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Fixed location rain shelters for studying precipitation effects on rangelands*

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Seasonal distribution of rainfall is thought to be important in structuring arid and semi-arid plant communities. Controlled studies of rainfall distribution have proven difficult, especially at the scale necessary to evaluate plant community changes. Simply comparing years with different rainfall distributions is problematic because rainfall amounts are seldom constant, and it is impossible to factor out other climatic variables (such as temperature). The authors describe an approach for studying rainfall distribution using large (12 × 30 m) fixed-location rain shelters. Rainfall was excluded and water was applied to three zones within each of five individual rain shelters. The treatments applied to the watering zones were: (1) average precipitation distribution from long-term records (50% from November to March, 30% April to June, and 20% divided among July, August, and October); (2) spring distribution (80% from April to July); and (3) winter distribution (80% from November to March). This approach allows for a comparison of treatments where only rainfall distribution is altered. Factors to consider in designing a study of this nature include: cost of structures and plot size necessary, quality of water to be applied to plots; differential animal use of treatments; and management of watering treatments.

Keywords: Artemisia tridintata; climate change; rainout shelters; precipitation distribution

Introduction

Structure and function of arid and semi-arid ecosystems of the world are strongly influenced by the nature of the precipitation they receive. Precipitation amount is certainly important, but so is seasonal distribution of precipitation. For example, Peco and Espigares (1994) found that floristic composition of annual Mediterranean pastures was influenced by the timing of autumn rains. Cook and Irwin (1992) suggested that summer rainfall patterns of the North American Great Plains favoured graminoid cover, whereas the winter rainfall pattern of the Great Basin favoured shrubs.

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Although the climate has never been static, human activities have the potential to alter global climate within a relatively short time scale. This possibility has focused attention on ecological responses to climatic patterns and climate change. Graham and Grimm (1990) analysed floristic responses to late Quaternary global warming and concluded that species responded individualistically, rather than as communities. Thus, new community patterns were created as climate changed. A difficult problem for the scientific community is to provide realistic assessments of how global change will influence agricultural and native ecosystems. In many parts of the world, rangeland assessment is based either partially or entirely on species composition. Evaluating climate change effects on intact plant communities has proven difficult at best. Much of the work on climate change has focused on increasing atmospheric CO_2 levels, and the majority of this research is single-species oriented and limited to either greenhouse or growth-chamber studies. The effect of timing and amount of precipitation on rangeland ecosystems has seldom been experimentally evaluated in the field. Most studies of this nature have been observational, comparing species changes over years, rather than manipulating precipitation.

One approach to studying amount and timing of precipitation is the use of rain shelters. These shelters have typically been moveable structures that slide on rails, and cover plots only during precipitation events (e.g. Ritchie, 1987). Rain shelters have been used quite extensively to study precipitation effects on crop and forage species. However, in cases where intact native communities are to be studied, and species richness and diversity are of interest, size limitations of moveable shelters become a problem. Shelter size is limited by costs and physical difficulties of moving a large structure (Upchurch *et al.*, 1983). A 350 m^2 moveable rain shelter cost nearly $95,000 in 1984 (Ries & Zachmeier, 1985). Another approach has been the use of fixed, small plot rain shelters, such as those described by Whitford *et al.* (1995). This type of shelter has typically been used to simulate drought during specific periods of the year, and is subsequently removed from the plots.

Research approach

The primary research goal was to evaluate the effect of precipitation timing on sagebrush steppe vegetation. The current climate is characterized by a predominance of winter and spring precipitation with dry summers and variable autumn precipitation. The annual average precipitation is about 30 cm. There is evidence that during the past 12,000 years the season of maximal precipitation has varied in what is presently the sagebrush steppe region of North America (Miller & Wigand, 1994). Although general circulation models (GCMs) do not effectively resolve climate in this region, the potential effect of atmospheric warming would be a decline in winter precipitation and an increase in summer precipitation (Nielson *et al.*, 1989). Thus, knowledge of precipitation timing shifts should aid in interpreting past vegetation change as well as allowing some prediction of what might be expected in the future. In the shorter term there is interest in how yearly variation might influence plant species composition. There is large yearly variation in precipitation pattern in this region, and land managers must attempt to separate the yearly climatic variation from impacts of management.

