

## Curlycup gumweed (*Grindelia squarrosa* [Pursh] Dunal [Asteraceae]): A native forb candidate for inclusion in Great Basin greenstrips

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Figure 1. Curlycup gumweed occurs naturally in disturbed habitats throughout western North America. It is currently being evaluated for selected class germplasm release for use in pollinator and wildlife habitat and may have potential for use in Intermountain greenstrip seedings. Photo by Derek Tilley.

## ABSTRACT

The introduction and expansion of the alien annual, cheatgrass (*Bromus tectorum* L. [Poaceae]) has led to significant changes in the North American sagebrush biome fire regime. Fires have become larger and more frequent due to the creation of continuous fine fuel load of cheatgrass biomass which fills large expanses of the Intermountain West. In an effort to compartmentalize and slow fire progress, land management agencies continue to install countless km of vegetative greenstrips, largely comprised of introduced forage grasses and sub-shrubs. While effective at suppressing fire progress, these greenstrips provide little ecological functionality due to their limited species composition. Curlycup gumweed (*Grindelia squarrosa* [Pursh] Dunal [Asteraceae]) (Figure 1) is a short-lived native perennial forb which may have potential for inclusion in Intermountain greenstrips, providing a pollen and nectar source without compromising the fire-suppressing capabilities of the greenstrip. We compared flammability traits of curlycup gumweed against 4 commonly utilized greenstrip species and cheatgrass during the summer months of June through September using collections made in southern Idaho. Curlycup gumweed maintained moisture content levels similar to those of forage kochia (*Bassia prostrata* [L.] A.J. Scott [Chenopodiaceae]). Curlycup gumweed similarly out-performed crested wheatgrass (*Agropyron cristatum* [L.] Gaertn. [Poaceae]), Siberian wheatgrass (*A. fragile* [Roth] P. Candargy [Poaceae]), and Russian wildrye (*Psathrostachys juncea* [Fisch.] Nevski [Poaceae]) for time to ignition and duration of combustion. Based on these results, we feel curlycup gumweed should be considered for use in Intermountain greenstrip seedings.

Nomenclature

Plants: USDA NRCS (2019)

Birds: ITIS (2019)

## INTRODUCTION

In recent decades, the sagebrush (*Artemisia tridentata* Nutt. [Asteraceae]) steppe biome of Intermountain Western North America has been significantly affected by wildfires of increasing size and frequency (Pellant, 1990; Shinneman et al., 2018). Although wildfires were an important factor in the development and maintenance of sagebrush ecosystems, recent changes, largely influenced by human activities, have dramatically altered the dynamics and impacts of wildfire beyond natural limits, creating huge expanses affected by fire (Shinneman et al., 2018). For example, Brooks et al. (2015) reported that 8.4 million ha of greater sage-grouse (*Centrocercus urophasianus* Bonaparte [Phasianidae]) range had burned between 1984 and 2013. In another report, a total of 566,000 burned ha was documented between 2000 and 2018 in Idaho public lands alone (EIIFC, 2019).

Much of the change in fire impact in the region can be attributed to the invasion of introduced annual grasses such as cheatgrass (*Bromus tectorum* L. [Poaceae]). High-density cheatgrass monocultures have resulted in accelerated fire frequencies (Balch et al., 2013; Brooks et al., 2015) and a significant increase in the number of large “megafires” caused by longer, hotter and drier fire seasons (Westerling et al., 2006). Cheatgrass has caused fire frequency in the Great Basin to shorten from once every 75 to 100 years to as little as every 3 to 5 years in certain areas (Whisenant 1990; Monsen and Memmott, 1999). Invasive annual grasses fill available open spaces and provide an abundance of continuous fine fuel (Pilliod et al., 2017) (Figure 2). Even in areas where the perennial vegetation is largely intact, the invasion of annuals creates conditions

conducive to wildfire. Likewise, cheatgrass responds quickly following fires with a new explosion of seedlings perpetuating the cheatgrass fire cycle (D'Antonio and Vitousek, 1992).



Figure 2. Intermountain shrublands in the sagebrush biome typically have a strong component of bare ground (forward). Cheatgrass (rear) however invades these interspaces and creates a continuous fuel load allowing fires to travel much farther than they naturally would. Photo by Derek Tilley.

Most fires in the region occur in the summer months of May through September (Shinneman et al., 2018) with peak fire activity beginning in July (EIIFC, 2019). At this time in the Intermountain basins, several weeks of continuous drought are met with frequent lightning storms. In Idaho, for example, lightning strikes account for 20 to 200 fires each year (EIIFC, 2019). Added to that are the human caused fires resulting from cigarettes, automobiles, mowing and gun fire.

Fuel breaks (any fuel treatment involving the removal or modification of vegetation in strips to disrupt fuel continuity and reduce fuel loads) are commonly implemented by U.S. Bureau of Land Management (BLM) and other land management agencies to slow and compartmentalize wildfires, allowing fire crews time to respond (Maestas et al., 2016). For example, the goal of the BLM's recent Paradigm Project in southwestern Idaho was to install approximately 480 km of fuel breaks in an area highly frequented by wildfire (USDI BLM, 2011). Greenstrips are a subset of fuel breaks developed to strategically install perennial plants with beneficial fire-suppressing attributes in locations where they might suppress or slow the advancement of a wildfire by changing the dynamics of the fire behavior triangle (fuels, weather, topography). Properly

developed greenstrips increase the proportion of plants with high moisture content and exclude those species that produce fine fuels (Pellant, 1994; Maestas et al., 2016).

