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Native
Grasslands
Association

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Mission Statement

The mission of the California Native Grasslands Association is to promote, preserve, and restore the diversity of California's native grasses and grassland ecosystems through education, advocacy, research, and stewardship.

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From the President's Keyboard

CNGA Funding Continues for Water Conservation Workshops

by Jon O'Brien

In April, Governor Jerry Brown issued the fourth in a series of Executive Orders to address California's severe drought, directing the state Water Board to implement mandatory water reductions in urban areas to reduce potable urban water usage by 25% statewide. In response, the City of Sacramento, like many municipalities around the state, has greatly restricted the times when residents can water their lawns and landscapes. For example, in my neighborhood, residents are only able to water twice a week, from 7 pm until 9 am. This is a great opportunity for people to make plans to convert their water-loving lawns to drought-tolerant California native landscapes, and CNGA is here to help!

I am pleased to announce that CNGA and the California Department of Water Resources (DWR) have finalized a 2015 contract, which awards funding to CNGA to continue developing and offering workshops around the state entitled "California's New Front Yard." These workshops take a step-by-step approach to converting lawns, from traditional turf grass and other water-loving plants, to beautiful, drought-tolerant California landscapes.

"California's New Front Yard" workshops will be held in Sacramento and Fairfield in 2015 and will be in Santa Cruz and Merced in 2016. More information is forthcoming on these workshops. You can also reach Administrative Director Liz Cieslak at admin@cnga.org or 530.902.6009 for more information.

CNGA continues to offer other workshops in addition to those funded by DWR. The May 2015 "Grass Identification" workshop in Point Reyes Station was a good mix of classroom grass ID, using specimens and the *Jepson Manual,* followed by an afternoon field tour. Given the popularity of this workshop, we look forward to offering it again in the near future.

Coming up on September 17 is the "Restoration Field Practices" workshop at UC Davis. This workshop focuses on the field aspects of non-residential restoration—site prep, equipment, installation, and site maintenance. For more information, check out the announcement on page 2 and visit **www.cnga.org** to register. You can also call the CNGA office at 530.902.6009.

Enjoy your summer, and continue figuring out creative ways to conserve water!

Grasslands Submission Guidelines

Send written submissions, as email attachments, to grasslands@cnga.org. All submissions are reviewed by the *Grasslands* Editorial Committee for suitability for publication. Contact the Editorial Committee Chair, Ingrid Morken, for formatting specifications: grasslands@cnga.org.

Written submissions include peer-reviewed research reports and non-refereed articles, such as progress reports, observations, field notes, interviews, book reviews, and opinions.

Also considered for publication are high-resolution color photographs. For each issue, the Editorial Committee votes on photos that will be featured on our full-color covers. Photos are selected to reflect the season of each issue. Send photo submissions, as email attachments, to Ingrid Morken at grasslands@cnga.org. Include a caption and credited photographer's name.

Submission deadlines for articles: **Fall 2015** — Aug 15, 2015 **Winter 2016** — Nov 15, 2015 **Spring 2016** — Feb 15, 2016 **Summer 2015** — May 15, 2016

Meet CNGA's New Administrative Director
Liz Cieslak

A warm welcome to Liz Cieslak, who has returned to CNGA as Administrative Director.

Liz began her involvement on the CNGA Board in 2010 as a Director-at-Large and continued in 2011 as Secretary of the Board of Directors. She was also Chair of the *Grasslands* Editorial Committee and changed the journal format to the current design with white paper and color photos.

Liz has a M.S. degree in Restoration Ecology (specifically of grasslands) from UC Davis and worked at Hedgerow Farms for 4 years. She took a break from work to have her daughter, now 2 years old, and she is happy to be involved with CNGA once again.

Liz's hobbies include running while pushing a jogging stroller and wrangling two dogs, caring for 13 chickens and a big garden, and trying to remember all of the plant identification information she learned in college.

A Continuing Role for
Rebecca Green

CNGA would like to thank outgoing Administrative Director Rebecca Green for her many contributions to CNGA. We are happy to report that she will continue to work with CNGA as Program Manager for the workshop series, *California's New Front Yard: Creating a Low-Water Landscape* (see p. 8 for more information). Rebecca wrote a California Department of Water Resources grant, which has been awarded to CNGA to create and execute this important workshop series. Thank you, Rebecca!

Register Now for Late Summer Workshop

Field Practices: *Hands-on Restoration Implementation and Maintenance*

Thursday, September 17, 2015 | UC Davis Putah Creek Reserve

Following CNGA's workshop hosted earlier this year, "Nuts and Bolts of Restoration," this workshop will show attendees how to prepare their site, implement the project, and maintain it.

Attendees will view a range of equipment for tilling, seeding, and maintenance and will learn how to calibrate various seeding implements. If time and weather allow, instructors may conduct a small burn as well as a short visit to an existing grassland at the end of the day.

Topics covered include: soil preparation (tilling, burning), seed selection, grass plug planting, seed drilling, broadcast seeding, and maintenance (e.g., mowing, grazing, burning, spraying). A folder of printed materials is also provided.

Note: this workshop focuses on small- to large-scale restoration projects. It does not focus on residential landscape design, implementation, and maintenance. See CNGA's "New Front Yard" workshop series (p. 8) to learn more about drought-tolerant landscape design and installation in your area.

