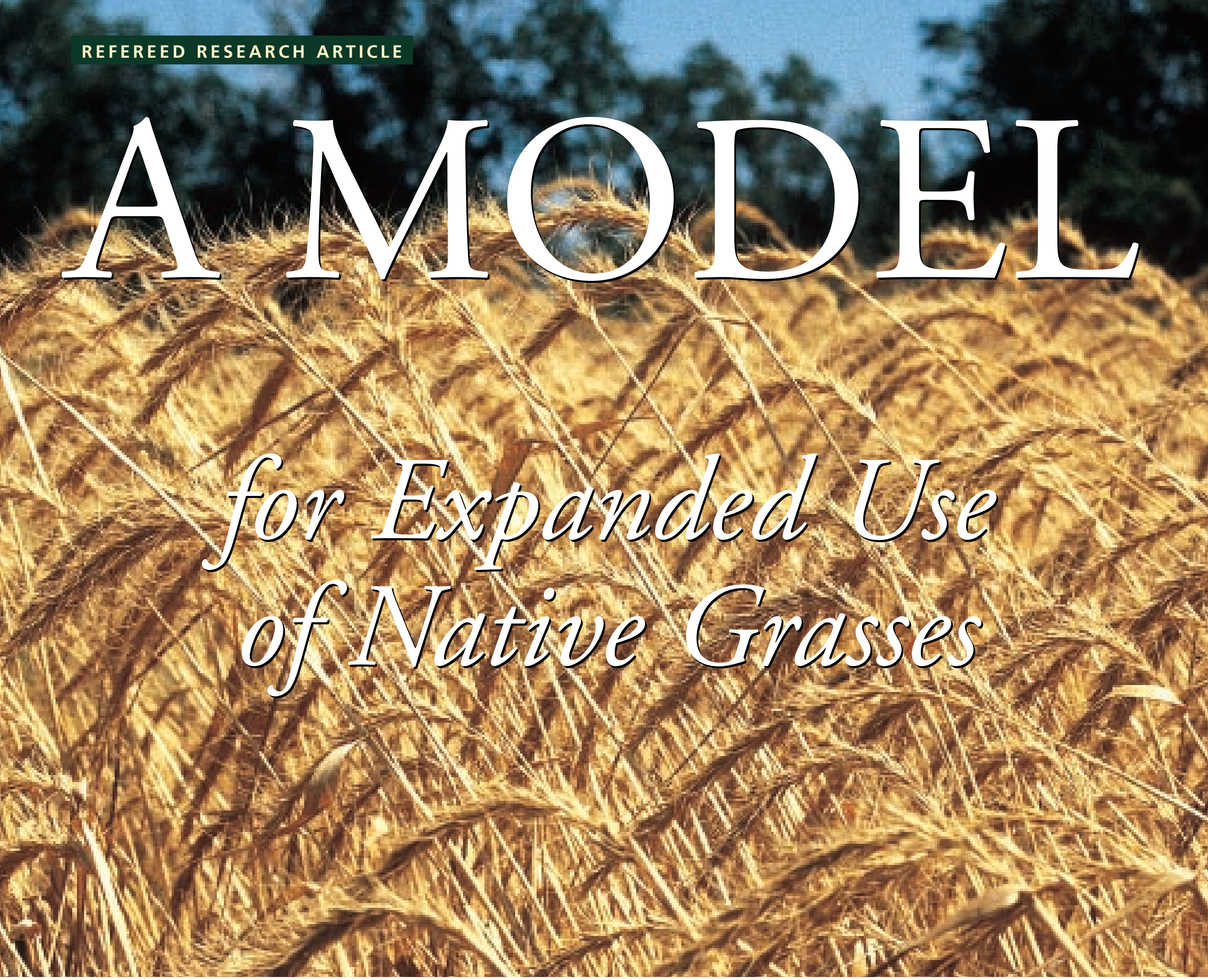
REFEREED RESEARCH ARTICLE

A MODEL

for Expanded Use of Native Grasses



*A test plot of ‘Mandan’ Canada wildrye (*Elymus canadensis *L. ‘Mandan’) in Pierre, South Dakota.*

Photo by Dwight Tober

S Ray Smith Jr and RDB Whalley

ABSTRACT

Interest in native grasses is increasing in the US, Australia, Canada, and worldwide. We propose a model that can be used as a step-by-step guide for plant breeders, ecologists, seed producers, and others interested in developing expanded uses for native grasses. The following steps, with relevant examples from North America and Australia, are described in detail: 1) determine the need; 2) choose an appropriate species; 3) determine breeding system; 4) assess geographic and ecological range; 5) make a collection; 6) assess genetic diversity; 7) determine limitations of species; 8) develop appropriate breeding methods; 9) determine proper release strategy; 10) develop seed conditioning and establishment techniques; 11) develop management techniques; and 12) market development.