Plant species used in Great Basin greenstrips should possess many of the following attributes: 1) stay green and retain moisture during the wildfire season, 2) be adapted to the site and have the ability to persist through periodic extended drought conditions, 3) be grazing tolerant, 4) reduce fuel continuity by being widely separated individual plants or produce relatively low amounts of fuel, 5) be capable of establishing and persisting among competitive annual species, and 6) be fire tolerant themselves (Maestas et al., 2016; Pellant, 1994; Monsen, 1994; Davison and Smith, 1997). Few species have been shown to meet these requirements. The most commonly recommended species for Intermountain green strip plantings include: forage kochia (*Bassia prostrata* [L.] A.J. Scott [Chenopodiaceae]), crested wheatgrass (*Agropyron cristatum* [L.] Gaertn. [Poaceae]), Siberian wheatgrass (*A. fragile* [Roth] P. Candargy [Poaceae]), and Russian wildrye (*Psathrostachys juncea* [Fisch.] Nevski [Poaceae]) (Maestas et al., 2016; Shinneman et al., 2018; St. John and Ogle, 2009).

The introduced sub-shrub, forage kochia, for example, has been shown to be effective at suppressing wildfires by disrupting fuel continuity and maintaining high moisture levels (Harrison et al., 2002; Waldron, 2011). Forage kochia was the primary species to be seeded in the BLM Paradigm Project (USDI-BLM 2011). In field trials conducted by Monsen and Memmott (1999), flame lengths going from dry grass stubble into plots of forage kochia were reduced from 3 to 4.5 m down to 0.6 to 1.5 m. Fires in 26 km/h winds burned into the forage kochia plot an average of only two feet before visibly diminishing (Monsen and Memmott, 1999). Crested wheatgrass, Siberian wheatgrass and Russian wildrye are all long-lived and highly drought-tolerant perennial grasses introduced from Eurasia. These species were initially planted in the region to provide forage for livestock, but their drought-tolerance and ability to stay (at least somewhat) green during the dry season, has led to their inclusion in greenstrip seedings.

One notable drawback of greenstrips in the Great Basin is the lack of plant species diversity and thus ecological function. Greenstrips are often monocultures of non-native perennials such as crested wheatgrass or forage kochia which offer little to native wildlife. Merriam et al (2006) found that non-native plant abundance was greater in fuel breaks than in adjacent areas. In monotypic greenstrips of forage kochia one often only sees forage kochia and bur buttercup (*Ceratocephala testiculata* [Crantz] Roth [Ranunculaceae]) (pers. obs.). The lack of diversity, in particular native forbs, creates miles of non-functional habitat effectively void of valuable resources such as native pollen and nectar. Adapted forbs that meet the fire management requirements could be beneficial in suppressing weed encroachment and provide food and habitat for native insects, upland birds and other wildlife. Monsen and Memmott (1999) concluded that greenstrips using a combination of species is practical and advisable; however, only a limited number of forbs have been evaluated for use in greenstrips in the Great Basin region.

Monsen and Memmott (1999) tested common yarrow (*Achillea millefolium* L. [Asteraceae]) and small burnet (*Sanguisorba minor* Scop. [Rosaceae]) and found significant reduction in flame lengths comparable to those observed with forage kochia. Maestas et al. (2016) and St. John and Ogle (2009) recommend common yarrow, blue flax (*Linum perenne* L. [Linaceae]), small burnet, and alfalfa (*Medicago sativa* L. [Fabaceae]) for inclusion in greenstrips based on their tendency

to remain green into late-summer. Davison and Smith (1997) further recommend Palmer's penstemon (*Penstemon palmeri* A. Gray [Scrophulariaceae]) for use in Nevada greenstrips.



Figure 3. Curlycup gumweed is often found naturally occurring along roadsides in the disturbed ground between the road and established perennials. Here shown in mid-July, still green. Photo by Derek Tilley.

One species worthy of consideration in Intermountain seedings is curlycup gumweed (*Grindelia squarrosa* [Pursh] Dunal) (Figure 3). Curlycup gumweed is a native, short-lived perennial forb of the sunflower family (Asteraceae) found throughout North America with the exception of the Southeastern states. It is well-adapted to conditions of disturbed, early-seral areas in the Intermountain West where it is commonly found along road margins and in degraded range (Welsh et al., 2003). Curlycup gumweed seems to meet many of the desirable attributes for greenstrip species, namely: green during the fire season, able to withstand drought (Welsh et al., 2003; Tilley and Pickett, 2016), and grazing tolerant (via low palatability) (Ogle and Brazee, 2009). A close relative, great valley gumweed (*G. camporum* Greene) native to the San Juaquin Valley of California, has been implicated in stopping the spread of wildfires in California grasslands (Dremann, 1994), and is listed as a “preferred” plant species for fire-wise landscaping in Marin County (FIREsafe MARIN, 2018).

Curlycup gumweed has potential to increase ecosystem function while providing benefits of desired greenstrip species. Curlycup gumweed is highly attractive to native bees and is recommended for inclusion in pollinator friendly habitat plantings (Lee-Mäder et al., 2016). The species' drought tolerance and late-season flowering make it especially valuable for Conservation Reserve Program (CRP) and other range plantings in the arid west where late-blooming forbs are limited. It has also been documented as a food source for sage-grouse (Peterson, 1970), a species being considered for listing under the U.S. Endangered Species Act (ESA) by the U.S. Fish and Wildlife Service (USFWS, 2005).

A study was initiated to describe curlycup gumweed's greenstrip attributes and compare its performance to that of commonly utilized species as well as cheatgrass to determine its potential for use in greenstrip seed mixes.

