Seed Production and Establishment of Western Oregon Native Grasses

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Abstract: It is well understood that native grasses are ecologically important and provide numerous benefits. However, unfavorable economics, low seed yields for some species, genetic issues, and a lack of experience behind the production and establishment of most western Oregon native grasses remain significant impediments for their expanded use. By necessity, adaptation of standard practices used by the grass seed industry and grassland specialists for introduced species provides the starting point for determining agronomic increase and establishment methods. The USDA Natural Resources Conservation Service, Plant Materials Center at Corvallis, Oregon, has experience increasing at least 15 species of native grasses. It has also conducted studies involving the effects of fertilization, row spacing, post-harvest residue management (burning versus baling), and herbicides on yields of select species. Results are usually species specific, indicating much more research is needed. Fortunately for some native grasses, practical experience has demonstrated the efficacy of certain customary techniques such as carbon banding, timely fertilization, pesticide use, and windrow-combining. Specialty equipment for small grain, seed increase, and processing can be directly transferred or modified for use on native grasses.

Whether for seed increase, revegetation, or restoration, many but not all native grasses possess special challenges. These include dormancy, seed appendages, seed quality, slow growth, and poor competition with weeds. Some are easier to address than others. Other considerations for establishment include equipment, site preparation, and soil amendments such as fertilization. While well documented methodologies readily apply to native grass seeding prescriptions, development of compatible mixtures and appropriate seeding rates requires considerable guess-work. General guidelines and experiences are provided, but substantial work is needed.

Keywords: native grasses, seed production, establishment, seed dormancy, seeding prescription, revegetation, restoration, seeding rates

Introduction

Native grasses are becoming increasingly popular in the Pacific Northwest and elsewhere for revegetation, restoration, erosion control, cover, landscaping, and other uses. However, in western Oregon, availability and wide scale use is limited by a number of factors including economics. With a small market value compared to other crops, there is a lack of research and history behind the seed production of these species. For many native grasses, lack of approved herbicides and established propagation protocols, low seed production, uneven maturity, and genetic issues such as diversity, drift, and isolation increase expense and risk. Restoration use is limited by small markets for individual ecotypes driven by the demand for high site specificity. Given all the unknowns, risks and expenses are considerably higher than for producers of highly bred, introduced pasture and turf grasses.

Furthermore, there are constraints for establishing many important native grasses from seeds. The major challenges are seed dormancy, seed appendages, seed quality, slow germination or initial growth, poor competitiveness with weeds, and a lack of information on seeding methods, such as compatible seed mixtures, fertilization, and seeding rates. Some of these challenges are more easily rectified than others.

Addressing seed production and establishment limitations for select native grasses is part of the role of the USDA Natural Resources Conservation Service, Corvallis Plant Materials Center (PMC). Experience has been gained through experimentation and practical experience. Studies have included the effect of row spacing, nitrogen fertilization, herbicides for annual grass control, and post harvest residue management on seed yield of several species. Over the past 20 years, seed production work has been conducted on 15 native grass species with varying degrees of success. New species are regularly added to the program. The purpose of this paper is to review the Center's seed increase methods for native grasses, provide examples of agronomic trials conducted at the PMC, describe characteristics of native grasses that create special challenges for their use, and provide considerations for site preparation, equipment, seeding methods, mixtures, and seeding rates that apply to revegetation and restoration.

Seed Production

Establishment of New Fields

The starting point for seed increase of native grasses in western Oregon is to evaluate, modify, and incorporate existing technology used by the local seed industry for introduced, cool season pasture and turf grasses. As expected, weed control in new and established stands is usually the premier issue. Herbicides may be effective, but most are labeled only for specific introduced grass seed crops. They cannot be used legally on native species without special licensing for research purposes. Fortunately, one of the most significant chemical weed control practices that can be used when planting native grass fields for increase involves activated charcoal banding (Lee 1973). The method has a label for general grass seed production. As seeds are drilled into the soil, a 1-in (2.5-cm) wide band of carbon slurry is applied directly over each row. Control of germinating annual grasses and other weeds between rows is achieved by broadcasting the herbicide diruon immediately afterwards. The carbon absorbs the chemical and prevents it from killing the crop seeds. Another herbicide used in this situation is pronamide, but it is only labeled for introduced perennial ryegrass (*Lolium perenne*), tall fescue (*Festuca arundinacea*), and orchardgrass (*Dactylis glomerata*) (Colquhoun 2003). Certain phenoxy herbicides may be applied at the 3-leaf stage of the grass crop or beyond for broadleaf weed control. Other herbicides are listed for specialized control (Colquhoun 2003).

Late summer and early fall is the preferred time to establish new production fields of most native grasses in western Oregon. Planting at this time has several advantages over spring seeding. Known and unknown seed dormancies can be overcome by exposing the seeds to cool, moist soil conditions over winter; the need for spring irrigation may be eliminated, and a good seed crop may be possible the first full growing season for rapid developing species. In general, the Corvallis PMC does not fertilize with nitrogen at the time of planting because it contributes to excessive weed competition. Exceptions may be made if the soils are known to be low in weed seed content. Usually, commercially available carbon slurry will already contain a low rate of starter fertilizer. There is little value to fertilizing at planting time if the seeds are dormant for 60 days or longer.