KEY WORDS: native plants, seed production, plant breeding, genetic diversity, indigenous grasses, Poaceae

NOMENCLATURE: (North American plants) Barnes and others 1995; (Australian plants) Wheeler and others 2002; all species are Poaceae

Native grasslands covered wide areas of the west central US and Canada (the Great Plains) and Australia before European settlement. During early colonization, grasslands were primarily viewed as fertile farmland and early settlers cultivated much of the original native grasslands for annual crop production. Certain grassland areas were not cultivated due to terrain or soil condition, but were grazed by livestock instead.

Crop production in more fragile areas of the Great Plains and Australia became increasingly marginal as wind and water erosion, excessive cultivation, and continuous crop production depleted soil organic matter and soil fertility. In the 1930s, a worldwide economic depression and a series of successive droughts combined to devastate crop production in the Great Plains. In Australia, the devastation was similar, but the primary cause was overgrazing by cattle, sheep, and rabbits. Sustained efforts were made to replant abandoned or fragile croplands to permanent cover when it was realized that much of these original grasslands should never have been cultivated (Atkins and Smith 1967). Government conservation agencies were formed in Canada, the US, and Australia with a mandate to reduce soil erosion and stabilize the agricultural economy.

It has long been thought that all native grasses had inferior productivity to introduced grasses for pasture and hay plantings. In recent years, researchers and producers have realized that certain native species are very resilient to climatic extremes and can provide good seasonal productivity (Jefferson and others 2002). New government regulations requiring native grasses for oil exploration, pipeline, and mine-site reclamation have also increased interest in native grasses. Although the recent interest in native grasses has been encouraging, the proportion of pasture and hay fields planted with native grasses is still quite low largely due to the high cost of seed and difficulties with establishment. Plant breeders, ecologists, seed producers, and others are working to develop improved native grass cultivars and a strong grassroots effort has developed to harvest local (provenance) seed stands, and establish seed production fields for restoration plantings. Even with these efforts, native grasses account for less than 5% of the grass seed sold annually in the US, less than 3% in Canada, and considerably less than 1% in Australia.

We propose a model that can be used as a guide for anyone interested in expanded uses for native grasses. The model uses a series of 12 steps that starts with determining the need and choosing the appropriate species, then progresses sequentially through collection strategies, potential breeding methods and release strategies, seed conditioning and establishment techniques, management techniques, and market development. Each step is described in detail and relevant examples are given from North America and Australia, but the model is designed to be applicable worldwide. It builds on previous government agency models (Figure 1) and local models (Lodge and Groves 1991). Some of the steps may not be applicable for all situations or with certain species, but using the model as a guide should increase the chances of success with any native grass species. The proposed 12 steps and detailed explanations form the body of this paper.

DESCRIBING THE MODEL

1. Determine the need

Although the first 2 steps are closely linked, their order is very important. The fundamental question "What is the need?" must come before the choice of species (Rumbaugh 1998). Too often plant breeders choose a given species and begin a selection or breeding program before considering the need for a new cultivar. If the cultivar does not address any present need, then a need has to be created or the cultivar abandoned.

This question is not only relevant to native grass breeders, but to anyone who believes that there is a place for expanded use of native grasses. A local livestock producer may want to plant native grasses in a pasture. Before planting the producer must clearly identify the need and then determine the species that best fits this need. Too often, species selection is not based on need, but on availability and cost of seeds.

2. Select an appropriate species that meets this need

After the need has been determined, then one or more species can be identified which have the potential to fulfill the need. Individuals and organizations in the US, Canada, and Australia have had varying levels of success with the first 2 steps of this model as shown from the following examples.

United States—USDA NRCS

The United States Department of Agriculture's Natural Resources Conservation Service (NRCS, formerly Soil Conservation Service), was formed in the 1930s after a series of severe droughts and unsustainable cultivation practices resulted in severe wind and water erosion (Weaver 1954). The need was simple, "reduce topsoil loss and soil degradation." Perennial grass cover provided an obvious solution and the NRCS facilitated grass seed harvest and distribution to landowners. Remnant native grass stands provided 1 source of seeds, but yield and dependability of production were variable. Although native grass seed production research was initiated (Blake 1939; Brown 1943; Kneebone 1957), NRCS personnel began to investigate other grass germplasm sources.

