Soil Moisture and Temperature Conditions Related to Cheatgrass Establishment Failure

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SOIL MOISTURE AND TEMPERATURE CONDITIONS RELATED TO
CHEATGRASS ESTABLISHMENT FAILURE

by
Lauren Ducas

A paper submitted in partial fulfillment
of the requirements for the degree

of
MASTER OF SCIENCE

in
Range Science

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ABSTRACT

Soil Moisture and Temperature Conditions Related to Cheatgrass Establishment Failure

by

Lauren Ducas, Master of Science
Utah State University, 2014

Major Professor: Dr. Scott B. Jones
Department: Wildland Resources

Invasive species have become an increasingly large concern, particularly in already degraded ecosystems, such as sagebrush (*Artemisia sp.*)-steppe of the Intermountain West. Much of this ecosystem is already infested with large cheatgrass (*Bromus tectorum*) stands and restoration efforts have not met with great success. If air temperatures and soil water potentials fall below its tolerance during the establishment phase, cheatgrass growth may be disrupted to the point of stand failure. In this case, cheatgrass stands may revert to bare ground, providing opportunities for other invasive plants to establish or with appropriate planning, restoration of native perennials. A combination of dry soil conditions in the cheatgrass rooting zone in fall 2007 and cool spring temperatures in spring 2008 provided partial explanation for the reversion of cheatgrass monoculture to bare ground in spring of 2008. Available soil resources left in the wake of cheatgrass failure represent an opportunity for restoration or exploitation by other invasive species. Conditions leading to cheatgrass invasibility may represent optimal conditions for restoration.
PUBLIC ABSTRACT

Soil Moisture and Temperature Conditions Related to Cheatgrass Establishment Failure

Lauren Ducas

Cheatgrass, a widespread invasive plant, has taken over many rangelands in the Intermountain West. Restoration efforts have not met with much success. Early in cheatgrass’ growth period, if air temperatures fall too low and soils too dry, growth may be disrupted to the point of death of the cheatgrass plants. In this case, cheatgrass stands may revert to bare ground, providing opportunities for other invasive plants to establish, or possible restoration of native perennials. We conducted a computer modeling and observational field study to determine if air temperature and soil moisture conditions below its tolerance are associated with failure of cheatgrass stands. We found that a combination of dry soil conditions in the cheatgrass rooting zone in fall 2007 and cool spring temperature in spring 2008 provided at least a partial explanation for the reversion of cheatgrass to bare ground in spring 2008. Available soil moisture and nutrient resources left unused by cheatgrass failure represent an opportunity for restoration or exploitation by additional invasive species. Conditions leading to invasion of cheatgrass by other invasive species may represent the best conditions for restoration to native perennial vegetation.
ACKNOWLEDGMENTS

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Lauren Ducas
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CHAPTER I
INTRODUCTION

Biotic impoverishment due to land-use practices and invasive plants, particularly
annuals, have altered ecosystems in arid and semi-arid areas\(^1\). In the Intermountain West,
the widespread **sagebrush** (*Artemisia* sp.)-steppe community has been affected by
reduction in the perennial herbaceous community and dense stands of woody vegetation
and novel invaders are now present on the landscape\(^2\). Of particular interest is the
invasive annual grass, **cheatgrass** (*Bromus tectorum* L.) that has altered the soil moisture
dynamics of the sagebrush-steppe where it has come to dominate\(^3\). Cheatgrass is a winter
annual, a vegetation type previously uncommon in the Great Basin\(^4\). These vegetation
changes are linked to altered resource value and ecosystem function. **For example, the
increased fire frequency fueled by cheatgrass costs at least $20 million/year in fire
control and land restoration**\(^5\).