Sign up online at **www.cnga.org** or contact CNGA at admin@cnga.org or 530.902.6009

$150/CNGA members | $175/Non-members | $95/Students with ID
Bring a Lunch or Purchase through CNGA $12

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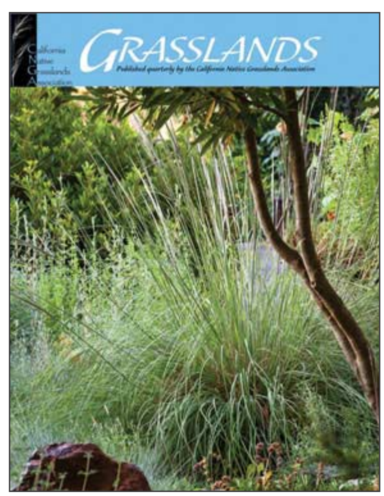

Mycorrhizal Influences on Lupine, Needlegrass, and Soft Brome Growth in a Road-edge Substrate

by V.A. Klaassen[1], K.A. Kane[1], and V.P. Claassen[1]

Introduction

Arbuscular mycorrhizal (AM) fungal amendments are often considered for revegetation projects with an expectation that they may improve plant growth, especially in harsher site conditions. Mycorrhizae, the interactive relationship (symbiosis) of specialized fungi with plant roots, have been shown to improve phosphorus (P) and trace nutrient uptake into the plants. In some cases they also increase moisture uptake, carbon flow from other plants, and resistance to root diseases (Emam 2015). However, these benefits to the plant also have a cost because part of the plant's photosynthetically fixed carbon has to be "paid" to the AM fungal partner through *arbuscules*, small tree-shaped exchange structures in the root cells.

Because of these variable costs and benefits, mycorrhizal relationships may be *mutualistic* (both partners gain from the interaction), or *commensal* (one partner gains while the other is not affected) or even negative or *parasitic* (one partner gains while the other partner is negatively affected) (Johnson et al. 1997). Different plant or fungal partners may have different growth characteristics, and not all species pairs may function equally well (Van der Heijden et al. 1998).

Soil or substrate conditions may also influence whether an interaction is positive, negative, or has no effect. A substrate may have so little P available for uptake that the fungi has no opportunity to increase this nutrient for the plant. As a result, the plant loses carbon to the fungi without gaining any increase in growth. In contrast, a substrate may have so much available P that the plant may already have a sufficient supply. The mycorrhizal relationship does not increase growth further, or perhaps the plant acts to reduce colonization frequency. Or, some other requirement such as nitrogen or moisture may be so strongly limiting that even increased P uptake through mycorrhizal colonization does not help. AM fungi also differ in how "infective" they are (often with rapid hyphal growth or production of numerous, small propagules) versus AM fungi that form strong and sustained "aggressive" colonization in the root (but may develop more slowly and have fewer, larger propagules) (Wilson and Tommerup 1992).

In order to understand at least some of these interactions for a common revegetation condition in the Central Valley, the influences of two sources of AM inoculum were tested with representative plants occurring on a roadway revegetation site along SR 70 in Yuba County (post mile YUB_70_2.5). These included the native valley sky lupine (*Lupinus nanus* Benth.), the native purple needlegrass (*Stipa pulchra* Hitchc.) and the invasive annual grass soft brome (*Bromus hordeaceus* L.). An experiment was developed in which plant growth was measured for different plant pair combinations using AM inoculum from two different sources and with or without a phosphorus fertilizer amendment.

Key Findings

Mycorrhizal inoculation increased growth of a native lupine and needlegrass while decreasing growth of the exotic annual soft brome in low phosphorus soils.

Inoculum sieved from an existing vegetated soil had stronger growth effects than that from a commercial source.

Phosphorus fertilization decreased these effects.

Methods

Different combinations of plant pairs were grown in 1-gallon pots that contained sieved, sterilized road embankment fill material. One AM inoculum source was obtained from the constructed fill slope that had been amended with commercial inoculum 3 years earlier (labelled "Fill" inoculum). The other inoculum source was from a relatively undisturbed, non-excavated, existing soil near the right-of-way fence line that currently supported weedy non-native annual grasses (labelled "Ambient").

The Fill inoculum consisted almost exclusively of small, white AM fungal species that are similar to the *Glomus* species commonly included in commercial inocula (Fig. 1, left). The Ambient AM population had a greater variety of spore types than the Fill AM (Fig. 1, right) even though the predominant vegetation at the time

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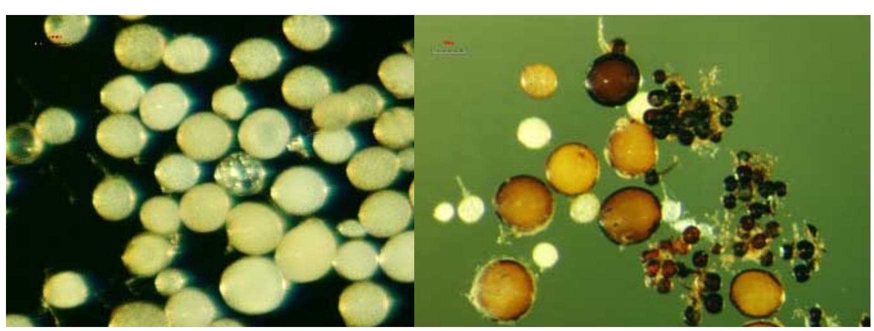

Figure 1. AMF spores sieved from Fill substrate (left, smaller, white spores) and Ambient, unexcavated soil (right, mix of spore colors and sizes). Both images are shown at approximately similar magnification. *Photos: V.P. Claassen*

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Mycorrhizal Influences

continued

of collection was invasive, weedy annuals rather than native species. To make a control treatment, Fill and Ambient inocula were mixed in equal portions and autoclaved to kill the AM fungi. Each pot then received 100 g of either Fill, Ambient, or Control inocula, along with a very finely sieved soil slurry to provide background microbial activity without including colonized root fragments, spores, or AM fungal hyphae, which are larger in size.

