REMEDIATION OF DEICER SALT CONTAMINATED SOILS USING NATIVE MONTANA PLANTS

Task 1 Report – Identification of Plant Candidates

Prepared by

Tom Raske

And

Claire Luby
Assistant Professor

And

Laura Fay
Senior Research Scientist
Western Transportation Institute

of the

at Montana State University – Bozeman

Prepared for the
MONTANA DEPARTMENT OF TRANSPORTATION
in cooperation with the
U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION

January 31, 2025

Disclaimer Statement

This document is disseminated under the sponsorship of the Montana Department of Transportation (MDT) and the United States Department of Transportation (USDOT) in the interest of information exchange. The State of Montana and the United States assume no liability for the use or misuse of its contents.

The contents of this document reflect the views of the authors, who are solely responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the views or official policies of MDT or the USDOT.

The State of Montana and the United States do not endorse products of manufacturers.

This document does not constitute a standard, specification, policy or regulation.

Alternative Format Statement

Alternative accessible formats of this document will be provided upon request. Persons who need an alternative format should contact the Office of Civil Rights, Department of Transportation, 2701 Prospect Avenue, PO Box 201001, Helena, MT 59620. Telephone 406-444-5416 or Montana Relay Service at 711.

Acknowledgments

The WTI Team would like to thank the MDT Research Programs Manager Rebecca Ridenour and our Research Project Manager Vaneza Callejas for their oversight. The WTI Team would also like to thank our Technical Panel, including: Darcy Goodson, Doug McBroom, Aaron Anderson, Steve Felix, Joe Radonich, Scott Brown, and Joe Weigand (FHWA) for their guidance and direction.

TABLE OF CONTENTS

List of Tables

Acronym List

DOT	Department of Transportation
EC	Electric conductivity
FHWA	Federal Highway Administration
MDT	Montana Department of Transportation
MT	Montana
NRCS	Natural Resource Conservation Service
PDF	Portable Document Format
USDA	United States Department of Agriculture
USU	Utah State University
WTI	Western Transportation Institute
avg.	average
dS/m	deciSiemens per meter
in	inch
min.	minimum

Project Background

Montana stores and uses up to 1,000,000 pounds of deicing salt across the state for use in winter maintenance operations. This salt is blended with sanding material up to 50% for the mixed material to serve for added traction on snow and ice covered roads and for deicing. This mixture is stored at locations ranging from covered piles on permeable ground to fully enclosed metal facilities on concrete foundations. Even while fully protected from the elements, deicing salt can still leach into the surrounding environment in measurable quantities. In addition to sand/salt storage facilities, studies have shown that runoff from roads containing deicing salts during the winter contributes to a substantial increase in salt concentration in nearby soil and water. This yearly cycle of snow and application of deicing salts means that watersheds and drinking water experience an annual influx of salt. Because chlorides from salts do not degrade, they continue to move through the water system. This can negatively impact both surface and ground water and lead to contaminated drinking water wells. Additionally, deicing salts can negatively affect roadside vegetation and soils by displacing nutrients, reducing soil permeability, and mobilizing heavy metals. Affected plants can present with browning leaves or needles, eventually leading to death. Treating salt-inundated soils has historically been a time, labor, and money-intensive activity. Excavating, pumping, and monitoring requires time, specific expertise and can cost a considerable amount. These issues have inspired a search for another remediation method.

Halophytic plants are adapted to grow in salty soils. These plants have evolved multiple times throughout history (Flowers et al., 2010), resulting in different metabolic mechanisms to survive in salty conditions. These mechanisms include excluding salts in the soil from entering the plant's roots, storing salts in different plant organs and performing detoxifying measures, or secreting salt through glands on surface tissue (Garcia et al., 2020). Understanding how halophytes metabolize salts is vital in finding suitable haloremediation candidates. Excluding salts from entering the plant will not aid in soil remediation. Excreting salts out of above-ground tissue may exacerbate saline conditions by bringing salt back to the surface, or in some cases, the salt crystals might blow away (McSorley et al., 2016).

These issues have led us to look for halophytes that store salt primarily in their tissue, specifically in their above-ground tissue. Planting these halophytes would allow for mowing, followed by removing the mowed plant tissue from the site and discarding to expedite remediation (Litalien & Zeeb, 2020). Finding plants that can sustain mowing is also significant. Shrubby plants like *Atriplex* will have woody growth that cannot be mowed, while low-growing plants like *Salicornia* may be too short for effective mowing.

Restoring soil around roads and salt storage facilities also entails finding plants that, if they leave the roadside environment, won't cause unwanted adverse ecosystem effects. Many salt—and toxin-tolerant plants are not native to western Montana and have known weedy growth habits. This has led us to record the native status of plants as we are not only considering soil remediation but also hoping to encourage sustainability and restore ecosystem health. By planting native halophytes in saline conditions, non-native plants could be replaced by native plant communities. Displacing current weedy species would be a significant benefit of planting native halophytes.

Prominent Families

The plant candidate list (Appendix A. Full List of Plants Identified) includes halophytes from the Amaranthaceae, Aizoaceae, Fabaceae, Juncaceous, Poaceae, and Sarcobataceae families. Amaranthaceae, Poaceae, and Fabaceae make up most of this list. These families are found worldwide and, as a result, have different mechanisms to metabolize salts. Additionally, they have various positive and negative adaptations for planting and mowing along roadsides.

Poaceae has the highest number of entries on the plant candidate list for many reasons. The growth habit of grasses is ideal for mowing and biomass removal as tall, slender, herbaceous growth is the easiest to cut and has a large capacity for salt storage. A wide range of variety in characteristics like salt tolerance, rooting habit, growth habit, water requirements, and ability to spread in native and non-native Poaceae makes for a robust halophytic selection. Additionally, extensive research has been done on the salt tolerance of many grasses in areas similar to the Intermountain-West region because of the persistence of saline seeps and the ability to restore and graze these toxic soils by planting Poaceae halophytes (Majerus, 2024; Masters et al., 2007; Roy & Chakraborty, 2014; Wichman & McCage, 2018).

