USING HERBICIDES TO RESTORE NATIVE SPECIES AND IMPROVE HABITAT ON RANGELANDS AND WILDLANDS

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Invasive winter annual grasses are one of the largest threats to rangelands and wildlands in the western U.S. Indaziflam is a new herbicide option that can provide long-term control of winter annual grasses in these areas. Benefits to the ecosystem include increases in native species richness and abundance, increased pollinator resource availability, and improved wildlife habitat.

Keywords: rangeland, indaziflam, downy brome, winter annual grass

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Invasive winter annual grasses are one of the largest threats to the arid and semiarid rangelands and wildlands in the Intermountain West of North America (Figure 1A). The most impactful species include downy brome (*Bromus tectorum*), medusahead (*Taeniatherum caput-medusae*), ventenata (*Ventenata dubia*), and to a lesser extent Japanese brome (*Bromus japonicus*), feral rye (*Secale cereale*), and jointed goatgrass (*Aegilops cylindrica*). These winter annuals can germinate in the fall, winter or early spring, exploiting soil moisture and nutrients before native plant communities begin active growth in the spring (Knapp, 1996). These characteristics impart a competitive advantage in the perennial grass dominated natural landscapes of the Intermountain West (Mack, 1981). Downy brome, a winter annual grass native to Eurasia, is the most widespread invasive species in the western U.S, covering an estimated 22 million ha and a projected 14% annual spread rate (Duncan *et al.*, 2004) (Figure 1B). Invasive winter annuals negatively impact these ecosystems by depleting soil moisture and nutrients, reducing native plant productivity and diversity, altering fire frequency, and diminishing pollinator and wildlife habitat (Knapp, 1996).

Large amounts of litter which act as a fuel source are left after these grasses senesce early in the summer, greatly increasing the frequency and spread of wildfires in invaded areas. Historically, fire frequency in the 41 million ha sagebrush steppe occurred every 60 to 110 years (Whisenant, 1990), but this interval has been shortened to less than every five years since the introduction of invasive annual grasses. Annual grasses quickly (re)invade after these fires while sagebrush (*Artemisia* spp.), the dominant vegetation type in the sagebrush steppe, can take decades to recover. Therefore, the altered fire regime has resulted in a substantial loss of sagebrush and converted millions of hectares into monocultures of winter annual grass (Whisenant, 1990; Knapp, 1996). This altered fire regime also negatively impacted the abundance of small mammals, birds, larger browsing mammals, and pollinating insects in the sagebrush steppe (Knapp, 1996; Clements & Young, 1997; Rohde *et al.*, 2019).

Chemical Control Options

In the last two decades, imazapic has been the primary herbicide used to control several annual grass species on rangeland because it has both preemergent and post-emergent activity, and is relatively selective at low use rates (Mangold *et al.*, 2013). Several other herbicides including glyphosate, sulfometuron, and rimsulfuron are used for short-term winter annual grass control. These herbicides can provide adequate short-term control, but often lack long-term soil residual control, resulting in rapid re-establishment of seedlings from the soil seedbank (Mangold *et al.*, 2013; Sebastian *et al.*, 2016a; Sebastian *et al.*, 2017). These herbicides can also cause injury to desirable species, especially when applied in early spring when desirable species are just beginning active spring growth (Sebastian *et al.*, 2016a; Sebastian *et al.*, 2016b).

Indaziflam is a newer herbicide option recently labelled for use on rangelands and wildlands showing great potential to aid land managers in reaching long-term invasive annual grass control. Indaziflam is a cellulose-biosynthesis inhibitor with broad spectrum preemergence activity and is currently registered for annual weed control in turf, non-crop areas, and established citrus, grape, and tree nut crops (Sebastian *et al.*, 2017). Initially, indaziflam was not evaluated for selective weed control on rangelands and wildlands, but university-initiated research trials showed multi-year annual grass control and minimal impact to desirable perennial species in range systems (Sebastian *et al.*, 2016a). Indaziflam cannot currently be used on lands grazed by domestic livestock, but inclusion of grazed lands on the label is being pursued. Indaziflam binds tightly to soil organic matter and therefore moves very little in the soil profile, inhibiting root elongation