Seeds of the native lupine and purple needlegrass were purchased from commercial growers. The lupine seed was supplied with a rhizobial inoculation coating. The soft brome seed was collected from the field site. Germinated seeds were placed in the pots to provide either four plants of any one species, or two plants of two different species. For example two lupines were grown with two needlegrasses (labelled: LN), two lupines with two soft brome plants (LB), or two needlegrasses with two soft brome plants (NB). Duplicate pots were constructed that had all four plants of only one species (LL, NN, BB). All combinations of plant pairs were tested either with Fill, Ambient, or Control inocula. Six replicate pots were prepared for each treatment.

In order for mycorrhizal fungi to be able to increase plant growth, phosphorus (P) in the substrate needs to be modestly available but not excessive. A minimal amount of P was added to a duplicate set of all plant and mycorrhizal combinations to test changes in growth effects with higher P availability.

Following 3 months of growth in the greenhouse in late spring and early summer, all plant shoots were harvested, dried, and weighed to determine biomass. Sub-samples of roots (20 root sections per pot, each approximately 1 cm long) were cleared and stained to evaluate AM structures and colonization using a compound microscope.

Shoot dry weights were used to calculate a mycorrhizal response (MR) ratio that indicates the overall plant response to colonization when compared to the same plant pair combination without any AM colonization.

Results

To evaluate quality control of the experimental set-up, roots were first checked for mycorrhizal colonization. Then the plant growth response was measured both by absolute size (shoot dry weight) and also by comparison of colonized to uncolonized plants (mycorrhizal response). Finally, the effect of a common environmental variable (phosphorus fertilization) on these same mycorrhizal effects was evaluated.

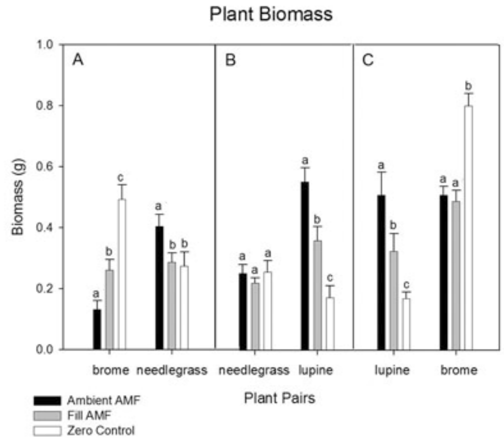

Figure 2. Average biomass weight comparisons for lupine (*Lupinus nanus*), needlegrass (*Stipa pulchra*), and soft brome (*Bromus hordeaceus*). Bars with the same letter within each group do not statistically differ at p = 0.10. In general, note that brome is always smaller with AM inoculation compared to control, while lupine is always larger. The Ambient AM from the soil is generally a stronger effect (positive or negative) than the Fill AM from the inoculated road edge.

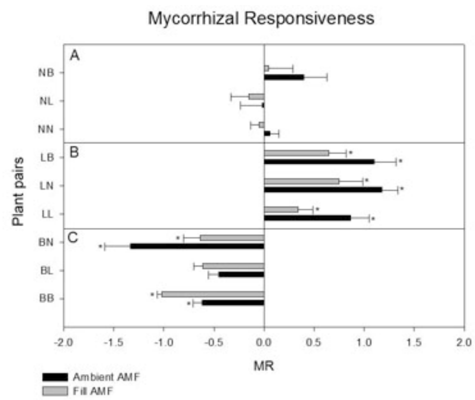

Figure 3. Mycorrhizal responsiveness (MR) of different plants (first letter of codes listed on left axis) when paired with different neighbors (second letter on left axis). Letter codes are: L (lupine, *Lupinus nanus*), N (needlegrass, *Stipa pulchra*), and B (brome, *Bromus hordeaceus*). Data show ratio of average plant biomass of inoculated compared to non-inoculated plants. Asterisks within a co-existing plant group denote significant differences at p=0.10.

Colonization

All plants inoculated with Ambient or Fill AM were colonized at a level between 32% and 45%, which is adequate to generate plant responses in appropriate condition. No control (uninoculated) plants were colonized. These data confirm that the AM treatments were established as intended.

Plant Growth Response

The native lupine showed the greatest increase in shoot growth with AM treatment (Fig. 2 and Fig. 4). All growth increases for lupine were significant; Ambient was greater than Fill, and Fill was greater than Control. This increase from AM source occurred whether the lupine grew in pots with either brome or needlegrass. Lupine growth was only 17% of total biomass when grown with brome and Control inoculum (uncolonized). However, when provided with Ambient AM inoculum, lupine biomass increased to become equal to the brome, generating 50% of all shoot weight.

Growth of soft brome was always greatest when grown without inoculation and it always decreased when colonized with AM. When brome was paired with lupine, both types of inoculation reduced brome growth about equally (Fig. 2, right panel). When paired with needlegrass, however, the Ambient inoculum significantly reduced brome growth further than did the Fill inoculum (Fig. 2, left panel). Brome biomass was reduced from about twice as large when uninoculated to about a third as large as needlegrass with the Ambient inoculum.