The Amaranthaceae family consists of 2,500 species worldwide in tropical, subtropical, and temperate regions. Chenopodiaceae is a recent subfamily of Amaranthaceae with particular adaptations to arid, disturbed, and salty soils. The genera *Atriplex*, *Salicornia*, and *Suaeda* are examples found in the plant candidate list. All three genera are native to the United States and cover a range of environments. *Salicornia* and *Suaeda* are often found in wet, salty soils like beaches or inundated roadsides. *Atriplex* species are often found in dry regions of the Intermountain West because they've evolved C4 photosynthesis which allows them to be more efficient in the heat (Kadereit et al., 2003). Their ability to survive in various habitats and high salt tolerance are major reasons for their inclusion in the plant candidate table.

Fabaceae is the last prominent family on the list. This family has a worldwide distribution, the ability to fix nitrogen, and diverse growth habits (Hasanuzzaman et al., 2020). Viable species were found in the genera *Lotus*, *Medicago*, and *Melilotus*. All three genera had species with herbaceous growth habits, perennial life cycles, flowers attractive to pollinators, and vegetative spreading. The Fabaceae candidates' ideal characteristics for a contaminated and disturbed roadside environment make the described specimens attractive. However, this family of halophytes is non-native to western Montana and has mid-range salt tolerance, reducing the feasibility of this family being the best candidate for remediation.

Table Description

The list of plant candidates has been developed that compares the identified factors for a successful phytoremediation candidate in Montana (Appendix A. Full List of Plants Identified). Each plant's native status and place of origin have been listed to inform decisions based on the region where it is from. Taxonomic information, including cultivars where relevant, is included for accuracy in research and ordering seeds. Reported salt tolerance of each plant is measured in deciSiemens per meter (dS/m) for straightforward comparisons between plants and to ensure that plants are being planted in sites where they can tolerate and remediate the saline soil conditions. Each plant's growth habits, limitations, and adaptations are listed for consideration, such as water requirements, soil texture, temperature range, root depth, and tolerance to roadside waste. Summary columns of relevant plant adaptation and potential limitations are provided. The last column of the plant candidate table lists information sources to simplify accessing more detailed information.

Final Plant Candidates

A final list of plant candidates was created and ordered by native status and salt tolerance. The final list of plants was determined based on key attributes that would fit our near-road or near-salt storage environment. A combination of root depth, seedling vigor, spread rate, competitiveness, and growth rate showed that a plant might work well and should be considered. Negative attributes such as shallow rooting, woody habit, low spread, low seedling vigor, high water requirements, and invasive tendencies meant a candidate would be excluded. This organization resulted in a larger list with more grasses. The final list includes 15 Poaceae species and one Fabaceae species (Table 1).

Foxtail Barley (*Hordeum jubatum*) is a perennial bunchgrass native to North America. It has a high salt tolerance and is noted for its resilience to roadside toxins (Natural Resources Conservation Service). Like H. vulgare, it is competitive with weeds and has a deep-growing root system. *H. jubatum* has been chosen particularly for its ability to proliferate in adverse conditions and for its potential to spread through seed (Tesky, 1992).

Beardless Wildrye (*Leymus triticoides*) is a perennial rhizomatous grass native to North America. It has a high salt tolerance of 24 dS/m and can grow well in all soil types. *L. triticoides* is one of our final candidates as its rhizomatous growth habit and rapid vegetative growth means it may spread and establish itself better than other candidates (Natural Resources Conservation Service; Wichman & Mccage, 2018).

Slender Wheatgrass (*Elymus trachycaulus*) is a bunchgrass native to North America with a salt tolerance of 20 dS/m. It is a competitive grass adapted to drought, various soils, and being cut back. E. trachycaulus was chosen for its high seedling vigor and rapid growth rate, influencing establishment and regrowth (Natural Resources Conservation Service; Wichman & Mccage, 2018).

Western Wheatgrass (*Pascopyrum smithii*) is a perennial rhizomatous grass native to North America. It has a salt tolerance of up to 14 dS/m, is tolerant of drought and flood but prefers clay soils. *P. smithii* made the final list because of its especially deep rooting habit and rapid growth after establishment and cutting back (Natural Resources Conservation Service; Wichman & Mccage, 2018; *Plant Fact Sheet for Western Wheatgrass*, 2002).

Alkali Sacaton (*Sporobolus airoides*) is a perennial bunchgrass native to North America. It has a salt tolerance of 14 dS/m, drought tolerance, and is adapted to a wide variety of soils (Conway, 2001). Although *S. airoides* has low seedling vigor it was chosen for its use in the Montana Department of Transportation's Roadside seed mix and for its moderate after-harvest regrowth (Natural Resources Conservation Service).

Thickspike Wheatgrass (*Elymus lanceolatus*) is a low-growing perennial rhizomatous grass native to the western United States. It has a decent salt of 11 dS/m and is also drought tolerant. *E. lanceolatus* was chosen specifically for its high seedling vigor and ability to spread rapidly through rhizomes (Natural Resources Conservation Service; Ogle et al., 2013).

Basin Wildrye (*Leymus cinereus*) is a bunchgrass native to the western United States with a salt tolerance of up to 10 dS/m. Although it uses more moisture, *L. cinereus* has good drought tolerance and is often used in reclamation projects. It was chosen primarily for its early spring growth and deep rooting habit (Natural Resources Conservation Service; Ogle et al., 2000).

Sand Dropseed (*Sporobolus cryptandrus*) is a perennial bunchgrass native to North America. It has a lower salt tolerance of 4 dS/m but has been recorded to be almost weedy. *S. cryptandrus* is tolerant of drought and a wide range of soil pH. It was chosen for its high spread rate through seeds and deep rooting (Natural Resources Conservation Service; Tilley et al., 2009).