Presently, most grasses grown at the Corvallis PMC are bunch grasses and suited to row culture. Production in well defined rows simplifies weed control and contributes to satisfying seed certification requirements. Row spacing and seeding rates vary by species and are interdependent. Most species with medium to large seed sizes are initially grown in 12-in (30.5-cm) rows and seeded at a rate of 10 to 15 PLS (pure live seed) lb/ac (11 to 17 PLS kg/ha). Because of equipment, row spacing is widened to 28 in (71 cm) when new fields are started from container stock using a 2-row transplanter. In order to refine these practices, trials and other work have been conducted on select species by the PMC. Flessner (2000a) found that for American sloughgrass (*Beckmannia syzigachne*), a seeding rate of 12 PLS lb/ac (13 PLS kg/ha) and a row spacing of 6 in (15 cm) optimized seed yield, suppressed weeds, and enhanced stand vigor. Experience has shown that species like blue wildrye (*Elymus glaucus*) and California brome (*Bromus carinatus*), with large seeds and vigorous seedlings, are well suited to 8 to 10 lb/ac (9 to 11 kg/ha) (20 to 35 live seeds/linear ft [66 to 117 seeds/linear meter]) seeding rates in 12-in (30.5-cm) rows. Rates can be adjusted lower for wider rows (Darris and others 1996). In contrast, tufted hairgrass (*Deschampsia caespitosa*) has small seeds (1.8 million/lb [4 million/kg]), and therefore a seeding rate of 1 to 2 PLS lb/ac (1 to 2 kg/ha) is acceptable (Darris and others 1995). An experiment comparing the effect of row spacing on seed yield demonstrated that the best production for this species occurs with 24- to 36-in (61- to 91-cm) wide rows under high soil fertility but no irrigation (Darris and Stannard 1997) (Figure 1).

Management and Harvest of Existing Stands

Pest Management—Pest management in established stands of native grasses at the PMC focuses on weed and disease control. Broadleaf weeds are controlled once or twice a year with phenoxy herbicides. Other fall or early winter application of herbicides like diuron, Prowl® (pendimethalin), or Axiom® (flufenacet+metribuzin) may be made for experimental control of annual bluegrass (*Poa annua*) and rattail fescue (*Vulpia myuros*) (Colquhoun 2003). However, these annual grass control chemicals are not labeled for native grasses and their use is limited to research. Figures 2 through 4 show the effects of 6 herbicide treatments on the control of annual grasses and seed production in meadow barley, California oatgrass (*Danthonia californica*), and tufted hairgrass respectively. The study was conducted at the PMC in 2001 to 2002. Results varied by species. Chemical names are used for information purposes only and are not an endorsement of the product. Other weed control measures include spot treatments with glyphosate, mowing of weeds that overtop the grass (primarily in year 1), and manual methods. Mechanical cultivation is rarely used. Shielded row spraying with glyphosate holds promise and needs evaluation. In terms of fungal pests, stem or leaf rusts (*Puccinia* spp.) appear most detrimental to Roemers fescue (*Festuca roemeri*), meadow barley (*Hordeum brachyantherum*), and pine bluegrass (*Poa scabrella*) grown at the PMC. The fungicides Bravo® (chlorothalonil) and Tilt® (propiconazole) are used in spring for their control (Pscheidt and Ocamb 2003). Fungal smuts (*Tilletia* spp. or *Ustilago* spp.) are a particular problem on California brome. Under some circumstances, the diseases may be legally controlled by treating the seeds with Vitavax® or other fungicide combinations (Pscheidt and Ocamb 2003). Other pests, such as insects, voles, nematodes, and slugs, may play a role in

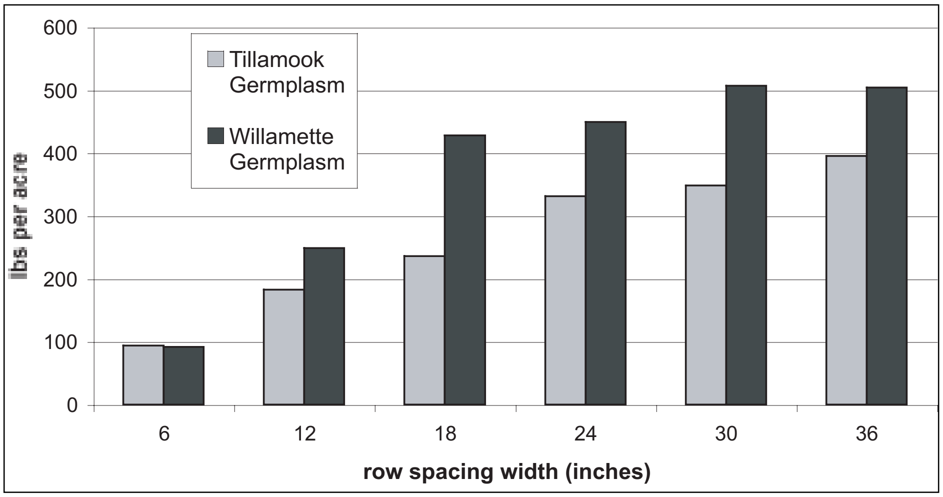

Figure 1—Effect of row spacing on seed yield of tufted hairgrass (1993 to 1995).