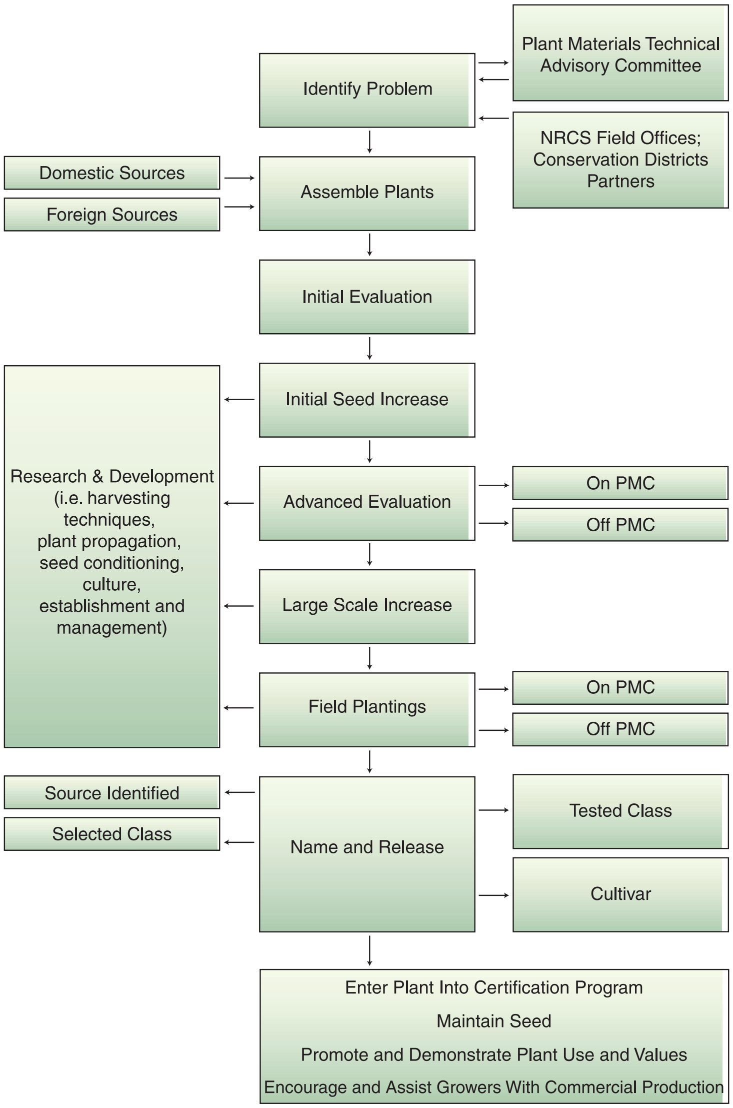


Figure 1 • Flow chart developed and used by the USDA Natural Resource Conservation Service (NRCS) Plant Materials Program to provide a systematic process to evaluate and release plant material to address the conservation problems outlined in their long-range program. (PMC=Plant Materials Center)

Seeds of Eurasian grass species like crested wheatgrass (*Agropyron desertorum* (Fisch.ex Link) J.A. Schultes and *Agropyron cristatum* (L.) Gaertn.) were soon being produced and distributed to landowners because of these species ease of establishment and higher seed yields relative to most North American native grasses. In the 1960s and 1970s, NRCS personnel realized that many North American native grasses were also well suited for soil conservation purposes. Environmental concerns also prompted and encouraged interest in native grasses for restoration, biodiversity, species preservation, and wildlife habitat.

The NRCS has probably released more native grass cultivars in the last 30 y than any other organization in the world. Species have been given priority based on their value for soil conservation. Recently, cultivar development (or ecotype development) for all major native grasses has been attempted (Vogel and Peterson 1993). The Plant Materials Program of the NRCS established a systematic process (Figure 1) to evaluate and release plant material to address conservation problems outlined in their mandate. The flow chart in Figure 1 serves as a useful comparison to the model proposed in this manuscript.

Canada—Ducks Unlimited Ecovars

Ducks Unlimited Canada (DUC) has been reestablishing nesting habitat for waterfowl and other animals for 50 y, but in the late 1980s it recognized that native grasses persisted longer and provided superior wildlife habitat compared with traditional introduced pasture and hay species from Europe and Asia (Duebbert and others 1981; Jacobson and others 1994). The lack of native plant material adapted to the climatic extremes of western Canadian prairies has been a major constraint to habitat establishment. Since 1992, DUC in cooperation with the University of Manitoba, Agriculture Canada, and others have developed about 20 ecovars™ (ECOlogical VARiety) from many native grass species in western Canada. The term ecovar was coined by an NRCS scientist, Earling Jacobson, and is now a DUC trademark that describes material developed under the philosophy that maintenance of genetic diversity is as important as improved growth characteristics. An ecovar has been developed of blue grama (*Bouteloua gracilis* (H.B.K.) Lag. ex Steud.), for example, one of the most naturally abundant species on harsh, dry, eroded, low fertility prairie knolls and a required species for nesting habitat of many migratory songbirds. Ducks Unlimited Canada's ultimate goal is to revegetate areas of the northern Great Plains with adapted native species in mixes because wildlife diversity is commensurate with plant diversity (Wilson and Belcher 1989; Romo and Grilz 1990). The innovative approach of DUC is leading the initiative to greatly increase the amount of regionally adapted native grass seeds available for planting in Canada. In many ways, DUC is using a similar plant selection approach as NRCS.

