Wet-dry Cycle Effects on Warm-season Grass Seedling Establishment

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Abstract

A series of 14-day field experiments were conducted to evaluate seedling establishment characteristics of *Bouteloua, Erogrostis,* and *Panicum* grass species with controlled wet-dry watering combinations. The objective of the study was to validate previously published greenhouse data of Frasier et al. (1985) on the effects of the first wet-dry watering sequence following planting on seedling emergence and survival. Seedling survival numbers were different between the field and greenhouse experiments but the same general responses to watering sequences were measured. With short wet periods (2 days), seeds generally did not germinate but survived the subsequent dry period as viable seeds. Most seeds germinated with 5 wet days and produced seedlings that were able to survive drought periods of 5 to 7 days. Fewer seedlings survived with 3 days wet than with either 2 or 5 days wet. High rates of soil moisture evaporation in a spring field experiment made it difficult to maintain adequate soil moisture for seed germination, and seeds which germinated failed to produce seedlings. Seedlings were successfully established in 2 experiments conducted later in the summer following the onset of summer rains, which increased the relative humidity and reduced the rate of soil moisture evaporation. This effect was verified in a greenhouse study. In both the greenhouse and field experiments, seedlings were established when the relative humidity exceeded 50% for over one-half of the time during the initial wet-dry period.

Key Words: ***Eragrostis* sp., *Panicum antidotale, Bouteloua curtipendula,* drought tolerance, plant survival, seeding**

The development of improved techniques for plant establishment under rainfed conditions in semiarid regions requires an understanding of seed germination and seedling responses to water quantity and frequency following planting. Cox and Jordan (1983) found that the amount and distribution of precipitation during the first growing season affected plant densities and forage production 10 years later.

There are several intervals during plant establishment when water availability is critical to seedling establishment. Wilson and Briske (1979) found that blue grama (*Bouteloua gracilis* (Willd. ex. H.B.K.) Lag. ex. Griffiths) requires 2 to 4 days of moist soil conditions for seed germination and initial root growth. A similar wet period, 2 to 8 weeks later, was necessary to ensure plant establishment. In a greenhouse study, Frasier et al. (1985) identified 2 factors that affected the survival of warm-season grass seedlings during the first wet-dry watering sequence following planting. They are: (1) the number of seedlings which developed sufficient vigor in the wet period to survive the subsequent dry period: and (2) the number of ungerminated but viable seeds which remain after the initial wet and dry periods following planting. Frasier et al. (1984) showed how seedling emergence and seedling survival probabilities, evaluated under various wet-dry watering sequences, could be combined with estimates of the joint probabilities of the lengths of the first wet and dry periods after planting to select the optimum time for seeding in a specific area, or identifying plant species which are best suited for a given climatic regime.

The objectives of the study were: (1) determine the effects of selected combinations and lengths of initial wet-dry watering sequences on the germination, emergence, and survival of 5 grasses in the field; and (2) determine if seedling establishment and survival responses to the initial watering sequences were qualitatively the same in the field as those observed in previously reported greenhouse studies (Frasier et al. 1984, Frasier et al. 1985). Following completion of the field study, a greenhouse study was conducted to evaluate the effect of air humidity on initial seedling establishment.

Materials and Methods

Field Study

Site Preparation

The field experiments were conducted on a Sonoita fine-loamy mixed thermic, Typic Haplargid soil (Gelderman 1970) at an elevation of 1,330 m (MSL) on the Walnut Gulch Experiment Watershed near Tombstone, Ariz. A 10 × 50-m area was cleared of all vegetation, smoothed with a road grader, and the top 12 cm of soil loosed with a rototiller. The entire area was covered with black polyethylene sheeting and methyl bromide injected under the sheeting for 48 hr to kill any plant propagules remaining in the soil surface.