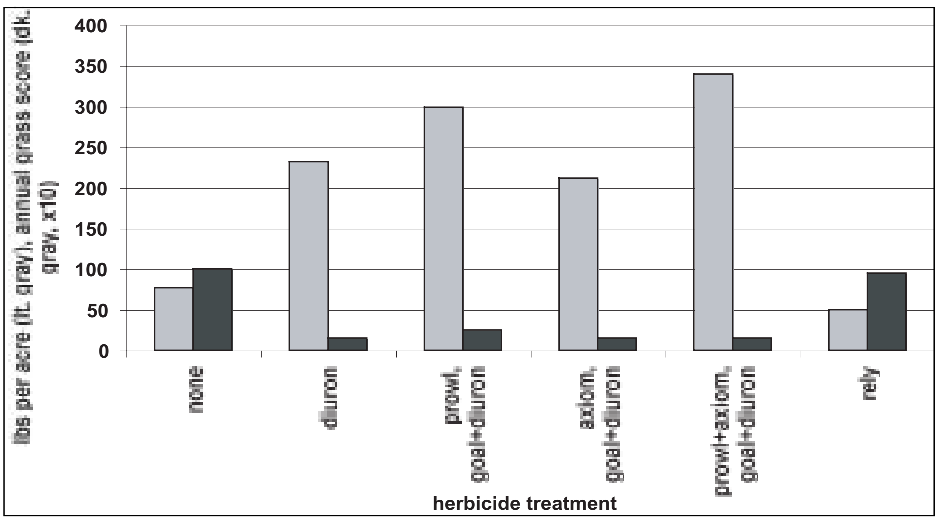

Figure 2—Herbicide effect on seed yield and annual grass control in meadow barley.

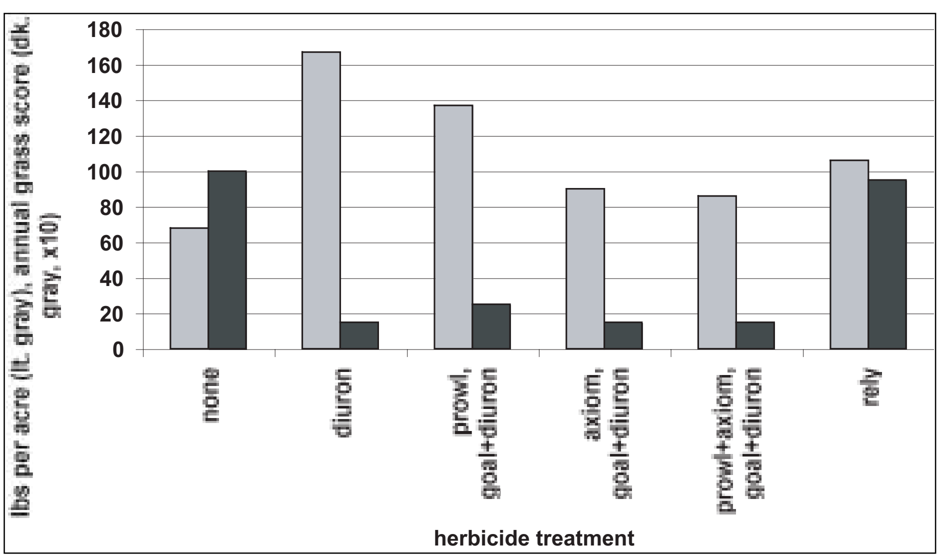

Figure 3—Herbicide effect on seed yield and annual grass control in California oatgrass.

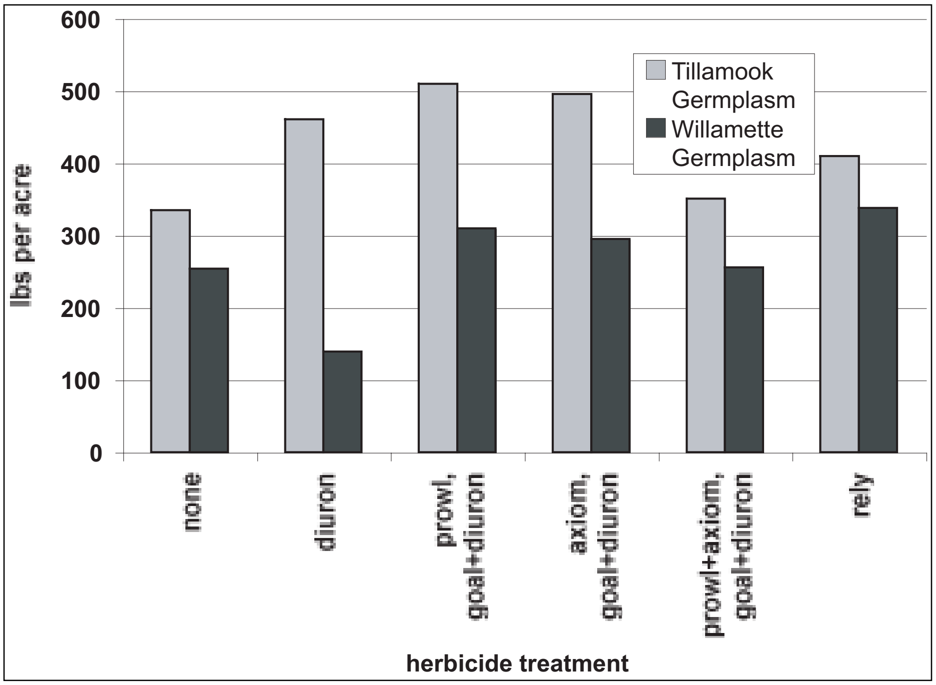

Figure 4—Herbicide effect on seed yield of tufted hairgrass.

native grass seed production as they do with introduced grasses in the Willamette Valley of Oregon (Lies 2002).

Irrigation—Irrigation is primarily used for establishment, although regular, summer irrigation has been successfully used to produce seeds of tall mannagrass (*Glyceria elata*), a wetland species being grown on a moderately well drained silt loam. The influence of fall irrigation on seed yield of some species needs to be investigated. Other wetland grasses, such as American sloughgrass, rice cutgrass (*Leersia oryzoides*), and bluejoint (*Calamagrostis canadensis*), are produced in ponds at the PMC using permanent shallow or intermittent inundation. Irrigated fields, seasonally wet depressions, and lowlands with poorly drained soils may also be suitable.