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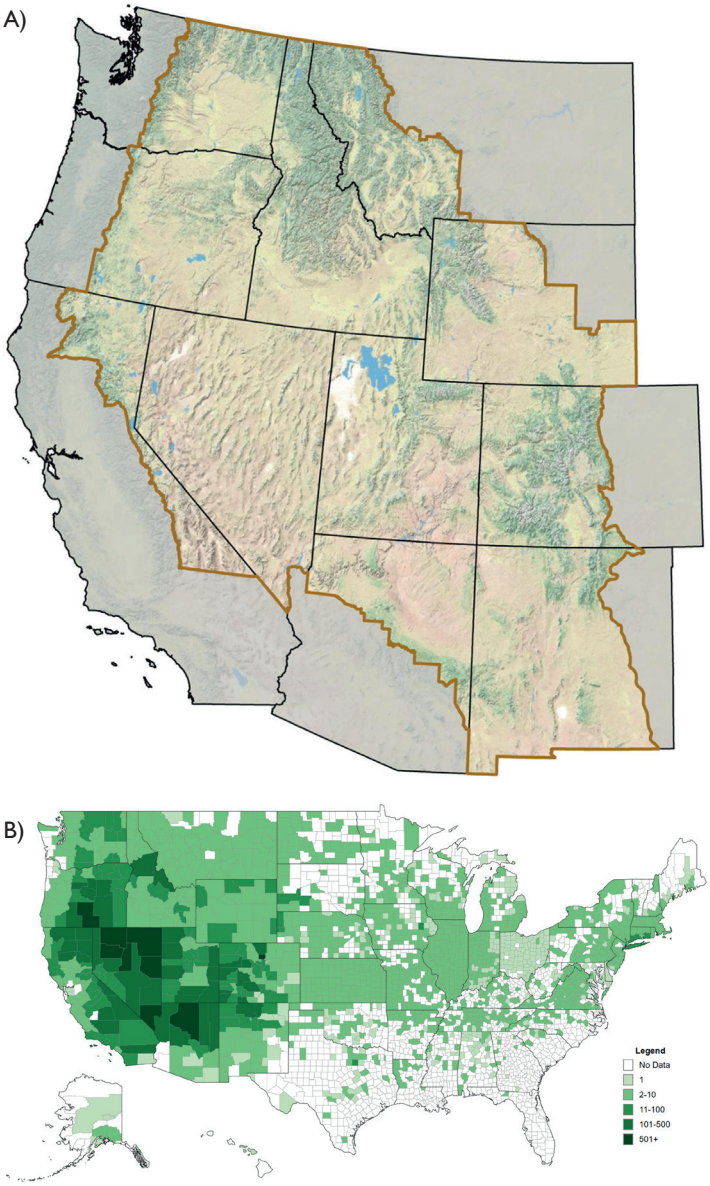

Figure 1. A) Map of 11 western U.S. states depicting the boundaries of the Intermountain West as reported by the United States Geological Survey. https://www.usgs.gov/media/images/map-intermountain-west. B) Current distribution of downy brome (*Bromus tectorum*) in U.S. from EDDMapS (January 2020). Shades of green represent the number of instances reported by county (0 to 501+). ttps://www.eddmaps.org/distribution/uscounty.cfm?sub=5214&map=density.

of germinating seeds only in the top layer of the soil (Sebastian *et al.*, 2017). This allows for increased safety on desirable perennial plants, which have established roots below the layer where the herbicide is active (Figure 2). In rangelands and wildlands, indaziflam is used at rates between 51 and 102 g ha^{-1} and has preemergence activity on several annual grass and broadleaf weeds (Sebastian *et al.*, 2016b).

Invasive Annual Grass Control and Desirable Vegetation Response with Indaziflam Applications

A single application of indaziflam provides three or more years of downy brome control with no measurable impacts

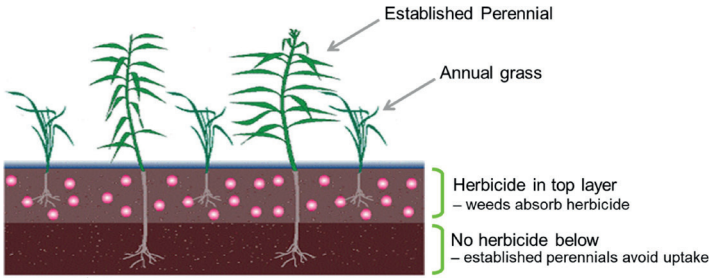

Figure 2. Depiction of indaziflam's interaction with annual grass seeds in the soil profile and safety of perennial roots (Figure courtesy of Derek Sebastian, Bayer CropScience).

to native perennial species (Sebastian *et al.*, 2016a) (Figure 3), whereas control by other annual grass herbicides (imazapic, rimsulfuron, and glyphosate) declines significantly after year one, and by year three there was essentially no downy brome control among treatments without indaziflam. Over 100 replicated field trials spanning most western U.S. states have documented indaziflam's efficacy on all major invasive winter annual grasses.