One disadvantage of working in a shrub-dominated ecosystem is that relatively large plots are required to assess plant community changes. The community of interest in this case was dominated by Wyoming big sagebrush (*Artemisia tridintata* spp. *Wyomingensis*) and several native bunchgrasses. Shrub cover averages 10 to 12%, and given the average shrub size it is calculated that a 7·5 × 7·5 m plot would be required to provide 10 sagebrush plants. Plots with an area of 7·3 × 8·0 m were used with a 2 m border around each plot, and three precipitation treatments per replicate. Thus each replicate would be about 10 by 30 m. From past experience it was concluded that five replications would be the minimum required to evaluate plant community response. Using the cost analysis of Ries and Zachmeier (1985) and assuming 3% annual inflation from 1984 to 1994, the cost of five moveable rain shelters of this size would be in excess of $600,000 U.S. Given the budgetary constraints of most research units and granting agencies, the moveable rain shelter approach appeared inappropriate. In addition, moveable rain shelters can be difficult to operate during harsh winters (Ries & Zachmeier, 1985).

An alternative approach is to construct fixed rain shelters to exclude natural precipitation and use sprinklers to apply predetermined distributions and/or amounts of precipitation. An additional benefit of sprinklers is that studies can be designed to evaluate more than just water stress. During late summer and fall of 1994, we constructed five 12 × 30 m rain shelters at the Northern Great Basin Experimental Range (119° 43′ W, 43° 29′ N) 70 km west of Burns, Oregon, U.S.A. The rain shelters were built with pole and truss construction and initially covered with transparent fiberglass glazing (Figs 1 and 2). The total cost of construction and materials for the five rain shelters (including sprinkler systems) was $105,200 U.S. Three precipitation-timing treatments were established under each shelter. The treatments were as follows: (1) average precipitation distribution from long-term records (50% from November to March, 30% April to June, 20% divided among July, August and October); (2) spring distribution (80% from April to July); and (3) winter distribution (80% from November to March). Experimental units were 7·3 × 8·0 m, with a 2 m buffer around each plot. Ambient plots of identical size were established outside of each rain shelter as well. In spring of 1996, gutters were added to divert water away from the border edges. The cost of the gutters was about $4000·00 U.S. During early summer of 1998 the fiberglass glazing material was replaced with Dynaglass®, a clear polycarbonate material.[1]

Results and discussion

Rain shelter microclimate

All plots were instrumented with temperature and moisture sensors. Rainout shelter effect on environmental parameters was determined by placing automated weather stations (Campbell Scientific Inc., Logan, UT, U.S.A.) underneath, and 50 m south of a shelter. Global solar radiation (W/m^2) was recorded with a silicon pyranometer (LI200X, LI-COR, Inc.) and photosynthetically active radiation (PAR) (umol/m^2/s) was measured with a quantum sensor (LI190SB, LI-COR, Inc.). Relative humidity (RH) was estimated using a thin-film capacitor. Air and soil temperatures were recorded with thermistors. Air temperature and RH sensors were housed in a radiation shield. Wind speed was recorded using a standard cup anemometer. Measurements presented in Table 1 were taken over a 240-day period between 5 April and 30 November, 1995. The fiberglass glazing reduced average total radiation to approximately 70% of ambient levels and PAR to 50% of ambient levels. Compared to ambient, the shelter reduced wind speed by 28%, relative humidity by 1·5%, and increased soil and air temperatures by 16 and 4%, respectively. Dynaglass® allowed more transmission of PAR compared to the original fiberglass glazing (Fig. 3). The wood structure of the shelters will result in some PAR reduction regardless of glazing material. Dugas & Upchurch (1984) investigated moveable shelters and also found significant changes in microclimate while shelters were over the plots. Both shelter designs alter microclimate, and researchers must take this into account when interpreting results.