Fertilization—Optimal fertilization rates for most native grasses are unknown, although an experiment with tufted hairgrass (Figure 5) illustrated the importance of a 50 to 100 lb/ac (56 to 112 kg/ha) nitrogen application in late winter or early spring (February to March). Surprisingly, fall fertilization was not a significant benefit as it is with other species. Until more is known about individual species, fertilization of established, cool season grasses at the PMC generally consists of 25 lb/ac (28 kg/ha) of nitrogen in the fall and a single or split application of nitrogen at 50 or

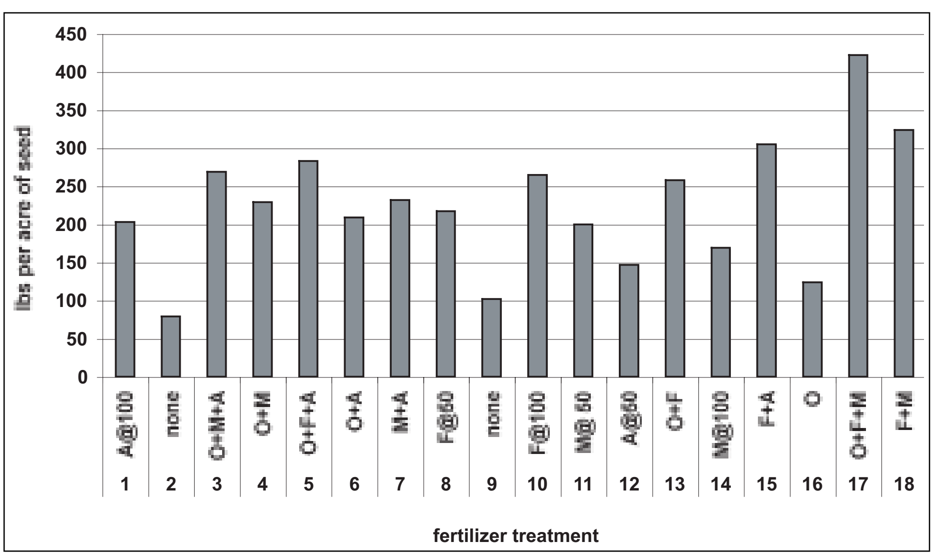

Figure 5—Effect of N fertilization on seed yields of tufted hairgrass (4 reps, 3 years). (For fertilizer treatments, O = October at 25 lb N/ac [28 kg N/ha] and F = February, M = March, and A = April at 50 lb N/ac [56 kg N/ha]. Exceptions are treatments 1, 10, and 14 where N was applied once at 100 lb/ac [112 kg/ha].)

75 lb/ac (56 or 84 kg/ha) in early spring. The total is 75 to 100 lb/ac (84 to 112 kg/ha) per year. Rates may be lowered to 25 lb/ac (28 kg/ha) for species that produce less herbage. In addition, an application of 10 to 15 lb sulfur/ac (11 to 17 kg sulfur/ha) per year is typical. Although soil pH, potassium, and phosphorous have rarely been limiting at the PMC, it is suggested that lime and other nutrients be applied according to soil ppm standards established for introduced fine fescue (Gingrich and others 2003) and tall fescue (Doerge and others 1983) when managing similar sized native grasses. Grass seeds produced in ponds are fertilized with low rates of slow release fertilizer or not at all to avoid algae bloom.

Harvest—Harvest of native grass seeds may follow standard procedures or incorporate specialized equipment and techniques. Estimated seed yield potentials are shown in Table 1. At the PMC, fields 0.25 ac (0.10 ha) or larger are first swathed (windrowed) when most seeds are in mid to hard dough stage of ripeness; this may occur earlier for certain species. The timing depends on the species resistance to shattering and the variation in maturity within each field. Windrowing allows for stems to dry and greener seeds to catch up and mature. If conditions have remained dry, harvesting is done with a mini-combine usually within 3 weeks after windrowing. Other methods used at the Center include manual harvesting with rice knives, hand clippers, and scythes, and direct harvesting with a hand-held seed stripper or flail-vac seed stripper. The flail-vac seed stripper is mounted on the front of a tractor like a front end loader. Its large spinning brush strips and vacuums seeds off the heads. Small areas may also be mowed with a sicklebar mower. The stalks are then gathered and dried on a tarp or warehouse floor prior to being run through a plot thresher to separate seeds from stems and chaff. Hand harvest and mechanical stripping methods are practical for a species like meadow barley, which matures downward from the terminus of the seed head, or for those fields with high genetic diversity, indeterminate flowering, and uneven maturation. Unfortunately, a substantial quantity of seeds is lost with mechanical strippers. A solution is to lay plastic between the rows and sweep or vacuum the seeds up after they drop onto the sheets. In other cases, light chaffy seeds may be vacuumed directly from seed heads (Burton and Burton 2004b). For species that lose excessive amounts of seeds in the windrow as they dry, strips of paper can be laid down in the field. The windrows or stalks are forked onto the sheets or they can be swathed directly onto the paper by a windrower equipped to handle paper rolls.

Finally, post harvest residue management is practiced on native grasses as it is with introduced grasses in western Oregon. Residue removal or related post harvest treatments are widely known to improve seed yields of most grass seed crops. With the gradual phase-out of field burning in Oregon, significant University and USDA research has gone into developing alternative methods of handling residue. There are more than a dozen common practices for introduced grasses in Oregon, from thermal to clean non-thermal and full straw load methods (Lies 2002). Many of these techniques are species specific and, unfortunately, few investigations have been conducted on native grasses in the area. The PMC found that for blue wildrye, there was no significant difference in seed yield between baling, baling and burning, baling and mowing, and baling, mowing, and burning with a propane field flamer (Darris and others 1996). In a demonstration with tufted hairgrass, burning did not improve yields over baling and mowing of residues. Until more investigations are conducted, standard practice for all field grown native grasses at the Center is to bale crop aftermath then flail mow the remaining stubble.