## MATERIALS AND METHODS

### Collection Locations

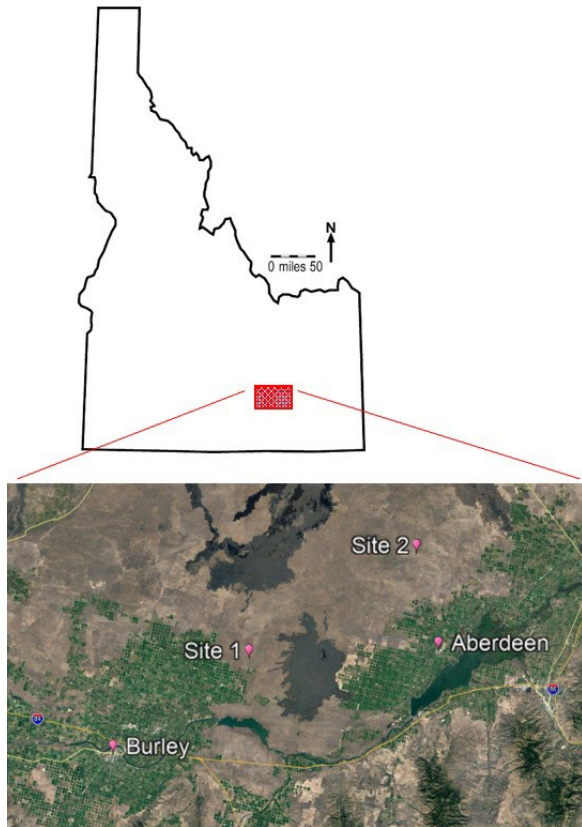


Figure 4. We made biomass collections from 2 sites in the Snake River Plain of southern Idaho. Also shown is the location of the Burley, ID weather station and Aberdeen PMC. Image courtesy of Google Earth.

Percent moisture and fire behavior of three commonly-used introduced perennial grasses, crested wheatgrass, Siberian wheatgrass, Russian wildrye and one introduced perennial shrub, forage kochia, were compared against the native forb curlycup gumweed. We also included samples of cheatgrass in our trial to observe undesirable characteristics. Biomass samples were collected monthly throughout the fire season (June, July, August and September) from populations in the Snake River Plains of southern Idaho (Figure 4). Cheatgrass, curlycup gumweed, crested wheatgrass and forage kochia were collected 8 km north of Minidoka, ID ( $42^{\circ} 49.709'$ ,  $-113^{\circ} 26.067'$ ) at an elevation of 1450 m (site 1). This site is a degraded basin big sagebrush (*Artemisia tridentata* ssp. *tridentata* Nutt. [Asteraceae]) and bluebunch wheatgrass (*Pseudoroegneria spicata* [Pursh] Á. Löve [Asteraceae]) plant community receiving an average of 20 to 30 cm precipitation. Collections of Russian wildrye and Siberian wheatgrass (site 2) were made 57 km NE of Aberdeen, ID ( $43^{\circ} 9.585'$ ,  $-112^{\circ} 58.55767'$ ) at 1395 m in a site which historically supported a Wyoming big sagebrush (*A. tridentata* ssp. *wyomingensis* Beetle & Young [Asteraceae]) and bluebunch wheatgrass community with similar precipitation (Web Soil Survey, 2019). Samples were hand harvested and put in gallon freezer storage bags and stored in an

ice-filled cooler for transport.

### Moisture Content

To determine moisture content (MC), samples of 10 to 20 g were weighed within 4 hr of collection, then dried in a forage oven at  $60^{\circ}$  C for 5 days. We computed MC based on 4 replicates as follows:

$$MC = ((WW - DW) / WW) \times 100$$

Where MC is the moisture content of the combustible material (in %), WW is weight (wet) of material at the time of collection, and DW is weight (dry) of material.

### Burn Characteristics

Burning characteristics are highly variable and dependent on numerous external factors including ambient temperature, wind speed and relative humidity, so it is very difficult to formalize

flammability scores for various plant species (Essaghi et al., 2017; Kauf et al., 2014). Dried cheatgrass has an ignition temperature of approximately 270° C (Kaminski, 1974). Launchbaugh et al. (2008) further defined 225 kg/ha or greater of cheatgrass as a fuel load with the potential to generate extreme fire behavior and equivalent to a fire line intensity of 100 BTU (British Thermal Units) per foot square per second (BTU/ft<sup>2</sup>/s). However, Beckstead et al. (2011) measured flame temperatures at 5 cm above the soil surface in prescribed burn sites of near-monoculture cheatgrass sites in Utah and Washington using temperature-indicating lacquer paints and found peak temperatures reaching just over 150° C. Though they reported cover values of 85%, they did not report on plant density or fuel load. Brooks (2002) likewise measured fire behavior in Mojave Desert species and found peak temperatures averaging 140° C in the understory, which was largely comprised of annual *Bromus* spp. with biomass averaging 1000 kg/ha. Their results seem at odds with on Kaminsky's ignition temperatures (1974).



Figure 5. We determined combustion temperatures of a high-density cheatgrass fire by igniting a 1.45 m<sup>2</sup> area of freshly dug material in a galvanized wash tub. In two replications we recorded peak temperatures of just over 500° C. Photo by Derek Tilley.

To estimate the temperatures of a cheatgrass fire, we dug a 1.45 m<sup>2</sup> circle of high-density dry cheatgrass monoculture, including the top 5 cm of soil, and placed it in a galvanized wash tub of the same diameter to maintain fuel orientation and ignited it on one end with a propane torch (Figure 5). Average aboveground biomass of the site was determined by taking 5, 0.5 m<sup>2</sup> samples and oven drying them for 5 days at 60° C. Average biomass at the site ranged from 1200 to 4560 kg/ha with a mean of 2460 kg/ha, which is well above Launchbaugh et al.'s (2008) definition of high fuel load and Brooks' (2002) Mojave Desert biomass.

We measured peak temperatures with a Lasergrip1022 infrared thermometer from Etekcity Corporation (Anaheim, CA) held 0.5 m from the flames. Site conditions during the burn were 20° C and 42% relative humidity. In two replications we recorded peak temperatures of 522° and 524° C.

