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Grasses for biofuels: A low water-use alternative for cold desert agriculture?

Lauren M. Porensky [a,*], Jay Davison [b], Elizabeth A. Leger [a], W. Wally Miller [a], Erin M. Goergen [a,1], Erin K. Espeland [a,2], Erin M. Carroll-Moore [a]

[a] Dept of Natural Resources and Environmental Science, University of Nevada, Reno, NV 89557, USA
[b] University of Nevada Cooperative Extension, Fallon, NV 89406, USA

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ABSTRACT

In arid regions, reductions in the amount of available agricultural water are fueling interest in alternative, low water-use crops. Perennial grasses have potential as low water-use biofuel crops. However, little is known about which perennial grasses can produce high quantity, high quality yields with low irrigation on formerly high-input agricultural fields in arid regions. We monitored biomass production, weed resistance, rooting depth, and root architecture of nine perennial grasses under multiple irrigation treatments in western Nevada. Under a low irrigation treatment (71 ± 9 cm irrigation water annually), cool-season grasses produced more biomass and were more weed-resistant than warm-season grasses. With additional irrigation (120 ± 12 cm water annually), warm- and cool-season grasses had similar biomass production, but cool-season species remained more weed-resistant. Among species within each grass type, we observed high variability in performance. Two cool-season species (*Elytrigia elongata* and *Leymus cinereus*) and one warm-season species (*Bothriochloa ischaemum*) performed better than the other tested species. Root depth was not correlated with biomass production, but species with deeper roots had fewer weeds. Abundance of fine roots (but not large roots) was correlated with increased biomass and fewer weeds. Both *L. cinereus* and *E. elongata* had deep root systems dominated by fine roots, while *B. ischaemum* had many fine roots in shallow soil but few roots in deeper soil. Cool-season grasses (particularly *E. elongata*, *L. cinereus*, and other species with abundant fine roots) may be worthy of further attention as potential biofuel crops for cold desert agriculture.

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* *Corresponding author*. Present address: USDA ARS, Rangeland Resources Research Unit, Crops Research Laboratory, 1701 Center Ave., Fort Collins, CO 80526, USA. Tel.: +1 970 492 7139.

E-mail addresses: lauren.porensky@ars.usda.gov (L.M. Porensky), davisonj@UNCE.unr.edu (J. Davison), eleger@cabnr.unr.edu (E.A. Leger), wilymalr@cabnr.unr.edu (W.W. Miller), erin.goergen@gmail.com (E.M. Goergen), erin.espeland@ars.usda.gov (E.K. Espeland), ecarrollmoore@gmail.com (E.M. Carroll-Moore).

[1] Present address: St. Petersburg College, Clearwater, Fl 33733, USA.

[2] Present address: USDA ARS, Pest Management Research Unit, Sidney MT 59270, USA.

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1. Introduction

In many arid ecosystems, the availability of fresh water for agriculture is declining due to increased drought frequency and intensity [1], as well as competing demands such as urban development [2,3] and aquatic ecosystem restoration [e.g., see Refs. [4,5]]. Over-use of limited water supplies can have strong, negative effects on ecosystems, economies, and human health [e.g., see Refs. [5–8]]. Given the increasing demands for and decreasing supplies of fresh water in arid ecosystems, arid-land agricultural practices will likely shift towards more water-efficient crops [4,9].

In the cold deserts of the western USA, agriculture is currently dominated by alfalfa, a relatively high-input crop [4,9]. Cellulosic biofuel crops could potentially serve as a low water-use alternative for this region. Climate change, increasing oil prices and decreasing oil supply have led to rising interest in biomass as an alternative fuel source [10–12], and efforts are underway to develop cost-effective techniques for transforming complex carbohydrates (e.g., cellulose, hemicellulose) into fuel [10,11]. Studies from more mesic ecosystems suggest that perennial grasses can produce large amounts of biomass while generating less carbon and requiring less water, herbicide, and pesticide than annual crops such as corn [13–16]. However, it is currently unclear whether perennial grasses growing in arid regions and irrigated with relatively small amounts of water (e.g., 0.6–0.8 m^3/m^2, vs. 1.2 m^3/m^2 for alfalfa) can produce enough biomass to be viable as alternative crops. To determine the feasibility of transitioning from traditional crops to low-input biofuel crops, researchers need a better understanding of which perennial grasses are best suited for arid-land biofuel crop development.