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Mycorrhizal Influences *continued*

The effect of mycorrhizal inoculation on needlegrass was variable. Ambient inoculum significantly increased needlegrass growth when paired with soft brome (Fig. 2, left panel). However, inoculation of either type appeared to have little effect when paired with lupine (Fig. 2, center panel).

In summary, inoculation with either source of AM was always beneficial to the growth of the native lupine. In contrast, inoculation always reduced the growth of the invasive grass, soft brome. For needlegrass, the AM effect was variable and non-significant except when grown with soft brome. Growth effects were positive, neutral, or negative depending on the other plant in the pair and the AM inoculum source.

Mycorrhizal Response (MR)

The effect of inoculation and source can be seen more clearly with MR ratios (Fig. 3). Growth of brome was always decreased by inoculation, either when grown with natives or when grown by itself (bottom panel). Ambient inoculum seemed to increase needlegrass while brome decreased, whereas Fill inoculum seemed to have little effect on needlegrass but still had a negative effect on brome (top panel). Lupine growth increased with both inoculum sources, whether grown by itself or with other species (center panel). Ambient inoculum treatments had greater growth than Fill. The mycorrhizal response of needlegrass, in contrast to brome and lupine, was variable and nonsignificantly different than uninoculated.

Phosphorus (P) Treatment

Addition of P always increased the growth of soft brome but did not have a significant effect on the biomass production of lupine, regardless of which AMF population was present (data not shown). Needlegrass increased growth with P addition when paired with lupine, but needlegrass growth was reduced when paired with fertilized soft brome. In general, fertilization increased the growth of soft brome to such an extent that it overwhelmed any improvements in growth of natives. The pre-existing levels of plant-available P in these soils was 6 ppm plant-available P with Bray extract and 3 ppm P with bicarbonate extract. This level was evidently adequate to allow these native species to form beneficial symbioses with AM that allowed them to maintain or increase growth when paired with the invasive soft brome. Increased P availability as a result of fertilization decreased this competitive advantage. Only soils with the lowest extractable plant-available P should be amended and, even then, only to bring P levels to relatively low levels.

Conclusions

These results illustrate that effects of AM colonization can vary with plant species combinations and fertility conditions. Because of these interactions, there is probably no one "right" inoculum to use across a range of sites. In the conditions of this study, use of local AM inocula collected from a vegetated site on an undisturbed soil with a potentially more diverse mycorrhizal

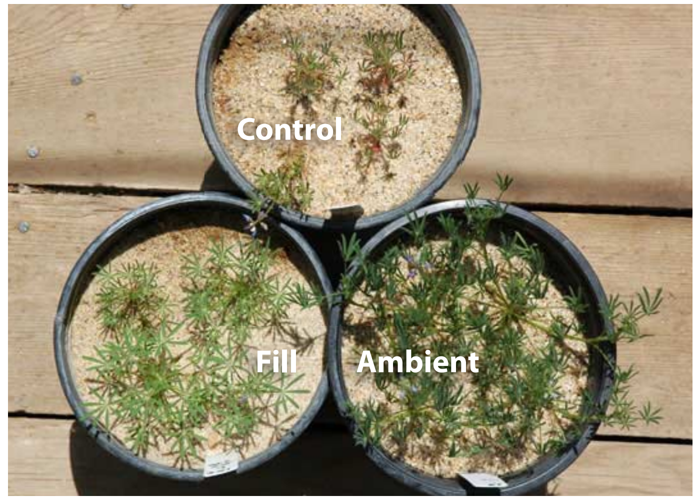

Figure 4. Photo shows differences in valley sky lupine (*Lupinus nanus*) growth using two different AM inocula and a zero control. This growth stage shows the first month of three during the greenhouse grow-out. *Photo: V.P. Claassen*

community was shown to have strong positive effects on lupine growth and also strong negative effects on the invasive brome. Using this type of diverse inocula from native soils, with its unknown viability, may require an extra step to increase local inocula. This could include using faster-growing native plant species in a field nursery in conditions that are somewhat improved but still represent the project site, followed by spreading and incorporating the bulk soil inoculum after it dries down for the summer. Because of this lack of easy availability, an attractive use of commercial inocula is that they are readily available and easily applied. However, this may come at a cost of less-effective establishment of native species and diversity. A broader conclusion is that an undisturbed soil has inherent value that may be lost if it is disturbed. Biological interactions, soil structure, soil organics, and hydrologic performance are reduced through disturbance and cannot readily be rebuilt after a soil has been disintegrated. Disturbance should be vigorously avoided on sites with intact soils.

Acknowledgments

Monica Finn, District 3 Landscape Biologist, was the Caltrans Research contract manager for this Research Technical Agreement 03A1065.

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An Extension Perspective on California Grassland Restoration

by Elise S. Gornish[1]

Grassland systems are some of the most economically, socially, and environmentally important habitats in California. Unfortunately, widespread development and massive degradation have eroded and continue to erode the persistence and health of these systems (e.g., Cameron et al. 2014), making them one of the most endangered ecosystems both within and outside of the state (Sampson and Knopf 1994, Peters and Noss 1995). As a result of grassland loss in California, restoration of these systems is becoming a more critical component of grassland conservation activities. Restoration in California grasslands generally facilitates revegetation and soil recovery by encouraging natural community reassembly processes that might otherwise take decades to occur in the absence of management (Beltran et al. 2014). This process includes extensive weed control before, during, and for several years after planting activities.