We found considerable variability in lab testing methods used to determine burn characteristics. Kauf et al. (2014) conducted flammability tests with an epi-radiator and 1 g samples at 250° and 420° C. Batista et al. (2012) similarly used 250° C for their epi-radiator tests, while Essaghi et al. (2017) used 2 g samples at 600° C. We decided to use larger samples and heat sources similar to those found in a cheatgrass/sagebrush fire. To quantify burning characteristics, a 12 g samples of loosely arranged fresh material was centered in a 10 x 15 cm cage made of 13 mm hardware cloth and placed the cage directly into the flames of a liquid propane burner (Kenmore RB2518TS) gas grill with individual burner output of 170 BTU/ft<sup>2</sup>/s. We measured flame temperatures of 300° to 400° C using a 7.6 cm stainless steel temperature gauge from GasSaf (Zengcheng Guangzhou, Guangdong) mounted with the sensor end held directly above the flame at the same height as the burn samples.

We measured time to ignition (TI) in seconds (visible flame sustained for more than 1 s) and duration of combustion (DC) (ignition to extinction from consumption of available fuel) using a hand-held digital timer. Each test was replicated 4 times. Data were not analyzed for significance, but means are presented here to show trends.

Weather data were obtained from Burley, ID, an area of similar site characteristics and historic plant communities which lies 27 km southeast of site 1 and 79 km southwest of site 2 (Web Soil Survey, 2019). Weather graphs for the period of June 15 to September 15, 2019 (Figure 6) were prepared using NOWData (NOAA NWS, 2019). Precipitation was normal for the testing period. Total precipitation from June 15 through September 15, 2019 was 300 mm. There were 4 rainfall events recorded in the study area during the period of evaluation: on July 3, the region received 23 mm; on July 25, 127 mm; on August 8, 23 mm, and between September 7 and 10 the area received 127 mm. Observed temperatures ranged from a low of 0.6° C on June 9 to a high of 37° C on July 22.

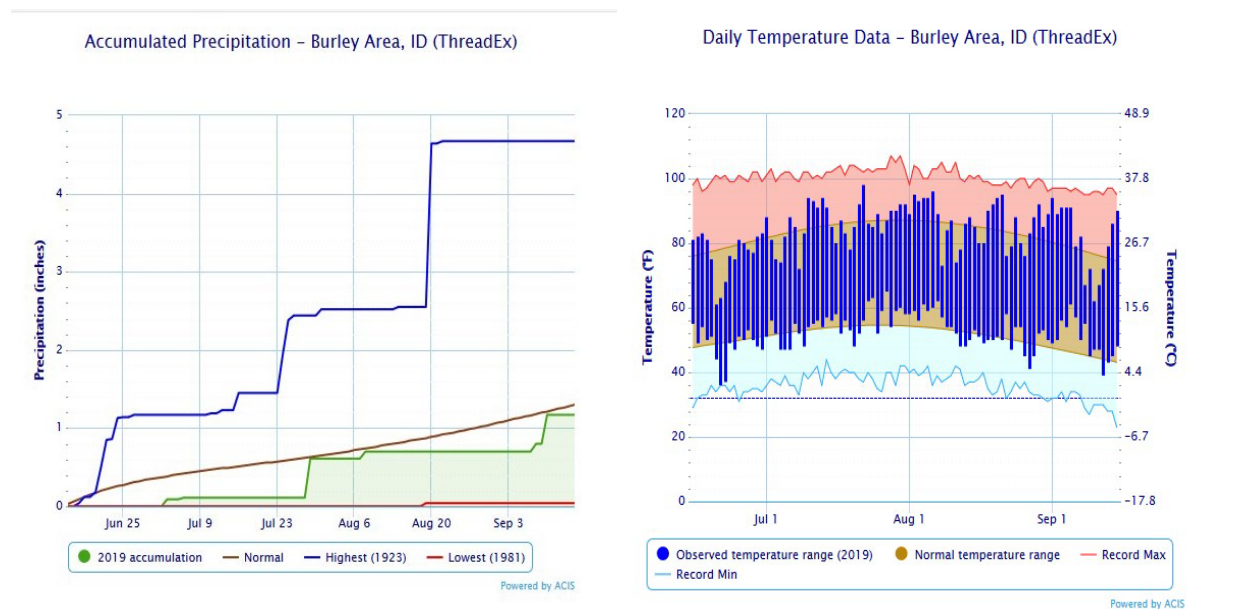


Figure 6. Accumulated precipitation (in) and daily temperature data from nearby Burley, ID. Courtesy of NOWData.

## RESULTS AND DISCUSSION

### *Moisture Content*

In mid-June all 6 species had MC of over 50% (Figure 7). Cheatgrass moisture levels dropped sharply between June and July as flowering had concluded, plants senesced, and seed matured. In July, August and September, cheatgrass MC was at essentially 0%. The two perennial wheatgrass species showed similar trends in MC with percent moisture starting at approximately 60% in June and decreased to 28% in August where it maintained for the remainder of the trial. Russian wildrye began with similar moisture levels as the other perennial grasses but maintained somewhat higher levels in August (40%). Russian wildrye also responded to late summer rain in early September with an increase of average MC to 49%. Forage kochia maintained consistent MC throughout the trial duration averaging just over 60% from June through August. In



September we observed a slight decline in MC of forage kochia at 56%. Curlycup gumweed had the highest MC in June (79%), after which MC declined steadily through July and August going from 68 to 55% and ending at 50% in September.

