WATER RELATIONS AND BIOMASS RESPONSES TO IRRIGATION ACROSS A TOPOGRAPHIC GRADIENT IN TALLGRASS PRAIRIE

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Abstract. A long-term study was begun in 1991 to assess the effects of water supplementation along a 100 m transect that spanned upland and lowland annually burned tallgrass prairie on the Konza Prairie in NE Kansas. Irrigation was scheduled to meet predicted evapotranspirational demands. At 12 points along the transect, and in an adjacent control transect, seasonal patterns in plant water status of big bluestem (*Andropogon gerardii* Vitman.) and end-of-season (peak) total aboveground biomass production were measured. In the control transect, greater levels of midday water stress were observed in uplands relative to hillside and lowlands, but irrigation resulted in similar plant water status along the entire topographic gradient. Seasonally, irrigation increased midday leaf water potentials in big bluestem by 42% in uplands, 35% in lowlands and 28% at hillside sites relative to the control transect. Biomass responses were also greatest in the uplands (61%) and least at the hillside sites (45%). This landscape-level experiment is scheduled to run for 10 years to assess long-term effects of water supplementation on site productivity, species composition and soil properties.

INTRODUCTION

In most grasslands, water availability usually limits key ecosystem processes, such as net primary production (NPP), during portions of the growing season. Although the tallgrass prairie lies at the eastern, and most mesic, edge of the extent of North American grasslands, multi-year and seasonal droughts, and their effects on the tallgrass biota, are well-documented (Weaver 1954; Knapp 1984). Relative to other grasslands, tallgrass prairies may experience the greatest year-to-year range in annual precipitation. For example, it is not uncommon for a year characterized by severe drought to be followed by a year in which virtually no water stress is measurable (Knapp 1984). Indeed, because annual precipitation in the tallgrass prairie is sufficient to support more mesic, woody vegetation (Bragg and Hulbert 1976), drought is often included with fire as key factors maintaining these systems as grasslands (Weaver 1954; Knapp and Seastedt 1986; Collins and Wallace 1990).

In the topographically dissected Flint Hills of NE Kansas, it is difficult to assess the degree of limitation to biotic processes caused by water limitation because of two factors: (1) soil types and depth vary significantly with topographic position, and (2) "control" data from sites where other climatic factors are similar, but water is non-limiting, are absent under natural conditions. A core research area of the Long Term Ecological Research (LTER) Program at Konza Prairie is to elucidate controls of NPP and other system characteristics (Callahan 1984). Hence, we established a long term (10 year) irrigation transect in 1991 to assess the role of water as a factor controlling ecological processes across topographic gradients in tallgrass prairie. Below, we describe the study, report results from the first year, and discuss several hypotheses to be tested by this experiment.

METHODS

Research was conducted on the Konza Prairie Research Natural Area (KPRNA) in NE Kansas. KPRNA is a 3,487 ha tract of unplowed, native tallgrass prairie dominated by big bluestem (*Andropogon gerardii*), Indian grass (*Sorghastrum nutans*) and a variety of forbs (Freeman and Hulbert 1985). In 1991, an irrigation transect was established near the KPRNA headquarters in an annually burned (spring) area. The transect is 100 m in length and spans upland, hillside and lowland topographic positions (Figure 1). A total of twelve 1.5 m tall high-impact sprinkler heads equipped with discharge regulators and supplied by 7.5 cm diameter irrigation pipe were installed at 10 m intervals. A grid of 24 rain gages located along a portion of the transect was used to quantify the amount and distribution of water added by the sprinklers (Figure 1). Maximum application rate along the center of the transect was 8 mm/hr. Distribution of water was non-uniform at the ends of the transect and at a rock outcrop where irrigation was from a single sprinkler head. Each rotating sprinkler head provided water to a radius of 15 m from the transect (Figure 1) and all measurements of tallgrass prairie responses were made within ±3 m of the sprinkler line, where the maximum amount of water was added. An adjacent transect north of the irrigated area was marked and used as a control site.