Plot Installation and Seeding

The study consisted of three, 14–16-day experiments conducted at different times during the summer of 1983. Experiment 1 was initiated on 25 May 1983, experiment 2 on 22 July 1983 and experiment 3 on 15 August 1983. There were 120 plots, 30.5 × 30.5 cm square with a 5-cm high wooden border in each experiment. Plots were grouped 10 cm apart in rows of 5. Rows were spaced 1 m apart. The grasses used in the study were 'Premier' sideoats grama [*Bouteloua curtipendula* (Michx.) Torr.], 'A-68' Lehmann lovegrass (*Eragrostis lehmanniana* Nees), 'Catalina' boer lovegrass (*E. curvula* var. *conferta* (Schrad.) Nees), 'Cochise' lovegrass (*E. lehmanniana* Nees × *E. trichophora* Coss & Dur.), and 'SDT' blue panicgrass (*Panicum antidotale* Retz). Each grass species was randomly located in each row.

All plots were wetted with 3 mm of water and the surface smoothed. One hundred small depressions, 0.6 cm deep and 2.5 cm apart on a 10 × 10 grid, were made on each plot surface with an impression plate. Each plot was seeded with 100 seeds, one seed in each depression, with a vacuum chamber seed planter (Frasier 1985) and covered with a 2- to 3-mm layer of soil.

Water Sequences and Application

The watering sequences consisted of: (1) an initial wet period, (2) a dry period, and (3) a final wet period. Three separate wet-dry-wet watering sequences and an everyday wet sequence were used simultaneously in each experiment (Table 1). Ten to 12 mm of water were applied immediately following seeding which wetted the soil to a depth of approximately 10 cm. A single fan-shaped deflector nozzle on a reciprocating spray bar sprayed water downward onto a single row from a height of 25 cm. The nozzle applied 0.8 mm of water per pass. All plots in a row received the same water quantity and distribution. In Experiment 1, the quantity of water applied on each subsequent day was determined by gravimetric measurement of the water lost from 4 small plastic cones (3.8-cm D. by 20-cm

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Table 1. Wet-dry-wet watering sequences used in the three field experiments.

Experiment No.	Water sequence identification	Period Wet	Dry	Wet
		(days)	(days)	(days)
1 and 2	2–5	2	5	7
	3–5	3	5	6
	5–5	5	5	4
	14–0	14	0	–
3	2–7	2	7	7
	3–7	3	7	6
	5–7	5	7	4
	16–0	16	0	–

long) filled with soil and buried level with the soil surface between the plots. In Experiments 2 and 3 the daily water application quantity was equal to a Standard Class A evaporation pan, next to the plots, loss that had occurred during the previous 24 hours. On the first day following the dry period the plots received 12–14 mm of water to insure adequate soil moisture below the depth of the rooting zone.

Soil water contents were measured in depth increments of 0–5 mm, 5–10 mm, 10–30 mm, and 30–60 mm by gravimetric sampling on separate unplanted plots, 1 plot for each watering sequence. Prior to water application, soil samples from 3 random locations within each plot were collected and combined into a single composite sample for each depth increment for each watering sequence.

A moveable translucent corrugated fiberglass roof was used to prevent wetting of the plots by rainfall. The roof was pulled over the plots at sunset or when a rainfall event was imminent and removed at sunrise the next morning or after the rainfall stopped. Air temperature and humidity were recorded at ground level with a hygrothermograph.

Data Collection and Analysis

Seedlings were counted daily at 0600 hours. A grid template was used to pinpoint the location of the planted seeds (Frasier 1985). Any visible sign of a plant was recorded as a seedling. Seedling counts were normalized relative to pure live seed (PLS) using 10-day filter paper and germination percentages determined in a constant temperature incubator at 29.5° C and 100% relative humidity.

The experimental design was a randomized block with 6 replications, 4 watering sequences, and 5 species. Five plots were aligned into a single row. Four rows were grouped into a block. Results of separate experiments were not directly compared because of different climatic conditions. Seedling count means for each experiment and each data set period were subjected to analyses of variance. When "F" values were significant, ($P<0.05$), Duncan's new multiple range test was used to determine differences among species and water sequences.

Greenhouse Study

The study was conducted in 2 separate greenhouses using the procedure reported by Frasier et al. (1984). The grass species were the same as used in the field study. Tapered plastic cones, 3.8 cm in diameter by 20 cm long, were filled with 210 g of dry 60-mesh silica sand. Ten seeds were placed on the dry surface of each cone and covered with a 2- to 3-mm layer of dry sand. Ten cones were prepared for each grass species per watering treatment for each greenhouse.