Estimates of rangeland ownership vary widely, depending on the classification of grasslands in different habitat types, but generally, from one-half to two-thirds of California's grasslands characterized as rangeland habitat are privately owned (L. Macaulay, University of California, Berkeley, pers. comm.). Therefore, the onus of restoration is increasingly falling on private landowners. However, despite the variety of valuable benefits that grassland restoration can provide to landowners, including forage for livestock, habitat for wildlife including pollinators, enhanced infiltration, and enhanced nutrient cycling, restoration activities on private lands are not sufficiently widespread to adequately cope with habitat degradation. As a member of UC Cooperative Extension, I have the opportunity to interact with diverse stakeholders at workshops, field days, and society conferences. At these events, I have conducted informal surveys to understand the factors that drive landowner restoration decision-making strategies. These factors can vary across landowner types, but they appear to all be connected by a single theme: uncertainty. And, until academic researchers and Cooperative Extension staff can adequately address the uncertainty associated with grassland restoration, the deployment of successful, widespread restoration activities on private lands will remain relatively uncommon.

Here, I outline some of the more convoluted aspects of restoration that might hinder widespread adoption and suggest several ways that these issues could be addressed in order to better serve the informational needs of the private landowner.

Context Dependency

Restoration success is hugely context-dependent (Young et al. 2015). Techniques that prove effective at a site during one year might not demonstrate particular utility the next year. This variability is likely due to differences in weather, which can be more important than applied management for modifying plant communities (e.g., Swiecki and Bernhardt 2008). Additionally, site-specific factors such as topography, soil moisture, soil type, soil microbial biomass, land use history, and micronutrient availability can directly and indirectly mediate restoration outcomes. Because landscapes are heterogeneous, successful restoration practices employed at one site might not be efficacious at a nearby, seemingly similar site. Research that attempts to understand mechanisms driving differences in germination, growth, and survival is critical for developing broad guidelines for grassland restoration that can accommodate site-specific characteristics. This type of research, which merges plant population biology with restoration ecology, is gaining more traction at the level of universities and experimental stations (e.g., James et al. 2011). However, until this becomes a more common research initiative, practitioners should be considerate of context dependency and perhaps explore the use of trait-based approaches where restoration candidates are identified based on their display of particular traits that confer resilience to local site characteristics (Funk et al. 2008).

Management Goals

Uncertainty is also associated with benefits that can be derived from grassland restoration. Despite examples of ecosystem services that might offset restoration costs in the short- and long-term, landowners lack information needed to confidently predict anticipated outcomes from restoration activities. Many studies have identified ecosystem services that can be enhanced with restoration; for example, effective restoration can arrest topsoil loss and rebuild soil carbon (Lal 2006), which increases forage production. Restoration and revegetation strategies can also markedly improve wildlife habitat, providing more valuable grasslands for hunting and recreation activities. Perhaps there needs to be improvement in the communication of this information from researchers and Cooperative Extension to landowners. This type of information can be effectively transmitted during field days, through publications in the popular press, and via a strong social media presence. Moreover, formal studies that directly link reseeding activities to other management goals, like forage production, are relatively uncommon. However, this avenue of research will be useful for highlighting how to accomplish multiple vegetation goals from single management activities.

Monetary Feasibility

Finally, uncertainty in restoration outcomes makes it difficult to assess whether management investment will pencil out financially in subsequent seasons. Depending on factors such as seed mix, seed source, and seed rarity, native grassland seed can be extremely expensive, and coupled with extensive pre-treatment activities such as weed management, site preparation, and drill rental, restoration

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[1]Elise Gornish is a new Cooperative Extension Specialist in Restoration Ecology, UC Davis. Dr. Gornish focuses on restoration of grassland and arid systems in both natural and working landscapes. She also conducts research and outreach on invasive annual grasses. The invasive species she most loves to hate is the invasive winter annual grass medusa head (*Elymus caput-medusae*).

Extension Perspective *continued*

can cost upwards of $3,000/acre. This cost is simply untenable for most private landowners. Avenues of less costly restoration and revegetation practices have been investigated, including strip seeding (Rayburn and Laca 2013), which can reduce seed quantities and labor costs. Using revegetation-based approaches involving non-local germplasm or non-native (desired, non-invasive) species in the short-term can enhance long-term establishment by natives (e.g., Davies et al. 2015) and replenish soil nitrogen (SER International 2004). Using seed from regional sources in the early stages of a revegetation project (D'Antonio and Meyerson 2002) can also enhance invasive species control because non-local germplasm can confer greater competitive response to newly invaded weeds (e.g., Davies et al. 2010, Herget et al. 2015). Costs for restoration or revegetation activities on private land can sometimes be partially offset by state programs, such as the California Department of Fish and Wildlife Landowner Incentive Program (LIP), as well as through associations with local groups, such as Habitat Conservation Planning branches and the Center for Land-Based Learning's Student and Landowner Education and Watershed Stewardship (SLEWS) program.

Despite these advances in the field, the cost of restoration can still be prohibitive for most landowners. Research developments in the field of horticulture could provide landowners with technologies to make native plant propagation a successful enterprise without taking large amounts of land out of production. Including regular cost/benefit analyses in restoration experiments (e.g., Palmerlee and Young 2010) is another way that researchers can add value to existing decision-making tools that help managers develop more successful, monetarily feasible restoration programs.

Conclusion

Several of the above suggestions involve creative approaches to grassland restoration and revegetation to minimize costs and efforts and make habitat improvements feasible. However, considering that many acres of privately held grasslands in California are working landscapes, I believe that realistic attempts to partner with private landowners to restore functional plant communities will only be successful when the needs and goals of all stakeholders are considered. Ultimately, large-scale successful restoration of grasslands on privately owned land will be possible through the cultivation of networks among academia, Cooperative Extension, agencies, non-profit organizations, and landowners and will rely on bidirectional communication among these groups.