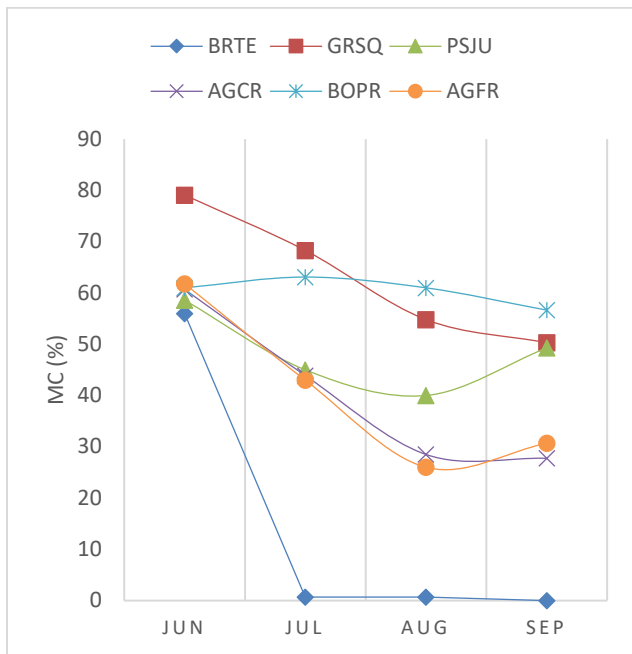


Figure 7. Moisture Content (MC) of wildland-harvested cheatgrass, 3 introduced forage grasses, forage kochia and curlycup gumweed from June 15 to September 15, 2019 in the Intermountain West. BRTE=cheatgrass, GRSQ=curlycup gumweed, PSJU=Russian wildrye, AGCR=crested wheatgrass, BOPR=forage kochia, AGFR=Siberian wheatgrass.

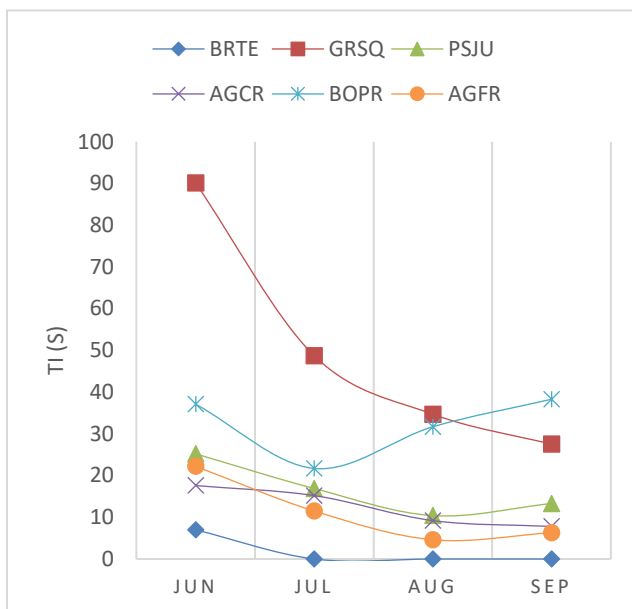


Figure 8. Time to Ignition (TI) at 440° C of 12 g samples of wildland-harvested materials. BRTE=cheatgrass, GRSQ=curlycup gumweed, PSJU=Russian wildrye, AGCR=crested wheatgrass, BOPR=forage kochia, AGFR=Siberian wheatgrass.

### Burn Characteristics

Cheatgrass had the fastest TI in every month of the trial (Figure 8). In June it took on average 7 s for cheatgrass to ignite. At this point the cheatgrass was a mixture of dried and green material with some plants at anthesis and others undergoing seed maturation. Crested wheatgrass, Siberian wheatgrass and Russian wildrye had similar trends of ignition with TIs averaging from 17 s (crested wheatgrass) to 25 s (Russian wildrye) in June and decreasing slightly during the latter months when plants were drier. August and September TI for the perennial grasses ranged from 5 to 13 s. Forage kochia TIs were consistently greater than those of the grasses. Curlycup gumweed was very difficult to ignite in June with an average TI of 90 s. TIs dropped in the subsequent months, corresponding to decreasing moisture levels; however, curlycup gumweed (Figure 9) had the longest



ignition times of the evaluated species each month with the exception of September where forage kochia had slightly slower ignition (38 s) compared to curlycup gumweed (28 s).

Figure 9. Curlycup gumweed had the longest time to ignition (TI) for each month except September. Photo shows material collected in June. Photo by Derek Tilley.

As MC decreased over the summer months, fires burned much more quickly in all species (Figure 10). Cheatgrass samples burned more quickly than any other species examined (Figure 11). The longest cheatgrass DC (80 s) was in June where much of the sample was still green. The dry, post-shatter

cheatgrass tested from July, August and September burned almost explosively with fires averaging approximately 10 to 20 s. We observed intermediate DCs from the perennial grasses. In the dry summer months of August and September, all three perennial grass species exhibited DCs of approximately 60 s. DCs of forage kochia and curlycup gumweed were notably longer than those of the other species averaging approximately 100 s in August and September.

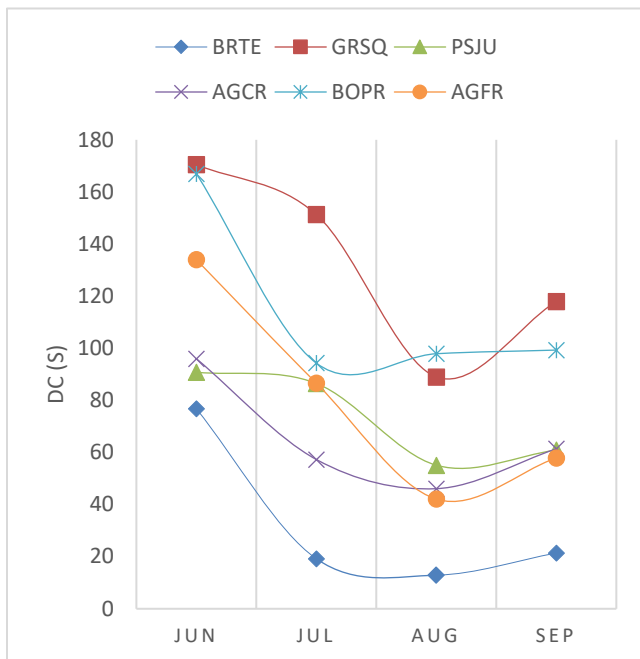


Figure 10. Duration of Combustion (DC) of 12 g biomass at 440° C of wildland-harvested materials. BRTE=cheatgrass, GRSQ=curlycup gumweed, PSJU=Russian wildrye, AGCR=crested wheatgrass, BOPR=forage kochia, AGFR=Siberian wheatgrass.