Irrigation was scheduled to maintain the sum of actual rainfall and supplemental water slightly above estimated actual evapotranspiration (ET) levels. ET was estimated with established Penman combination equations (Lamm et al. 1987) and data from a weather station located <200 m from the transect.

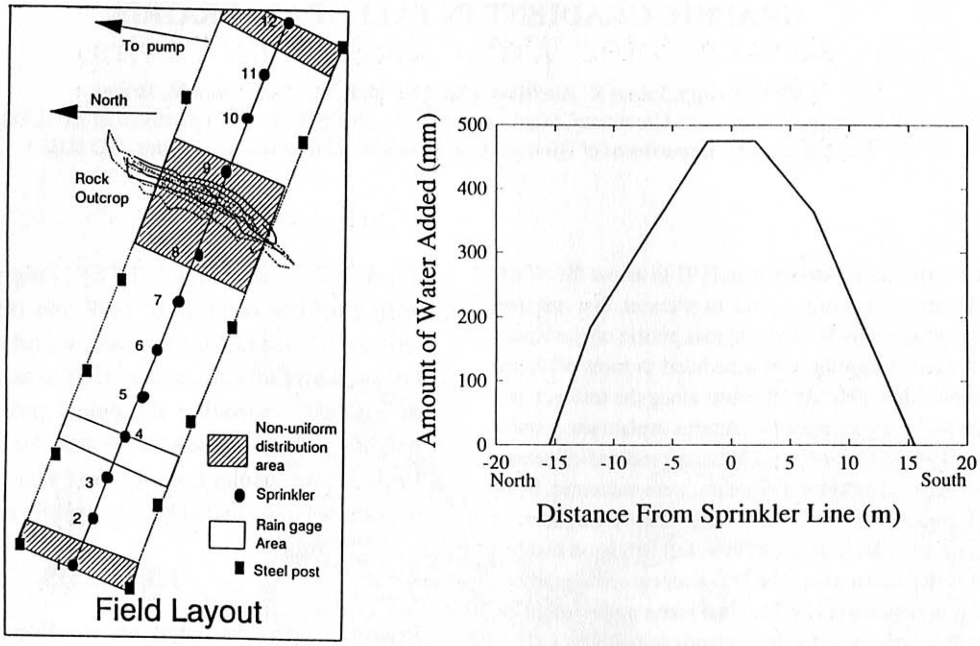

Figure 1. Diagram of irrigation transect (left) with locations of sprinklers numbered. Upland sites are 9-12, hillside sites are 6-8, and lowland sites 1-5. Steel posts delimit the perpendicular extent of water supplied by the sprinklers. Non-uniform distribution areas occur where individual sprinklers do not have adjacent sprinkers on either side. The rain gage area is where a grid of gages is used to quantify the distribution of water added. The amount of water added during the 1991 season within this rain gage area is shown in the right panel. Water reached 15 m on either side of the line of sprinklers (denoted by "0").

Water status of the dominant tallgrass prairie species, big bluestem, was measured at about 2 week intervals throughout the growing season in both the irrigation and the control transect. Water status was assessed by estimating xylem pressure potential (XPP) with a pressure chamber (PMS model 1000) in 5-7 leaves collected at predawn and midday (1300 CST). Predawn values provide an estimate of maximum XPP after plants have equilibrated with soil moisture overnight, and midday values represent the lowest values of XPP occurring during the day. Reductions in XPP below -1.5 MPa reduce physiological activity in big bluestem (Knapp et al., 1993).

Near the end of the growing season (Sept.), aboveground NPP was quantified by harvesting all biomass within 4 0.1 m^2 quadrats randomly placed adjacent to each of the 12 sprinkler locations along the irrigation transect, and at parallel sites in the control transect. Biomass was separated into grass and forb components, oven-dried and weighed to the nearest 0.1 gram.