Watering sequences used in the study were the same as in field Experiments 1 and 2 (Table 1). Water was applied to the cones with an overhead reciprocating spray system. Ten percent of the total number of cones in an experiment were randomly selected and marked for daily weighing to determine evapotranspiration losses and verify the quantity of applied water. All cones were initially wetted to field capacity with 20 g of water (10% moisture by weight). In wet periods, the cones were sprinkled daily with sufficient water to bring the average moisture content to the original weight.

One greenhouse (high humidity) was cooled by a standard evaporative cooler. The other greenhouse (low humidity) had the same ventilation system but without water applied to the evaporative pads. Air movement was provided by an oscillating fan. The cones in the low humidity greenhouse were moved to the high humidity greenhouse for watering. Following the end of the dry period of each watering sequence, the cones were permanently moved to the high humidity greenhouse. Cones in the 14–0 watering sequence were moved into the high humidity greenhouse on Day 8.

Live plants in each cone were recorded daily. The plant count of 10 cones for each species was averaged for the replication mean. The study consisted of 3 identical experiments conducted during the summer of 1985. No attempt was made to make direct comparisons of plant counts in the field study to the greenhouse study. Analysis of variance was used to determine differences among species and watering sequences. When "F" values were significant ($P<0.05$), Duncan's new multiple range test was used to separate means.

Results and Discussion

Field Study

Experiment No. 1

No seedlings emerged in this experiment on any watering sequence. This period of the year was characterized by high air temperatures and low relative humidities which rapidly dried the soil. One hour after sprinkling, the measured soil moisture contents in the top 60 mm were 11 to 12% by weight (field capacity). Twenty-three hours later, the soil moisture in the seed zone (0–5mm) was less than 1.5% (approximately −1.5 MPa), (Table 2).

Table 2. Climatic and soil moisture parameters for the three field experiments.

Item	Units	Experiment No. 1		2		3	
Length of experiment	(days)	14		14		16	
Starting date		25 May		22 Jul		15 Aug	
Pan Evaporation							
Daily (24 Hour)	(mm)	13	2.1	9	2.9	9	2.2
Nighttime (1800–0600)	(mm)	——[1]		3	1.3	3	0.8
Air temperature							
Maximum	(C)	35	2.2	35	1.3	35	2.6
Minimum	(C)	14	4.4	20	0.9	17	3.0
Humidity							
Maximum	(%)	73	14	100	1	95	5
Minimum	(%)	30	4	33	10	33	6
Soil Moisture[2]							
0–5 mm	(% by weight)	1.2	0.4	7.4	3.9	4.4	1.4
5–10 mm	(% by weight)	1.2	0.4	9.1	2.8	6.1	1.4
10–30 mm	(% by weight)	4.8	0.9	10.4	1.6	7.8	1.9
30–60 mm	(% by weight)	5.7	1.9	10.5	1.4	8.1	1.9

[1]Value not determined.
[2]Mean values for the experiment duration from the 14–0 watering sequence plot at 0600 each day prior to water application starting with Day 2.

Following the 14-day experiment, water was sprayed on the plots with a set of low-pressure lawn-soaker hoses for 4 hours daily for 6 days. A seedling count on Day 6 of this post-experiment watering period showed that less than 50% (PLS) of the seeds had survived the initial wet-dry watering sequences.

Experiment No. 2

Seedlings of all species were established with all watering sequences during this mid-summer experiment. This experiment was conducted after the onset of the summer "rainy" season and late afternoon or evening thunderstorms were common. The relative humidity increased and the evaporative demand on soil moisture decreased. These conditions are conducive to seedling establishment, but there were fewer seedlings with the 3 wet-dry watering sequences than with the 14–0 water sequence (Table 3).

Table 3. Mean seedling counts (PLS), for the initial wet period and Day 14 for field experiment No. 2 with 4 watering sequences (5-day dry).