Figure 11. A 12 g sample of cheatgrass harvested in mid-September ignites quickly and burns explosively. Photo by Derek Tilley.

## CONCLUSION

Burning characteristics are dependent on numerous external factors and are very difficult to nail down (Essaghi et al., 2017; Kauf et al., 2014); however, between species comparisons can be made. Our results from using low-tech test methods show trends and comparative values for 6 species important in the Intermountain Western sagebrush ecosystem, as they occurred throughout the summer.

MC is perhaps the most important factor when determining a species' flammability. Cheatgrass TI and DC changed significantly as MC levels dropped. Russian wildrye responded to late summer rain events with greenup and increased MC, though that did not appear to translate to longer TI or DC. Curlycup gumweed and forage kochia both maintained high MC throughout the summer. Curlycup gumweed response to fire was similar to forage kochia, though decreased MC of curlycup gumweed in September corresponded with slightly decreased TI. Both curlycup gumweed and forage kochia were quite slow to ignite and to burn, mostly just drying up and withering away rather than creating a significant flame. Curlycup gumweed was clearly less prone to ignition and the creation of a hot flash during the fire season than the commonly planted perennial grasses.

To our knowledge, curlycup gumweed has rarely been recommended for seeding in Intermountain Western restoration and reclamation projects. This is likely due to its being considered a weedy species by some due to its low palatability and its tendency to increase under grazing (Ogle and Braze, 2009; Whitson et al., 1996). However, curlycup gumweed possesses numerous attributes desirable for native wildlife habitat restoration practices, namely drought tolerance, easy establishment, adaptation to disturbed sites, attractive to pollinators, and fall flowering (Tilley and Pickett, 2016). As such, multiple accessions are currently being investigated by the authors for selected class germplasm release at the USDA NRCS Plant Materials Center in Aberdeen, Idaho.

Despite its performance in our evaluations curlycup gumweed may possess some attributes that limit its feasibility in greenstrips. Curlycup gumweed is a short-lived perennial or biennial which naturally serves as an early-seral colonizer of disturbed areas. Typically, curlycup gumweed decreases in abundance after a few years giving way to longer-lived, late-successional climax species such as sagebrush and perennial bunch grasses. It is possible that the niches created as curlycup gumweed decreases can be exploited by invasive annuals (Maestas et al., 2016). However; greenstrip areas do not typically phase towards a climax community, but rather remain in a state of semi-disturbance thanks to periodic mowing. Under such management, curlycup gumweed may continue to re-establish and persist if allowed.

Interestingly, curlycup gumweed has been investigated as the feedstock for producing sustainable biodiesel and aviation fuels (Neupane et al., 2016). Researchers found that that 12 to 25% of the dry weight of the plant (depending on agronomic factors) is made of terpenoid compounds, primarily grindelic acid, a diterpene acid which could be converted to hydrocarbons that can be used directly as an aviation fuel. Despite containing these flammable compounds, we saw no evidence that field-harvested curlycup gumweed material was abnormally combustible.

Our results indicate curlycup gumweed possesses many traits desirable for a greenstrip species and should be considered for inclusion in Intermountain seed mixes. Its presence in greenstrips could increase species diversity and provide a pollen and nectar source for native insects.