Tall Wheatgrass (*Thinopyrum ponticum*) is a nonnative perennial bunchgrass with a very high salt tolerance of 22 dS/m. It has been used for its high competitiveness and flexibility with water. *T. ponticum* was chosen specifically for its high seedling vigor, deep rooting, and rapid growth (Monsen et al., 2004; Natural Resources Conservation Service).

Green Wheatgrass (*Elymus hoffmannii*) is a nonnative perennial rhizomatous grass with a very high salt tolerance of 22 dS/m. It has decent drought tolerance and is a long-lived perennial. *E. hoffmannii* was chosen for its ease of establishment and ability to outcompete invasive weeds (Hybner et al., 2014).

Altai Wildrye (*Leymus angustus*) is a nonnative perennial bunchgrass with a very high salt tolerance of 20 dS/m. Although this grass has lower seedling vigor, it can use deeper water tables. *L. angustus* was chosen for its qualities, competitiveness, and ability to root deeply (Natural Resources Conservation Service; St. John et al., 2010).

Russian Wildrye (*Psathyrostachys juncea*) is a nonnative perennial bunchgrass with a high salt tolerance of 16 dS/m. It is adapted to clay and loamy soils and is weed-competitive, but difficulties have been noted in its establishment. P. juncea was chosen because it is non-invasive and tolerant of extreme cold and drought (Natural Resources Conservation Service; Taylor, 2005).

Pubescent Wheatgrass (*Thinpyrum intermedium*) is a nonnative perennial rhizomatous grass with a good salt tolerance of 12 dS/m. It is noted to have a growth habit similar to sod and grows rapidly. *T. intermedium* was chosen because it is easy to establish and is competitive with weeds (Hybner & Jacobs, 2012; Natural Resources Conservation Service).

Barley (*Hordeum vulgare*) is a nonnative annual bunchgrass that can tolerate salt up to 12 dS/m. It has a long active growth period and a low mature height but is primarily adapted to medium-textured soils. H. vulgare was chosen to compare to native Hordeum species for its rapid growth and high seedling vigor (Natural Resources Conservation Service).

Hybrid Crested Wheatgrass (*Agropyron cristatum X desertorum*) is a nonnative perennial bunchgrass with a salt tolerance of 10 dS/m. It has been used for reclamation projects and is tolerant of drought and extreme cold. *A. cristatum X desertorum* was chosen specifically because it is easy to establish, competitive, and deeply rooted (Ogle, 2002).

Alfalfa (*Medicago sativa*) is a non-native perennial forb with a low salt tolerance of 6 dS/m. Although it has a lower salt tolerance, it fixes nitrogen, and some varieties are drought tolerant. M. sativa was chosen because its growth habit is desirable for mowing, it has deep-spreading roots, and it has high seedling vigor (Natural Resources Conservation Service).

Next Steps

The revised list of final plant candidates has been approved by the MDT project panel (see 1/28/25 meeting notes for reference). The research team will work to purchase seeds for the 16 plants identified. In addition to this effort, the research team will work to develop the soil sampling plan and greenhouse testing plan.

Table 1. List of final plant candidates identified.

Common / Scientific / Family / Variety	Native Status	Salt Tolerance dS/m	Growth Habit	Limitations	Adaptations	Final Decision
Foxtail Barley / *Hordeum jubatum* / Poceae	Y	**High**	-Bunch	-spikes can harm grazers -cold period required for seed germination -not totally drought resistant	-Grows along contaminated roadsides -Grows best in saline conditions -prolific seeding -pioneer	-Pioneer species -High seeding and spread
Beardless Wildrye / *Leymus triticoides* / Poceae / Shoshone	Y	**24**	-Rhizomatous	-High seed dormancy -Slow seedling development -Long germination -Difficult establishment	-Rhizomatous -Palatable to livestock -Widely adapted to different soils -Tolerant of inundation -Rapidly spreading	-Low seedling vigor and spread rate -Rapid growth rate -Rapid spreading
Slender Wheatgrass / *Elymus trachycaulus* / Poceae / Pryor	Y	**20**	-Bunch	-Intolerant of prolonged flooding -Limited seeding rate -Short lived	-Moderately competitive -High seedling vigor -Adapted to many soils -Rapid growth -Drought tolerant -Moderate after-harvest regrowth	-High seedling vigor -Rapid growth rate

Western Wheatgrass / *Pascopyrum smithii* / Poceae / Rosana	Y	**14**	-Rhizomatous	-Needs to be planted early -Prefers clay soils -Low seeding vigor -Low seed spread rate	-Drought and flood-tolerant -Good erosion control -Medium after-harvest regrowth -Rapid growth	-Low seedling vigor and spread -Rapid growth -Deep rooting
Alkali Sacaton / *Sporobolus airoides* / Poceae	Y	**14**	-Bunch	-No vegetative spreading -Low seedling vigor	-Adapted to many soils -High drought tolerance	-Drought tolerant -Wide soil adaptability -Low seedling vigor
Thickspike Wheatgrass / *Elymus lanceolatus* / Poceae	Y	**11**	-Rhizomatous	-Low growth form -Require well drained soils	-Wildlife forage -Drought tolerant -Spreading -Stabilize disturbed soils	-High seedling vigor -Rapid vegetative spread
Basin Wildrye / *Leymus cinereus* / Poceae	Y	**10**	-Bunch	-Not shade-tolerant -High moisture use -Slowly vegetative and seedling spreading -Not tolerant of long term inundation	-Deep roots -Perennial -Moderate after-harvest regrowth rate -Drought tolerant -Good in reclamation projects -High seedling vigor -Early spring growth	-Wide soil adaptability -Deep rooting
Sand Dropseed / Sporobolus cryptandrus / Poceae	Y	**4**	-Bunch	-Low salt tolerance -Can become weedy/invasive -Low seedling vigor	-Perennial -Deep root -Spreading roots and seeds -Drought tolerant -Wide pH range	-Weedy habit -High spread rate -Deep rooting

