ARTICLE IN PRESS

Journal of Arid Environments xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Journal of Arid Environments

journal homepage: www.elsevier.com/locate/jaridenv

Using germination prediction to inform seeding potential: II. comparison of germination predictions for cheatgrass and potential revegetation species in the Great Basin, USA

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ARTICLE INFO

Keywords:
Thermal time models
Germination
Mechanical treatments
Prescribed fire
Sagebrush
Cheatgrass

ABSTRACT

Germination models predict germination timing under seedbed water potential and temperature conditions. Using a wet thermal time model for germination prediction, we estimated progress toward germination (PTG) of 31 seedlots (10 species) as a function of hourly seedbed temperature (> 0 °C) when soils were above a water potential of -1.5 MPa. Seasonally-summed progress toward germination with a value > 1 indicates that germination will occur for that season. We used near surface (1–3 cm) soil water potential and temperature measurements collected at 24 sites in the Great Basin to determine effects of site, season, and year on PTG. On tree encroached sites, we also determined effects of tree infilling phase at time of tree removal, removal method, and microsite on estimated PTG. Soils were wet and warm enough in early spring, late spring, and fall for PTG > 1 indicating potential germination for most seedlots and species on most sites and years. Prescribed burning increased PTG as much as three times more than either tree cutting or mechanical shredding. Germination prediction could help to screen for plant materials adapted to specific sites or assess effects of seed additives or treatments that time germination to maximize seedling survival.

1. Introduction

Cheatgrass (*Bromus tectorum* L.) and infilling of woodlands threaten the sagebrush (*Artemisia* L.) ecosystem in the Great Basin by preemptively utilizing available resources and altering the fire cycle (Harris and Wilson, 1970; Chambers et al., 2014; Pyke et al., 2014; Roundy et al., 2014a, 2014b). Allowing sagebrush communities to naturally recover after wildfires is preferred when ecological thresholds have not been crossed (Whisenant, 1999). However, recovery fails when insufficient residual grasses and shrubs are left to resist cheatgrass (Miller et al., 2007). Another rehabilitation approach is to seed desirable species after wildfire (Whisenant, 1999; Call and Roundy, 1991) or in conjunction with controlled burning or other fuel control methods (Bybee et al., 2016). Seeding success may be increased by the selection of adapted plants for climatic conditions, seeding during specific seasons, and preparing the seedbed to maximize soil water availability (Hardegree et al., 2016; Roundy and Call, 1988). Plant materials for seeding are selected based on regional adaptation, but germination is constrained by site and year-specific soil water and temperature conditions (Rawlins et al., 2012b). Seedings often fail when site, annual, and seasonal weather is not conducive to soil moisture and temperature conditions that promote seedling survival (Ryel et al., 2010; Condon et al., 2011; Hardegree et al., 2016; Knutson et al., 2014). Predicting germination timing in relation to soil water availability and temperature for weeds and seeded revegetation species may help develop strategies to improve seedling survival (Call and Roundy, 1991).

Successful plant establishment in sagebrush communities of the Great Basin requires that seeds germinate and seedlings establish under a climatic context of cool wet winters and warm, dry summers (Caldwell, 1985; Donovan and Ehleringer, 1994). Germination may occur in fall when precipitation is sufficient and before temperatures are too cold, or in spring when water is available from winter and spring recharge and temperatures are favorable (Campbell and Harris, 1977; Caldwell, 1985). Rehabilitation seeding is generally done between summer and early winter after summer wildfire or before fuel control treatments such as mechanically shredding are implemented (Hardegree et al., 2016; Bybee et al., 2016). Recent research suggests that germination is generally not limiting in sagebrush communities for several Great Basin revegetation species or for competing cheatgrass (Roundy et al., 2007; James et al., 2011). However, germination timing may play an important role in seedling survival. Manipulating

