 \times \text{Small events } (\%) - 0{\cdot}613 \times \text{PET (cm)}$$

($P \leq 0{\cdot}001$; $R^2 = 0{\cdot}77$). Regardless of the soil type, the maximum number of wet days (a day when any

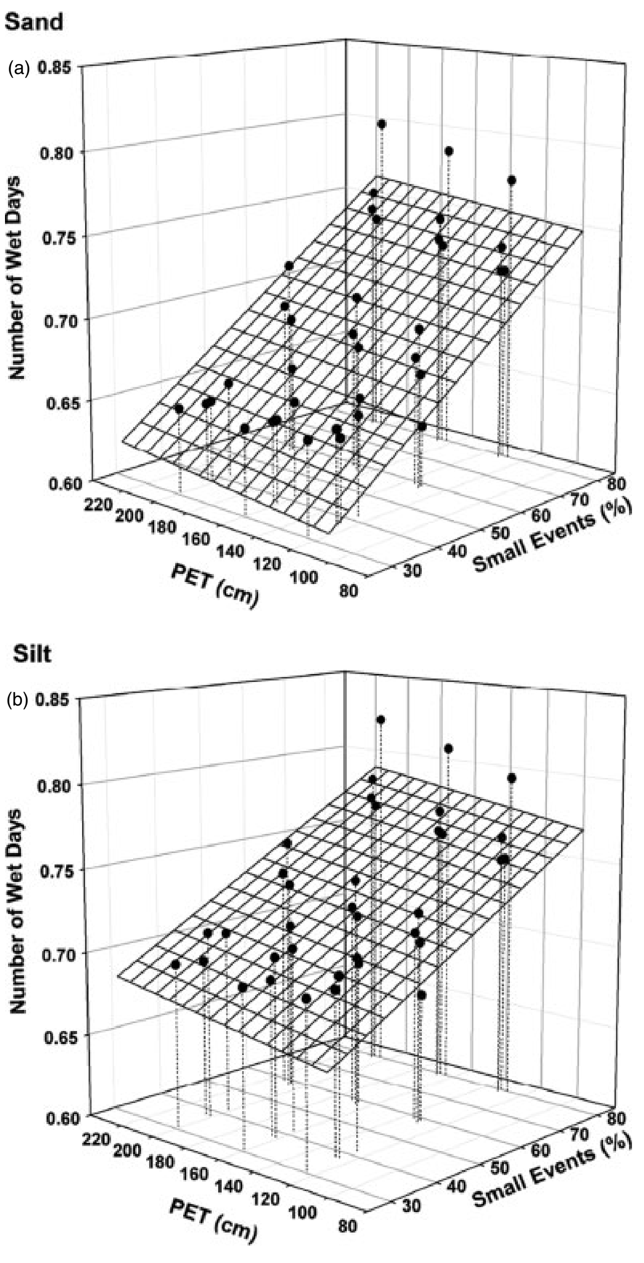

Figure 1. Regression relationship between the proportion of AET accounted for by total evaporation (interception plus bare soil) and PET and the percentage of small (0–5 mm) precipitation events in the precipitation regime for a sandy loam (a) and a silt loam (b) soil type.