Special Challenges and Solutions

Seed Dormancy

Certain characteristics of native grass seeds can pose challenges or complications for seed production as well as for use in revegetation and restoration. As alluded to earlier, a number of these species possess seed dormancies that influence establishment procedures. While there are many types of seed dormancy, it appears that the most common types found in native grasses can be overcome, at least in part, by cold, moist stratification. This method is the same as moist pre-chilling, or placement of seeds into a cool environment on, or in, a moist medium. Table 1 shows results of seed germination work done at Center. Results may not necessarily agree with those published elsewhere. Dormancy within a species may vary between populations, by age of the seed lot, or by crop year. Precision planting may require both a seed germination and TZ (tetrazolium) viability test to ascertain the amount of dormancy. In general, stratified and imbibed seeds can be spring sown with certain equipment, but the simplest solution for handling dormancy is to fall plant untreated, dry seeds.

While seed dormancy impacts the establishment of seed production fields, it complicates the formulation of compatible seed mixtures and seeding rates for revegetation and restoration prescriptions. Therefore, it is often best to sow dormant seeds alone. However, if temporary cover is required for erosion control, a simple grass seed mixture may be the only option. In this situation, it is suggested that only a small portion (10 to 20% of the mix) of a less competitive, short-lived grass be used with a large amount of the grass with dormant seeds. Otherwise, too much of one grass, especially a fast germinating or competitive one, may fully occupy the site and preclude establishment of target species. Two potential choices are native slender hairgrass (*Deschampsia elongata*) and annual hairgrass (*Deschampsia danthoniodies*). They are short-lived and appear to be less competitive. Seeding alone also provides the opportunity to use an herbicide or fire to kill weeds that emerge after planting but prior to emergence of the grass seedlings. Breeding or selection for non-dormant seeds is not considered an option for restoration work where preservation of genetic diversity and integrity within species is a top priority.

Seed Conditioning and Cleaning

Some native grasses have seed appendages and hulls that may need to be removed by physical conditioning to improve flow through seeding equipment, improve germination, or

Table 1—Seed production and seed characteristics of major western Oregon native grasses.

Common name	Scientific name	Habitat[a]	Seed yield[b]	Seeds/lb[c] w/hulls (w/o hulls)	Seed stratification[d] (cold/moist)	Seeds/ft² 1 lb/ac	Remarks
Pine (rough) bluegrass	*Poa scabrella* (*P. secunda*)	DU, MU	Low	1,520,000	14-60 days	35	Florets may need separating
Roemer's fescue	*Festuca roemeri*	DU, MU	Low	502,000	14 days (optional)	12	Poor seed fill may occur, prone to rust
California oatgrass	*Danthonia californica*	DU, MU, WP	Low	95,000 (220,000)	70-90 days	2.2 (5)	Slow development, scarifiing may incr. germ.
Prairie junegrass	*Koeleria macrantha*	DU, MU	Low	1,250,000	None	29	Poor seed fill may occur
California brome	*Bromus carinatus*	DU, MU	High	82,000	None	1.9	Easy to produce, weedy, prone to smut
California fescue	*Festuca californica*	DU, DF, MU	Low	130,000	None	3	Slow seedling development
Slender wheatgrass	*Elymus trachycaulus*	DU, MU	High	110,000	None	2.5	Easy to produce, vigorous seedlings
Lemmon's needlegrass	*Achnatherum lemmonii*	DU	Low	92,000	60-90 days	2.1	Hard to produce, remove awns
Western needlegrass	*Stipa occidentalis*	DU, MU	Low	274,000	90 days	6.3	Hard to produce, remove awns
Hall's bentgrass	*Agrostis halli*	DU, DF, MU	Low	5,000,000	None	115	Slow seedling development, has rhizomes
Harford's melic	*Melica harfordii*	DF, MF, MU	Low	140,000 (195,000)	70-90 days	3.2 (4.5)	Can be hulled, has short rhizomes "bulbs"
Slender hairgrass	*Deschampsia elongata*	MU, MF, WP	Medium	2,400,000	None	54	Easy to produce, delint seed, can be hulled
Blue wildrye	*Elymus glaucus*	MU, DF, MF	High	140,000	None	3.2	Remove awns, vigorous, easy to produce
Sitka brome	*Bromus sitchensis*	DF, MF, MU	High	83,000	None	1.9	Easy to produce, weedy, vigorous
Columbia brome	*Bromus vulgaris*	MF	Medium	92,000	None	2.1	Needs partial shade, can be hulled
Bearded fescue	*Festuca subulata*	MF	Low	267,000	30 days	6.1	Needs partial shade, remove awns
Western fescue	*Festuca occidentalis*	DF, MF	Low	600,000	None	14	Hard to produce, needs partial shade
Alaska oniongrass	*Melica subulata*	DF, MF	Low	? (180,000)	70-90 days	4.1	Can be hulled, has short rhizomes "bulbs"
Nodding trisetum	*Trisetum cernuum*	MF	Low	1,000,000	None	23	Remove awns
Spike bentgrass	*Agrostis exarata*	MU, WP	Low	5,400,000	None	124	Easy to produce, volunteers readliy
Tufted hairgrass	*Deschampsia caespitosa*	MU, WP	Medium	1,400,000 (1,800,000)	none	32 (41)	Needs wide rows, delint seed, can be hulled
Meadow barley	*Hordeum brachyantherum*	MU, WP	Medium	150,000	None	3..4	Remove awns, multiple harvests needed
Annual hairgrass	*Deschampsia danthonioides*	WP	Medium	900,000	None	21	Can be hulled, delint seed, poor competitor
Western sloughgrass	*Beckmannia syzigachne*	M, WP	Medium	238,000	None	5.5	Irrigate, hull removal improves germ.
Tall mannagrass	*Glyceria elata* (*G. striata*)	MF	Medium	1,600,000	14-60 days (optional)	37	Irrigate, slow or uneven germination
Western mannagrass	*Glyceria occidentalis*	M	Low	? (360,000)	None	8.3	Irrigate, shatters when green, seed in stem
Slimheaded mannagrass	*Glyceria leptostachya*	M	Low	1,300,000	None	30	Irrigate, may need multiple harvests
Rice cutgrass	*Leersia oryzoides*	M	Medium	361,000	180-240 days	8.3	Not suited to rows (rhizomatous), irrigate
False mannagrass	*Torreyochloa pallida* var. *pauciflora*	WP, M	Medium	1,955,000	None	45	Rhizomatous, irrigate
Bluejoint	*Calamagrostis canadensis*	MF, M, B	Low	4,050,000	None	93	Rhizomatous, may have poor seed fill, irrigate
Nodding semaphoregrass	*Pleuropogon refractus*	MF, B	Low?	59,000	60-90 days	1.4	Irrigate, slow establishment