Australia—CSIRO Project

In the early 1980s, CSIRO (Commonwealth Science and Industry Research Organization) began to investigate alternatives to the traditional introduced grasses used for highway rights-of-way (Lodder and others 1986). The need was summarized by the following criteria: 1) grasses that were relatively short statured to reduce maintenance costs (mowing); 2) grasses that produced a varied and interesting landscape (different colors and textures); and 3) grasses that produced less biomass than traditionally planted roadside species to reduce fire hazard. A number of native species were compared for early seedling growth, biomass production, landscape qualities, and seed production (Lodder and others 1986; Lodder 1989; Lodder and others 1994). Two species, wallaby grass (*Austrodanthonia richardsonii* (Cashm.) H.P. Linder) and kangaroo grass (*Themeda triandra* Forssk.) (Sindel and Groves 1991; Sindel and others 1993), were chosen for their attributes and a plant breeding program was initiated. The cultivars, 'Hume' wallaby grass (Anonymous 1995a) and 'Tangara' kangaroo grass (Anonymous 1997, 2000), were registered under the Plant Breeder's Rights (PBR) Act (1994), but commercial quantities of seeds of these 2 cultivars are not yet available.

Australia—NSW Agriculture–UNE Project

Researchers from New South Wales (NSW) Agriculture and the University of New England (UNE) met in the early 1980s to discuss how to encourage native grass use. Initial discussions led to the identification of species within 3 genera that had production and survival characteristics suitable for agriculture. These researchers decided that the most practical way to encourage the use of native grasses was to develop improved cultivars with superior agronomic and seed production characteristics that could be protected under the Australian Plant Breeder's Rights Act.

Whalley and Lodge successfully developed improved cultivars of microlaena (*Microlaena stipoides* (Labill.) R. Br.) and wallaby grass (*Austrodanthonia bipartita* (Link) H.P. Linder) and *A. richardsonii*) and registered them under PBR (5 cultivars; Anonymous 1992, 1995b), but their decision to choose the species before determining the need may limit the potential use of these cultivars. Seed production of these cultivars has occurred, but supplies are limited and very expensive.

Photo by Dwight Tober

*Test plots of prairie sandreed (*Calamovilfa longifolia *[Hook.] Scribn.) at the USDA NRCS Bismarck Plant Materials Center, North Dakota.*

3. Determine the breeding system and ploidy level of the selected grass species

Knowledge of the breeding system of a grass species is critical before initiating a breeding or selection program. Additionally, if seeds are being collected from local or provenance stands for commercial sale over a wide range of environmental conditions, then knowing the breeding system and ploidy level is important to determine if collected material will be suitable for the new environment. Breeding systems of grasses are many and varied (Conner 1987; Groves and Whalley 2001) and range from obligate outcrossing species to obligate apomicts. Grasses are the most successful plant family, in terms of the range of habitats occupied, in part due to this flexibility in breeding systems.

A wide range of ploidy levels exists among different grass species and even within a single species. Within the Australian species kangaroo grass, diploid populations reproduce sexually and tetraploid populations appear to be apomictic (Woodland 1964). The exchange of genes between the 2 ploidy levels is limited however, if it occurs at all.

In North America, McGinnies and others (1988) reported 3 different ploidy levels for blue grama in a single pasture and Snyder and Harlan (1953) reported blue grama ploidy ranging from diploid to hexaploid. Basin wildrye (*Leymus cinereus* [Scribn. and Merr.] A. Löve) is a predominately tetraploid species, but exclusively octoploid in the northwestern portion of its distribution (northeastern Oregon, northern

Photo by Dwight Tober

*A display of little bluestem (*Schizachyrium scoparium *[Michx.] Nash) at the USDA NRCS Bismarck Plant Materials Center, North Dakota.*

Idaho, Washington, British Columbia), while bluebunch wheatgrass (*Pseudoroegneria spicata* [Pursh] A. Löve) is predominately diploid with occasional tetraploid populations scattered throughout its distribution in the western United States and Canada (Jones 2001). A wide range of ploidy levels within a species suggests high levels of genetic diversity. Knowledge of the ploidy levels and biosystematics for a species is also important for genetic integrity in seed increase and setting isolation distances for certified seed production. Formerly, determination of ploidy level involved laborious slide preparation and microscope work, but recent advances in flow cytometry instrumentation now allow rapid and inexpensive determinations of ploidy level (Arumuganathan and Earle 1991).

The following 2 examples from Australia illustrate the importance of understanding breeding system and ploidy level when commencing selection or breeding work. Lodge (1991) made a collection of individual plants of 2 wallaby grass species (*Austrodanthonia bipartita* and *A. richardsonii*) to produce cultivars for pasture and hay stands. Previous work by Abele (1959) and Brock and Brown (1961) had shown the percentage of selfing to be about 85% for these 2 species. Therefore, Lodge was able to initiate a single plant selection program for 3 or 4 generations with little concern for inbreeding depression. In addition, contamination between adjacent lines in the selection nurseries was unlikely to be a major problem. Had these 2 species been self-sterile, obligate outcrossers, then a quite different selection strategy would have been necessary.

Robinson (1991) made a series of collections of common wheatgrass (*Elymus scaber*) that showed improved summer persistence and good seed yields. Facultative apomixis was known to be present in this species, but the breeding systems of individual collections were unknown. Attempts were made to make crosses between selections, but no fertile seeds were produced and the project was discontinued. Essentially, the project failed because of insufficient knowledge about the breeding system of the common wheatgrass species complex. Recent research has elucidated the different breeding systems within common wheatgrass species complex in Australia (Murphy and Jones 1999).