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https://doi.org/10.1016/j.jaridenv.2017.11.019
Received 14 November 2016; Received in revised form 24 February 2017; Accepted 29 November 2017

germination timing to minimize competition with weeds (Hardegree and Van Vactor, 2000), frost (Boyd and Lemos, 2013; Roundy and Madsen, 2016), or drought may enhance seedling survival and revegetation success (Madsen et al., 2012). Spatial and temporal differences, rehabilitation treatment, tree infilling phase, and associated microsites affect the time of soil water availability and temperature of the seedbed environment for both cheatgrass and revegetation species (Cantón et al., 2004; Weisberg et al., 2007; Young et al., 2013; Roundy et al., 2014b). The effects of these factors on germination timing should be determined to help predict effects on seedling survival.

Thermal time models estimate potential germination timing of a seedlot, e.g. days to 50% germination of the seed sample. Potential germination models are developed by measuring percent germination over time for a range of constant incubation temperatures. The inverse of the time to germination (germination rate) for each seed subpopulation at various constant temperatures are fitted to linear and non-linear regression equations for each seedlot (Roundy and Biedenbender, 1996; Hardegree et al., 1999; Rawlins et al., 2012a). Germination rate is summed as progress toward germination (PTG) and a value > 1 indicates positive germination potential for specific temperatures and water potential of the seed incubation environment. Thermal time models that characterize soil conditions as either wet or dry using a threshold water potential are referred to as wet thermal time models (Finch-Savage et al., 2001; Roundy et al., 2007; Rawlins et al., 2012b). Wet thermal time models provided accurate predictions for greater than 75% of estimations of germination of six species at two locations in Utah during late winter through early spring (Rawlins et al., 2012b).

Here we used a wet thermal model and *in situ*-measured soil water potential and temperature to determine differences in seasonal PTG for various seedlots of revegetation species and cheatgrass in Great Basin communities. We compared seasonal PTG by site, season, year, tree (*Juniperus* spp. and *Pinus* spp.) removal methods, tree infilling phase, and various microsites for multiple sites across the Great Basin region.

2. Methods

2.1. Study sites

We used soil water potential and temperature data collected at 24 sites across the Great Basin described in Cline et al. (2018). Sites were divided into four experiments and were designated (1) “sagebrush (*Artemisia* spp.) and perennial grass- NV UT”, (2) “sagebrush and perennial grass-SageSTEP” (3) “crested wheatgrass” (*Agropyron cristatum* L.), and (4) “woodland” (Cline et al., 2018). The sagebrush and perennial grass-NV UT experiment was located on six sagebrush sites with associated native bunchgrasses, two sagebrush sites seeded to crested wheatgrass and recolonized by sagebrush, and a squirrel tail (*Elymus elymoides* (Raf.) Swezy) site with scattered big sagebrush and shadscale (*Atriplex confertifolia* (Torr. & Frem.) S. Watson) shrubs, all having data from 2002 to the spring of 2011 (Chambers et al., 2007; Roundy et al., 2007; Cline et al., 2018). The sagebrush and perennial grass-SageSTEP experiment was located on three sagebrush and perennial bunchgrass sites and was measured from 2008 to the spring of 2011 (McIver et al., 2010; Cline et al., 2018). The crested wheatgrass experiment was located in two fire rehabilitation seedings that resulted in near complete crested wheatgrass dominance with data from 2006 to the spring of 2011 (Hulet et al., 2010; Rawlins et al., 2012b; Cline et al., 2018). The woodland experiment was located on three western juniper (*Juniperus occidentalis* Hook.) sites in California and Oregon, two single-leaf pinyon (*Pinus monophylla* Torr. & Frém.) and Utah juniper (*Juniperus osteosperma* Engelm.) sites in Nevada, two Utah juniper sites in Utah, and two Colorado pinyon (*Pinus edulis* Engelm.) and Utah juniper sites in Utah. Data available varied with site and years since tree reduction treatment (Cline, 2014; Roundy et al., 2014b). Woodland plots were placed across three tree infilling phases according to relative cover (Miller et al., 2005): in Phase I the majority of cover is perennial grasses and shrubs, in Phase II the cover is shared by perennial grasses, shrubs, and trees, and in Phase III the majority of cover is trees. Plots used in the sagebrush and perennial grass-NV UT, sagebrush and perennial grass-SageSTEP, and crested wheatgrass experiments were untreated. Woodland sites had both treated and untreated plots. Woodland treatments included prescribed burning, tree cutting and mechanical shredding. Mechanical shredding was conducted only at the Utah sites and all woodland sites included untreated plots.

