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Simulating diverse native C_4 perennial grasses with varying rainfall

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ABSTRACT

Rainfall is recognized as a major factor affecting the rate of plant growth development. The impact of changes in amount and variability of rainfall on growth and production of different forage grasses needs to be quantified to determine how climate change can impact rangelands. Comparative studies to evaluate the growth of several perennial forage species at different rainfall rates will provide useful information by identifying forage management strategies under various rainfall scenarios. In this study, the combination of rainfall changes and soil types on the plant growth of 10 perennial forage species was investigated with both the experimental methods, using rainout shelters, and with the numerical methods using the plant growth simulation model, ALMANAC. Overall, most species significantly increased basal diameter and height as rainfall increased. Like measured volume, simulated yields for all species generally increased as rainfall increased. But, large volume and yield increases were only observed between 350 and 850 mm/yr. Simulating all species growing together competing agrees relatively well with observed plant volumes at low rainfall treatment, while simulating all species growing separately was slightly biased towards overestimation on low rainfall effect. Both simulations agree relatively well with observed plant volume at high rainfall treatment.

1. Introduction

Climate change will significantly affect water resources through changes in rainfall rates and increases in extreme events such as drought. Over the last two decades, the U.S. has seen an increase in average annual rainfall, but there are regional differences, with some areas having increases and others having decreases (Melillo et al., 2014). According to the IPCC (2007), more rain is expected in the equatorial belt (humid tropics) and at higher latitudes, whereas less rain is expected in mid-latitudes, semiarid areas, and the dry tropics. As the spatial extent and severity of drought increases (Dai, 2010), the frequency of short-term drought is expected to double, and long-term drought will become three times more common in regions with less rainfall (Sheffield and Wood, 2008). This extreme variability in rainfall will have diverse effects on soil moisture availability and consequently, forage production and quality (Rötter and Van de Geijn, 1999). Forty percent of variation in annual forage production is associated with annual precipitation over a wide range of areas (Lauenroth and Sala, 1992). Therefore, a better understanding of the impacts of changing rainfall change on forage production will ideally translate into reduced enterprise risk and more efficient forage production through increased predictive capacity to improve management decisions with expected climate change.

Many studies have focused on the relationship between rainfall and forage production with varying thoroughness using several forage grass types (Nelson, 1934; Paulsen and Ares, 1962; Cable, 1975; Knapp et al., 2006; Derner and Hart, 2007; Miranda et al., 2011; Hou et al., 2013; Chaplin-Kramer and George, 2013). Forage species show various growth and production patterns in different rainfall patterns and amounts because of differences in their vegetative and root structures. According to Barker and Caradus (2001), at low rainfall status (high soil moisture deficit), it is preferable for the plant to have low green leaf area to minimize leaf water loss and heating from radiation. For example, highly drought-tolerant forage species such as blue grama and black grama have lower leaf area index (LAI) at high water deficit (Kiniry et al., 2002). These prairie grasses are able to survive and grow in drier soils and in more drought-prone regions (Leithead et al., 1976;

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Schleicher and Anderson, 2007; Lloyd-Reilley and Masher, 2011; Tober and Jensen, 2013). Gherardi and Sala (2015) also reported that shrubs, described as long-lived perennial plants with deep root systems, showed increasing production with increasing precipitation variability. In contrast, the production of dominant grasses, described as short-lived perennial grasses with shallow root systems, decreased forage yield with increasing precipitation variability. According to these results, growth and production patterns vary among plant species under different rainfall patterns. Thus, comparative studies evaluating growth of diverse perennial forage grass species at different rainfall rates will provide useful information that helps producers estimate annual forage production at different rainfall rates and better understand growth of perennial grasses.

In this study, the effect of rainfall on growth of ten perennial forage grass species was investigated both by experimentally varying rainfall using a rainout shelter and with the plant growth simulation model ALMANAC (Kiniry et al., 1992). Because soil texture can have a major role in modifying the spatial and temporal availability of water to plants (Bristow et al., 1984; Smith et al., 1995; Schlesinger and Pilmanis, 1998; Sperry et al., 1998; Hacke et al., 2000), the field experiment was carried out in two different soil textures (clay, and mixture of clay and sandy soils). The objectives of this study were to (i) evaluate grass responses to various rainfall rates in terms of plant volume and plant stand structure (basal diameter and height); (ii) determine the dependence of those responses on soil texture; and (iii) determine how reasonably ALMANAC simulates grass production under these rainfall rates.

