Technical Note

A Passive Application Watering System for Rangeland Plots

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Abstract

Soil water is generally the most limiting factor for plant growth in arid and semiarid rangeland ecosystems. Interactions between precipitation regimes and optimum air temperatures for growth of different species often have measurable effects on peak standing herbage and species composition. Simulating multiple precipitation regimes in a single year will enhance our ability to quantify plant–environment interactions. Evaluating the seasonal effects of variation in timing and quantity of precipitation will require controlled water applications with little or no runoff. A diversity of plot watering systems has been developed for different kinds of agronomic and rangeland research. However, most of these systems were designed to simulate heavy precipitation events and features of all previously described systems limit the number of plots and/or variation in site characteristics that can be included in rangeland field studies. Therefore, we developed the Passive Application Watering System (PAWS), which is composed of a graduated polyethylene application tank connected to a discharge system of polyvinyl chloride (PVC) and soaker hose subunits. It is portable and suitable for applying water over a wide range of slope, soil texture, and residual herbage conditions with little or no runoff. Application rates are controlled by the amount of hydrostatic pressure, which is determined by the head, the difference in height between the tank's water level, and the soaker hoses. Heads of 0.1 m and 2.0 m produce application rates of 5 mm $\cdot$ hr^{-1} and 40 mm $\cdot$ hr^{-1} which correspond to the permeability of clay loam and silt loam, respectively. Application rates increase about 1.8 mm $\cdot$ hr^{-1} $\pm$ 0.15 SE for each 10-cm increase in head. We have successfully used the PAWS in 3 research projects on range sites with sandy and loamy soil texture classes.

Resumen

En los ecosistemas de pastizales áridos y semiáridos, el agua del suelo generalmente es el factor más limitante para el crecimiento de las plantas. Las interacciones entre los regimenes de precipitación y las temperaturas óptimas para el crecimiento de diferentes especies a menudo tienen efectos medibles sobre el pico de la biomasa y la composición de especies. Simular múltiples regimenes de precipitación en un solo año mejorará nuestra habilidad para cuantificar las interacciones planta-ambiente. Evaluar los efectos estaciónales de la variación en tiempo y cantidad de precipitación requerirá de aplicaciones controladas de agua con poco o nada de escurrimiento. Una diversidad de sistemas para humedecer las parcelas han sido desarrollados para diferentes investigaciones agronómicas y en pastizales. Sin embargo, muchos de estos sistemas fueron diseñados para simular eventos de precipitación fuerte y las características de todos los sistemas previamente descritos limitan el número de parcelas y/o la variación de las características del sitio que pueden ser incluidas en los estudios de campo en pastizales. Por lo tanto desarrollamos el Sistema de Aplicación Pasiva de Agua (PWAS) el cual esta compuesto de un tanque graduado de polietileno para aplicación conectado a un sistema de descarga de cloruro de polivinilo (PVC) y subunidades de mangueras para empapar. Este sistema es portátil y adecuado para aplicar agua sobre un amplio rango de pendientes, texturas de suelo y condiciones de forraje residual, con poco o sin escurrimiento superficial. Las tasas de aplicación son controladas por la cantidad de presión hidrostática, la cual es determinada por la cabeza, que se refiere a la diferencia en altura entre nivel del agua del tanque y las mangueras para empapar. Cabezas de 0.1 m y 2.0 m producen tasas de aplicación de 5 mm $\cdot$ hr^{-1} y 40 mm $\cdot$ hr^{-1}, las cuales corresponden a la permeabilidad de franco arcilloso y arcillo limoso respectivamente. Las tasas de aplicación se incrementan aproximadamente 1.8 mm $\cdot$ hr^{-1} $\pm$ 0.15 DE por cada 10 cm de incremento en la cabeza. Nosotros hemos usado exitosamente el PAWS en 3 proyectos de investigación es sitios de pastizal con clases de textura de suelos arenosa y limoso.