Tall Wheatgrass / *Thinopyrum ponticum* / Poceae / Alkar	N	**22**	-Bunch	-Not tolerant of short mowing -Competitive in mixtures -non vegetatively spreading	-Water flexible -Good for snow management -Rapid growth -Moderate after harvest regrowth rate	-High seedling vigor -Rapid growth -Deep rooting
Green Wheatgrass / *Elymus hoffmannii* / Poceae / AC Saltlander	N	**22**	-Rhizomatous	-Hard to distinguish from quackgrass -Requires tilled seedbed -Lower drought tolerance	-Rhizomatous -Displace unwanted grasses	-Easy to establish -Displace unwanted weeds -Requires tilled seedbed
Altai Wildrye / *Leymus angustus* / Poceae / Prairieland	N	**20**	-Bunch	-Low seeding -Poor seedling vigor and competition	-Competitive once grown -Uses deep water table -10 to 13ft deep roots	-Deep rooting -Competitive once established -Low seeding vigor
Russian Wildrye / *Psathyrostachys juncea* / Poceae / Bozoisky II	N	**16**	-Bunch	-Needs to be seeded alone with spacing -Flood intolerant -Loams and clay loams -Slow seeding spread rate	-Cold and drought-tolerant -Weed competitive -Rapid after-harvest regrowth	-Non-invasive -Very cold and drought-tolerant -Difficult establishment
Pubescent Wheatgrass / *Thinopyrum intermedium* / Poceae / Luna	N	**12**	-Sod forming		-Easy establishment -Sod forming -Green in summer with soil moisture	-Easy to establish -Competitive -Higher water requirements (13 inches annually)
Barley (Hay) / *Hordeum vulgare* / Poceae	N	**12**	-Annual Bunch	-Salt reduces grain	-High salt tolerance for small grain	-Rapid growth -High seedling vigor -Low soil adaptability

Hybrid Crested Wheatgrass / *Agropyron cristatum X desertorum* / Poceae / Hyrcrest	N	**10**	-Bunch	-Limited flood tolerance -Intolerant of high water table	-Good seedling vigor -Drought tolerant	-Competitive -Easy to establish -Deep rooting
Alfalfa / *Medicago sativa* / Fabaceae / FSG 423ST	N	**6**	-Herbacous cover	-Not very salt tolerant -Even lower seedling salt tolerance	-Deep rooting -Nitrogen fixing -Some varieties drought tolerant -Root spreading	-High seedling vigor -Desirable growth habit -Deep roots -Low salt tolerance

References

Conway, T. (2001, February 5). *Plant Materials and Techniques for Brine Site Reclamation*. Plant Materials Technical Note; USDA-Natural Resources Conservation Service. https://www.nrcs.usda.gov/plantmaterials/kspmstn260201.pdf

Fertig, W. (2010). *Baltic Rush*. Usda.gov. https://www.fs.usda.gov/wildflowers/plant-of-the-week/juncus_arcticus.shtml

Flowers, T. J., Galal, H. K., & Bromham, L. (2010). Evolution of halophytes: multiple origins of salt tolerance in land plants. *Functional Plant Biology*, *37*(7), 604. https://doi.org/10.1071/fp09269

Garcia, J. S., França, M. G. C., & Prasad, M. N. V. (2020). Haloremediation for Amelioration of Salinity. In M.-N. Grigore (Ed.), *Handbook of Halophytes: From Molecules to Ecosystems towards Biosaline Agriculture* (pp. 1-19). Springer International Publishing. https://doi.org/10.1007/978-3-030-17854-3_88-1

Hasanuzzaman, M., Araújo, S., & Gill, S. S. (2020). *The Plant Family Fabaceae: Biology and Physiological Responses to Environmental Stresses* (1st 2020. ed.). Springer Singapore. https://doi.org/10.1007/978-981-15-4752-2

Hybner, R., & Jacobs, J. (2012, September). *Intermediate Wheatgrass (Thinopyrum intermedium L.): An Introduced Conservation Grass for Use in Montana and Wyoming*. Plant Material Technical Note; Natural Resources Conservation Service. https://www.nrcs.usda.gov/plantmaterials/mtpmctn11288.pdf

Hybner, R., St. John, L., & Steppuhn, H. (2014, September). *Hybrid Wheatgrass (Elymus hoffmannii) Introduced Grasses for Conservation Use in Montana and Wyoming*. Natural Resource Conservation Service; NRCS−Montana−Technical Note −Plant Materials−MT-101 1 United States Department of Agriculture. https://www.nrcs.usda.gov/plantmaterials/mtpmctn12311.pdf

Kadereit, G., Borsch, T., Weising, K., & Freitag, H. (2003). Phylogeny of Amaranthaceae and Chenopodiaceae and the Evolution of C4 Photosynthesis. *International Journal of Plant Sciences*, *164*(6), 959-986. https://doi.org/10.1086/378649

Lair, Kenneth. (2018). Salt Tolerance Value Ranges for Selected / Example Western Reclamation and Forage Species [Unpublished Data]

Litalien, A., & Zeeb, B. (2020). Curing the earth: A review of anthropogenic soil salinization and plant-based strategies for sustainable mitigation. *Science of The Total Environment*, *698*, 134235. https://doi.org/https://doi.org/10.1016/j.scitotenv.2019.134235

Majerus, M. (2024). *Plant Materials for Saline-Alkaline Soils - MSU Extenison Animal and Range Science | Montana State University*. MSU Extension Animal and Range Sciences; Montana State University. https://animalrangeextension.montana.edu/forage/saline_alkaline_soils.html