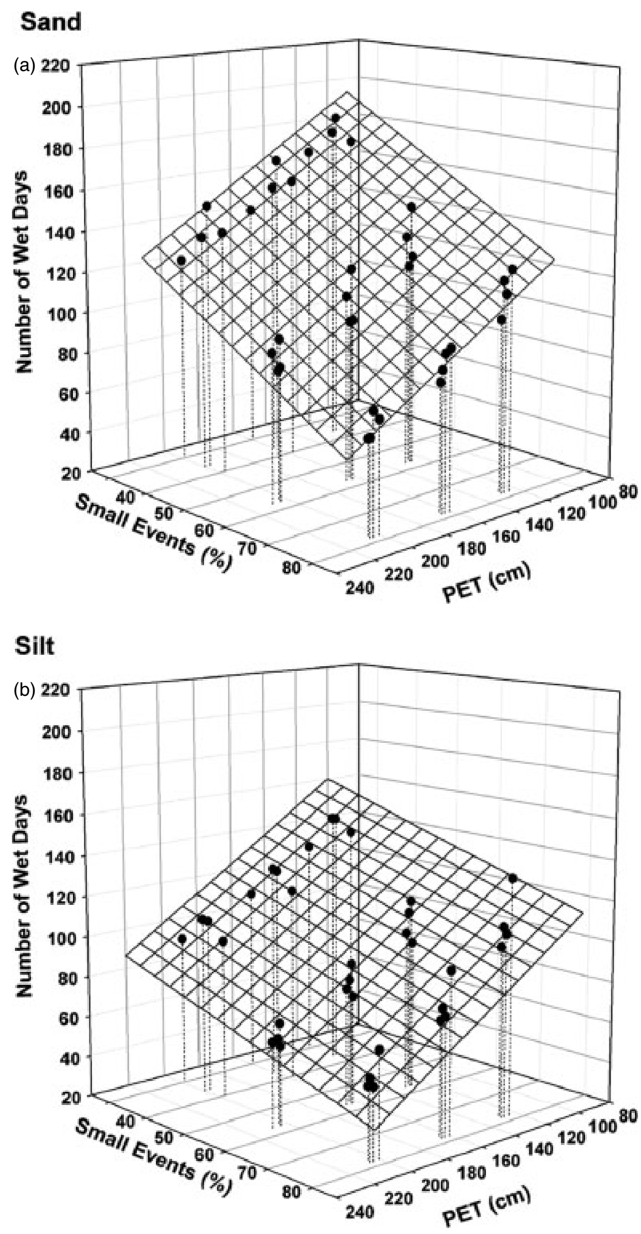

Figure 2. Regression relationship between the maximum number of wet days in a single soil layer and PET and the percentage of small (0–5 mm) precipitation events in the precipitation regime for a sandy loam (a) and a silt loam (b) soil type.

layer had a soil water potential greater than or equal to −1·0 MPa) in a single layer was greatest under the minimum percentage of small events and the lowest PET. In the sandy soil, the maximum occurred in the 15–30 cm layer for few and many small events and in the 30–45 cm layer for the median number of small events (Figure 3a and c). The 7·5–15 cm and the 15–30 cm layers had similar maximum values for few and the median number of small events in the silt loam (Figure 3d and e). For many small events, the maximum occurred in the 7·5–15 cm layer (Figure 3f). In all cases for both soils, the depth of the maximum was independent of PET. The sandy soil had a larger number of wet days at each combination of the percentage of small events and PET than the silt loam.

For both soil types, the initial slope of the cumulative frequency distribution of wet layer days was steeper for the highest percentage of small events compared to the median or fewest (Figure 4a and b). A wet layer day is a day when a particular soil layer had a soil water potential greater than −1·0 MPa. This relationship was obtained for both soil types. In the sandy soil with many small events, at least 70% of the wet layer days occurred at depths shallower than 30 cm (Figure 4a) and more than 90% of the wet layer days occurred at depths of 60 cm or less. With many small events, more than 60% of the wet layer days occurred at depths shallower than 15 cm in the silt loam soil and approximately 90% occurred at 30 cm or less (Figure 4b). Results for the median and minimum percentages of small events were