Water sequence	Cochise lovegrass	Catalina Boer lovegrass	A-68 Lehmann lovegrass	SDT blue panicgrass	Premier sideoats grama	Water Sequence Means
	Maximum Initial Plant Count					
2–5	5.4[1]	12.7	6.2	5.3	51.9	16.3 c[2]
3–5	19.2	19.2	32.6	30.8	75.7	35.5 b
5–5	35.0	21.3	29.2	50.2	73.2	41.8 b
14–0	100.4	30.9	43.3	54.3	87.0	63.2 a
Species Means	40.3 b[3]	21.0 c	27.8 c	35.2 bc	72.0 a	
	Day 14 Plant Count					
2–5	71.7	35.9	34.2	33.8	60.8	47.3 ns
3–5	62.9	33.4	51.8	43.9	75.3	53.5 ns
5–5	85.5	32.4	36.6	54.3	71.0	56.0 ns
14–0	115.0	37.6	49.9	63.2	84.1	69.8 ns
Species mean	83.8 a	34.8 b	43.1 b	48.6 b	72.8 a	

[1]Mean seedling count of 6 blocks normalized for germination percentage (PLS).
[2]Water sequence means with the same letter are not significantly different ($P<0.05$).
[3]Species means with the same letter are not significantly different ($P<0.05$).

Two seedlings count data sets are of major interest for evaluating seedling survival characteristics (Frasier et al. 1985). These are: (1) the maximum number of seedlings from the initial wet period; and (2) the final seedling count at the end of the experiment. The 14-day wet treatment does not include a dry period; therefore the maximum seedling count on Day(s) 6–8 were used for the initial period data set (Table 3).

Water treatment and species interactions were not significant for either the initial or Day 14 counting periods ($P<0.05$). Species means in both the initial maximum and the Day 14 counting periods were different (Table 3). In the initial count there were 10 times more sideoats grama seedlings with the 2-day wet watering sequence than with the other 4 species. With 5 days wet, there were twice as many sideoats grama seedlings compared to the other species. These differences were not present in the Day 14 count period. There were no changes in the number of sideoats grama seedlings between the 2 counting periods, indicating that the final sideoats grama seedlings were plants that had been established during the first wet period. Conversely, with the SDT blue panicgrass, Catalina lovegrass, and A-68 Lehmann lovegrass, seedling numbers increased approximately 1.5 times and the Cochise lovegrass doubled between the initial and Day 14 counting periods. This indicates that the seeds of these 4 species did not germinate in the first wet period but remained viable through the 5-day dry period.

Seedling counts on several Cochise lovegrass plots on Day 14 were greater than 100% PLS. Germination percentages at 10 days on filter paper in the constant temperature incubator were: Premier sideoats grama–73%, A-68 Lehmann lovegrass–87%, Catalina lovegrass–87%, Cochise lovegrass–40%, and SDT blue panicgrass–81%. The germination percentage and/or germination rate of some of the species were evidently higher in soil than on filter paper.

Mean seedling counts differed among water sequences in the initial count period but not on day 14 ($P<0.05$) (Table 3). The 2 days wet watering treatment initially produced less than 50% as many seedlings as the other water treatments. The exception was sideoats grama, which had a threefold increase in seedling numbers with the 2 days wet treatment between the 2 counting periods. This indicates that many of the final seedlings of the other 4 species were from seeds that survived the dry period. There were smaller increases in seedling counts between the 2 counting periods with the 3 and 5-day wet treatments. The final seedlings with these watering sequences were from plants established in the initial wet period which survived the dry period.

Experiment No. 3

There were no significant interactions of water sequence and species for either the initial maximum period or on Day 14 ($P<0.05$). There were no significant differences in mean seedling counts among species and among watering sequences in both the initial wet and Day 14 periods (Table 4).

Table 4. Mean seedling counts (PLS), for the initial wet period and Day 14 for field experiment No. 3 with 4 watering sequences (7-days dry).