RESULTS AND DISCUSSION

Almost 500 mm of water was added to the irrigation transect in 1991 (Figure 1). Actual rainfall was substantially below the 30-yr mean for Manhattan, KS (located 12 km north of KPRNA), but 20 irrigation events, each adding about 20 mm of water, resulted in the sum of natural rain plus supplemental water to be in excess of estimated ET (Figure 2). The decision to irrigate was made weekly based on estimates of ET and the previous week's rainfall, thus, irrigation events were not spaced evenly throughout the season. Instead, irrigation occurred most frequently during July and August when rainfall was lowest and temperatures were the highest.

Irrigation appeared to increase the water status (XPP) of big bluestem relative to control plants along the entire topographic gradient (Figure 3). When data from topographically similar sites were combined for the control transect, big bluestem at the upland sites had lower seasonally averaged XPP ($p < 0.05$, ANOVA) compared to hillside and lowland sites for both predawn and midday sampling periods. In contrast, there were no differences among topographic positions in XPP for the irrigated plants. Thus, at predawn, irrigation at the uplands sites resulted in the greatest reduction in potential water stress, with hillside and lowland sites similarly affected (Figure 3). At midday, the smallest difference between irrigated and control XPP occurred at the

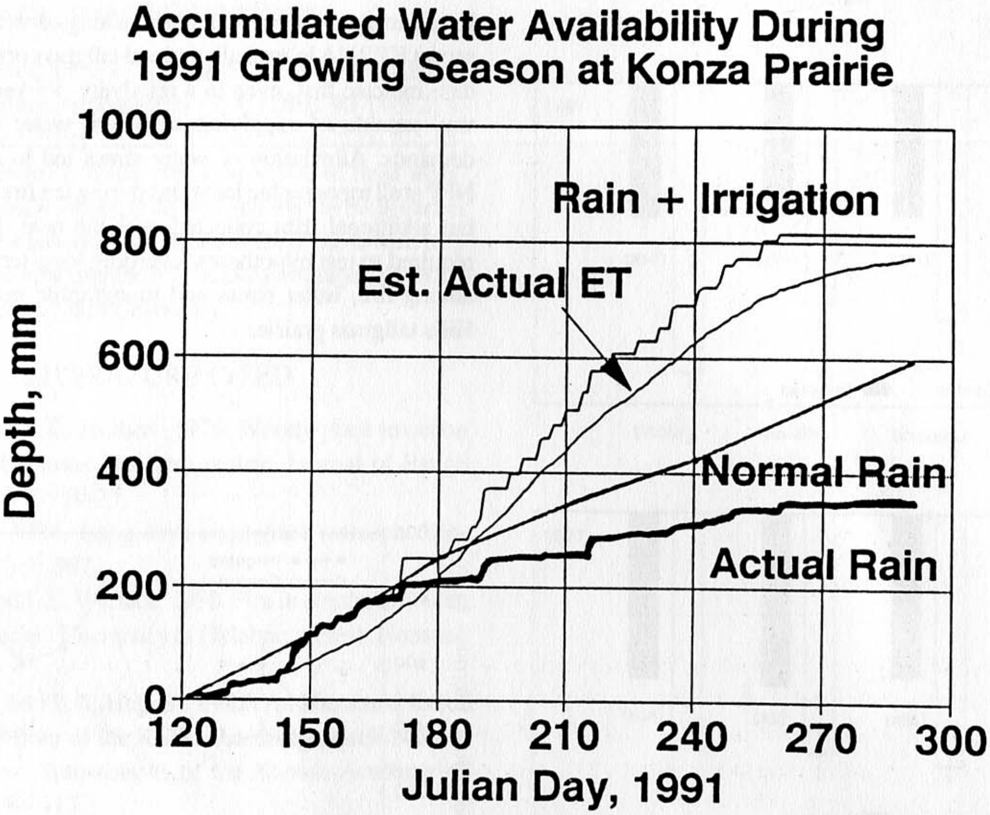

Figure 2. Season course of actual rainfall at headquarters on Konza Prairie (1991), "normal" rainfall (30-yr mean) for Manhattan KS (<15 km from Konza Prairie), estimated actual evapotranspiration (ET) based on weather data from headquarters, and the sum of rainfall plus irrigation water added to the transect.

hillside locations with the greatest difference again at the upland sites (Figure 3). These data show the expected pattern of greater water stress at upland sites with shallow soils (Knapp 1985) but they also suggest that topographic interactions with plant water status may be absent in very wet years.