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California's New Front Yard: *Creating a Low-Water Landscape*

Now Registering for Fall 2015 Locations

CNGA is taking this popular workshop series on the road beginning Fall 2015. Registration is open for Fairfield and Sacramento workshops. Spring 2016 workshops will be offered in Merced and Santa Cruz.

Fairfield: Thursday, October 1, 8 a.m.–3 p.m.
Willow Hall, Fairfield Community Center, 1000 Kentucky Street

Sacramento: Thursday, October 29, 8 a.m.–3 p.m.
Coloma Community Center, 4623 T Street

Presentations in the morning will be followed by afternoon demonstrations and hands-on activities that will show you how to carry out your project from beginning to end.

$25/CNGA Members | $30/Non-Members. *Included in your fees are morning refreshments, lunch, and course materials.*

Come to one of these workshops to find out more about landscape alternatives, including the use of native grasses, and forbs in the drought-tolerant landscape. Workshops will include the latest research and practices on design, installation, and maintenance of a low-water landscape, as well as proper plant selection, lawn removal methods, irrigation, and long-term care.

To register visit **www.cnga.org** or call 530.902.6009.

Extension Perspective *continued*

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Rainfall Infiltration of Soils Under Annual versus Perennial Grasses in California

by Matthew J. Curtis[1], Daniel E. Rider[1], Stefan Lorenzato[2], Ryan E. O'Dell[1], Arek Fristensky[1], and Vic Claassen[1]

Abstract

Rainfall infiltration rates of soils under either annual or perennial grass stands were measured with a rainfall simulator at seven sites in central and northern California. Soils under perennial grasses had infiltration rates that were nearly 73% greater than adjacent, paired locations dominated by annual grasses. Soil bulk density and penetrometer resistance in the top 1 foot (30 cm) were lower in perennial grassland plots (more porous) than in the paired annual grassland plots. These data suggest that managing grasslands for perennial species could potentially increase surface infiltration on a landscape scale. Further investigation may determine the extent to which this increase in regeneration of infiltration could reduce peak flood flows and increase recharge to shallow aquifers in the annual grasslands that dominate much of the California landscape.

Introduction

Water is a common limiting resource in California and across much of the western United States, and improved management of water resources is increasingly important. Land use practices have resulted in hydro-modification of large areas of the landscape, with associated shifts in the water balance that generate flashier storm runoff and less groundwater recharge (Stein et al. 2012). Increasing the amount of water recharged into shallow aquifers during winter months could potentially increase base flow of watersheds and may also reduce some peak storm flows and flooding (Daniel 1999, Murphy et al. 2008).

Large areas of the Sacramento Valley floor and adjacent foothills historically supported deep-rooted, summer-active perennial grasses and forbs. Now, as a result of tillage, invasion pressures, or grazing, much of this area has been converted to shallow-rooted, winter-active annual grasses (Barry et al. 2006, D'Antonio et al. 2007). This change of plant types, especially when associated with repeated winter grazing, may be contributing to observed hydro-modification effects.

Plant growth forms influence infiltration in several ways. Annual grasses typically are more shallow-rooted, whereas perennial grasses tend to be more deeply rooted (Holmes and Rice 1996, Dyer and Rice 1999). Perennial grasses, as well as native summer-active forbs, utilize water more extensively and from deeper soil horizons through the summer (Gordon and Rice 1993). The organic inputs of deeply rooted species more rapidly build up the soil's biological and physical properties, including soil aggregates (Culman et al. 2010, Glover et al. 2010, Milne and Haynes 2004). The basal area of perennials is larger than for annuals. The bunch-grass growth form creates long-lasting drainage pores around plant crowns, disrupts crusts with litter accumulation and biological activity, and slows surface water flow through the dense, stiff stems (Williamson et al. 2004).

Key Finding

Soils under perennial grasses had infiltration rates that averaged nearly 73% greater than similar soils dominated by annual grasses.

Many soils in California are susceptible to the formation of rainfall dispersion seals on their surfaces under saturated conditions (Le Bissonnais and Singer 1993). Soil seals form when raindrop impact disperses soil aggregates and they settle into a thin surface layer with low permeability. These dispersed silt and clay particles plug soil pores and reduce infiltration. All grass sites may be susceptible to the formation of seals if grazing leaves little residual dry matter to protect the soil surface. But since annuals do not germinate until after fall rains begin, the soil surface remains exposed to raindrop impact. In contrast, many perennial grasses begin to regrow before the onset of fall rains.

For these reasons, we hypothesized that a grassland with a significant component of perennial grasses will have a greater steady-state infiltration rate (saturated hydraulic conductivity, K_{sat}) than a similar location covered only with annual grasses, given the same soil texture and grazing history. If these differences between plant growth forms occurred widely across a grassland, they may offer the potential for greater recharge of the soil profile and of shallow aquifers, with a potential reduction in runoff during storm events.