Key Words: application efficiency, application rates, plot irrigation, portability, soaker hoses

INTRODUCTION

During the past 60 years plot watering systems have been designed for an array of research objectives (Zwolinski 1969; Selby 1970; Blackburn et al. 1974; Grierson and Oades 1977; Wilcox et al. 1986; Radke 1995; Williams et al. 1998; Wilson 1999; Loch et al. 2001; Motha et al. 2002). Many of these systems are rainfall simulators designed to study crust forma-

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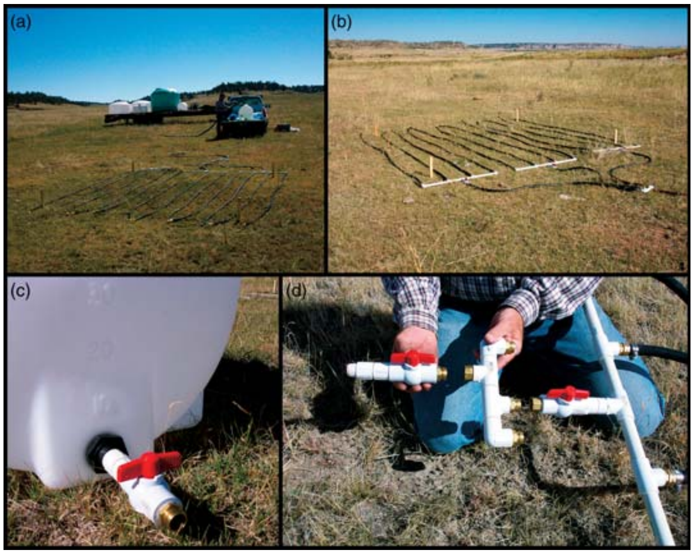

Figure 1. Overall view of a passive application watering system (PAWS) and the reservoir and transfer components (**a**). In this example, the 1609-L polyethylene pickup tank is on the end of a gooseneck trailer and the 246-L application tank has been placed in the pickup bed to increase the hydrostatic pressure. Networks of soaker hoses (**b**) are attached to a 246-L application tank (**c**) with PVC spreaders (**d**) and heavy-duty garden hoses.

tion, infiltration, runoff, and sedimentation. Previously designed watering systems encompass a wide range in cost, complexity, and portability. Systems designed to irrigate plots with little or no runoff use stationary raindrop-producing modules (Lavin and Knipe 1975) or drop emitters (Bittman et al. 1986) or rocking dripper units (Ross and Bridge 1985) that may be affected by wind. Additionally, most plot watering systems have a relatively narrow range of application rates, which limits the ability to adjust for differences in infiltration rate, slope, amount of bare ground, or microrelief common to rangeland. The microcomputer-controlled drip infiltrometer designed by Ross and Bridge (1985) is an exception; however, the complex unit is limited to relatively small plot sizes on level sites. Variation in rangeland surface characteristics is likely to cause differences in soil water profiles within and among plots, regardless of how water arrives at the surface. The greatest challenge in evaluating simulated precipitation regime effects on rangeland vegetation is keeping uniformly applied water from running off plot areas.

Our objective was to develop a portable system without moving parts and without external power requirements to apply variable quantities of water at different rates to rangeland plots without runoff. In addition, we evaluated the system for precision of application rates at different heads (pressure) and environmental conditions. There were no comparisons with previously described plot watering systems at sub-runoff rates.

MATERIALS AND METHODS

System Components

Primary components of the Passive Application Watering System (PAWS) units (Fig. 1a) include a 246-L polyethylene graduated application tank (Fig. 1c) and a water distribution system composed of 1.9-cm polyvinyl chloride (PVC) pipe and fittings, 1.9-cm brass threaded adaptors, heavy duty 1.9-cm garden hose, and 2.5-cm outside/1.5-cm inside diameter professional grade soaker hoses (Figs. 1b and 1d; Table 1). We used Osmile® Professional Soaker Hose (Lawson Products, Inc, 1140 Main St, Indianapolis, IN 46224, www.lawsonproducts.net; retail: A. M. Leonard, Inc, 241 Fox Drive, Piqua, OH 45356, www.amleo.com) because it had the most consistent application rates of the 4 brands evaluated in preliminary tests.

Table 1. Parts list for a 12-hose, 3.7 × 3.7 m passive application watering system (PAWS).