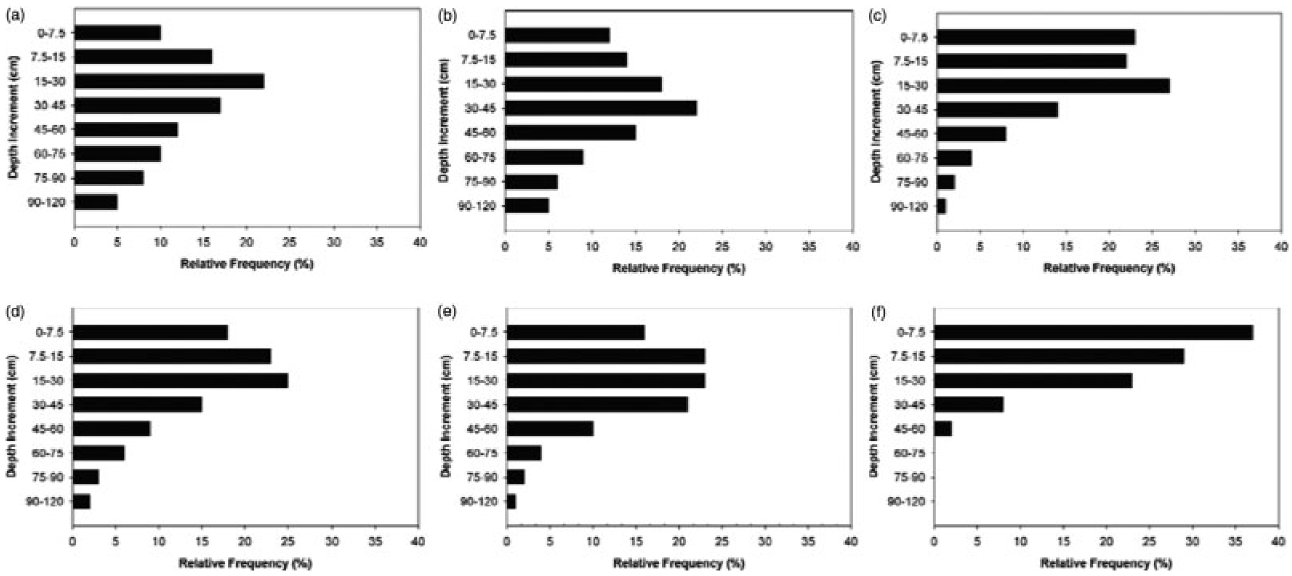

Figure 3. Relative frequency distributions of wet layer days for sandy loam sites having few (a), the median number (b) or many (c) small precipitation events and for silt loam sites having few (d), the median number (e) or many (f) small precipitation events. See text for details about numbers of small events and soils.

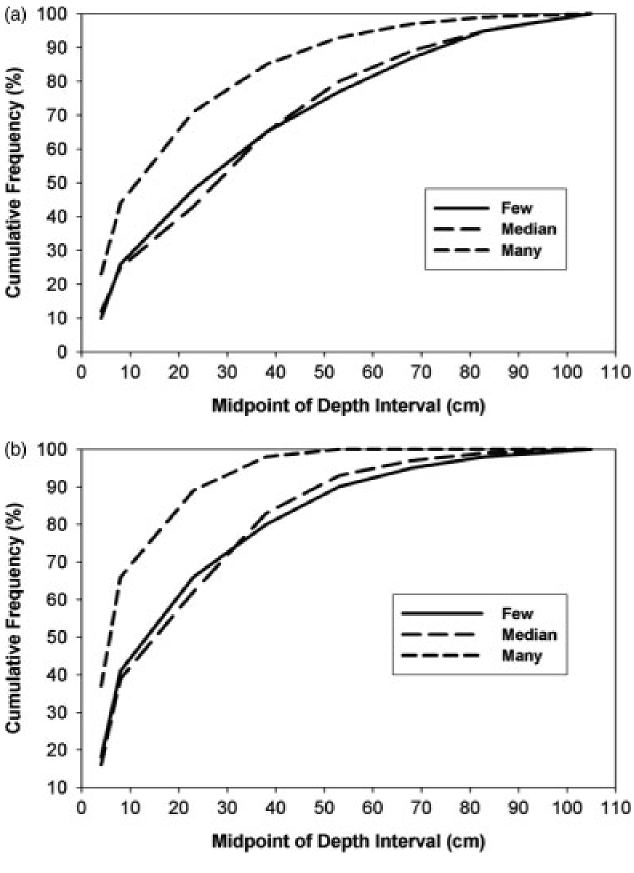

Figure 4. Cumulative frequency of the number of wet layer days throughout the soil profile for a sandy loam (a) and a silt loam (b) soil type.

similar within but different between soil types. In the sandy soil, 90% of the wet layer days occurred with the top 75 cm of the soil, but in the silt loam the top 60 cm of the soil accounted for 90% of the wet layer days.