4. Determine the geographic and ecological range of the species and assess the proportion of this range that should be sampled to meet the need

Large variations occur in both the geographical and ecological ranges of different native grasses. In North America, several species have geographic ranges that extend from Mexico to Canada (for example, blue grama) (Hitchcock 1950). The geographical and ecological ranges of many Australian species (for example, kangaroo grass) are extremely wide, and in some cases, extend beyond Australia (Harden 1993). Therefore, it is reasonable to assume that a widespread species would usually be a better prospect to fill a specific need than a species with a narrow range. A species with a large geographic range also provides a stable market for seed growers and reduces seed cost. Grasses with narrow geographical and ecological ranges often fall into the rare and endangered category. Such species would not normally be appropriate for widespread expanded use.

In North America, most native grass species where seeds are readily available originally occurred over wide geographic ranges (Alderson and Sharp 1995). The process of commercial seed production and widespread sowing of these species led to an increase in their present ranges, although genetic diversity has probably decreased compared with that in original populations. The recent development of ecovars is an attempt to redress the problem of reduced genetic diversity associated with the widespread use of native grass cultivars with a narrow genetic base. When considering a native grass for expanded use, its range should first be surveyed through existing herbarium collections, species distribution maps in the literature, and by surveying botanists, taxonomists, and grassland managers. "On the ground" surveys may also be required for verification when the above information sources are limited.

5. Make a collection of the species over the selected geographic and ecological range

After determining geographic and ecological range, a collection strategy should be designed to collect across this range. Latitudinal ranges are important in terms of winter survival and day length requirements for flowering. It is an accepted rule in North America that warm-season grasses are adapted within 400 to 480 km (250 to 300 miles) north or 160 to 250 km (100 to 150 miles) south from their source of origin (Cooper 1957). East and west adaptation may be greater or less depending on precipitation and elevation. Species with a wide geographic range encompass a myriad of distinct ecological environments that, in turn, shape the genetic structure into populations (sometimes called ecotypes) (Turesson 1922a, b; Miller 1967).

The ideal collection should include plant material from each of the distinct ecological environments across the selected range. It is common for plant collectors to drive along highways, stopping at prescribed intervals to make a collection. Care should be taken using this strategy because traffic and road maintenance equipment are very efficient in the lateral movement of propagules, creating a measure of genetic uniformity in plant material growing along roadsides. If the full ecological range of a species is to be sampled, then the final collection should also include sites with widely differing management histories in terms of grazing (Carman and Briske 1986), fertilizer history, time since cultivation, and fire management. Additional important features are position in the landscape, lithology, and soil type. Where local collections are required, it is important that the ecological features of the seed collection site and the site where the material is to be used are carefully matched. The number of collected plants or genotypes from each site should be sufficient to represent the genetic diversity from that site.

A collection may be in the form of seeds, plants, vegetative parts (individual tillers, rhizomes, or stolons), or a combination of the above. The amount of plant material (for example, number of plants or seeds) to be collected from each collection site will be determined by the breeding system of the species, the expected genetic diversity of the species, the number of sites to be sampled, and the resources available for the project (for example, land area available for an evaluation nursery, labor available, and funding).

6. Assess the genetic and morphological diversity of the species collection

Diversity should be determined by characterizing plant morphology from each collection site as individual genotypes and as groups of genotypes. This information is important to describe each collection, to evaluate inter- and intra-collection genetic diversity, and to determine if the collection should be expanded. Desirable genotypes also can be selected as specified by the selection strategy.

Characterizing a collection is typically conducted by establishing an evaluation nursery containing all genotypes at one or more locations. Common nurseries should be established in locations (environments) where the cultivar, ecotype, or ecovar will eventually be used. Individual plant measurements are then taken throughout the growing season for durations ranging from 1 to 4 y. Individual plant measurements usually include plant height and width, leaf characters, tiller characters, flowering date, health (vigor), emergence and survival, invasive tendencies, and components of seed yield. Other characters also can be measured depending on their importance and on cost, labor, and time limitations (Phan and Smith 2000). Phan and Smith (2000) established evaluation nurseries at 2 locations with regional collections of blue grama and little bluestem. Their protocol allowed evaluation of plant characteristics and statistical analysis within and between collection sites.

Morphological characterization provides extensive information on each genotype and indicates the genetic diversity within and between collection sites. The use of molecular techniques allows assessments of diversity not subject to environmental effects (Welsh and McClelland 1990; Williams and others 1990). Recent molecular evaluation results with buffalograss (*Buchloe dactyloides* (Nutt.) Engelm.) (Huff and others 1993; Peakall and others 1995) and blue grama (Phan 2000) show the potential for these techniques. These researchers all used AMOVA (analysis of molecular variance), which easily partitions variation in molecular data into hierarchical levels of within- and among-population components (Excoffier and others 1992). Molecular techniques should be used only to complement morphological information and not as a substitute.