Methods

A survey of grassland sites in the Sacramento Valley and adjacent foothills was undertaken to identify locations where both perennial and annual grassland communities are closely co-located within the predominantly annual grasslands that have become naturalized in California (Fig. 1). Seven sites were selected from a list of over twenty identified perennial grass locations (Fig. 2). Criteria for selection included density of total cover (ideally 100% grasses with no forbs or woody plants), perennial coverage (greater than 80% relative cover of perennial grasses), proximity of annual/perennial grass stands for paired site comparisons, similarity of soil textures under the two vegetation types, land owner cooperation, and accessibility and

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From left: *Figure 1*. Typical landscape with adjacent annual and perennial grass swards. *Figure 2*. Locations of the seven field sites in central and northern California. *Figure 3*. Rainfall simulator used for field measurement of saturated hydraulic conductivity. *Figure 4*. Overhead view of Redding infiltration plots with rainfall simulator frame: annual (top) and perennial (bottom). *Photos & drawing: M. Curtis*

Rainfall Infiltration *continued*

information about recent management history. A brief summary of the history of each site regarding grazing and time since establishment is listed in Table A, Appendix A*. Four of the sites having adjacent stands of annual and perennial grasses were located in naturally established vegetation communities. These stands had not been grazed within 10 years of our study, but they had been grazed prior to that time. These sites are representative of the general region in which grazing is the predominant land use. Three of the seven sites were intentionally replanted from annual to perennial grasses. The Black Butte, Davis Airport, and Redding sites were planted with perennial grasses approximately 11, 5, and 2 years before infiltration measurements were taken. At these replanted sites, plots were measured on adjacent locations that had established as annual or perennial stands. There had been no fires at any of the sites for at least 5 years.

Each study site had six measurement plots (three annual plots and three perennial plots) within a constrained 65 x 65 ft (20 x 20 m) area. This minimized variations in soil differences and past management practices. Because of the uniformity of grazing management, soil tillage, fire history, soil type, and landform position, these conditions are considered to not be confounding factors in this study.

Most of the perennial-dominated sites contained common California native perennial bunch grasses such as *Elymus glaucus* (blue wild-rye) and *Stipa pulchra* (purple needle grass). One of the native perennials, *Elymus triticoides* (bearded wild rye), is rhizomatous rather than bunch-forming. One non-native forage grass, *Elymus hispidus* (intermediate wheat grass) occurred at one site. The annual grass sites consisted mainly of *Bromus diandrus* (ripgut brome), *Bromus tectorum* (cheat grass), *Festuca perennis* (rye grass), *Elymus caput-medusae* (medusa head), and *Bromus madritensis* ssp. *rubens* (red brome).

A drop-forming rainfall simulator (RS) was used to measure infiltration (K_{sat}; Battany and Grismer 2000) (Fig. 3). The simulator rains over a 1 x 1 m area. Metal delineation frames (80 x 80 cm) are centered and slotted into the soil beneath the simulator (Fig. 4). Surface runoff was collected from the downhill lip of the frame. Rainfall was applied at known rates of between 60–240 mm/hr depending on the infiltration rate of the soil. As a default procedure, a rainfall rate of 120 mm/hr was used initially and increased by increments of 60 mm/hr if no runoff occurred in the first 20 minutes. If the initial runoff was too great, the simulated rainfall rate was reduced, and the plot was allowed to re-establish equilibrium hydrologic conditions. This usually took 5–10 minutes, as indicated by measurement of consistent runoff volume in 1-minute increments. A steady runoff rate was used as an indication that the infiltration was also at steady state (K_{sat}), and the simulation was terminated. The difference between applied rainfall rate and runoff yield represents the amount of water entering the soil profile. Rainfall simulations, plant cover and species, and soil measurements were taken from all three replicate plots for both perennial and annual plant types at each site.

Soil characteristics were measured at each site in order to help interpret the infiltration data. Soil bulk density (at 0–10 cm and 20–30 cm) was taken using a coring device (137 cm^3 sample volume, Soilmoisture Equipment Corp., Santa Barbara, CA, USA) (Blake and Hartage 1986). These samples were taken just outside of the RS frame. Soil samples were sieved to < 2 mm and then analyzed for texture (hydrometer method; **http://www.naptprogram.org**; A&L Agricultural Laboratories, Modesto, CA, USA). Immediately following RS, a cone penetrometer was used to measure the resistance of the soil within the RS frame when all soils were uniformly saturated (Field Scout 900, Spectrum Technology, Inc., Plainfield, IL, USA). Penetration resistance was measured every 2.5 cm to a depth of 30 cm.

The statistical analysis conducted was a fixed-effect generalized, randomized complete block design analysis (Kutner et al. 2005). The response variables were K_{sat}, bulk density, and penetrometer resistance. The independent terms included treatment type (i.e., annual vs. perennial plant type) and site location (blocking factor). A model term was also included to account for block-treatment

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*Tables A–E of Appendix A are available at **http://cnga.org/Grassland-Issues**.

Rainfall Infiltration

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interaction effects. The model assumptions of residual normality (normal distribution about the mean) and homoscedasicity (uniform variance of random variables) were verified according to the Shapiro-Wilk and Levene tests, respectively, which verified that the statistical tests worked correctly. Statistical significance for all tests was determined at the $p < 0.05$ level.

Table 1. Soil Infiltration (saturated hydraulic conductivity, K_{sat}) of the Seven Paired Annual or Perennial Grass Sites

Location	K_{sat} (mm/hr) Annual Grasses	K_{sat} (mm/hr) Perennial Grasses	% change in K_{sat} Infiltration, Perennial vs. Annual
Auburn	149 (51)*	238 (1)*	+ 59.7
Black Butte	60 (9)	142 (11)	+ 137.6
Davis Airport	119 (15)	159 (10)	+ 33.6
McLaughlin # 1	153 (27)	206 (18)	+ 34.6
McLaughlin # 2	120 (15)	205 (6)	+ 70.8
Redding	69 (5)	164 (4)	+ 137.7
Pacheco State Park	72 (6)	97 (11)	+ 34.7
Average Change			+ 72.6

*Values in parentheses are the standard error of the previous mean value.