DISCUSSION

Precipitation event size and specifically the frequency of the smallest size (5 mm) is an important determinant of partitioning among processes in the water balance of arid and semiarid ecosystems. We found the percentage of 0–5 mm events to be the single most important control on both the proportion of water lost to evaporation (E/AET) and the number of days with wet soil. Soil characteristic, coarse texture (low water holding capacity) versus fine texture (high water holding capacity), was an important modifier of the details of our results. Atmospheric evaporative demand (PET) was also influential, but of lesser importance than either event size or soil texture. The partitioning of losses between evaporation and transpiration and the number of wet days were both significantly related to the percentage of small events and PET and were different for sandy loam and silt loam soils. These relationships suggest explanations for scale-driven complexities in water balance patterns across landscapes with variable soils and regions with variable precipitation regimes and atmospheric demands.

Event size on evaporation and transpiration

Ecosystem water balance in arid and semiarid regions is heavily influenced by evaporative losses (Lauenroth and Bradford, 2006). Our results clearly indicate that the degree to which the precipitation regime of a particular site is dominated by small events will magnify the importance of evaporative losses in the water balance. Canopy and litter interception can account for a substantial fraction of a 5 mm event and bare-soil evaporation losses can be large (Table II). Together they can account for 75–80% of the return of a 5 mm event to the atmosphere. Interception is influenced by aboveground biomass and bare-soil evaporation by soil texture (Alizai and Hulbert, 1970; Wythers *et al*., 1999; Lauenroth and

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Bradford, 2006). In contrast, large events (20 mm) lose a much smaller percentage to interception (7 vs 15% for 5 mm), but a similar percentage to bare-soil evaporation (Table II). Lower interception and similar bare-soil evaporation make a larger proportion of water from large events available for transpiration (33–34% for a 20 mm event vss 20–26% for a 5 mm event) (Table II). Recent research in the semiarid shortgrass steppe of the US Great Plains found that increasing event size without changing the total amount of growing season precipitation resulted in a 30% increase in aboveground net primary production suggesting a shift in the partitioning of water between evaporation and transpiration (Heisler-White *et al*., 2009). These results are consistent with the prediction that large precipitation events will favour carbon capture over carbon loss (Sala and Lauenroth, 1982, Huxman *et al*., 2004). Our results also indicate that the effect of event size on the proportion of water utilized by transpiration is more pronounced in sandy loam than in silty loam soils (Table II), suggesting that coarse textured soils are more able to effectively store water from large precipitation events and that soil texture may influence how ecosystems will respond to alteration in precipitation regimes.

Event size and PET on transpiration and evaporation

Soil texture modified how the percentage of small events and PET influenced the partitioning of water loss between E and T (represented as E/AET in Figure 1a and b), but the effect was small. In all cases, the soil with the highest water holding capacity (silt loam) produced greater losses by evaporation. The largest differences occurred at the minimum percentage of small events. A greater evaporative loss from fine textured soils is consistent with empirical studies (Alizai and Hulbert 1970; Wythers *et al*., 1999). Soil texture is often a small-scale trait of landscapes typically varying on a scale of meters to tens of meters (Pan and Wang 2009; Anguela *et al*., 2010). Differences in water balance among microsites with dissimilar soil textures can be one of the explanations for variable success of plant functional types across landscapes (Coffin and Lauenroth, 1993).