7. Determine the limiting factors for expanded use of this species

Native grasses have a long list of attributes, including longevity, low input requirements, ecological diversity, wildlife habitat, and environmental adaptation over thousands of years, but their limitations have often prevented or hindered replanting efforts. Researchers and seed producers must first identify the major limitations within a species before solutions can be developed that will allow expanded use. Overcoming limitations will range from breeding for specific traits to improved agronomic practices during establishment and seed production (Wark and others 1995; Smith and Smith 1997). In some cases limitations may be only perceived.

Seed production is a major limitation in many native grasses. Most of these grasses can be best described as conservative seed producers, partitioning photosynthate to maximize plant survival rather than seed production (Smith and Smith 1997). Breeding has been the traditional method to overcome limitations in seed yield (Smoliak and Johnston 1980, 1983; Lodder 1989; Lodge and Groves 1991). In many cases improvements in management practices also have the potential to allow substantial increases in seed yield (Smith and Smith 1997). High seed yields will allow economic seed production and reasonable seed prices will perpetuate a native grass release in the marketplace.

Variable seed quality is another common limitation. Seed quality refers to common seed characteristics of germination and seed viability, but also can be used to describe characteristics like seed dormancy, rate of seedling emergence, and seedling vigor. In other words, seed quality reflects the ability of a seed to germinate and develop into a healthy plant. Seed quality characteristics like high seed dormancy provide an adaptive advantage in nature, but a limitation for establishment. Such characteristics may require modification through plant breeding or seed treatments before expanded use of native grasses occurs (Smith and Smith 1997).

Although it is important to identify limiting factors, it is also important to determine factors perceived as limiting that are actually advantages. For example, slow establishment rate is usually considered a limitation, but this characteristic allows many native grasses to adjust and grow better in low-fertility environments than introduced grasses and weeds. Therefore, rather than to attempt to breed for improved seedling vigor, it may be better to plant these species under low-fertility conditions. Seed dormancy mechanisms provide many native species the ability to avoid or resist undesirable environmental cycles and sustain themselves.

8. Formulate and implement an appropriate selection strategy for development and commercial release

The appropriate selection or breeding strategy should be determined by such factors as: 1) the need; 2) conservation problems; 3) key limiting factors within the species; 4) the breeding system and ploidy level; 5) selection criteria; and 6) personal preference of the breeder or developer. For certain needs, such as native grassland restoration, little or no selection may be required. In other cases, focused selection may be necessary to develop an agronomically superior cultivar that fits the distinct, uniform, and stable (DUS) criteria required for registration under the Plant Variety Protection system in the US and the Plant Breeder's Rights system in Canada and Australia. It is important to remember that although the terms cultivar and variety have different technical definitions, with grass species they are synonymous.

The following breeding strategies are all possibilities: mass selection, recurrent phenotypic selection, restricted recurrent phenotypic selection, half-sib progeny selection, clonal selection (vegetatively propagated material), superior genotype selection (self-pollinated and apomictic), a combination of the above, or a range of other techniques. Vogel and Pedersen (1993) described key breeding techniques for cross-pollinated grasses, but the best way to assess the merits and limitations of each technique is to refer to one or more plant breeding textbooks (Fehr 1987; Poehlman and Sleper 1995). Recurrent phenotypic selection is the most common plant breeding technique currently being used for cross-pollinated grass breeding because it is relatively simple and straightforward, and large numbers of plants can be evaluated at minimal expense. The majority of North American native grasses are cross-pollinated with high levels of self-incompatibility. Exceptions include the self-pollinated species slender wheatgrass (*Elymus trachycaulus* (Link) Gould ex Shinners ssp. *trachycaulus*) and the apomictic species buffalograss (*Cenchrus ciliaris* L.). Conversely, complex breeding systems are common in many Australian native grass species (Groves and Whalley 2001).

The goal of any selection or breeding strategy with a cross-pollinated species is the development of an improved population of plants or genotypes.

Hybridization among selected plants forms the basis for these improved populations. Hybridization can take the form of manual crosses between 2 selected plants or the combining of a large number of plants from multiple-origins (Larson and others 2000) into an improved population.

For example, 'Badlands' little bluestem is comprised of selected plants that were similar in phenology and were rated as superior to the nursery average for vigor, leafiness, seed production, and disease resistance from an initial collection from 68 sites across North and South Dakota (USDA NRCS 1997a). The selection of superior plants to develop 'Badlands' used the recurrent phenotypic selection technique, involving a relatively simple nursery layout and selection protocol. Alternatively, 'Bad River' blue grama originated from a single seed collection from 1 small area along the Bad River in South Dakota (USDA NRCS 1997b). When compared with other collections it was clearly superior for seedling and mature plant vigor and seed yield. There was no need to pursue a strict selection strategy since 1 collection contained the necessary genetic background for a successful release.