[a] For generalized habitat, DU = dry upland (sun), MU = moist (mesic) upland, DF = dry forest, MF = moist forest, WP = wet prairie, M = marsh, B = bog.
[b] Estimate only. Yields vary substantially due to genetics, pollination, management, age, and so on, and can be higher or lower than estimate. Low = 50 to 250 lb/ac (55 to 280 kg/ha), Medium = 250-450 lb/ac (280 to 500 kg/ha), High = 450-700 lb/ac (500 to 785 kg/ha).
[c] Seeds per pound are estimates only. Results will vary as much as 30%, depending on seed lot, year, genetics, and other factors. Amount of seed conditioning such as de-awning, de-hulling, de-linting, and so on can also significantly effect seed weight per pound.
[d] Seed stratification requirements (and thus dormancy) may differ between and within populations, by age of seed, or by seed lot. Other seed treatment methods besides stratification and fall sowing/overwintering may eliminate or reduce dormancy in certain species.

reduce bulk. Conditioning also facilitates seed cleaning, resulting in higher quality seeds. Examples of troublesome appendages are the long awns on blue wildrye and the pubescence found on hairgrass and bluejoint seeds. In either case, failure to remove them can hamper the effective use of common seed drills and cyclone seeders. Seed hulls are the “seed leaves” (lemma and palea) that surround the true seeds (caryopsis). They may or may not be tightly fused to the hard outer seed coat (pericarp). Normally, hulls don’t cause a problem unless some of the seeds readily separate from the hulls. In this case, all the seeds should be mechanically hulled to create a uniform seed size and prevent the waste of good seeds during cleaning. The PMC accomplishes both appendage and hull removal with a huller/scarifier or “brush machine.” It operates by means of brushes that spin inside a drum shaped cage. The brushes rub seeds against the walls of the drum to condition it. Other types of machines can work as well, including debearders and hullers. Hulling or rubbing, which in turn scarifies the pericarp, may also improve germination in certain species (Trask 1996; Flessner 2000b).

Obtaining only the purest, high quality seeds, even beyond the standards set by law and seed certification, should be the goal of any native grass seed producer. One of the underlying reasons for using natives is to avoid and counteract the spread of exotic weeds. Therefore, there should be “zero tolerance” for noxious and other troublesome weed seeds in any seed lot (Burton and Burton 2004a). Seed cleaning to remove weed seeds, as well as empty seeds, stems, and trash, is primarily accomplished with an air screen machine (fanning mill). It separates seeds by size and weight. Other specialty equipment used by the Center includes an indent cylinder which separates by seed length, a vibrating table which separates by seed surface texture and shape, and an air density separator that distinguishes by seed weight and ballistics. Meeting the challenge of exceptional purity often means natives must be re-cleaned more frequently and meticulously than the typical introduced grass seed crop.

Seed Lot Size and Equipment

With both native grass seed production and revegetation, practitioners regularly deal with small quantities of seeds, often just a few pounds or even grams. There are relatively few economical options for working at this scale, requiring either extensive hand labor or an investment in expensive garden, lab size, or specialized harvest, seed processing, and planting equipment. For some applications, commercial devices are unavailable and equipment may need to be fabricated. In other cases, equipment meant for grain production must be modified to handle grass seeds, which are much lighter and finer. One of best ways to stretch scarce seeds and improve volume for use in larger equipment is to dilute seeds with rice hulls. When planting mixtures, rice hulls suspend seeds in the hopper and help prevent different sizes from separating out and being sown unevenly. For manual seeding with smaller or darker seeds, rice hulls allow for better visual inspection of broadcast uniformity. Other inert carriers include cracked or roasted grains, cat litter, and vermiculite. An inexpensive alternative to hand seeding and costly equipment is the old fashioned cyclone spreader or “belly grinder.” Single row manual seed drills such as the planet junior are still commercially available. For cleaning small quantities of seeds at low cost, hand-held screens and sifters are useful. Manual rubbing boards or troughs may be used to remove awns and pubescence.