Atmospheric demand for water represented by PET was positively related to the fraction of AET lost as E. The rate of change of E/AET with increasing PET was greater for the sandy loam than for the silt loam (Figure 1a and b). This suggests that high evaporative demand can negate some of the positive influence that sandy soils have on plant available water under arid and semiarid conditions (Alizai and Hulbert, 1970; Noy-Meir, 1973; Jalota and Prihar, 1998; Wythers *et al*., 1999). PET is a regional characteristic that is closely related to mean annual temperature. In the US Great Plains, mean PET is a relatively smooth feature that decreases from a high of greater than 200 cm/year in the southeast to less than 120 cm/year in the north (Lauenroth and Burke, 1995). Over the same area, mean annual temperature decreases from 20 C to less than 5 C. Analysis of the percentage of small events versus mean annual temperature indicated that, south to north in the Great Plains, they range from less than 50% to more than 70% of all daily events (Lauenroth and Bradford, 2009).

The key control on E/AET in our simulations was the proportion of 0–5 mm events (Figure 1a and b). Alone they accounted for the largest fraction of the variance explained by our regression analysis. Locations with precipitation regimes consisting of a large percentage of small events will have high proportional losses to interception as well as to bare-soil evaporation (Table II). Every 5 mm rainfall event, in our simulations, resulted in 0·75 mm of water being captured by the canopy and evaporated back to the atmosphere. This amounted to 15% of the water deposited by the event. By comparison, twice that amount of water, but only 7% of a 20-mm event, was captured by the canopy and subsequently evaporated (Table II). The depth of the soil vulnerable to bare-soil evaporation is related to soil texture, but regardless of texture water stored in shallow layers is more vulnerable to evaporation than water stored in deep layers (Jalota and Prihar, 1998; Wythers *et al*., 1999). Under our highest percentages of small events, more than 70% of AET was accounted for by the combination of interception and bare-soil evaporation regardless of soil texture or PET (Figure 1). These values are at the upper end of the range reported by other authors (Ng and Miller, 1980; Floret *et al*., 1982; De Jong and Hayhoe 1984; Wight *et al*., 1986; Paruelo and Sala, 1995; Reynolds *et al*., 2000). Precipitation regime, as indicated by the proportion of 0–5 mm events, in the arid and semiarid western United States is a regional attribute varying over both latitude and longitude (Lauenroth and Bradford, 2009). In the intermountain zone, because of its topographic complexity, both latitude and longitude are important dimensions of variability in small events where as in the Great Plains only latitude is important. Our analysis removed the correlation between the percentage of small events and PET and treated them as independent effects. This resulted in a potential for overestimation of E/AET, but because the percentage of small events was such an overwhelmingly large influence it minimized or negated the overestimation problem.

Event size and PET on wet days

The percentage of small events was the most important determinant ($r^2 = 0{\cdot}55$) of the number of wet days in our simulations on sandy loams soils, but not on silt loam soils where PET accounted for the largest percentage of the variance ($r^2 = 0{\cdot}55$). These results make clear that soil texture had a larger influence on the maximum number of wet days than it did in E/AET. The maximum number of wet days, which occurred at the lowest values of small events and PET, was 195 for the sandy loam and 158 for the silt loam (Figure 2). On average, each combination of small events and PET produced 38 more wet days for the sandy loam than for the silt loam. Our predicted decreases in wet days as both the percentage

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of small events and PET increase is consistent with the results of Sala *et al*. (1992). For the shortgrass steppe they reported a large increase in the amount of water received in large precipitation events in wet years and a very small increase for small events resulting in decreased relative importance of small events.

Our texture results are consistent with greater bare-soil evaporative losses from fine than from coarse texture soils (Alizai and Hulbert, 1970; Jalota and Prihar, 1998; Wythers *et al*., 1999). The results for our analysis of wet layer days provide the basis for an explanation of the wet day results. For both textures, the maximum percentage of small events (80%) resulted in shallower depth distributions of wet layer days and the distribution for the silt loam was considerably shallower than for the sandy loam (Figure 3). Many small events occurring on a silt loam resulted in 90% of the wet layer days occurring at 20-cm depth or shallower (Figures 3 and 4). In contrast, the results for the sandy loam indicated that 90% of the wet layer days occurred at a depth of 50 cm or shallower. These differences between textures persisted for the median and few small events, but they were considerably smaller.