As expected, supplemental water increased ($p < 0.05$) aboveground biomass production along the irrigation transect relative to adjacent control sites (Figure 4, top). When measurements from topographically similar sites were combined along the control transect, NPP was greater ($p < 0.05$, ANOVA) at the hillside locations relative to the lowland, with the upland sites not different from either the lowland or the hillside sites (Figure 4, bottom). In contrast, no difference in NPP was detected among topographic positions along the irrigation transect, although trends were similar to the control transect. Irrigation resulted in the greatest proportional increase in NPP at upland and lowland sites relative to control data, with the smallest increase at hillside locations (Figure 4, bottom).

These patterns in NPP in response to irrigation are consistent with estimates of midday XPP (Figure 3). The hillside sites (6, 7 and 8) occurred below a rock outcrop (Figure 1). Such outcrops typically result in intermittent "seeps" caused by the downward flow of soil water being deflected by relatively impermeable limestone strata. Moreover, the finer textured soils in the lowlands apparently had lower infiltration rates relative to the uplands sites (inferred from the presence of standing water at lowland sites) and this may have led to reduced differences in XPP and NPP between uplands and lowlands than might have been expected. The lack of differences in NPP among topographic locations along the irrigation transect supports the view that all sites may be equally productive given similar water availability.

Additional Goals Of The Irrigation Experiment

Although estimates of NPP and plant water status will continue to be made during the scheduled 10-year duration of this experiment, replicate irrigated and control transects will be established in 1993 to allow for more robust statistical analysis of the data. Along these transects, a number of other variables will be measured to address additional hypotheses. Soil moisture in irrigated and control sites measured using a time domain reflectometry system and an array of probes is scheduled to begin in 1993. This will enable us to better characterize differences in water availability across topo-

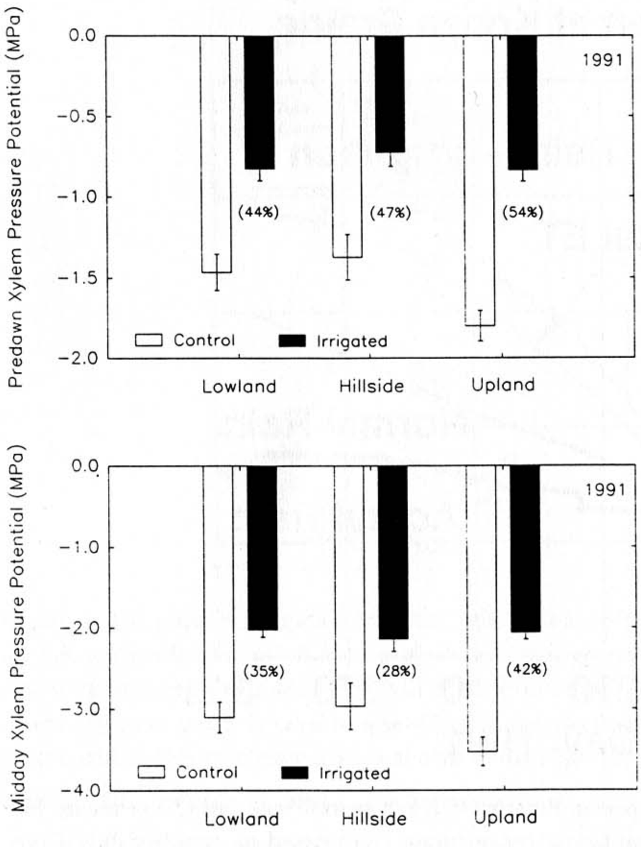

Figure 3. Comparison of seasonally averaged predawn and midday xylem pressure potential measurements for big bluestem at three topographic positions along the irrigated and control transects. Numbers in () indicate the per cent difference between irrigated and control values. Vertical bars represent ± 1 standard error of the mean. Lowland (1-5), hillside (6-8) and upland (9-12) sites refer to locations in Fig. 1.