Results

Infiltration rates measured in soils of the annual and perennial grass types are presented in Table 1, with a summary of statistical comparisons in Table E (Appendix A*). At all seven sites, plots vegetated with perennial grasses had greater infiltration rates (saturated hydraulic conductivity, K_{sat}) than the plots with annual grasses. The average increase in infiltration rate from annual to perennial grass plots was 72.6%. The range of increases in infiltration rate from annual to perennial paired plots was between 33 and 138%. The three most recent sites (Black Butte, Davis Airport, and Redding) all showed significantly greater infiltration in the perennial plots compared with the annual plots. On the sites with long-term existing vegetative cover that had not been grazed by cattle for at least 10 years (McLaughlin #1 and #2; Pacheco), the same pattern of higher rates of infiltration under perennials was measured. This suggests that the same trend also occurs on historically grazed rangeland.

In all cases, penetrometer resistance was less (soils were more porous) in the perennial than in the annual grass plots (Table B, Appendix A*). Resistance in the perennial plots decreased by an average of about 37% compared with that of the annual plots, with decreases ranging from 11% to 63%.

Average soil bulk density in the 0–10 cm depth was 4% lower in the perennial grass plots (more porous) compared with annual grass plots, with a range from a 15% decrease to a 16% increase (Table C, Appendix A*). Bulk density was an average of at least 8% lower at the 20–30 cm depth, with a range from a 19% decrease to no change. All subsoil bulk densities under perennials were lower (more porous) than the paired subsoil under the annual grass.

Soil texture was measured and compared for each annual–perennial plot pair (clay data shown in Table D, Appendix A*). Clay and sand contents for each pair were analyzed statistically, and neither was found to be significantly different between pairs at each location (data not shown). If there had been a difference in soil texture between the vegetation pairs, then particle size would be suspected to be a potential cause of a difference in infiltration, bulk density, and penetrometer resistance rather than plant type. In fact, no significant textural differences between plots with different plant types were observed.

Discussion and Implications

The observed increase in water infiltration into soil under native perennial grasses compared with annual grasses indicates that there is an opportunity to use grassland management to recapture some of the lost water-balance characteristics of California grasslands. However, whether infiltration is adequate to avoid surface runoff also depends on the rain intensity, rainfall duration, and soil depth.

To evaluate these interacting components, the soil characteristics presented here can be used in combination with soil hydrology simulation programs to estimate hydrologic performance of a range of potential storm scenarios (Scott et al. 2000, Mertens et al. 2002). Using these infiltration data as an example of this process, various rainfall events were simulated (Hydrus 1D; **www.pc-progress.com**) using averages of soil textures measured at the seven field sites. Soil textures fell into two general categories, a heavy sandy loam (19% clay) and a clay loam (33% clay). Rainfall patterns for two of the more centrally located plots (McLaughlin #1 and #2) were obtained for a range of rainfall intensity and probability (Recurrence Interval) events using data from NOAA's Precipitation Frequency Data Server website (**http://hdsc.nws.noaa.gov/hdsc/pfds/**).

These scenario simulations indicated, for example, that annual grasses on sandy loam soils will be at the threshold of runoff in a 1-hr storm of between 1- and 2-yr Recurrence Interval. More intense storms will produce overland flow. Simulations using characteristics from the perennial grass plots, with their lower bulk density, do not start to produce runoff until a larger 5-yr, 1-hr event. All moisture from a less intense event will infiltrate into the soil under perennials but not under annual cover.

Although a 1-hr storm duration is a widely used standard for evaluating surface erosion resistance, significant overland flow can also occur in longer lasting, multi-day events, even though the rainfall rate per hour is less intense. Soils under annual grass stands are especially susceptible in these events if they are shallow, have a relatively low capacity to imbibe rainfall volume, and readily become saturated. To illustrate this scenario, the soil conditions measured under annual grass plots with clay loam soil textures are indicated to produce runoff in an extreme, multi-day event (200-yr Recurrence Interval, 4-day duration event, such as a "pineapple express" or

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"atmospheric river" system). In contrast, the soil characteristics measured from perennial grass plots on the same soil texture produce no runoff in the same multi-day storm scenario. In these perennial grass plots, the combination of higher infiltration at the surface and subsurface horizons, lower bulk density, and deeper rooting provides the infiltration capacity to capture all rainfall from this extreme event.

These types of modeling scenarios illustrate the use of actual field-measured soil conditions to simulate soil hydrology in various target rainfall events before they occur in the field. Reduced runoff, in turn, reduces sediment mobilization and reduces flooding of lower watersheds, while increasing recharge to the shallow aquifers and maintaining base flows of local watersheds. More evaluation needs to be done in order to quantify how large of an effect these changes in vegetation management would have on local water budgets, partly reflecting the scarcity of local soil profile data for California grasslands and rangelands (Silver et al. 2010). Evaluation is also needed of the management impacts of changes in forage quality of native grass pasture mixtures and of the financial costs and benefits (including increased subsoil moisture for forage production). The results from this study, as an initial step, indicate that regeneration of perennial grasslands, or conversion from annual to perennial grasslands, or management to increase density of existing perennial grasses can offer potentially significant hydrological benefits at local and watershed scales.

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