Majeski, M., & Scianna, J. (2021). *Plant guide for gardner's saltbush*. USDA Plant Guide; USDA-Natural Resources Conservation Service, Bridger Plant Materials Center. Bridger, MT. https://plants.usda.gov/DocumentLibrary/plantguide/pdf/pg_atga.pdf

Masters, D. G., Benes, S. E., & Norman, H. C. (2007). Biosaline agriculture for forage and livestock production. *Agriculture, Ecosystems & Environment*, *119*(3-4), 234–248. https://doi.org/10.1016/j.agee.2006.08.003

McSorley, K. A., Rutter, A., Cumming, R., & Zeeb, B. A. (2016). Chloride accumulation vs chloride excretion: Phytoextraction potential of three halophytic grass species growing in a salinized landfill. *The Science of the total environment*, *572*, 1132-1137. https://doi.org/10.1016/j.scitotenv.2016.08.023

Monsen, S. B., Stevens, R., & Shaw, N. L. (2004). *Restoring Western Ranges and Wildlands, vol. 2*. 325, 327. https://doi.org/10.2737/rmrs-gtr-136-v2

Natural Resources Conservation Service. *PLANTS Database*. United States Department of Agriculture. Accessed November 11, 2024, from https://plants.usda.gov.

Ogle, D. (2002). *Plant Fact Sheet for Crested Wheatgrass (Agropyron desertorum)*. Natural Resources Conservation Service; United States Department of Agriculture. https://plants.usda.gov/DocumentLibrary/factsheet/pdf/fs_agde2.pdf

Ogle, D., St. John, L., Holzworth, L., Winslow, S., & Jones, T. (2000). *Plant Guide for Basin Wildrye*. USDA-Natural Resources Conservation Service. https://www.nrcs.usda.gov/plantmaterials/idpmspg4848.pdf

Ogle, D., St. John, L., Holzworth, L., Winslow, S., & Jones, T. (2013). *Plant Guide for thickspike, streambank, and Great Lakes wheatgrass (Elymus lanceolatus)* (D. Tilley, Ed.). USDA-Natural Resources Conservation Service; Aberdeen Plant Materials Center. Aberdeen, Idaho 83210. https://www.nrcs.usda.gov/plantmaterials/idpmcpg11637.pdf

Plant fact sheet for western wheatgrass. (2002). USDA Plant Fact Sheet; USDA-Natural Resources Conservation Service. https://plants.usda.gov/DocumentLibrary/factsheet/pdf/fs_pasm.pdf

Roy, S., & Chakraborty, U. (2014). Salt tolerance mechanisms in Salt Tolerant Grasses (STGs) and their prospects in cereal crop improvement. *Botanical Studies*, *55*(1). https://doi.org/10.1186/1999-3110-55-31

Skaradek, W., & Miller, C. (2010). Plant Fact Sheet for Saltgrass (Distichlis spicata). In *USDA Plant Fact Sheet*. USDA-Natural Resources Conservation Service. https://plants.usda.gov/DocumentLibrary/factsheet/pdf/fs_disp.pdf

Stevens, M., Hoag, C., Tilley, D., & St. John, L. (2012). *Plant guide for mountain rush (Juncus arcticus ssp. littoralis)*. USDA Plant Guide; USDA-Natural Resources Conservation Service, Aberdeen Plant Materials Center. Aberdeen, Idaho 83210 https://plants.sc.egov.usda.gov/DocumentLibrary/plantguide/pdf/pg_juarl.pdf

St. John, L., Ogle, D., Duckwitz, W., & Tober, D. (2010). *Plant Guide for Altai wildrye (Leymus*

angustus). USDA- Natural Resources Conservation Service; Aberdeen, ID Plant Materials Center. https://plants.usda.gov/DocumentLibrary/plantguide/pdf/pg_lean3.pdf

Taylor, J. (2005). *Species: Psathyrostachys juncea*. Fire Effects Information System; U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. https://www.fs.usda.gov/database/feis/plants/graminoid/psajun/all.html

Tesky, J. L. (1992). *Hordeum jubatum. In: Fire Effects Information System*. Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory; U.S. Department of Agriculture. https://www.fs.usda.gov/database/feis/plants/graminoid/horjub/all.html

Tilley, D. J., Ogle, D., John, L. St., Duckwitz, W., Holzworth, L., Majerus, M., & Tober, D. (n.d.). *Plant guide for creeping foxtail (Alopecurus arundinaceus)*. USDA Plant Guide; USDA-Natural Resources Conservation Service. https://www.nrcs.usda.gov/plantmaterials/idpmcpg5595.pdf

Tilley, D., St. John, L., & Ogle, D. (2009). *Plant guide for sand dropseed (Sporobolus cryptandrus)*. USDA Plant Guide; USDA-Natural Resources Conservation Service. https://plants.usda.gov/DocumentLibrary/plantguide/pdf/pg_spcr.pdf

Young-Mathews, A. and S.R. Winslow. (2010). *Plant guide for beardless wildrye (Leymus triticoides)*. USDA Plant Guide; USDA-Natural Resources Conservation Service, Plant Materials Center. Lockeford, CA 95237. https://www.nrcs.usda.gov/plantmaterials/capmcpg9969.pdf

Wichman, D., & McCage, E. (2018). MSCA Recommended Salt-Tolerant Forage Species [Review of MSCA Recommended Salt-Tolerant Forage Species, by L. Holzworth].