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[1] Mention of trade names does not indicate endorsement by either USDA or Oregon State University.

Figure 1. Fixed location rain shelter. Both this picture and the one in Fig. 2 were taken after the Dynaglass® glazing had been installed.

Figure 2. Close-up view of rain shelters. Sprinkler pipes radiate from mainline at top, center of the rain shelter.

Table 1. *Seasonal environmental data measured by shelter and ambient weather recording stations located under and 40 m south of a shelter, respectively. Solar averages are for daytime hours; all others are 24-hr means. Summaries are for 240 days between 5 April and 30 November, 1995*

	Average		Maximum		Minimum	
	Ambient	Shelter	Ambient	Shelter	Ambient	Shelter
Total solar (Watts/m^2)	420	298	1021	811	0	0
PAR (μmol/m^2/s)	840	422	2006	1413	0	0
Wind (m/s)	3·6	2·6	10·4	7·9	0	0
Re. Hum. (%)	51·7	50·9	100	100	4·3	4·8
Soil °C (5·10 cm)	15·4	17·9	38·1	41·3	– 5·6	– 5·5
Air °C	11·4	11·9	33·2	33·8	– 17·3	– 15·2

Irrigation

Artificial precipitation was applied to rain shelter plots with an overhead sprinkler system. The system was divided into three zones per rain shelter, and was constructed of polyvinylchloride (PVC) piping and garden-type sprinkler heads (Fig. 2). Each plot was watered using a 3 × 3 array of 1/4, 1/2, and full circle sprinklers (15′ series, 1·65 gpm @ 30 psi; Toro Company, Riverside, CA, U.S.A.). The system is designed to drain when turned off to prevent pipe breakage during freezing weather. Five rain gauges were placed at ground level in each plot (15 total plots; 3 treatments × 5 rain shelters) to assess the total amount of artificial precipitation applied to a plot. We used the approach described by Wrage *et al.* (1994) for construction of inexpensive rain gauges. The data in Table 2 is for one watering in February, 1995. The standard errors in Table 2

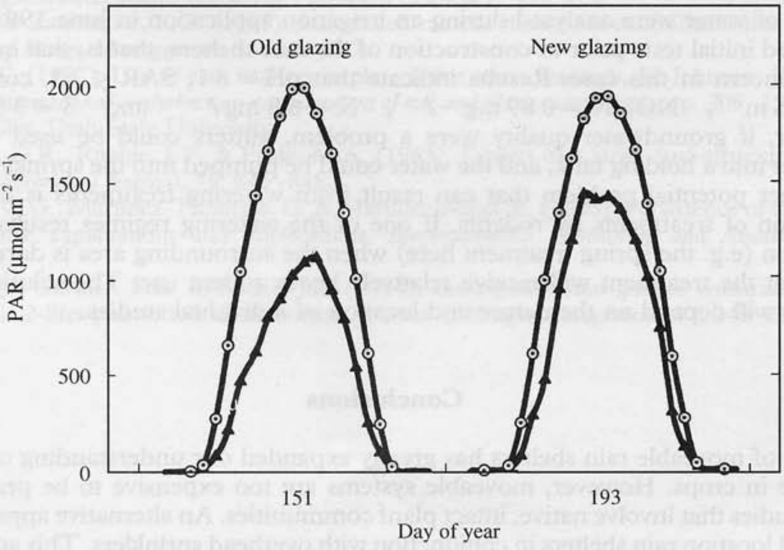

Figure 3. Photosynthetically active radiation (PAR) under a rain shelter and adjacent to the shelter during full sun days in 1998. On day 151 the shelter had fiberglass glazing and by day 193 the glazing had been replaced with Dynaglass®. —▲— Under shelter; —○— Full sun.