Yield, Maturation, and Genetic Integrity

Low seed yields, non-uniform maturity, and maintenance of genetic integrity are inherent challenges when producing many native grasses. Breeding or intensive selection are typically not an option for natives used in restoration, so naturally low yields can only be maximized by refining agronomic techniques. While non-uniform maturity is often the result of desirable genetic variability within a population, it poses additional problems. Failure to capture seeds that mature at different times not only means a loss in production, but also a reduction in diversity through genetic shift. The method of windrowing then combining is better than direct combining for harvesting seeds of uneven maturity. However, when maturity differences and shattering losses are extreme, multiple harvests of the same field are the best but costliest solution. For small plots, the PMC resorts to hand harvesting smaller fields on different dates. For larger stands, several passes with a flail-vac stripper have been used with some success on meadow barley and California oatgrass. Another option is to grow several subsets of the same population with different maturities in adjacent fields or rows.

Besides unintentional selection by harvesting species with uneven maturation, genetic modifications could occur for other reasons. To address this, variety and pre-variety seed certification guidelines are applied by the PMC whenever possible (Oregon State University Extension Service 2004). The Center minimizes genetic changes over time by restricting the number of successive generations or stands to 2—G1 and G2—with G0 being wild seed. If seed lots leave the PMC for commercial increase, production may be limited to G2 or G3. The number of years a field is in production may be kept short as well. The Oregon Seed Certification Service now has tentative pre-variety germplasm (G1, G2, and so on) standards for 14 native grasses (Schrumpf 2003). Lastly, to minimize unwanted cross pollination between ecotypes of the same species, the PMC uses a target isolation distance of at least 1,000 to 1,200 ft (300 to 365 m) for both open and self-pollinated species, regardless of field size.

Germination, Growth, and Competition

Slow germination, slow growth, and a lack of competitiveness with weeds are frequently interrelated and may be the most limiting factors for establishing many native grasses from seeds. To compensate, sowing a species alone at higher rates is one possible solution. However, seeds are expensive, and seeding rates have upper limits because of intraspecific competition. In order to ensure success, one of the best strategies is to reduce the weed seed content in the soil through site preparation methods that include 1 to 2 years of fallowing prior to planting. Ideally, several cycles of tillage and glyphosate applications are utilized to encourage and then destroy germinating weed seedlings at critical times of the year. However, this technique may not be possible on steep banks or in certain non-agricultural settings. It may be unnecessary on recently farmed fields where the weed seed levels are already low. If the native grass seedlings are slow to germinate and emerge, weeds that appear in the interim after planting can be killed by herbicides or burning, as described for dormant seeds. Like the establishment of seed increase fields, timely mowing of weeds that overtop the native grass and the use of selective herbicides may be options for revegetation plantings as well.

Further Considerations for Revegetation and Restoration

When it comes to seeding prescriptions for revegetation and restoration using native grasses, there is no "cookie cutter" approach because almost every site is in someway unique. Furthermore, with the exception of a couple species, long term experience using native grasses in western Oregon and western Washington is lacking. Therefore, technology is often extrapolated from work on introduced grasses in the region or from native species in other parts of North America with a longer history of use. Suggested methods and factors to consider when using native grasses are based on work by others and experience gained by the PMC.

Site Preparation and Weeds

As discussed, site preparation and early weed competition are critical considerations for success. One suggestion is to sample the top layer of soil from the site and conduct "grow outs" to estimate weed seed load and species composition. The soil should be placed in shallow trays in a greenhouse or similar environment, watered for 4 weeks, the seedlings harvested, and the soil allowed to dry. It is re-watered to permit seeds to germinate several times (Waters and others 2001). Because different species will germinate in the spring versus fall, seedling counts could be recorded at both times. Additional counts should be taken after overwintering the soil sample outdoors in a moist condition. Another method is to create open test plots for 2 to 3 years in advance on the site and observe what species volunteer. In a few cases, there may be a valuable seed bank of native species. Knowledge of potential weeds will aid in the choice of a site preparation technique. Attempts to preserve existing, desirable species on site will substantially affect methods as well (Campbell 2004). Techniques usually include some combination of burning, mowing, deep ripping, disking, harrowing, herbicides, soil solarization, fertilization, and incorporation of organic amendments. Soil fallowing and formation of a firm, weed-free seedbed for shallow seed placement are still the best methods for proper seed-soil contact, but they are not suitable for all situations.

Fertilization

The decision to use fertilizer or not is site specific and not without controversy. Most restoration projects in the region leave fertilizer out of the prescription because it exacerbates weed competition. There are also water quality issues with high rates of soluble fertilizers, especially near waterways. However, some seeding guides recommend fertilizer for quicker establishment and higher canopy cover. The PMC avoids fertilizing new plantings where topsoil is well developed, water quality is a concern, or weeds are a major factor. The Natural Resources Conservation Service only recommends fertilizing when subsoil is exposed and a soil test is done. It does not recommend fertilizing diverse mixes of forbs, legumes, and grasses, or seedings on rangeland, wetland, Conservation Reserve land, permanent pastures, and riparian sites (USDA-NRCS 2000). In special situations, slow release fertilizers may be an option, but they are expensive. Some States have specific guidelines for their use (Minnesota Department of Transportation 2003). Seed coating or prilling may be another possibility. Nitrogen, phosphorous, lime, or other nutrients are attached to the seeds of introduced pasture grasses. The method also improves ballistics for aerial seeding and reduces wildlife seed predation; testing is needed with native grass seeds. Nitrogen can be added naturally to a soil by including a native legume in the seed mixture. The fact that nitrogen may favor weed growth over natives is often problematic. In the last 10 years, several researchers have been evaluating "reverse fertilization." It involves application of sawdust or other high carbon material to the soil in an attempt to reduce nitrogen levels available for exotic weeds, thereby favoring the growth of native species. Results have been mixed (Averett and others 2002; Blumenthal and others 2003; Corban and D'Antonio 2004).