Plant phenology may be an important driver of productivity in arid regions, where water stress can preclude growth for large portions of the year. Cool-season species grow during the fall and spring, while warm-season species grow during the summer. In the USA, most existing work on perennial grass biofuels has focused on a few warm-season species (e.g., *Panicum virgatum* and *Miscanthus giganteus*) [11,12,17]. Cool-season species dominate the cold deserts of the western USA (where most precipitation falls during winter), but have received relatively little attention as potential biofuel crops. Recent work from Utah suggests that warm-season species can maintain viable stands in cold deserts [18], but cool-season species may be able to produce more total biomass than warm-season species [19]. These studies did not report on the weed resistance of warm- vs. cool-season species, which may be a critical element of agronomic viability. Moreover, these studies occurred at a relatively wet site (476 mm annual precipitation vs. 129 mm in western Nevada).

Root architecture can also affect plant performance in arid ecosystems [e.g., see Ref. [20]]. In particular, rooting depth and root diameter can impact a plant's ability to acquire water and nutrients from the soil. Coarse roots have longer lifespans and more rapid elongation, whereas fine roots allow more efficient resource acquisition but are shorter-lived [21,22]. While several studies report positive relationships between average root diameter and aboveground biomass production for herbaceous plants [e.g., see Refs. [23–25]], at least one study suggests that under water stress, species able to produce additional fine roots can maintain higher growth rates [20]. Few studies have documented differences in rooting structure among potential cellulosic biofuel crops [but see Ref. [26]], perhaps because most of the research on biofuel crops has occurred in mesic ecosystems.

We monitored the biomass production, weed resistance and root characteristics of five warm-season and four cool-season perennial grasses over four growing seasons and under multiple irrigation regimes in western Nevada. The study addressed two questions:

1. Does grass seasonality or species identity affect biomass production or weed resistance, and does the answer to this question depend on irrigation treatment?
2. Do root depth and density vary based on grass seasonality, species identity or irrigation treatment, and are certain root structures associated with higher biomass production or weed resistance?

At our cold desert sites, we expected cool-season species to produce more biomass and have higher crop water productivity than warm-season species. Because cool-season grasses take up water and nutrients throughout the fall and spring, we expected cool-season species to be more weed-resistant than warm-season species. Finally, we expected root depth, large root abundance and fine root abundance to be positively associated with biomass production and weed resistance.

2. Materials and methods

2.1. Study sites and species

Two study sites were located 11.5 km south of Mason, Nevada USA along the lower reaches of the Walker River (which feeds Walker Lake, one of only eight fresh water terminal lakes >100 km^2 worldwide) [4]. The Valley Vista Ranch (VV) site (38°50′58″N, 119°11′04″W) was used for alfalfa production until the start of the experiment. The 5C Cottonwood Ranch (5C) site (38°50′45″N, 119°11′02″W) was a denuded, formerly grazed pasture. Both sites are located on Malapais (loamy-skeletal, mixed, superactive, mesic Typic Haplocambids) complex soils (dominated by Malapais gravelly sandy loam and Malapais stony sandy loam) [27].

Natural vegetation near the sites is dominated by long-lived desert shrub species. Annual precipitation averages 127 mm but is highly variable across years. Most precipitation falls during the cold winter months, when plants are dormant. Annual precipitation was 68, 165, 177 and 68 mm from 2008 to 2011, respectively.

We planted commercial varieties of nine perennial grasses (see Appendix A for varieties and authorities). Warm-season species were *Andropogon hallii* (sand bluestem, native), *Bothriochloa ischaemum* (old world bluestem, non-native), *Calamovilfa longifolia* (prairie sandreed, native), *P. virgatum* (switchgrass, native), and *Sorghastrum nutans* (indiangrass, native). Cool-season species were *Elytrigia elongata* (tall wheatgrass, non-native), *Festuca arundinacea* (tall fescue, non-