Table 2. *Average irrigation volume (mm ± SE) received by five rain gauges located in each current, winter and spring precipitation plot. Water was applied by overhead sprinklers to individual plots within each of the five shelters during a 2-day watering period in February, 1995. Gauges were located in the centre and corners of each plot*

Shelter Number	Irrigation Water Applied (mm ± S.E.)		
	Current	Spring	Winter
1	20·2 ± 2·1	21.9 ± 2·8	20·5 ± 1·8
2	18·7 ± 2·8	24·1 ± 4·4	13·6 ± 2·5
3	18·2 ± 3·9	18·1 ± 4·4	14·9 ± 3·4
4	18·8 ± 3·5	17·5 ± 3·3	18·8 ± 3·5
5	21·9 ± 5·7	12·6 ± 3·4	18·9 ± 4·1

represent the variation among the five rain gauges within each individual plot. The variation in artificial precipitation among the rain gauges may be a result of wind or irregularity of sprinkler heads. The variation over the course of an entire season has not yet been evaluated. The variation in water applied to the same treatments in different shelters (the average of the five rain gauges within a plot) can be adjusted in subsequent irrigations. It was felt that collecting actual irrigation amounts was critical to adjusting precipitation treatments, because fluctuations in the pressure of the water delivery system made it difficult to use timed applications. Pressure regulators at each shelter helped equalize application rates across shelters. However, low pressure situations were occasionally experienced which influenced application rates. With many small irrigation events natural precipitation was able to be mimiced more closely, and the amounts of irrigation water applied to each plot over the course of the season could be easily adjusted. For the 1997–1998 watering season, the variation in amount of water applied to a treatment across replications (standard error as a % of the mean) was 5·6% for current, 0·7% for winter and 0·4% for spring.

The quality of water used for irrigation can be a concern in studies of this type. Five samples of water were analysed during an irrigation application in June 1998. Results confirmed initial tests prior to construction of the rain shelters, that is, that quality was not a concern in this case. Results indicate that $\mathrm{pH} = 8{\cdot}1$, $\mathrm{SAR} \leq 2{\cdot}3$, conductivity $\leq 0{\cdot}02\ \mathrm{S\,m^{-2}}$, $\mathrm{NO_3{-}N} = 0{\cdot}89\ \mathrm{mg}\ \ell^{-1}$, $\mathrm{K} = 6{\cdot}8\ \mathrm{mg}\,\ell^{-1}$ and $\mathrm{S} = 3{\cdot}5\ \mathrm{mg}\,\ell^{-1}$. However, if groundwater quality were a problem, gutters could be used to collect rainwater into a holding tank, and the water could be pumped into the sprinkler system.

Another potential problem that can result from watering treatments is differential defoliation of treatments by rodents. If one of the watering regimes results in green vegetation (e.g. the spring treatment here) when the surrounding area is dormant, it is likely that the treatment will receive relatively heavy rodent use. The solution to this problem will depend on the nature and location of individual studies.

Conclusions

The use of moveable rain shelters has greatly expanded our understanding of drought response in crops. However, moveable systems are too expensive to be practical for many studies that involve native, intact plant communities. An alternative approach is to use fixed location rain shelters in conjunction with overhead sprinklers. This approach is much less expensive per unit area covered. The disadvantage is that the shelters reduce solar radiation and wind speed, and increase soil temperatures. However, changes in microclimate will be the same for all treatments under the shelters. The Dynaglass®

glazing allows a higher transmission of PAR than does fiberglass. The shelters also influence the nature of precipitation received for regions where snow is a major part of the annual water budget. However, this approach is suitable when the research objective is to evaluate native plant community responses to precipitation timing. As Diaz (1995) has pointed out, much of the global change research has focused on individual species, and predictions based on single-species experiments often do not match behaviour of multi-species communities. The approach outlined in this paper is a reasonable bridge between greenhouse and growth chamber studies, and the largely observational research documenting plant community changes over time.

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