Photo by Dwight Tober

*'Pierre' sideoats grama (*Bouteloua curtipendula *[Michx.] Torr. 'Pierre') growing at the USDA NRCS Bismarck Plant Materials Center, North Dakota.*

The NRCS has selected hundreds of native grass cultivars and ecotypes over the last 50 y and their preferred selection strategies have usually been some form of the recurrent phenotypic selection technique or the direct release of a superior collection (Alderson and Sharp 1995). The current ecovar development program uses an alternative strategy with recurrent phenotypic selection to select for improved seed yield and maintenance of plants from every collection site to guarantee genetic diversity (Phan 2000). Australian selection programs with wallaby grass and microlaena used a modified form of mass selection, whereby the superior genotype was selected over a series of generations. Single genotype selection was possible because self-pollination predominated (Abele 1959; Brock and Brown 1961; Clifford 1962).

When the selection and development process is completed, remote site testing should be carried out. Replicated experiments that compare the new selection with a common or known cultivar validate the superiority or inferiority of the selection in the real world. These comparisons are important in making the decision as to whether a release is warranted and to provide the necessary data for registration. During this same time period small-scale seed increases should be occurring.

9. Determine the system for registration and release to end users

Release to end users may take many forms including public, proprietary, Plant Breeder's Rights protected, trademark releases and local, and source-identified or provenance releases from individual collection sites. The type of release will be determined by the need (for example, a local collection release to preserve specific germplasm), the selection strategy, and by the amount of capital investment during selection and/or the legal production desired (for example, Plant Breeder's Rights protected to ensure tight legal protection and to recoup investment). The form of quality control during seed production and sale (for example, seed certification, internal quality control, or other methods) is also important to determine at this stage.

In the US and Canada the traditional release system for introduced and native grasses has been either public or proprietary cultivars. In some cases, native grass releases did not fit into either category and seed supplies were merely increased and sold as common or "variety not stated" seeds. Traditional releases fit neatly into the existing seed certification systems of each country and fit the legal distinct, uniform, and stable definition of a cultivar. In recent years, organizations within both countries have adopted other terms for plant material where selection and testing of plant material is limited. Ducks Unlimited Canada uses the term "ecovar" to describe genetically diverse native grass releases and the NRCS uses "ecotype." Changes within the seed certification system of both countries now allow for seed sales of certified seed within these categories, referred to as "pre-variety germplasm." Both countries also allow for seed collected directly from native stands to be certified using the term "source identified" (Smith and Smith 1997). Although seed certification does not offer the developer or discoverer legal protection for a pre-variety germplasm, cultivar, or other form of release, it does allow the seed increase process to be tightly controlled.

In Australia, public or proprietary cultivar release is the standard procedure, but plant breeders and administrators have been seeking alternatives to traditional release procedures for native grasses. Since market size is often limited, the cost of developing, testing, and releasing varieties is often prohibitive. Recently Archer and Lazenby developed 6 options for the release of native grasses (Archer 1999). Options 1 and 2 involve variety release after obtaining Plant Breeder's Rights protection. Options 3 and 4 are modifications of the traditional public variety release process.

The last 2 options suggested by Archer and Lazenby (Archer 1999) are particularly suited for native grass species where prior commercialization is limited and growers and seed companies have little or no experience. Option 5 provides seed under a memorandum of understanding to selected growers for trial prior to entering into a more permanent arrangement. It allows interested parties to gain experience with no long-term commitment and cultivar owners to evaluate a number of potential partners to maximize the potential for success. Option 6 provides small quantities of seed to producers who have a serious commitment to produce and harvest seeds primarily for their own use, but surplus seeds can also be sold. Obviously, this option prevents monetary return to a cultivar developer, but is a true example of research being conducted for the "public good."

10. Develop procedures for the successful establishment of native grass stands

Native grasses will find expanded uses if they satisfy end users. In other words, it is essential that those who buy and plant native grass seeds are satisfied with the result (Whalley 1997). Overwhelmingly, the experience in Australia has been negative to date and there are only a few examples where native grasses have been successfully established on a large scale. The experience in the US and Canada has been much more positive with millions of hectares successfully established with native species. It is worth exploring the reasons for the Australian difficulties both from the perspective of solving the local problems and also for improving the situation in North America.

Conventional sowing and establishment techniques have been developed for European grasses that have been "domesticated" for a long time (Scott 1997). The temptation has been to transfer these techniques to native grasses, often when seeds have been simply harvested from wild stands. Generally, this approach has been unsuccessful with Australian native grasses. A better approach is to study natural establishment of these species and then devise large-scale techniques mimicking these natural mechanisms. This approach requires knowledge of the ancillary structures and their functions as well as when successful seedlings emerge and subsequent growth patterns of the species.

Ancillary structures

Ancillary structures are associated with seed dispersal (Peart and Clifford 1987) and seed orientation and behavior when they come in contact with the ground. Problems arise because most structures cause seeds to cling together so that they will not flow freely through the metering devices of conventional sowing equipment. In addition, seed dormancy of some species is associated with ancillary structures (Mott 1974; Lodge and Whalley 1981).

Post-harvest seed treatment

Threshing seeds to the caryopses level is one way to remove the problem of ancillary structures. This increases the ease of seed handling and reducing dormancy (Lodge and Whalley 1981), but it can reduce seed longevity, seed shelf life, and establishment success with some species (Bellotti 1989; Grice and others 1995).