Water sequence	Cochise lovegrass	Catalina Boer lovegrass	A-68 Lehmann lovegrass	SDT blue panicgrass	Premier sideoats grama	Water Sequence Means
	Maximum Initial Plant Count					
2–7	0.0[1]	0.0	0.2	0.2	36.3	7.3 b[2]
3–7	1.3	0.4	4.0	1.0	56.2	12.6 b
5–7	66.3	25.0	59.3	40.6	78.7	54.0 a
14–0	96.7	39.7	52.0	41.6	81.6	62.3 a
Species Means	41.0 b[3]	16.3 d	28.9 c	20.9 c	63.2 a	
	Day 14 Plant Count					
2–7	97.1	23.0	25.0	12.5	49.4	41.4 b
3–7	39.2	13.1	13.1	6.4	57.6	25.9 c
5–7	67.5	23.6	57.5	38.3	80.3	53.4 b
14–0	118.7	43.5	62.3	48.4	87.5	72.0 a
Species Mean	80.5 a	25.8 b	39.5 b	26.4 b	68.7 a	

[1]Mean seedling count of 6 blocks normalized for germination precentage (PLS).
[2]Water sequence means with the same letter are not significantly different ($P<0.05$).
[3]Species means with the same letter are not significantly different ($P<0.05$).

Final seedling counts were lower in the wet-dry water sequences compared to the 14-day wet treatment, indicating a seed/seedling mortality during the 7-day dry period. Some specific similarities in the results to Experiment 2 were: (1) high initial counts of sideoats grama seedlings which survived the dry period as seedlings; and (2) low initial seedling counts of the other 4 species with 2 and 3-day wet watering sequences, and a subsequent increase in seedling count at Day 14 from seeds surviving the dry period. With the exception of sideoats grama, there were fewer surviving seedlings in the Day 14 plant count period with the 3-day wet sequence than with the other watering sequences. One possible interpretation, is that the species were vulnerable to an extended dry period if the first wet period initiated germination but there is insufficient moisture for subsequent seedling development (Frasier et al. 1984).

Effect of Time of Year on Seedling Establishment

Cox et al. (1982) reported that a common recommendation in the southwestern United States is to seed prior to the summer rains. In the same report it was also stated that the success rate of seeding trials in many areas was only 1 in 4. Schreiber and Sutter (1972) showed that the probability of water availability for plant growth in southeastern Arizona, defined as 'four consecutive days of wet soil,' was best from 5 July to 10 Aug. Smith and Schreiber (1973) showed that the peak summer rainfall frequency occurs in the period 15 Jul–15 Aug. This would indicate that soil moisture conditions may be more favorable for plant establishment with later planting dates.

In our later summer studies (Experiments 2 and 3), successful seedling establishment was achieved with the same length of wet periods as used in Experiment 1. While these experiments were not dependent upon natural rainfall, a micro-climate favorable for seedling establishment was created during the "rainy period." This is evidenced in the climatic data collected at the site (Table 2). The maximum air temperatures and minimum relative humidities were similar in all 3 experiments. There were differences in the maximum relative humidity and the length of time during the day that the high relative humidity persisted. In Experiments 2 and 3, the relative humidity exceeded 50% for more than half the time, compared to 20% of the time during Experiment 1 (Table 5). The high relative humidities with the onset of the summer storms from increased cloud cover during Experiments 2 and 3 contributed to a lower evaporative demand as reflected in the soil moisture measurements. The higher soil moisture in the upper soil profile for a longer time was sufficient to stimulate seed germination and aid in seedling establishment.

Table 5. Percentage of time the relative humidity was greater than 30%, 50% and 70%, and air temperatures greater than 21° C, 27° C, and 32° C for the three field experiments.

Experiment Number	Percent of Time					
	Relative Humidity			Air Temperature		
	>30%	>50%	>70%	>21° C	>26° C	>32° C
	(%)	(%)	(%)	(%)	(%)	(%)
1	60	19	4	64	39	8
2	93	64	39	79	32	11
3	93	58	36	62	31	8

Greenhouse Study

The everyday wet (14–0) watering sequence was the only sequence which produced any plants in the initial wet period in the low humidity greenhouse (Table 6). Water treatment and species interactions were not significant in the initial plant count for either greenhouse condition ($P<0.05$). In the high humidity greenhouse there were significantly fewer seedlings in the initial wet period with the 2 day wet water sequence. There were differences among species with the A-68 Lehmann lovegrass having approximately twice as many initial seedlings as the other 4 species. There were no differences among species in the low humidity greenhouse.