2.2. Thermal time analysis

Experiments were originally set up in a randomized block design to determine vegetation treatment effects (Chambers et al., 2007; Rawlins et al., 2012b; Roundy et al., 2014a, 2014b). Cline et al. (2018) described the experimental design and characterized the climate conditions and seedbed soil moisture and temperature conditions for each experiment over the same time periods as in the present study. Soil matric potential from gypsum blocks and soil temperature from thermocouples buried at 1–3 cm were read every 60 s and hourly averages recorded by Campbell Scientific, Inc. microloggers (Cline, 2014).

We compiled 31 germination prediction equations to estimate PTG. Nineteen germination prediction equations were compiled from the median germination rate of 18 seedlots from previous studies (Table 1; Roundy et al., 2007; Rawlins et al., 2012a). There were eight cheatgrass, two crested wheatgrass, one bluebunch wheatgrass (*Pseudoroegneria spicata* (Pursh) A. Löve), one Snake River wheatgrass (*Elymus wawawaiensis* J. Carlson & Barkworth), one squirreltail, two common yarrow (*Achillea millefolium* L.), one Lewis flax (*Linum lewisii* Pursh), one blue flax (*Linum perenne* L.), and one longspur lupine (*Lupinus arbustus* Douglas ex Lindl.) seedlots. Another 13 seedlot equations for five species were derived from constant incubation temperature data compiled from Hardegree et al. (2008, 2010). There were five squirreltail, two big squirreltail (*Elymus multisetus* M. E. Jones), two bluebunch wheatgrass, two basin wildrye (*Leymus cinereus* (Scribn & Merr.) Á.), and two Sandberg bluegrass (*Poa secunda* J. Presl.) seedlots.

Germination rate or 1/days to 50% germination of germinable seeds was regressed on constant incubation temperatures for all seedlots using a combination of best fit linear and nonlinear regression equations as derived from Tablecurve® 2D curve fitting software (Table 1, Roundy et al., 2007; Rawlins et al., 2012a). Linear regressions were derived from the lowest two incubation temperature rates as described by Roundy et al. (2007) and were used to estimate PTG for the lower sub-optimal temperature range (< 0–5 °C, 0–10 °C, or sometimes 0–15 °C) as described in Hardegree et al. (1999), Roundy et al. (2007), and Rawlins et al. (2012a). Best fit linear and nonlinear regressions were selected utilizing the highest R^2 and F-values with minimum residuals for incubation temperatures > 10 or sometimes 15 °C (Roundy et al., 2007; Rawlins et al., 2012a). Hourly field soil temperature average was used as the independent variable in these regression equations to calculate hourly PTG for each seedlot. Progress toward germination for a season was calculated by summing hourly PTG for each hour when soil water potential was > -1.5 MPa. When hourly PTG sums to 1, 50% of seeds are predicted to germinate for that seedlot. Sums of PTG > 1 indicate increasing potential for seeds to germinate. We report cumulative summing of PTG across intermittent wet periods as was found to be most accurate in predicting field germination by Rawlins et al. (2012a).

We used mixed model analysis of variance (Littell et al., 2006) to analyze each experiment separately. Site was considered a random block across the region for the sagebrush and perennial grass-NV UT, sagebrush and perennial grass-SageSTEP, and woodland experiments, while four replicated blocks per site were used as a random factor for the crested wheatgrass experiment. Fixed factors were seasons, years, and seedlots for all experiments. Site was a fixed factor in the crested wheatgrass experiments, while woodland experiments had additional