graphic gradients. Vegetative species composition was quantified in 1991 and will be reassessed annually along the irrigated and control transects to test the hypothesis that annual spring fires are sufficient to maintain the grasses dominant even if water is not limiting. Soil organic matter and nutrient content was also measured initially and will be measured again at the conclusion of the study. These data, along with annual measures of site productivity, will be used to test hypotheses regarding the effect of long-term annual burning on soil fertility. Results from simulation models predict that soil C, N and ultimately NPP will be reduced under an annual burning regime (Ojima et al. 1990). The long term addition of supplemental water to annually burned tallgrass prairie may accelerate these changes.

In summary, we have established a long-term irrigation transect at KPRNA in annually burned tallgrass prairie. First year data indicate that, even in a relatively dry year, our system was capable of supplying sufficient water to exceed ET demands. Alleviation of water stress led to an increase in NPP at all topographic locations during the first year of study, but additional data collected over the next decade will be required to test hypotheses regarding long-term interactions among fire, water stress and topographic position in Flint Hills tallgrass prairie.

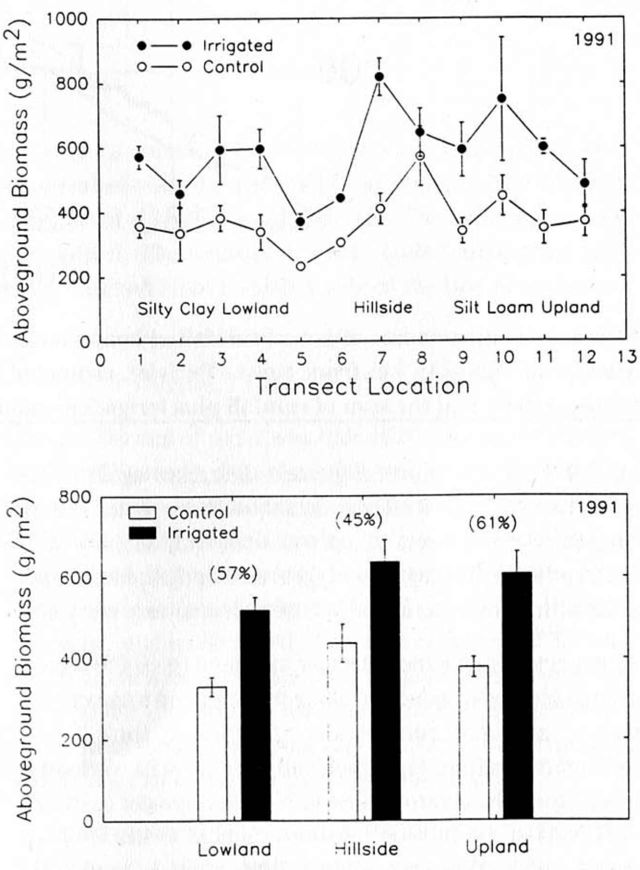

Figure 4. Top: Variation in aboveground biomass (an estimate of NPP) along the irrigation and control transects in 1991. Transect location numbers correspond to the sprinkler numbers in Figure 1. Vertical bars denote ±1 standard error of the mean. Bottom: Comparison of aboveground biomass in irrigated and control transects according to topographic positions (see Figure 3). Numbers in () indicate the per cent differences between irrigated and control values. Vertical bars denote ±1 standard error of the mean.

ACKNOWLEDGEMENTS

Research was supported by a National Science Foundation Long-Term Ecological Research grant (DEB 90-11662) to Kansas State University, and the Kansas Agricultural Experiment Station. Patrick Avila provided valuable field assistance and Thomas Rosburg reviewed and improved an earlier version of the manuscript. Information about these data may be obtained by contacting the LTER Data Manager, Division of Biology, Kansas State University.

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