The size distribution of precipitation events, especially the large proportion of events in the smallest size classes, is a dominating influence on the water balance of ecosystems in the arid and semiarid regions of the United States. Precipitation regime is a large-scale character and contributes to regional variability in water balance. Small precipitation events are an important control on how much of the water from the atmosphere reaches the soil surface and where it is stored in the soil. These small events suffer a large percentage loss to canopy and litter interception and the water reaching the soil surface tends to be stored in the most superficial layers where it is vulnerable to large losses via bare-soil evaporation. PET influences these losses and similar to precipitation regime is a large-scale feature that influences regional water balance variability. Soil texture can have a mitigating or a reinforcing effect on bare-soil evaporation losses. Coarse texture soils will minimize bare-soil evaporative losses and fine texture soils will maximize them. Soil texture varies at the landscape scale and therefore results in small-scale variability in water balance. Regardless of the texture of surface soils, ecosystems in dry regions lose a huge portion of the water they receive from precipitation back to the atmosphere via evaporation.

Implications of climate change

Predicted climate change can influence the water balance of arid and semiarid ecosystems by changing precipitation amounts and seasonality, changing the distribution of event sizes, and changing atmospheric evaporative demand. The suite of global climate models utilized in the IPCC (2007) made predictions for each of these potential changes. All the predictions about changes in precipitation were more uncertain than those associated with changes in temperature (IPCC, 2007). Translating these predictions into results relevant for our analysis means that predictions about changes in event sizes are more uncertain than predictions about changes in PET (temperature). The IPCC (2007) simulation analyses suggested that the frequency of the smallest precipitation events would decline by 5% over the next century (Karl *et al*., 2008). Our results suggest that this decline would decrease the proportion of precipitation that is lost via evaporation by approximately 1% for both sandy loam and silt loam soils and increase the number of days with wet soil by up to 4% on silt loams and by up to 6% for sandy loams (Table III).

Will this enhanced water availability as a consequence of alterations in precipitation event sizes offset the increased evaporative demand created by the warming climates that are predicted for essentially all areas in the western United States over the next century (Seager *et al*., 2007, Karl *et al*., 2009)? Annual temperatures for the Great Plains are predicted to rise by 1·4 C (low emissions scenario) to 6·5 C (high emissions scenario) by the end of the century (Karl *et al*., 2009). The Lauenroth and Burke (1995) relationship between temperature and PET in the Great Plains suggests those changes will translate into average increases in PET of 7 cm for the low emission scenario and 32·5 cm additional PET for the high scenario. In the Northern Great Plains, the temperature increases would convert to 6 and 27% increases in atmospheric demand. In the southern Great Plains, it would mean a 3–15% increase in PET.

Regressing our maximum wet day results on annual PET alone suggests that wet days will decrease 0·6 days per cm increase in PET. On sandy loam soils, the low emission scenario would cause a decrease of up to 4% per year and for the high emission scenario the decrease would be 13–21% (Table III). On silt loam soils the decrease would be from 3 to 6% for the low scenario and 15 to 28% for the high scenario.

Table III. Predictions of the effects of changes in small precipitation events and temperatures on E/AET and wet days under climate change scenarios for the Great Plains of the United States.

	Decreased small events	Increased temperature low scenario	Increased temperature high scenario
Sandy loam			
E/AET	Small decrease (<1%)	Small increase (<1%)	Small increase (<1%)
Wet days	Moderate increase (1–6%)	Moderate decrease (3–4%)	Large decrease (13–21%)
Silt loam			
E/AET	Small decrease (<1%)	Small increase (<1%)	Small increase (<1%)
Wet days	Moderate increase (1–4%)	Moderate decrease (3–6%)	Large decrease (15–28%)

Our results suggest that declines in water availability stemming from higher temperatures and increased evaporative demand will overshadow the potential increases in water availability as a consequence of decreasing importance of the smallest precipitation events. Our findings concur with other analyses that have concluded that there will be a net drying over the region (Seager *et al*., 2007, Karl *et al*., 2009).

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