2. Materials and methods

2.1. Plant materials

Ten perennial forage species were included in this study (Table 1). Purple three-awn (*Arisida pupurea*) is a bunchgrass with densely turfed culms that is commonly found in dry coarse or sandy soils in desert valley (Tilley and John, 2013). Three *Bouteloua* species, sideoats grama (*Bouteloua curtiperdula*), black grama (*Bericopoda ericopoda*), and blue grama (*Bouteloua gracilis*), were used in this study. Sideoats grama is a deep rooted bunchy or sod-forming grass that is adapted to a broad range of sandy to clayey textured soils (Wynia, 2007). Black grama is a tufted grass with wiry, woolly culms that grows mostly on dry gravelly or sandy soils (Magee, 2016). Blue grama is a bunchgrass commonly found on the plains, prairies, and foothills and grows well on soil types that are sandy to clayey in texture (Wynia, 2007). Hall's panicum (*Panicum hallii*) is an erect turf grass grown on sandy to clayey calcareous soils (Lloyd-Reilley and Masher, 2011). Big bluestem (*Andropogon gerardii*) is a tall bunchgrass that is well adapted to moist, well-drained sandy and clay loam soils (Owsley, 2011). Little bluestem (*Schizachyrium scoparium*) is a bunchgrass with culms slightly flattened and is also well adapted to sandy and clay loam soils (Tober and Jensen, 2013). Switchgrass (*Panicum virgutum*) upland type is a tall bunch grass and grows well on moderately deep to deep, somewhat dry to poorly drained, sandy to clay loam soils (Carter, 2011). Indiangrass (*Sorghastrum nutans*) is a tall bunchgrass and grows well in deep, well drained floodplain soils, and in well drained upland sandy loam soils (Owsley, 2011). Tall dropseed (*Sporoloulus coupsitus*) is a bunchgrass well adapted to deep clay soils that are intermittently wet and dry (Magee, 2005).

Table 1
Identification of plant materials used in this study.

Scientific name	Common name	Origin
Aristida purpurea	Purple three-awn	Native American Seed
Bouteloua curtipendula	Sideoats grama	Native American Seed
Bouteloua eriopoda	Black grama	Native American Seed
Bouteloua gracilis	Blue grama	Native American Seed
Panicum hallii	Hall's panicum	Wildflower Center Seed Bank
Andropogon gerardii	Big bluestem	Native American Seed
Schizachyrium scoparium	Little bluestem	Native American Seed
Panicum virgatum	Switchgrass	Native American Seed
Sorghastrum nutans	Indiangrass	Native American Seed
Sporoloulus compositus	Tall dropseed	Wildflower Center Seed Bank

Seeds of the ten species were purchased from Native American Seed (Junction, TX) or provided by the University of Texas at Austin Lady Bird Johnson Wildflower Center Seed Bank (Table 1). The seeds were germinated and grown in seedling trays on field soils under ambient greenhouse conditions for 12 weeks before transplanting into field plots on August 19, 2010. After transplanting, the plants were established and maintained by watering 2–3 times per week at 1000 mm/yr before rainfall treatments began. No data were collected in 2011. Rainfall treatments were imposed on May 22, 2012.

2.2. Experimental design

The plant growth experiment was conducted in rainout shelter plots from 2012 to 2014. The rainout shelter is located at the Lady Bird Johnson Wildflower Center of The University of Texas at Austin in Texas, U.S. (Fig. 1A). The experiment was laid out in a split plot based on a randomized completed block design with four replications. Rainfall treatment was considered as the main plot and two soil types were treated as subplots. To avoid high competition for water and light, 10 forage grass species were divided into two communities based on plant size: shortgrass and tallgrass. The shortgrass community included purple three-awn, black grama, blue grama, Hall's panicum, and sideoat grama; the tallgrass community included big bluestem, little bluestem, indiangrass, tall dropseed, and switchgrass. Shortgrass and tallgrass communities were planted on same replicate plot and were treated by every unique treatment combination. In each replicate plot, 3 individuals of each species were planted, in a grid with 0.5 m spacing. Positions were assigned in a stratified random design and repeated across all replicate plots. Three rainfall treatments (350 mm/yr, 850 mm/yr, and 1331 mm/yr) were selected based on the driest, average, and wettest ten years in the historical record for Austin, TX (Fig. 1B). The rain treatment applications were created using a stochastic weather generator, LARS-WG 5.5 (Semenov et al., 1998), which was calibrated using an 87-year precipitation record. The rainfall sequences approximated the historic mean amount, seasonality, size distribution, and spacing of rainfall events. Two soil types were used in this experiment: clay and a mix of clay with sand. Clay soil was collected from the local area (Speck stony clay loam), and rocks greater than 50 mm in diameter were sieved out. The clay-sand mix was local clay soil mixed 3:1 with 99.7% silica sand mesh size with 5 mm openings.

2.3. Plant measurements

Plant sizes were measured annually in July 2012–2014. To estimate total plant volume, we measured the maximum basal diameter, basal diameter perpendicular to the maximum basal diameter, and plant height. Plant height was measured from the ground to the top of the tallestleaf. Basal diameter was calculated by averaging the two measured basal diameters. Plant volume was calculated assuming the plant was a cone. This consisted of multiplying the basal surface area by the plant height, and then dividing the outcome by 3. Basal area was calculated by multiplying