Appendix A. Full List of Plants Identified

Common Name	Species	Family	Variety	Native (Yes/No)	Origin	Salt Tolerance (dS/m)	Growth Habit	Limitations	Adaptations	Sources	Availability
Black Greasewood	*Sarcobatus vermiculatus*	Sarcobataceae		Y	Western US	**>12**	-Shrub	-Moderate toxicity -Small pH range (7.5-8.5) -No resprout ability -Shrub	-Rapid growth rate -High drought tolerance -High seedling vigor -Medium hedge tolerance -Deep root system -Adapted for many soils -Tolerant of inundation	USDA Forest Service USDA Plant Guide USDA Plant Database CalFlora Salt Tolerance	Great Basin Seed Co Stevenson Intermountain Seed Inc
Sea-blite*	*Suaeda calceoliformis* *Suaeda nigra*	Amaranthaceae		Y	North America	**>12**	-Forb/ Subshrub	-annual	-Tolerant of disturbed soils, even roadsides	USDA Plant Database Flora of NA CalFlora Salt Tolerance	
Beardless Wildrye	*Leymus triticoides*	Poaceae	Shoshone (*Leymus multicaulis*)	Y	Western US	**24**	- Rhizomatous	-High seed dormancy -Slow seedling development -Long germination -Difficult establishment	- Rhizomatous -Palatable to livestock -Widely adapted to different	USDA Plant Database USDA Plant Guide Wichman, D., &	Larner Seeds Stevenson Intermountain Seed Inc

Common Name	Species	Family	Variety	Native (Yes/No)	Origin	Salt Tolerance (dS/m)	Growth Habit	Limitations	Adaptations	Sources	Availability
									soils -Tolerant of inundation -Rapidly spreading -High seedling spread rate	McCage, E. (2018). MSCA Recommended Salt-Tolerant Forage Species [Review of MSCA Recommended Salt-Tolerant Forage Species, by L. Holzworth].	
Tall Wheatgrass	*Thinopyrum ponticum*	Poaceae	Jose, Alkar, Largo, Orbit	N		**22**	-Bunch	-Not tolerant of short mowing -Competitive in mixtures -non vegetatively spreading	-Water flexible -Good for snow management -Rapid growth -Moderate after harvest regrowth rate	USDA Plant Database Wichman, D., & McCage, E. (2018). MSCA Recommended Salt-Tolerant Forage Species [Review of MSCA Recommended Salt-Tolerant	Great Basin Seed Co Stevenson Intermountain Seed Inc

Common Name	Species	Family	Variety	Native (Yes/No)	Origin	Salt Tolerance (dS/m)	Growth Habit	Limitations	Adaptations	Sources	Availability
										Forage Species, by L. Holzworth].	
Green Wheatgrass	*Elymus hoffmannii*	Poaceae	AC Saltlander	N		**22**	- Rhizomatous grass	-Hard to distinguish from quackgrass -Requires tilled seedbed -Lower drought tolerance	- Rhizomatous -Displace unwanted grasses	Wichman, D., & McCage, E. (2018). MSCA Recommended Salt-Tolerant Forage Species [Review of MSCA Recommended Salt-Tolerant Forage Species, by L. Holzworth].	Great Basin Seed Co L&H Seeds
Hybrid Wheatgrass	*Elytrigia repens X Pseudoroegneria spicata*	Poaceae	Newhy	N		**22**	-Slightly rhizomatous	-May need fall planting -14" rainfall or high water table	-slightly rhizomatous - Manageable	Wichman, D., & McCage, E. (2018). MSCA Recommended Salt-Tolerant Forage Species [Review of MSCA	Stevenson Intermountain Seed Inc Granite Seed

Common Name	Species	Family	Variety	Native (Yes/No)	Origin	Salt Tolerance (dS/m)	Growth Habit	Limitations	Adaptations	Sources	Availability
										Recommended Salt-Tolerant Forage Species, by L. Holzworth].	
Altai Wildrye	*Leymus angustus*	Poaceae	Prairieland Pearl, Eejay	N		**20**	-Bunch	-Low seeding -Poor seedling vigor and competition	-Competitive once grown -Uses deep water table	USDA Plant Database Wichman, D., & McCage, E. (2018). MSCA Recommended Salt-Tolerant Forage Species [Review of MSCA Recommended Salt-Tolerant Forage Species, by L. Holzworth].	Stevenson Intermountain Seed Inc Granite Seed
Slender Wheatgrass	*Elymus trachycaulus*	Poaceae	Pryor	Y		**20**	-Bunch	-Intolerant of prolonged flooding -Limited seeding rate -Short lived	-Moderately competitive -High seedling vigor -Adapted to	USDA Plant Database Wichman, D., & McCage, E.	Prairie Resoration Inc. Prairie Moon

Common Name	Species	Family	Variety	Native (Yes/No)	Origin	Salt Tolerance (dS/m)	Growth Habit	Limitations	Adaptations	Sources	Availability
									many soils -Rapid growth -Drought tolerant -Moderate after-harvest regrowth	(2018). MSCA Recommended Salt-Tolerant Forage Species [Review of MSCA Recommended Salt-Tolerant Forage Species, by L. Holzworth].	-Lower seed amounts Great Basin Seed Co
Russian Wildrye	*Psathyrostachys juncea*	Poaceae	Bozoisky-Select, Bozoisky II	N	Russia	**16**	-Perennial bunch	-Needs to be seeded alone with spacing -Flood intolerant -Loams and clay loams -Slow seeding spread rate	-Cold and drought-tolerant -Weed competitive -Rapid after-harvest regrowth	USDA Plant Database Wichman, D., & McCage, E. (2018). MSCA Recommended Salt-Tolerant Forage Species [Review of MSCA Recommended Salt-Tolerant Forage	Curtis and Curtis Seed Great Basin Seed Co