### LITERATURE CITED

- Baker, W. L. 2011. Pre-Euro American and recent fire in sagebrush ecosystems. Pages 185–201 in S. T. Knick and J. W. Connelly, editors. Ecology and conservation of Greater Sage-grouse: a landscape species and its habitats. Studies in Avian Biology, vol. 38. University of California Press, Berkeley, California, USA.
- Balch, J. K., Bradley, B. A., D'Antonio, C. M. and Gómez-Dans, J. 2013. Introduced annual grass increases regional fire activity across the arid western USA (1980–2009). *Glob Change Biol.*, 19: 173–183. doi:10.1111/gcb.12046
- Batista, A.C., Biondi, D., Tetto, A.F., de Assuncao, R., Tres, A., Travenisk, R.C.C. and B. Kovalsyki. 2012. Evaluation of the flammability of trees and shrubs used in the implementation of green barriers in Southern Brazil. General Technical Report PSW-GTR-245.
- Beckstead, J. Street, L.E., Meyer, S.E. and P.S. Allen. 2011. Fire effects on the cheatgrass seed bank pathogen *Pyrenophora semeniperda*. *Rangeland Ecology and Management* 64: 148-157.
- Brooks, M.L. 2002. Peak fire temperatures and effects on annual plants in the Mojave Desert. *Ecological Applications* 12(4): 1088-1102.
- Brooks, M.L., Matchett, J.R., Shinneman, D.J. and P.S. Coates. 2015. Fire patterns in the range of greater sage-grouse, 1984-2013-Implications for conservation and management. US Geological Survey Open-File Report 2015-1167. 66 p.
- Coates, P.S., Ricca, M.A., Prochazka, B.G., Doherty, K.E., Brooks, M.L., and Casazza, M.L. 2015. Long-term effects of wildfire on greater sage-grouse—Integrating population and ecosystem concepts for management in the Great Basin: U.S. Geological Survey Open-File Report 2015–1165, 42 p.
- D'Antonio, C.M. and P.M. Vituosek. 1992. Biological invasions by exotic grasses, the grass/fire cycle, and global change. *Annual Review of Ecology and Systematics*. 23: 63-87.
- Davison, J. and E. Smith. 1997. Living with Fire – Greenstrips: Another Tool to Manage Wildfire. University of Nevada Cooperative Extension Fact Sheet 97-36. 5p.
- Eastern Idaho Interagency Fire Center. 2019. [https://www.idahofireinfo.blm.gov/east/info\\_statistics.html](https://www.idahofireinfo.blm.gov/east/info_statistics.html). (accessed 17 Sep 2019).
- Essaghi, S., Hachmi, M., Yessef, M. Dehhaoui, M., and F.E. Arty. 2017. Assessment of flammability of Moroccan forest fuels: new approach to estimate the flammability index. *Forests* 8: 443; doi:10.3390/f8110443.
- [FMSI] Fire Management Systems Laboratory. 2019. University of Toronto. [http://www.firelab.utoronto.ca/behaviour/grass\\_fire.html](http://www.firelab.utoronto.ca/behaviour/grass_fire.html) (accessed 16 Sep 2019).
- Harrison, R.D., Waldron, B.L., Jensen, K.B., Page, R., Monaco, T.A., Horton, W.H. and A.J. Palazzo. 2002. Forage kochia helps fight range fires. *Rangelands*. 24 (5): 3-7.
- Havlina, D.W., Anderson, P., Kurth, L., Mayer, K.E., Chambers, J.C., Boyd, C., Christiansen, T., Davis, D., Espinosa, S., Ielmini, M., Kemner, D., Maestas, J.D., Meador, B., Pellant, M., Tague, J., and J. Vernon. 2015. Fire and Fuels Management Contributions to Sage-Grouse Conservation: A Status Report. Western Association of Fish and Wildlife Agencies. Unpublished Report. Cheyenne, Wyoming. 73 pp.

- [ITIS] Integrated Taxonomic Information System. 2019. URL: <http://www.itis.gov> (accessed 20 Aug 2019).
- Kaminsky, G.C. 1974. Ignition time vs temperature for selected forest fuels. University of California at Riverside, San Dimas Equipment Development Center. <https://www.fs.fed.us/t-d/programs/fire/spark/html/74511201/74511201.html> (accessed 19 Sep 2019).
- Kauf, Z., Fangmeier, A., Rosavec, R. and Z. Spanjol. 2014. Testing vegetation flammability: the problem of extremely low ignition frequency and overall flammability score. *Journal of Combustion*; doi 10.1155/2014/970218.
- Launchbaugh, K.L., Brammer, B., Brooks, M.L., Bunting, S.C., Clark, P., Davison, J., Fleming, M., Kay, R., Pellant, M., Pyke, D., and B. Wylie. 2008. Interactions among livestock grazing, vegetation type, and fire behavior in the Murphy Wildland Fire Complex in Idaho and Nevada, July 2007. Open-File Report 2008–1214. U.S. Geological Survey, Reston, VA.
- Lee-Mäder, E., Fowler, J., Vento, J., and J. Hopwood. 2016. 100 Plants to Feed the Bees: Provide a Healthy Habitat to Help Pollinators Thrive. Storey Publishing, North Adams, MA. 239p.
- Maestas, J., Pellant, M., Okeson, L., Tilley, D., Havlina, D., Cracraft, T., Braze, B., Williams, M., and D. Messmer. 2016. Fuel breaks to reduce large wildfire impacts in sagebrush ecosystems. Plant Materials Technical Note No. 66. USDA-NRCS. Boise, ID. 33 p.
- Merriam, K.E., Keeley, J.E. and J.L. Beyers. 2006. Fuel breaks affect nonnative species abundance in Californian plant communities. *Ecological Applications* 16(2): 515-527.
- Monsen, S.B., 1994. Selection of Plants for Fire Suppression on Semiarid Sites. The competitive influences of cheatgrass (*Bromus tectorum*) on site restoration. Pages 363-373 in: S.B. Monsen and S.G. Kitchen, compilers. *Proceedings: Ecology and Management of Annual Rangelands*. USDA Forest Service General Technical Report INT-GTR-313.
- Monsen, S.B. and K.L. Memmott. 1999. Comparison of burning reliance of forage kochia, crested wheatgrass, bluebunch wheatgrass, small burnet, and western yarrow in simulated burned greenstrips. p. 113-122. In: *Cooperative research studies 1989-1998*. USDA Forest Service, Rocky Mountain Research Station, Shrub Sciences Lab., Provo, UT. Report submitted to U.S. Dept. of Interior, Intermountain Greenstripping Program. Boise, ID. 285 p.
- Moriarti, K., Okeson, L. and M. Pellant. 2015. Fuel breaks that work. Great Basin Fact Sheet Series. No. 5. [http://www.sagegrouseinitiative.com/wp-content/uploads/2015/07/5\\_GBFS\\_Fuel-Breaks.pdf](http://www.sagegrouseinitiative.com/wp-content/uploads/2015/07/5_GBFS_Fuel-Breaks.pdf)
- Neupane, B.P., Shintani, D., Lin, H., Coronella, C.J. and G.C. Miller. 2016. *Grindelia squarrosa*: a potential arid lands biofuel plant. *Sustainable Chemistry and Engineering*. 5: 995-1001.
- [NOAA NWS] National Oceanic and Atmospheric Administration, National Weather Service. 2019. NOAA Online Weather Data (NOWData). <https://nowdata.rcc-acis.org/pih/> (accessed 24 Sep 2019). Silver Spring (MD).
- Ogle, D. and B. Braze. 2009. Estimating initial stocking rates. NRCS Plant Materials Technical Note. No. 3. USDA-NRCS. Boise, ID. 39 p.
- Pellant, M. 1990. The cheatgrass-wildfire cycle: Are there any solutions? p. 11–18. In E.D. McArthur, E.M. Romney, S.D. Smith, and P.T. Tueller (comps.). *Proceedings-Symposium on cheatgrass invasion, shrub die-off, and other aspects of shrub biology and management*. 5–7 April 1989. Las Vegas, NV. GEN. Tech. Rep. INT276. USDA Forest Service, Intermountain Research Station, Ogden, UT. 351 p.
- Pellant, M. 1994. History and applications of the intermountain greenstripping program. p. 63–68. In: S.B. Monsen and S.G. Kitchen (comps.). *Proceedings-symposium on ecology and management of annual rangelands*. 18–21 May 1992. Boise, ID. Gen. Tech. Rep. INT-GTR-313. USDA Forest Service, Intermountain Research Station, Ogden, UT. 416 p.