Table 6. Mean seedling counts (PLS), for the initial wet period for the greenhouse experiment with 4 watering sequences (5-day dry).

Water sequence	Cochise lovegrass	Catalina Boer lovegrass	A-68 Lehmann lovegrass	SDT blue panicgrass	Premier sideoats grama	Water Sequence Means
	Wet Greenhouse					
2–5	7.7[1]	16.3	58.3	28.7	29.7	28.1 b[2]
3–5	40.3	49.0	97.0	48.0	47.7	56.4 a
5–5	82.7	79.0	105.7	68.0	55.0	78.1 a
14–0[3]	62.3	66.7	111.0	61.3	47.3	69.7 a
Species Means	48.3 b[4]	52.8 b	93.0 a	51.5 b	44.9 b	
	Dry Greenhouse					
2–5	0.0	0.0	0.0	0.0	0.0	0.0 b
3–5	0.0	0.0	0.0	0.0	0.0	0.0 b
5–5	0.0	0.0	0.0	0.0	0.0	0.0 b
14–0[3]	5.7	11.0	8.7	9.0	10.7	9.0 a
Species mean	1.4 ns	2.8 ns	2.2 ns	2.3 ns	2.7 ns	

[1]Mean seedling count (PLS) of 3 replications.
[2]Water sequence means with the same letter are not significantly different ($P<0.05$).
[3]Day 7 was used for the initial plant count of the 14–0 sequence.
[4]Species means with the same letter are not significantly different ($P<0.05$).

There were no significant differences in the Day 14 count among species, water sequences or greenhouse condition ($P<0.05$). In the low humidity greenhouse, soil moisture contents of the seeded zone could not be maintained at adequate levels for sufficient time to induce seed germination and seedling emergence, even with 5 consecutive days of morning water application. The data from the hygrothermograph in the low humidity greenhouse shows that the relative humidity was less than 50% for over one-half of the time (Table 7), similar to field Experiment No. 1.

Table 7. Percentage of time the relative humidity was greater than 30%, 50% and 70%, and air temperature greater than 21° C, 27° C, and 32° C for the greenhouse experiments.

Greenhouse Condition	Experiment Number	Percent of Time					
		Relative Humidity			Air Temperature		
		>30%	>50%	>70%	>21°C	>26°C	>32°C
		(%)	(%)	(%)	(%)	(%)	(%)
Wet	1	100	95	0	100	95	2
	2	—[1]	—	—	—	—	—
	3	100	100	93	100	96	25
Dry	1	48	6	0	100	85	39
	2	91	46	17	100	95	58
	3	79	36	17	98	66	30

[1]Malfunction of hygrothermograph

Conclusions

This study reinforces the conclusions of Frasier et al. (1984). If the wet period is very short, most of the seeds will not have time to germinate and will survive the following dry period as viable seeds. In longer wet periods, many seeds will germinate. There may be a critical length of wet period during which a high percentage of seeds will germinate but the seedlings may not be sufficiently developed to withstand a short drought period. In our studies a 3-day wet period followed by 7 dry days produced fewer seedlings than either 2 or 5 wet days followed by 7 dry days.

The field and previously reported greenhouse studies (Frasier et al. 1985) did show similar seedling establishment characteristics. Most of the final seedlings of the sideoats grama were from plants which emerged from the first wet period and survived the dry period. Final seedlings of the other 4 species were from ungerminated seeds which survived the initial wet-dry period. The number of seedlings which died in the field studies was less than reported for the greenhouse studies. The soil at the field site has a finer texture and a higher water holding capacity than the silica sand used in the greenhouse study. The soil at the field site did not dry out as fast as the silica sand in the greenhouse study.

The study indicates that slight changes in climatic conditions at the time of seeding can be a major factor in achieving successful seedling establishment. High air temperatures and low relative humidities in an early summer experiment resulted in a high potential evaporative demand of soil moisture. With short interval watering periods, it was not possible to maintain soil moisture at levels adequate for seedling establishment. Later in the summer, with the onset of the rainy season, the increased relative humidity reduced the evaporative demand, allowing successful seedling establishment.

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