This region appears to be susceptible to plant invasions, which may partially be
explained by the broad similarity of its climate with the climate of grain-growing regions
of central and southern Eurasia and history of agricultural shipments, including weeds,
from Eurasia\(^6\). Cheatgrass entered the Intermountain West as a grain contaminant in the
1880s and by 1930 had reached its present distribution\(^6\). In response to the threat to
rangeland health posed by invasives, especially cheatgrass, Seed Purity Laws were
passed around 1900, but had little effect on preventing future novel invaders from
arriving on agricultural shipments from Eurasia, as halogeton arrived in this manner in
1934\(^6\).
Cheatgrass is “invasive because it originates outside of North America, it is able to dominate ecosystems, outcompete native species, and alter ecosystem functioning, and it is currently widespread and expanding in range”\textsuperscript{7}. The invasion process is not completely understood, but the timing of the availability of resources required for plant establishment and growth may have a large role in creating opportunities for both invasion and restoration\textsuperscript{8}. In the Great Basin, interannual variability in precipitation is high; as the annual total precipitation decreases, interannual variability increases\textsuperscript{8}. Ecosystems subject to large fluctuations in resources are predicted to be more susceptible to invasion than systems with more stable resources\textsuperscript{8}; systems with less stable resources present more opportunities through shifting temperature and soil moisture conditions from year-to-year for management of undesirable annual invasives, like cheatgrass, which are dependent on a given set of temperatures\textsuperscript{9} and soil moisture conditions\textsuperscript{10} during the coolest part of the growing season for continued persistence on the landscape.

The native herbaceous perennial seedbank, if present at all, is short-lived\textsuperscript{8} and the cheatgrass seedbank is able to germinate in the fall and under colder winter temperatures than the native herbaceous perennial seedbank\textsuperscript{8}. Growth of cheatgrass seedlings is highly dependent on temperature and soil moisture conditions and is reduced when nighttime temperatures are below 5 C and when daytime temperatures are below 10 C\textsuperscript{8}. Cheatgrass is much less drought tolerant than native species, senescing when soil moisture potentials in the upper portions of the soil reach -1.0 MPa to -1.5 MPa\textsuperscript{3}.

In a typical year, cheatgrass proceeds through its lifecycle as a winter annual, able to take advantage of the soil moisture resources and lower temperatures present in the sagebrush-steppe in the spring. Cheatgrass sets seed and senesces in late May or early
June, before the warmest and driest parts of the growing season. In less typical years, cheatgrass can act as a fall annual. If soils at water potentials below -1.0 MPa to -1.5 MPa and temperatures outside its tolerance range occur during the establishment phase, then growth may be disrupted to the point of failure of the cheatgrass stand. In this case, cheatgrass stands may revert to bare ground, providing opportunities for another invasive plant to establish or for restoration of native perennials.

We conducted an observational and modeling study to assess whether temperature and soil moisture conditions leading to cheatgrass establishment failure could be identified. A goal of the study was to identify times of increased chances of restoration success in cheatgrass-infested areas. We found the cheatgrass monocultures to be susceptible to establishment failures in years when they experienced fall germination, coinciding with specific temperature and soil moisture conditions. During the course of our study, we identified a pathway to determine when restoration efforts to convert cheatgrass monocultures to native perennial vegetation may be most successful.
CHAPTER II
METHODS

Site Description:

We worked at a cold desert field site in Rush Valley, west-central Utah (112°28′W, 40°17′N, and elevation 1600 m). Vegetation types include large patches of near-monocultures of cheatgrass, big sagebrush (*Artemisia tridentata*), and crested wheatgrass (*Agropyron desertorum*). Cheatgrass established at the site following fire in 1992\(^1\). Cattle graze our study area each spring.

Soils at the site vary by depth and vegetation type. In cheatgrass, the soils are loams to 60 cm depth, sandy clay loam between 60 and 90 cm, and fine sandy loam from 90 cm to the maximum measured depth of 305 cm. The climate is temperate with cold winters and hot summers. Mean annual precipitation measured at Vernon, UT (located 30 km south of study site) is 252.9 mm with a mean annual temperature of 10.70 °C. Temperatures warm enough for plant growth occur from late March to late October.

Spring snowmelt recharges the soil moisture to depth\(^3\); the few summer rains are usually too small to recharge moisture to depth\(^12\).