Native grasses are usually sown 3 ways: 1) as naked caryopses or achenes; 2) as complete seeds with the lemma, palea, and/or any ancillary structures attached; or 3) as seeds plus other trash including seeds of other species, leaves, stalks, and infertile spikelets. In general, naked caryopses or achenes can be sown using conventional equipment. In the case of complete seeds, much ingenuity has been used to design equipment that will sow seeds with their ancillary structures intact. Whatever form is chosen for sowing, it is important to know the number of viable seeds of the target species that are sown per unit area. This figure must be calculated before sowing occurs and involves appropriate sampling and testing of purity and germination of the material to be sown. Establishment success can depend on sowing system. For instance, kangaroo grass has been successfully established by sowing intact seedheads plus trash harvested using either a forage harvester or a brush harvester (Stafford 1998). Then the seedheads plus trash are spread on the soil surface and the hygroscopic awns ensure that seeds bury themselves over a period of several months. Burning at the appropriate time removes the trash and also aids in germination (Stafford 1998).

Depth of Sowing

Sowing depth recommendations for native grasses are usually 0.5 to 1 cm (0.2 to 0.4 in) or as shallow as possible with soil covering the seed. Ancillary structures evolved to allow natural burial of surface sown seeds (Peart 1979, 1981). Proper depth of sowing becomes all the more important when harvesting and seed processing remove these structures or render them inoperable.

Weed Management

Competition from weeds appears to be a major constraint to successful establishment of native grasses. Semple and others (1999) showed that of several sowings of native grasses into previous pasture, satisfactory establishment only occurred when the ground was fallowed for over a year to reduce the size of the weed seedbank in the soil. Therefore, it is critical to have some idea of the soil weed seedbank during project planning. Soil low in weed seeds will give the greatest chance of success. Mine spoil and newly formed landscapes following highway construction often have low weed seedbanks so weed competition is often not an initial problem, but the weed seeds may be the only ones to survive in topsoil that has been stockpiled for several years. Therefore the use of such topsoil may be counter-productive and it might be better to sow directly into the exposed subsoil, rather than adding topsoil with a large seed seedbank. Effective herbicides and herbicide combinations need to be identified for pre-emergence and post-emergence weed control in native grass stands. A limited number of registered products are available in North America, but herbicide registration in Australia has just recently been initiated (Cole 1999).

11. Develop and release an extension management package for end-users

Expanded use of native grasses will not occur unless seed increase efforts are successful by growers and end users are successful in establishing and maintaining stands. Since each species has unique characteristics, much of the establishment and maintenance requirements are also unique. Therefore, management recommendations should follow a 2-phase approach: 1) general recommendations that apply over all species; and 2) specific recommendations that are unique to each individual species.

Two recent publications have chosen this approach. The *Native Grass Seed Production Manual* (Smith and Smith 1997) includes the general section entitled “General Principles of Native Grass Seed Production” followed by the species specific section “Seed Production Guidelines: Individual Species.” Australia researchers have chosen a similar approach with their recent publication *Grassed-Up: Guidelines for Revegetating with Australian Native Grasses* (Waters and others 2000). Two additional comprehensive publications contain detailed information about establishing native grass stands: *Revegetating with Native Grasses* (Wark and others 1995) and *Vegetating with Native Grasses in Northeastern North America* (Dickerson and Wark 1997).

12. Develop national markets (international markets if appropriate)

If this model is followed then a marketable native grass seed product should be produced. If a valid need was identified in step 1, then there should be demand for seeds. Markets will not develop on their own. Market development is an important and essential last stage in this process. The release of all native plant material should include field trials and demonstrations across the known and all potential regions of adaptation. These trials should be designed not only to show climatic adaptation but also to show the value and use of the new native plant release.

Once a needed native grass product has been developed, new markets also may be available. For example, the blue grama ecovar developed for wildlife plantings in Manitoba may be adapted for planting in much of the north central US and in Saskatchewan and Alberta in Canada. This product not only has potential for wildlife plantings but also for road and pipeline rights-of-way, mine reclamation, and prairie revegetation. If economical seed production occurs, then plantings for pasture and rangeland overseeding are also possible.

Blue grama and other low-growing species have shown potential as low-maintenance turfgrasses, and this is one of the fastest growing markets for grass seeds in North America (Mintenko and Smith 1999). Although the primary market for native grasses in North America and Australia is expected to be within each continent, some plant material may even have potential uses in other continents. Species adapted for low-maintenance turfgrass use provide one such example. Blue grama may be well adapted in Australia, South Africa, or other countries, while

Microlaena may be well adapted in North America. Many uses of native grasses, both domestically and internationally, are possible.

CONCLUSIONS

The interest in the expanded use of native grass species is increasing in the US, Canada, Australia, and many other countries around the world. Our proposed model was developed to serve as a guide for researchers, plant breeders, seed producers, and others who are interested in seeing expanded uses for native grasses. This model is not meant to be a "how to" manual, but instead is designed to provide guidelines for interested parties. Further information on how to implement this model in a specific situation can be found in the references provided, by speaking with experts, or by searching for additional information on appropriate reference databases.

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