Common Name	Species	Family	Variety	Native (Yes/No)	Origin	Salt Tolerance (dS/m)	Growth Habit	Limitations	Adaptations	Sources	Availability
										Species, by L. Holzworth].	
Tall Fescue	*Festuca arundinacea Schedonorus arundinaceus Lolium arundinaceum*	Poaceae	Fawn, Bridgestone, Johnstone	N		**14**	- Rhizomatous	-Not good in a mixture -Invasive -Slightly toxic -Slow vegetative spreading	-Good winter hardiness -Deep rooting -Tolerant of a wide range of climates/soil -Rapid after-harvest regrowth rate -Medium drought tolerance -High seedling vigor	USDA Plant Database Wichman, D., & McCage, E. (2018). MSCA Recommended Salt-Tolerant Forage Species [Review of MSCA Recommended Salt-Tolerant Forage Species, by L. Holzworth].	Great Basin Seed Co
Western Wheatgrass	*Pascopyrum smithii*	Poaceae	Rosanna, Rodan	Y	United States	**14**	- Rhizomatous	-Needs to be planted early -Prefers clay soils -Low seeding vigor -Low seed spread rate	-Drought and flood-tolerant -Good erosion control -Medium after-harvest regrowth	USDA Plant Guide USDA Plant Database Wichman, D., & McCage, E. (2018).	Great Basin Seed Co

Common Name	Species	Family	Variety	Native (Yes/No)	Origin	Salt Tolerance (dS/m)	Growth Habit	Limitations	Adaptations	Sources	Availability
									-Rapid growth	MSCA Recommended Salt-Tolerant Forage Species [Review of MSCA Recommended Salt-Tolerant Forage Species, by L. Holzworth].	
Pubescent Wheatgrass	*Thinopyrum intermedium*	Poaceae	Greenleaf, Manska, Mandan 759	N		**12**	-Sod forming		-Easy establishment -Sod forming -Green in summer with soil moisture	USDA Plant Database Wichman, D., & McCage, E. (2018). MSCA Recommended Salt-Tolerant Forage Species [Review of MSCA Recommended Salt-Tolerant Forage Species, by	Great Basin Seed Co

Common Name	Species	Family	Variety	Native (Yes/No)	Origin	Salt Tolerance (dS/m)	Growth Habit	Limitations	Adaptations	Sources	Availability
										L. Holzworth].	
Intermediate Wheatgrass	*Thinopyrum intermedium*	Poaceae	Oahu, Greenar, Rush	N		**12**	-Sod forming	-Limited summer growth	-Sod forming -decent drought tolerance	USDA Plant Database Wichman, D., & McCage, E. (2018). MSCA Recommended Salt-Tolerant Forage Species [Review of MSCA Recommended Salt-Tolerant Forage Species, by L. Holzworth].	Great Basin Seed Co
Barley (Hay)	*Hordeum vulgare*	Poaceae	Lavina, Haymaker, Stockford	N		**12**		-Salt reduces grain	-High salt tolerance for small grain	Wichman, D., & McCage, E. (2018). MSCA Recommended Salt-Tolerant Forage Species [Review of	

Common Name	Species	Family	Variety	Native (Yes/No)	Origin	Salt Tolerance (dS/m)	Growth Habit	Limitations	Adaptations	Sources	Availability
										MSCA Recommended Salt-Tolerant Forage Species, by L. Holzworth].	
Foxtail Barley*	*Hordeum jubatum*	Poaceae		Y	North America	**High**	-Bunch	-spikes can harm grazers -cold period required for seed germination -not totally drought resistant	-Grows along contaminated roadsides -Grows best in saline conditions -prolific seeding -pioneer	Utah State Extension Minnesota Wildflowers US Forest Service USU Digital Commons	Prairie Moon
Hybrid Crested Wheatgrass	*Agropyron cristatum X desertorum*	Poaceae	Hycrest, Hycrest II	N		**10**		-Limited flood tolerance -Intolerant fo high water table	-Good seedling vigor -Drought tolerant	Wichman, D., & McCage, E. (2018). MSCA Recommended Salt-Tolerant Forage Species [Review of MSCA Recommended Salt-Tolerant Forage	Great Basin Seed Co

Common Name	Species	Family	Variety	Native (Yes/No)	Origin	Salt Tolerance (dS/m)	Growth Habit	Limitations	Adaptations	Sources	Availability
										Species, by L. Holzworth].	
Creeping Foxtail	*Alopecurus arundinaceus*	Poaceae	Garrison	N		**8**	- Rhizomatous grass	-Drought intolerant -Difficult to plant seed -Need high water table -Less salt tolerant as a seedling	-Spreading -Withstands floods	USDA Plant Database Wichman, D., & McCage, E. (2018). MSCA Recommended Salt-Tolerant Forage Species [Review of MSCA Recommended Salt-Tolerant Forage Species, by L. Holzworth].	Sheffield's Seed
Yellow Sweetclover	*Melilotus spp.*	Fabaceae	Commercial	N		**8**	-Short herbacous cover	-Biennal -Limited salt-tolerance	-Tolerant of wide range of climate/soil -Good seed producer -Nitrogen fixing	Wichman, D., & McCage, E. (2018). MSCA Recommended Salt-Tolerant Forage Species	Great Basin Seed Co

Common Name	Species	Family	Variety	Native (Yes/No)	Origin	Salt Tolerance (dS/m)	Growth Habit	Limitations	Adaptations	Sources	Availability
										[Review of MSCA Recommended Salt-Tolerant Forage Species, by L. Holzworth].	
Alfalfa	*Medicago sativa*	Fabaceae	Ladarius 65, Spredor III, Cooper, Travois, Rambler	N		**6**	-Herbacous cover	-Not very salt tolerant -Even lower seedling salt tolerance	-Deep rooting -Nitrogen fixing -Some varieties drought tolerant -Root spreading	USDA Plant Database Wichman, D., & McCage, E. (2018). MSCA Recommended Salt-Tolerant Forage Species [Review of MSCA Recommended Salt-Tolerant Forage Species, by L. Holzworth].	
Saltbush	***Atriplex gardneri*** *Atriplex canescens*	Amaranthaceae		Y	Montana	**8-15**	-Subshrub	-Woody -Seed sourcing -Slow establishment	-Shorter habit -Yellow flowers	MT Native Plants MT Field	Great Basin Seed Co Great Basin