Quantity	Item
	PAWS Components
1	246-L polyethylene leg tank
1	10.1-m farm hand hose (1.9-cm inside diameter)
2	2.1-m farm hand hose
1	1.5-m farm hand hose
12	3.7-m Osmile® professional soaker hose
6	27.0-cm sections of 1.9-cm PVC schedule 40
6	11.8-cm sections of 1.9-cm PVC schedule 40
5	4.5-cm sections of 1.9-cm PVC schedule 40
3	1.9-cm PVC male and female nipple
8	1.9-cm PVC 90° elbow female inside pipe thread
11	1.9-cm PVC tee female inside pipe thread
4	1.9-cm PVC schedule 40 ball valve
5	1.9-cm brass female garden hose thread to 1.9-cm male pipe thread
16	1.9-cm brass male garden hose thread to 1.9-cm male pipe thread
16	Metal female hose coupling
16	Metal male hose coupling
32	Stainless steel hose clamps 1.3–2.9 cm
4	Filter washer
28	Plastic hose washer
12	Plastic soaker hose end cap
2	6.6-m spool of Teflon tape
	Reservoir and transfer components[1]
1	1609-L polyethylene pickup tank (reservoir)
1	5.1-cm dust plug for tank outlet
2	5.1 × 15.2 m discharge hose
1	5.1 × 7.6 m discharge hose
2	5.1-cm female quick-release coupler to female thread
2	5.1-cm male quick-release coupler to male thread
2	5.1-cm polybolted ball valve, stainless steel bolts, nuts and washers
2	5.1 × 7.0 cm threaded pipe coupling
2	5.1 × 15.2 cm nipple
2	5.1 × 10.2 cm nipple
2	5.1-cm elbow 90°
6	Stainless-steel hose clamps 4.0–6.4 cm
2	6.6-m spool of Teflon tape

[1]Fittings for reservoir and transfer components are polypropylene, schedule 80.

Laboratory Evaluation

To better understand how the system performs, we evaluated PAWS in a laboratory (average air temperature = 25°C) using

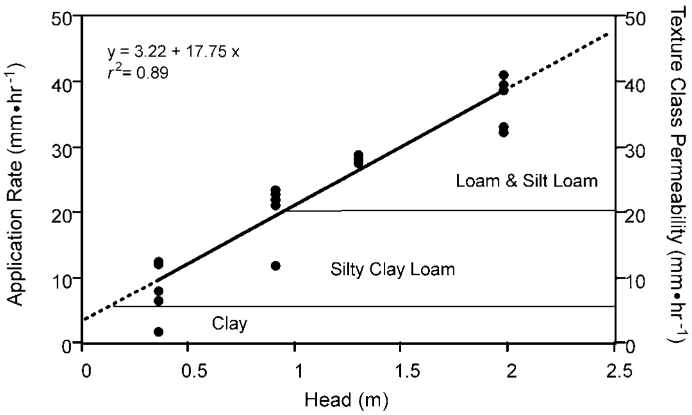

Figure 2. Effects of head on the application rate of water through Osmile® soaker hoses and the range in permeability of soil texture classes (based on Yost et al. 1968).

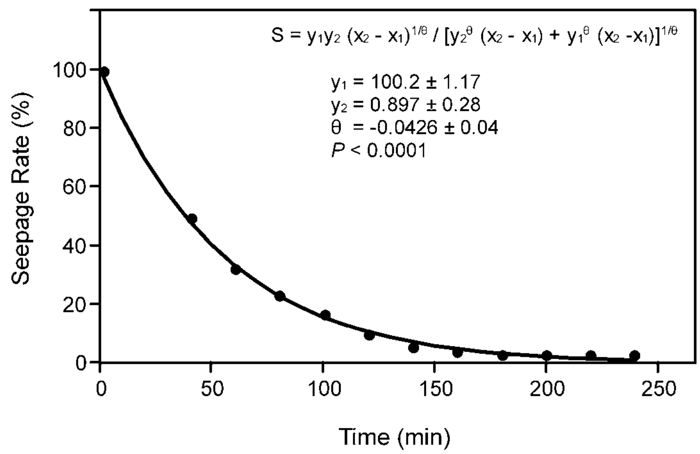

Figure 3. Effects of time on the rate of seepage from wet Osmile® soaker hoses after flow of supply water has ended. Seepage is expressed as percentage of water volume capacity inside the soaker hose walls.