A Colorado field trial demonstrated that indaziflam applications had over 98% annual grass control two years after treatment with a 28- to 42-fold increase in desirable perennial grass biomass and a three- to five-fold increase in desirable forb biomass (e.g., blanketflower (*Gaillardia aristata*), dotted gayfeather (*Liatris punctata*) and slender-flowered scurfpea (*Psoralidium tenuiflorum*)) (Sebastian *et al.*, 2017). Species richness (number of species present at a site) also increased from an average of 4.3 species per plot to 7.9 species per plot. In eastern Washington state, ventenata biomass was reduced to <20 kg ha^{-1} in indaziflam treated plots compared to 500 kg ha^{-1} in control plots, 17 months after treatment (Koby *et al.*, 2019). Desirable perennial grasses also increased two- to three-fold among indaziflam treated plots compared to control plots. Furthermore, indaziflam had no negative impacts on species richness or abundance (number of individuals per species at a site) of 46 native grasses, forbs and shrubs at two locations in Colorado (Clark *et al.*, 2019). Subsequently, large-scale indaziflam applications covering over 600 ha at 78 natural area sites in Boulder County, Colorado have been monitored for canopy cover and weed control (Figure 4). These sites averaged nearly 100% annual grass (downy brome, feral rye, Japanese brome) control one to three years after treatment which resulted in significant increases in desirable cool- and warm-season grasses as well as native forbs.

Pollinator Resource Impacts

Invasive plant species can have debilitating effects on native pollinators through exclusion of native species (Herron-Sweet *et al.*, 2016). Improvements in flowering plant richness, diversity and abundance following indaziflam applications greatly benefits pollinators, by providing more diverse resources for nectar and pollen acquisition. Across three annual grass invaded sites in Colorado, the average flowering forb richness increased from 34.7 in control plots to 64.3 in indaziflam treated plots, and weekly observations recorded more species of forbs flowering each week in treated plots (Seshadri & Sauer, 2018).