- Pilliod, D.S., Welty, J.L., and R.S. Arkle. 2017. Refining the cheatgrass-fire cycle in the Great Basin: precipitation timing and fine fuel composition predict wildfire trends. *Ecology and Evolution*. 7(19): 8126-8151.
- Peterson, J.G. 1970. The food habits and summer distribution of juvenile sage grouse in central Montana. *Journal of Wildlife Management*. 34(1): 147-155.
- Pyke, D.A., Shaff, S.E., Lindgren, A.I., Schupp, E.W., Doescher, P.S., Chambers, J.C., Burnham, J.S. and M.M. Huso. 2014. Region-wide ecological responses of arid Wyoming big sagebrush communities to fuel treatments. *Rangeland Ecology and Management* 67: 455-467.
- Schupp, E.W., Boyd, C.S. and S. Green. 2015. Woody fuels reduction in Wyoming big sagebrush communities. Great Basin Factsheet Series. No. 13.
- Shinneman, D.J., Aldridge, C.L., Coates, P.S., Germino, M.J., Pilliod, D.S. and N.M. Vaillant. 2018. A conservation paradox in the Great Basin-Altering sagebrush landscapes with fuel breaks to reduce habitat loss from wildfire. U.S. Geological Survey Open-File Report 2018-1034. 70p.
- St. John, L. and D. Ogle. 2009. Green strips or vegetative fuel breaks. NRCS Plant Materials Technical Note. No. 16. USDA-NRCS. Boise, ID. 16 p.
- Syphard, A.D., Keeley, J.E. and T.J. Brennan. 2011b. Factors Affecting Fuel Break Effectiveness in the Control of Large Fires on the Los Padres National Forest, California. *International Journal of Wildland Fire* 20: 764-775. doi: 10.1071/WF10065
- Tilley, D. and T. Pickett. 2016. Plant Guide for curlycup gumweed (*Grindelia squarrosa*). USDA -Natural Resources Conservation Service, Aberdeen Plant Materials Center. Aberdeen, ID. 83210. 5 p.
- [USDA NRCS] U.S. Department of Agriculture, Natural Resources Conservation Service. 2019. The PLANTS database. URL: <http://plants.usda.gov> (accessed 9 Sep 2019). Goldsboro (NC): National Plant Data Team.
- [USDI BLM] U.S. Department of Interior 2011. Paradigm Fuel Break Project: Draft Environmental Assessment DOI-BLM-ID-B010-2011-0060-EA. Four Rivers Field Office. Boise (ID). 151p.
- [USDI]. U.S. Department of Interior 2015. Secretarial Order Number 3336, Rangeland Fire Prevention, Management, and Restoration. <http://www.forestsandrangelands.gov/rangeland/documents/SecretarialOrder3336.pdf>
- [USFWS] U.S. Fish and Wildlife Service. 2005. Endangered and threatened wildlife and plants- 12 month finding for petitions to list eh greater sage-grouse as threatened or endangered. *Federal Register* 70: 2244-2282.
- [USFWS]. U.S. Fish and Wildlife Service. 2015. Endangered and threatened wildlife and plants; 12-month finding on a petition to list the greater sage-grouse (*Centrocercus urophasianus*) as an endangered or threatened species; proposed rule. *Fed. Register* 80: 59858-59942.
- Waldron, B. 2011 Strategic Use of Forage Kochia (*Kochia prostrata*) to Revegetate Wildlife Habitat. *Natural Resources and Environmental Issues: Vol. 17, Article 17.*
- Web Soil Survey. 2019. U.S. Department of Agriculture, Natural Resources Conservation Service. Available online at: <https://websoilsurvey.sc.egov.usda.gov/> (accessed 19 Sep 2019).
- Welsh S.L., Atwood N.D., Goodrich S. and L.C. Higgins. 2003. A Utah flora. Third edition, revised. Provo (UT): Brigham Young University. 912 p.
- Westerling, A.L., Hidalgo, H.G. Cayan, D.R. and T.W. Swetnam. 2006. Warming and earlier spring increase Western U.S. forest wildfire activity. *Science* 313 (5789): 940-943.

- Whisenant, S.G. 1990. Changing fire frequencies on Idaho's Snake River plains: ecological and management implications. In: Proceedings of the Symposium on Cheatgrass Invasion, Shrub Die-Off, and Other Aspects of Shrub Biology and Management. (eds McArthur et al.), pp. 4–10. Forest Service General Technical Report INT-276. Intermountain Research Station, Las Vegas, NV.
- Whitson T.D., Burrill L.C., Dewey S.A., Cudney, D.W., Nelson B.E., Lee R.D., and R. Parker. 1996. Weeds of the West. 5<sup>th</sup> Edition. Pioneer of Jackson Hole. Jackson (WY). 630 p.

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