a factorial array of hydrostatic pressure and water temperature combinations. Hydrostatic pressure is determined by the amount of head, which is the difference in height between the tank's water level and the soaker hoses. Prior to testing, 4 application tanks were positioned at different levels to produce heads of 0.36 m, 0.91 m, 1.30 m, or 1.98 m, resulting in hydrostatic pressure ranging from about 0.04 kg • cm^{-2} to 0.20 kg • cm^{-2}. Water temperatures were set at 15°C, 23°C, 33°C, 38°C, or 42°C based on mixing 0%, 25%, 50%, 75%, or 100% hot tap water with the corresponding level of cold tap water. The water was thoroughly mixed and allowed to stand for 10 minutes to ensure an even temperature throughout the water supply. Water temperature was checked and, if necessary, adjustments made before tests were initiated.

We measured discharge from 4 3.7-m sections of soaker hose to determine the effects of different head/temperature combinations on water application rates. The proximal ends of the soaker hoses were attached to the water supply via a PVC pipe frame and connecting garden hose. Prior to testing, soaker hoses were filled with water and any remaining air was released by partially unthreading and then securing the end caps. During testing, each 3.7-m section of hose was suspended on hail screen over a 37.9-L (10-gallon) plastic tub for 10 minutes while water flowed through the system. At the conclusion of the tests, the water supply was turned off, the hose sections were immediately removed, and the volume of water in each tub was measured with the use of graduated cylinders.

To evaluate retention of water inside the soaker hose walls after the system was turned off, we filled 4 3.7-m sections of moist soaker hose with water, capped both ends, suspended each section over a 37.9-L (10-gallon) plastic tub, and allowed them to drip without hydrostatic pressure to quantify seepage rate. Water volume released was initially measured after 40 minutes of seepage and at 20-minute intervals thereafter. Prior to each measurement, hose sections were gently moved to alternate tubs to continue dripping.

Statistical Analysis

We used linear and nonlinear regression analyses (SAS, 2002) ($\alpha = 0.05$) to examine interaction effects. The application rate equation was fit to hydrostatic head by temperature means and the seepage equation was fit to the means of 4 soaker hoses measured at 20-minute intervals.

Other Considerations

Following laboratory evaluation, the PAWS has been used successfully in 3 research projects at sites with sandy and loamy soils to study defoliation and precipitation regime effects on subsequent-year herbage production on sandhills and mixed-grass prairies. We used PAWS units to break drought-induced summer dormancy of cool-season graminoids and fall clipping to determine how fall grazing affects subsequent-year yields. Considerations for operational use are discussed. We also present information on the design and cost of the PAWS.

RESULTS AND DISCUSSION

Laboratory Evaluation

Water temperatures from 15°C to 42°C had no measurable effects on water emission ($P = 0.927$). Application rates of PAWS units increased about 1.8 mm • hr^{-1} ± 0.15 SE for each 10-cm increase in head (Fig. 2). Variation in application rates among different sections of soaker hose was generally greater at lower levels of hydrostatic pressure, resulting in lower application rates than expected based on the regression equation (Fig. 2). Delays in complete application of measured quantities of water in the application tank were minimal.

After delivery of water to the hoses is terminated (simulated by tests with filled and capped soaker hoses), seepage rates, expressed as the percentage of water remaining in the soaker hose, declined exponentially over time (Fig. 3). This relationship is described ($P < 0.0001$) by a nonlinear model (Bleasdale and Nelder 1960). Initial rate of seepage is nearly constant for the first half of the water volume, but declines rapidly for the remaining volume. Water volume capacity inside the soaker hose (1.5-cm inside diameter) would be equivalent to an application error of about 0.6 mm, which is not likely to be biologically important. For water applications ≥ 12 mm, errors related to the timing of removal of PAWS units from plots will be ≤ 5%. At 25°C, PAWS units should remain in place 40 minutes following the termination of water delivery to allow 95% of the water in a 6.0-mm application to reach the soil surface and 90 minutes for a 2.5-mm application.

