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Extending the Growing Season: Forage Seed Production and Perennial Grains

Douglas J. Cattani¹ and Sean R. Asselin¹

¹Department of Plant Science, University of Manitoba, Winnipeg, Mb, Canada, R2T 2N2.

Doug.Cattani@umanitoba.ca corresponding author.

Abstract

Production agriculture relies primarily on seeding of annual crops for food, feed, fuel and fibre in western Canada. Annual seeding and harvesting commonly leave land non-productive for a portion of the year. There is the potential for both soil and nutrient loss from this unused land base, and as important, we are missing the potential for photosynthesis. Capture of carbon in these off-season times may aid in carbon sequestration. Forage production (feed) relies on an animal market for its consumption. Forage seed production in Canada, accounts for approximately 65,000 ha year⁻¹, and is almost exclusively located in western Canada. It is unlikely however that forage seed production area will dramatically increase due to limited markets. Perennial grains could greatly increase the land area dedicated to perennial seed production and provide alternative markets to forage products and forage seed. Intermediate wheatgrass (*Thinopyrum intermedium* (Host) Bark. & Dewey) (KernzaTM) is the perennial grain closest to release and some potential niche markets are currently emerging. Improvement has been made through selection for grain production on individual plants for characteristics that are likely of importance at field scale production. Agronomic packages for intermediate wheatgrass production are lacking, although forage seed production agronomy will guide this development. Agronomic benefits attributed both to perennial seed production and the inclusion of perennials

in cropping systems will be greatly enhanced when the potential for perennial grain production (breeding and agronomy) is realized.

Key Words: forage seed, perennial grains, agronomy, perennial crop cycle.

The Issue

Annual production agriculture does not take full advantage of the opportunity to capture the solar energy during the growing season in the temperate areas of western Canada. Planting annuals in the spring after the threat of killing frosts have passed is standard for most crops, with winter annuals being an obvious exception (see Larsen et al., this issue). The land area is either left as is post-harvest (e.g. for zero-till establishment or spring tillage) or is subjected to mechanical disturbance. While this disturbance can have agronomic benefits such as aiding in the fall germination of seed that escaped harvest and in seedbank depletion (Geddes and Gulden 2017), it leaves the area susceptible to both nutrient loss and soil erosion.

In most of Canada much of the early and late season solar energy is not, or is grossly under-utilized on agricultural land. For example, at the University of Manitoba Ian N. Morrison Research Farm at Carman MB, there were 65.7, 26.6, 84.3, 184.4, and 128.9 accumulated growing degrees day (GDD), base T 0°C, in April for the years 2012- 2016, respectively (Table 1). This is in general below the 1991-2010 20-year average. September has had a higher than average GDD accumulation in the years 2012-2016 and rainfall has been above average for three of the past five years (Table 1). October has also had higher than average accumulated GDD for the past three years, however precipitation has been lower than average (Table 1). Failure to capture this energy in crop producing areas could lead to moisture accumulation and a delay in access to the land base the following spring. Active plant growth could reduce water impacts on crop land at these times of the year via both transpiration and growth.

Jaikumar et al. (2016) found that older (5-yr old vs. 2-yr old) intermediate wheatgrass (*Thinopyrum intermedium* (Host) Bark. & Dewey) plants could have up to 17% of maximum photosynthesis at 1.2°C, indicating that; they are active under sub-optimal growing conditions, and; perennial plantings may become more photosynthetically efficient as they age. This activity should increase plant water use at a time when non-planted areas are relying solely of evaporation and drainage for excess water relief.

Forage seed and perennial grain production would also allow for by-passing adverse spring seeding conditions and can provide greater flexibility in the timing of seeding. Early August seeding dates (up to August 15) are permissible in some insured forage grass seed crops (MASC 2017).

A Potential Solution

In order to reduce the potential for erosion of soil and nutrients and to intercept more solar energy, herbaceous perennials should be considered for use. Forage production is discussed elsewhere (McGeough et al., this issue), therefore, this review and discussion will focus on forage seed and the potential for perennial grain production.

Forage Seed - Current Production

There have been on average approximately 63,740 hectares of forage seed production in Canada between 2005 and 2016 (Wong 2016; CSGA 2017) (Table 2). Production has taken place in seven provinces with the Manitoba, Saskatchewan, Alberta and British Columbia accounting for approximately 99.8% of this production area during this period (Table 2). There are seven broad species categories of production; alfalfa (*Medicago sativa* L.), birdsfoot trefoil (*Lotus corniculatus* L.), brome-grasses, fescues, ryegrasses, timothy (*Phleum pratense* L.) and wheatgrasses. In order of average area in production year⁻¹, alfalfa, followed by timothy,

ryegrasses and then the fescue grouping all averaged greater than 5,000 hectares year⁻¹ between 2005 and 2016 (Table 2).

The price that a forage seed producer can obtain for their product influences the desirability to produce an individual forage seed crop. Prevailing climatic conditions also can impact the producer's desire to retain production fields. For example, an increase in precipitation may influence producers to either keep in or plan to plant new forage seed fields to reduce the risk of wet conditions delaying or negating spring seeding operations.

Forage seed has become part of the agricultural framework within the western provinces to the extent that provincial government agriculture departments include cost of production worksheets for some of the forage seed species and may provide crop insurance for field establishment. Table 3 shows the 2016 Manitoba estimate of cost of production for some annual crops and forage seed crops. Cost of establishment is variable, however forage seed crops in general benefit from companion crop use. Lower fuel costs are associated with perennial seed production versus annual crop production.