Field Measurements

We collected plant community composition data by walking 50-m line transects through relatively homogenous cheatgrass stands in 2007 and 2008. We stopped every 0.5 m along four transects to identify plants. Species cover was estimated as the portion of points that contained each species.
Simulation Modeling:

Numerical modeling of unsaturated soil hydrodynamics were carried out using HYDRUS 1-D (H1D) simulation software\textsuperscript{13}. Processes of soil water transport including uptake by plants were driven by Hargreaves ET estimation and a climate forcing surface boundary condition. We simulated soil temperature, soil moisture, and cheatgrass root growth and uptake for 2006-2008 using H1D. Inputs to the model include soil hydraulic properties, root distribution, and root water uptake rates. We obtained necessary temperature, precipitation, and snow depth inputs from the Tooele, UT and Vernon, UT Global Historical Climatology Network-Daily (GHCN-Daily) monitoring stations\textsuperscript{14}. Since Vernon, UT is more representative of Rush Valley, but does not have as complete a record as Tooele, the precipitation from Tooele was scaled by 0.56, the ratio of Vernon to Tooele long-term average precipitation. Based on depth of plant water use\textsuperscript{3} (Ryel, unpublished data), roots of cheatgrass were assumed to be limited to the top 45 cm of the soil, while Russian thistle (\textit{Kali tragus}) roots were assumed to tap moisture stored throughout the 60 cm soil depth simulated. The root water uptake parameters were taken from the HYDRUS 1-D Feddes root water uptake database for similar species. In 2008 the site experienced extensive establishments of Russian thistle and minimal cheatgrass cover. Normal cheatgrass crops established in the spring of 2006 and 2007.
Simulated soil water potentials in the fall at 3 cm depth in the profile are generally high, above -0.15 MPa (Figure 1). This depth is close enough to the surface to be recharged by both smaller summer rains and larger fall rains\textsuperscript{12}. It is also a critical depth for seed germination since nearly all cheatgrass seeds buried above 5 cm depth germinate\textsuperscript{15}. In 2006 and 2007, the soil water potentials are at their lowest at the start of September and experience recharge events near the end of the month for the 3 cm layer (Figure 1A, 1B). In contrast, for fall 2008, the soil water potential in the 3 cm layer starts September at nearly its highest water potential of the season and experiences draw-downs and recharges throughout the fall (Figure 1C). The years 2006, 2007, and 2008 end with water potentials of at least -0.01 MPa (Figure 1). When considering only the soil water potentials in the 3 cm layer, all years appear to have sufficient resources to allow for cheatgrass germination and early establishment.

Cheatgrass plants in their early establishment phase grow roots to 30 cm depth\textsuperscript{16}. The water stored at the 30 cm depth is to be used as a resource for cheatgrass during the rest of its life cycle, until the spring snowmelt recharges the soil to depth. Sufficiently large soil moisture resources were present for cheatgrass establishment as a fall or winter annual in 2006 and 2008. In 2006, the 30 cm layer experienced a slight recharge at the end of September, and was at -0.015 MPa for the remainder of the season, until a small recharge in December (Figure 1A). We observed a similar trend in 2008, although the soil only reached -0.04 MPa (Figure 1C). In 2007, the 30 cm depth layer contained
relatively little water and had a water potential of -1.45 MPa (Figure 1B). This is below the adult cheatgrass plant’s water stress tolerance. During germination and establishment, cheatgrass is intolerant of daily maximum temperatures below 10 C and daily minimum temperatures below 5 C. Temperatures during the fall of 2006, 2007, and 2008 were generally high enough for cheatgrass to proceed with the early phases of its life cycle. In the spring, a critical time for cheatgrass maturation, the minimum daily temperatures rose consistently above 5 C beginning on April 25 in 2006 and 2007 (Figures 1A, 1B). In spring 2008, the daily minimum temperatures remained below 5 C until May 25, although there were considerable fluctuations in minimum temperatures starting on April 10 (Figure 1B). Spring daily maximum temperatures consistently above 10 C began on April 25 in 2006 and May 5 in 2007 and 2008. Spring 2007 experienced major temperature fluctuations in the maximum temperatures prior to May 5. The combination of low daily minimum temperatures during much of spring 2008 and low soil moisture resources in fall and winter 2007 (Figure 1B; Figure 1C) may have impeded cheatgrass establishment. The low minimum temperatures in spring 2008 may be at least a partial explanation for why the remaining cheatgrass seedbank did not germinate and establish as a spring annual in 2008.
Figure 1: Soil water potential at 3 cm and 30 cm depth in the soil and minimum spring air temperatures for A) 2006-cheatgrass dominant; B) 2007-cheatgrass dominant; C) 2008-Russian thistle dominant. Approximate start of fall cheatgrass establishment in 2007 and Russian thistle invasion in 2008 are shown by arrows on the graph.
CHAPTER IV
DISCUSSION