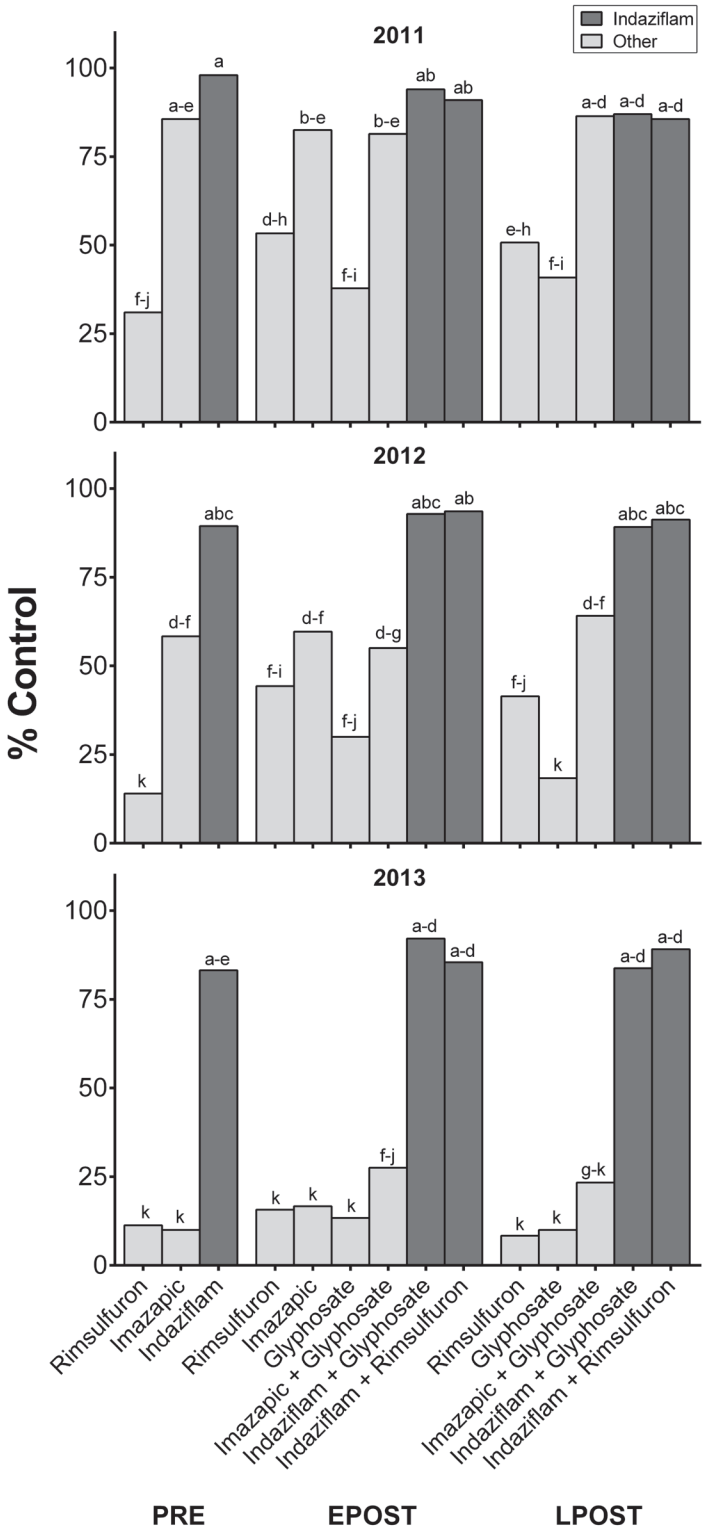

Figure 3. Downy brome control compared with the nontreated 1, 2, and 3 years after treatment. Application timings included preemergence, applied August 2010 (PRE), early post-emergence, applied December 2010 (EPOST), and late postemergence, applied March 2011 (LPOST). Letters indicate differences among herbicide treatments across all three timings and years, using least squares means ($P < 0.05$). (From Sebastian *et al.*, 2016a).

Figure 4. Comparison of treated (left) and non-treated (right) at site in Boulder County, CO at 18 months after treatment for downy brome (*Bromus tectorum*).

Wildlife Habitat Impacts Across the Intermountain West

In mountainous shrub ecosystems across the Intermountain West, native shrub species provide essential habitat for several types of wildlife but are especially critical as a food source for mule deer (*Odocoileus hemionus*) during winter months (Clements & Young, 1997). Downy brome is now the number one threat to mule deer populations in the Intermountain West, as it competes directly with critical shrub species and increases fire frequency in mule deer habitat. Across six sites within critical mule deer winter range of Colorado, new growth on three key shrub species was measured 6 to 18 months after indaziflam applications were made to control downy brome. Increases in new shrub growth directly translate to more forage availability and the ability for that area to support more mule deer. Across the sites, downy brome litter was reduced from 408 kg ha^{-1} to 54 kg ha^{-1} in sites sprayed 6 months earlier, while the litter in sites sprayed 18 months earlier had completely decomposed, suggesting a rapid reduction in the flammable fuel that increases the risk of wildfire.

Conclusion

Managing the weed seedbank is the key to long-term control of invasive winter annual grasses on rangelands and wildlands. Past herbicides have provided adequate short-term control but have often failed due to annual grasses reinvading from the soil seedbank. Indaziflam is a new tool for land managers to achieve multi-year control of the annual grass seedbank while promoting restoration of native species. As wildlife and pollinator habitat continue to be degraded and fragmented through development and agricultural production, indaziflam is a viable option for restoring the rangelands and wildlands impacted by winter annual grasses in the Intermountain West that serve as critical habitat areas.

Disclaimer

The utility of indaziflam to restore native species and improve habitat on rangelands and wildlands was discovered by university scientists. Bayer CropScience subsequently provided financial support for several of the experiments cited in this review. However, Bayer CropScience was not involved in writing nor made any contribution or suggestion regarding the content of this review.

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Dr. Shannon Clark received her Ph.D. in Weed Science at Colorado State University in Fort Collins, CO in 2019. She is now a postdoctoral researcher in the Department of Agricultural Biology at Colorado State University. Her research focuses on evaluating herbicides for invasive species management on rangelands and wildlands and the subsequent impacts to ecosystem processes.