Common Name	Species	Family	Variety	Native (Yes/No)	Origin	Salt Tolerance (dS/m)	Growth Habit	Limitations	Adaptations	Sources	Availability
	Atriplex corrugata								-Spreads vegetatively -Extensive root system -Can be established on mined sites -Wildlife forage -Evergreen -Resprout ability -bare root, seed, cutting props	Guide NRCS Plant Materials USDA Plant Database canescens USDA Plant Database gardneri	Seed Co Great Basin Seed Co
Red Swampfire *	*Salicornia rubra (europaea instead?)*	Amaranthaceae		Y	Western US	**>12**	-Forb/Subshrub	-Annual -Low drought tolerance -No commercial seed source -Only spread/propagates by seeds -Slow post-harvest growth	-Rapid growth -Widely adapted to different soils -Moderate reseeding potential	USDA Plant Database CalFlora Salt Tolerance	Special Plant Nursery
Blue Grama	*Bouteloua gracilis*	Poaceae		Y	North America	**4-8**	-Bunchgrass	-Intolerant of inundation -Intolerant of shade -Only seed propagation -does not spread	-High CaCO3 tolerance -High drought tolerance -Quickly growing	USDA Plant Data Base CalFlora Salt Tolerance	Native American Seed

Common Name	Species	Family	Variety	Native (Yes/No)	Origin	Salt Tolerance (dS/m)	Growth Habit	Limitations	Adaptations	Sources	Availability
Thickspike Wheatgrass	*Elymus lanceolatus*	Poaceae		Y	Western North America	**10-12**	-Rhizomatous	-Low growth form -Require well drained soils	-Wildlife forage -Drought tolerant -Spreading -Stabilize disturbed soils	USDA NRCS Utah NRCS	Great Basin Seed Co
Tall Wheatgrass	*Thinopyrum ponticum*	Poaceae		N	Southern Europe and Asia Minor	**15**	-Bunchgrass	-Does not spread -Not native -10 inches precipitation -Shade intolerant -Rapid growth	-High seedling vigor -Moderate regrowth	USDA Plant Database USDA Forest Service	Great Basin Seed Co
Bearded Sprangletop	*Leptochloa fusca*	Poaceae		Y	North America	**10-30**	-Multiple Stemmed Grass	-Sow after harvest growth -Low drought tolerance -Annual -No commercial seed source -Slow seed spread rate	-Rapid growth -Decent height -Palatable	USDA Plant Database Research Journal of Agriculture and Biological Sciences	Native American Seed -Not exact species
Verrucose Seapurslane	*Sesuvium verrucosum*	Aizoaceae		Y	Southwestern US					Flora of North America	
Bird's-foot trefoil	*Lotus corniculatus*	Fabaceae		N	**Invasive**	**8**	-Forb	-Invasive -Only spreads by seed slowly -Intolerant of shade	-Nitrogen-fixing -Forage -Rapid after-growth harvest rate	USDA Plant Database CalFlora Salt Tolerance	Great Basin Seed Co

Common Name	Species	Family	Variety	Native (Yes/No)	Origin	Salt Tolerance (dS/m)	Growth Habit	Limitations	Adaptations	Sources	Availability
									-Tolerant of all soil conditions -Tolerant of inundation -Decent height	USDA Plant Materials	
Basin Wildrye	*Leymus cinereus*	Poaceae		Y	Western US and Canada	**10**	-Bunch	-Not shade-tolerant -High moisture use -Slowly vegetative and seedling spreading -Not tolerant of long term inundation	-Deep roots -Perennial -Moderate after-harvest regrowth rate -Drought tolerant -Good in reclamation projects -High seedling vigor -Early spring growth	USDA Plant Database USDA Plant Guide USDA Plant Guide	Great Basin Seed Co Seed Trust Montana DNRC
Sand Dropseed	*Sporobolus cryptandrus*	Poaceae		Y	North America	**<4**	-Bunch	-Low salt tolerance -Can become weedy/invasive -Low seedling vigor	-Perennial -Deep root -Spreading roots and seeds -Drought tolerant -Wide pH range	USDA Plant Database USDA Plant Guide	Prairie Moon Nursery Agrecol Native Seed & Plant Nursery Native

Common Name	Species	Family	Variety	Native (Yes/No)	Origin	Salt Tolerance (dS/m)	Growth Habit	Limitations	Adaptations	Sources	Availability
											American Seed Great Basin Seed Co
Desert Saltgrass	*Distichlis spicata*	Poaceae		Y	North America	**High**	- Rhizomatous	-Low after-harvest regrowth rate -Medium drought tolerance -Excretes salt through glands	-Cold tolerant -Wide pH range -Long-lived perennial -Spread by seed and rhizomes	USDA Plant Guide	Great Basin Seed Co Wildland Seed Co
Baltic Rush	*Juncus balticus*	Juncaceae		Y	North America (Not southeast)	High	- Rhizomatous	-Primarily wetland plant -Low drought tolerance -Slow seed spread rate	-Forage for grazers and birds -Perennial -Moderate after-harvest regrowth rate -Rapid growth rate -High tolerance to inundation -High vegetative spread rate	USDA Plant Database US Forest Service Plant of the Week Minnesota Wildflowers	Great Basin Seed Co Prairie Moon Nursery
Alkali Sacaton	Sporobolus airoides	Poaceae		Y	Western US	**14**	-Bunch	-No vegetative spreading	-Adapted to many soils -High	USDA Plant Database	Great Basin Seed Co

Common Name	Species	Family	Variety	Native (Yes/No)	Origin	Salt Tolerance (dS/m)	Growth Habit	Limitations	Adaptations	Sources	Availability
								-Low seedling vigor	drought tolerance	USDA Plant Materials	Larner Seeds