Seeding Methods

The choice of seeding method depends on site conditions, site preparation, seed characteristics, equipment availability, labor, economics, and other factors. A standard grain drill may be used following conventional tillage. No-till drills minimize site disturbance and may reduce weed invasion. However, drill rows can leave an unnatural appearance for restoration. Therefore, broadcast seeders equipped with fluted feeders and cultipackers or cyclone seeders may be more desirable. To ensure flow, standard equipment requires that certain grass seeds be conditioned first or carriers added with the seeds. If seed appendages, chaff, or pubescence have not been removed during seed processing, or the seeds are very light, special native grass drills are available. They have picker wheels in the seed box and large drop tubes that prevent the seeds from bridging and plugging up. Depth bands on the furrow openers ensure shallow seeding depth. In addition, hydroseeding is an option for steep, inaccessible sites. Finally, mulches or erosion control blankets applied at seeding time are almost always a good idea, especially on erosive, steep, and dry sites. Common materials and methods readily apply to native grasses.

Seed Mixtures and Monocultures

Prescribing a seed mixture requires knowledge of species compatibility as well as seed and seedling characteristics. As described earlier, species with dormant seeds may best be seeded alone or only with a short-lived, weak competitor. For quick cover and erosion control, consider seeding large, fast establishing native grasses like California brome, blue wildrye, and slender wheatgrass (*Elymus trachycaulus*) alone or in their own mix. If they are included with slower, smaller species, it is generally recommended their rates be kept low and not exceed 5 to 10% of the total PLS seeding rate in order to avoid dominating the stand. Seeding mixtures with 5, 10, and even 25 different species can be found in the literature for other regions of North America. However, given the limited experience and high cost of native herbaceous seeds in western Oregon, one suggestion is to keep mixes simple by including no more than 2 to 4 native grasses. Seeding trials by the PMC have resulted in the complete exclusion of certain grasses in a mix. In addition, many forbs are not competitive with grasses and may need to be planted later or separately. Exceptions include adding a native legume for nitrogen fixation or another forb that is a competitive pioneer. If forbs are included in the mix, early weed management options are reduced, including the use of broadleaf herbicides. Mixes should also be site specific. Those designed for diversity and ecological restoration should follow the concepts of mosaic seeding (Campbell 2004) and sculptured seeding (Jacboson and others 1994) to mimic natural patterns in the environment.

Monocultures are appropriate for temporary, fast cover such as on construction sites and landslides, or they could be used in progressive stages. A site could be restored by first establishing a less expensive, native cover crop that competes well with residual weeds. Other situations could begin with a long-lived species that will serve as the dominant matrix of the plant community. By the third year, slower growing and more expensive grasses are interseeded, alone or as mixes, into the existing stand or newly created bare areas. Finally, by the third or fourth year, forbs are likewise interseeded, planted as container stock, or sown in patches. This staging process allows for simplified “plot management” and retains optional use of selective herbicides. It may also improve the chances of success with expensive, slow, and difficult to establish species, but may significantly add to other costs. The process needs more testing.

Seeding Rates

Given the lack of history behind the use of native grasses in the region, seeding rate development involves substantial guesswork and the search for comparable experiences. Rates will depend on factors including objectives, growth rate, seed and seedling traits, site conditions, and method of planting. They may vary from as low as 0.5 lb/ac (0.6 kg.ha) for species with tiny seeds, to over 250 lb/ac (280 kg/ha) for turf plantings. For revegetation and restoration, the general range is 1 to 20 (5 to 15) lb/ac (1 to 22 [6 to 17] kg/ha) where weed competition is minor and seedbed preparation nearly ideal. The total amount per acre is the same for single species and mixes. Higher rates in the scope of 25 to 60 lb/ac (28 to 67 kg/ha) may be needed for erosion control on steep banks or weed suppression. Critical areas and broadcast seeding methods often specify doubling the drilled amount. Rates should be calculated on a PLS lb/ac and not a bulk lb/ac basis. Furthermore, the most accurate method of rate determination uses pure live seeds/ft^2. For many PMC projects, an initial target rate of 50 live seeds/ft^2 (555 live seeds/m^2) is common. It is then adjusted up or downward depending on species, site conditions, and objectives. In practice, the recommended range may vary from 18 to 90 seeds/ft^2 (200 to 1,000 live seeds/m^2) (USDA-NRCS 2000). Under extreme conditions, this quantity could be higher because estimates are that 90% or more of the seeds are readily lost for various reasons, including dehydration, predation, erosion, and improper planting depth. For certain situations, the PMC has found it useful to sow at densities up to 300 seeds/ft^2 (3,330 live seeds/m^2). Amounts above this are probably a waste of good seeds. Table 1 contains information on seeds/lb and the number of seeds/ft^2 at a 1 lb/ac (1.1 kg/ha) seeding rate.

Present and Future Work

The Corvallis Plant Materials Center has been evaluating and producing seeds of native grasses for more than 2 decades. While the principle species have been blue wildrye, tufted hairgrass, California brome, and California oatgrass, at least 10 new species have been added since 1996. Seeds are produced for research use, special agency field plantings, commercial growers, and cooperative agreements. Presently the PMC has several increase projects targeted for land restoration by the National Park Service and Bureau of Land Management. Evaluations will continue on refining seed production and revegetation techniques with native species.

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