Field-Use Considerations

Runoff is most likely to occur on clay soils because of low permeability (≤ 1 mm • hr^{-1} to 5 mm • hr^{-1}, Yost et al. 1968) (Fig. 2). In western Nebraska, permeability ranges from 20 mm • hr^{-1} to 64 mm • hr^{-1} for loam and silt loam, from 64 mm • hr^{-1} to 127 mm • hr^{-1} for fine sandy loam, and from 127 mm • hr^{-1} to 254 mm • hr^{-1} for loamy fine sand (Yost et al. 1968).

We have successfully used the PAWS on range sites with sandy and loamy soil texture classes. Based on surface wetness, spacing soaker hoses at 30-cm intervals has provided relatively uniform distribution of water on sites with a wide range of surface roughness, with soil textures from silt loam to sand, and up to 50% slope. Intuitively, time required for uniform surface wetness varies with soil texture. Relatively low infiltration rates of fine-textured soils will result in lateral movement of surface water away from soaker hoses more rapidly compared to coarse-textured soils. Lateral movement of subsurface water is likely to be more rapid for coarse compared to fine-textured soils. Adding more soaker hoses to reduce the distance between hoses will increase costs and reduce portability. If levels of applied water are relatively small, it may be beneficial to select plot dimensions that allow soaker hose networks to be lifted and offset 15 cm (Fig. 1b) for the second half of the application based on water levels in the graduated application tank. Application rates decline as water levels in the tank decline (Fig. 2), resulting in less water for subsequent time intervals.

Effects of slope on hydrostatic pressure within the network of soaker hoses can be minimized by placing hoses perpendicular to the slope. Additionally, PVC ball valves (Figs. 1b and 1d) for each subset can be turned down to offset visually apparent differences in flow rates between lower and upper sets of soaker hoses. When runoff is imminent, valves can be progressively turned down to eliminate loss of water from the plot.

During field use, we consistently observed a decline in application rates when air temperatures were ≥ 30°C. Given the lack of water temperature effects on application rates over a range of 15°C–42°C in the laboratory, reduced water emission in the field appears to be related to relatively high soil surface temperatures rather than air temperatures. Air should be bled from soaker hoses by temporarily loosening each end cap when high soil surface temperatures reduce application rates.

All PAWS components should be flushed with clean water before use and prior to storage to minimize clogging of the soaker hoses. Screens located on the intake side of 3-way and 4-way PVC spreaders (Fig. 1d) should be routinely cleaned or replaced. Storing PVC components in plastic tubs with lids eliminates problems with dust, insects, or rodents. Application tanks should be drained and plugged before storage. If small amounts of water remain in the tanks that cannot be drained, action should be taken to prevent microbial growth. We suggest either allowing the residual water to evaporate by placing tanks in full sunlight with the caps open, or treating the water with an appropriate chemical amendment.

Costs and Construction Considerations

The reservoir and transfer components listed in Table 1 have worked well for us (Fig. 1a). Using a power miter saw, the construction of a 12-hose, 3.7 × 3.7 m PAWS unit (Figs. 1b and 1d) required about 16 hours of labor. Total material costs for a comparable unit is currently about $440.00 (US). Seepage rates, internal diameter, and uniformity of emission rates per linear unit of soaker hose differ among manufacturers; therefore, all soaker-hose sections should be from the same manufacturer. The soil temperature effects we observed in the field are likely to occur with any brand of soaker hose.

Passive Application Watering Systems can be constructed to fit a wide range of plot dimensions, and different lengths of soaker hoses can be used with the same PVC spreaders. Subunits, sets of soaker hoses, should generally not exceed 4 hoses, to ensure ease of transport and assembly. Additionally, vehicle effects on study areas can be minimized by supplying water from a pickup tank to multiple PAWS units, via 5.1-cm discharge hoses and fittings.

Practical Applications

Knowledge of precipitation regime effects on current- and subsequent-year herbage production will enhance our ability to accomplish natural resource management and livestock production objectives. Given the current prolonged drought in the Great Plains, PAWS units could also be used to identify critical dates beyond which drought-stressed vegetation is no longer able to meet the forage requirements of livestock enterprises even with abundant precipitation.

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