Cheatgrass monocultures are often seen as alternate stable states for Great Basin rangelands. This viewpoint is based on the observation that “stable vegetations of annuals are to be found in semi-arid climates with a reliable growing season and a drought in the remainder of the year”. This is true of the Great Basin, characterized by a climate regime of cool, wet winters and hot, dry summers. It has been suggested that in the absence of grazing, cheatgrass monocultures will still be present on the landscape as an alternate stable state for the sagebrush-steppe. Cheatgrass persistence on the landscape may be linked to its ability to act as an ecological filter on the seedlings of more desirable species planted during restoration projects. The filtering effect acts to prevent any of the other plants from establishing until disturbance to the cheatgrass eliminates the filtering effect. Cheatgrass, like other plants, modifies its environment, in part through altering the soil moisture dynamics, drawing down the upper 30 cm of the soil profile early in the growing season to levels where nutrient diffusion becomes limited. This may severely limit germination, growth, and establishment of other species that germinate in spring or summer.

Time to germination for cheatgrass seeds differs throughout the year. The two most important times for cheatgrass germination and establishment are in the spring, from the start of March to the end of May and in the fall, especially in September and October. Seeds in September require 20 days to germination, decreasing to 10-15 days in October, the second shortest time in the year. From March to May, cheatgrass seeds will germinate within a week. Disruptions at these points due to unfavorable
temperatures or soil moisture conditions may result in failure of cheatgrass to establish.

Our work suggests the same features which make the site more prone to cheatgrass establishment failure may also be useful in guiding establishment of desired vegetation during restoration efforts. Westoby et al. described a model of transitions, triggered by environmental conditions and land management decisions, between different vegetation states. Transitions may be either slow or fast. Our results suggest transitions away from cheatgrass may be the result of simple environmental conditions, such as dry conditions in part of the soil and low spring temperatures. During its establishment phase, cheatgrass rapidly sends roots to 30 cm depth and may be especially sensitive to dry soil layers at any point in this rooting depth (Figure 1). Fall 2007 had unusually low soil moisture potentials at the 30 cm depth and this may have inhibited successful establishment of cheatgrass at this time (Figure 1B). Years where cheatgrass had experienced more successful germination and establishment had much higher soil moisture potentials in this soil depth range, providing a substantial resource for establishment for the cheatgrass crop (Figure 1A and 1C). In a typical cheatgrass year, such as 2006, the majority of the above-ground growth occurs in the spring in Rush Valley, when both temperatures and soil moisture are favorable. The soil water in the 3 cm layer is depleted to approximately -1.5 MPa in the late spring (Figure 1A). The soil water potential at 30 cm depth remains high throughout the year (Figure 1A). Summer rains recharge the soil water potential to early spring levels (Figure 1A). This recharge comes at a time when temperatures may be too high to allow for germination of cool season native perennials. The combination of cheatgrass failure, spring germination impeded by low temperatures, and a recharge of the soil moisture resources by spring.
Snowmelt opens a pathway for the restoration of native perennials. Although cheatgrass can germinate in either the fall, winter, or spring\textsuperscript{15}, and spring 2008 had high enough soil water potentials to allow for germination (Figure 1C), further germination likely did not proceed due to the unusually low minimum temperatures during Spring 2008 (Figure 1C). The combination of a dry fall and cool spring may lead to an open soil resource due to cheatgrass not establishing and tapping soil moisture resources stored in the upper soil depths. This open space is primed for invasion by other undesirable species, as we observed, or can be used to increase the chances of restoration success.

In conclusion, we found a combination of dry soils in fall 2007 near the bottom of the cheatgrass rooting zone and low spring temperatures in 2008 contributed to the failure of the cheatgrass monoculture in 2008. Continual monitoring of environmental and vegetation conditions is important to be able to capitalize on times when cheatgrass stands can be restored to more desirable native perennials. Land managers must be prepared to begin efforts to restore native perennials once ideal conditions are observed.
REFERENCES