The potential for the expansion of forage seed production is related to the demand for seed. Unless there is a large increase in forage acreage, the expansion potential for forage seed production is limited. Therefore, in order for an increase in the utilization of seed from herbaceous perennial species in the agricultural landscape, expansion into commodity products is required.

Perennial Grains for Canada

Perennial grains and oilseeds have the potential to expand the utilization of herbaceous perennial species into main stream of agricultural production systems. Perennial grains may be used for food, feed, forage, and fibre. Dual use, for use as food or feed and then forage within a

single growing season is a possibility (Bell et al. 2008). Currently perennial grains are not yet available for widespread plantings. Issues with adaptation to Canadian growing conditions, especially the Prairie Provinces, have historically delayed the introduction of both established and new crops into the region and can still be a concern (e.g. Fowler 2012 and Salmon et al. 2015 and winter hardiness in winter wheat). Perennial grains will not be exceptions (e.g. Cattani 2017). Whether the first introduction will be intermediate wheatgrass or a wheat x wheatgrass hybrid (*Triticum* sp. x *Thinopyrum* sp.) in North America, refinements will be required for seed production of the selected crop.

Perennial grains, in contrast to forage seed production which are restricted in stand longevity by CSGA regulations, would not have a dictated stand life that impacts its seed (grain) value (CSGA 2017). Intergenerational populations would not demote a perennial grain crop as it would a pedigree seed production field (CSGA 2017). Globally, other perennial grain species are being investigated with perennial rice likely to be the first perennial grain commercially grown in Asia (Zhang et al. 2017).

Perennial Grain and Oilseed Progress in Manitoba

Interspecific and Intergeneric Hybrids

Our attempts to grow wheat x wheatgrass hybrids in Manitoba have been unsuccessful with all lines either failing to regrow after harvest or not surviving a second winter. Researchers in Australia however have had greater success with hybrid materials. Hayes et al. (2012, 2016) tested hybrids in Australia and have found that yields were 2-4x greater than the intermediate wheatgrass check (forage type), although the intermediate wheatgrass yields were well below anticipated economic production values (Bell et al. 2008). Their initial screening found adequate regrowth in some lines, moderate bread making qualities and enough variability to recommend a

breeding program (Hayes et al. 2012). Washington State University has recently announced a new hybrid (*Triticum aestivum* L. x *Thinopyrum ponticum* (Podp.) Z.-W. Liu & R.-C. Wang) named 'Salish Blue' and describe it as follows, "... a polycarpic habit, setting seed for two or more seasons." (Curwen-McAdams et al. 2016).

We have attempted to grow ACE-1 perennial cereal rye, (*Secale cereale* L. x *S. montanum* L.) (Acharya et al. 2004) to ascertain its potential for perennial grain use in Manitoba and found two primary factors that resulted in our abandoning its use. First, on average only 10% of the individuals survived a second winter; and secondly, ergot (*Claviceps purpurea*) was a major issue, with some individuals producing more ergot than seed (D. Cattani, data not published). Ergot occurrence was most likely due to floret infertility (Reimann-Philipp 1995). It should be noted that Acharya et al. (2004) recommended that perennial cereal rye should be grown in drier regions for forage use where ergot is less likely to develop, and they warned that harvest for forage should take place prior to seed production to avoid ergot contamination in the forage. Floret fertility is of concern for all inter-specific and -generic hybrids with its potential for ergot development.

Intermediate Wheatgrass

Our primary focus has been on developing intermediate wheatgrass as a perennial grain crop due to it being occasionally grown as a forage seed crop in Manitoba (K. Shmon, Imperial Seeds, Winnipeg, MB, personal communication). Understanding the dynamics of seed production and persistence of intermediate wheatgrass has been the focus of the University of Manitoba's breeding program to date (Cattani 2017). There are other larger established breeding efforts for intermediate wheatgrass grain production (The Land Institute (Cox et al. 2006); University of Minnesota (Zhang et al. 2016)). Intermediate wheatgrass is hexaploid ($2n = 6x =$

42), is generally considered an obligate outcrossing species and has been shown to respond to selection for seed yield (Ross 1963; Knowles 1977). Jensen et al. (1990) did find some self-compatibility in intermediate wheatgrass so this may not remain a constraint in population development.

Development of genomic resources has moved quickly to where a consensus genetic map has recently been developed for intermediate wheatgrass (Kantarski et al. 2017) and optimization of genome wide association mapping for grain production has also been undertaken (Zhang et al. 2015). Development of these genetic resources and tools should aid in more rapid progress under selection in this species.

Bread making quality of intermediate wheatgrass has been shown to be poor relative to wheat (Gazza et al. 2016). However, there are many other uses of the grain including sour-dough bread, pancakes, snack bars, flour mixtures, muffins and beer (Karnoski 2017). We have also received enquiries as to the use in flatbreads and other potential uses (D. Cattani, personal communication).

Evaluation of accessions of intermediate wheatgrass for seed yield and its components took place over a four year period from 2011-2014 in Manitoba (Cattani 2017). Within this study, in-depth plant measurements were made within each growing season on a set of one hundred plants across the three years of reproductive growth. Approximately 25% of the tracked individuals originated from USDA-GRIN accessions with the remainder being individuals originating from the third cycle of selection at The Land Institute. The relationship of fertile tiller density on seed yield cm^{-2} is shown in Figure 1 for 2012, 2013 and 2014. In general, TLI individuals had higher seed yield cm^{-2} than the GRIN accessions. This is not surprising as TLI materials had progressed through three cycles of selection for seed yield. This relationship has

been identified in other perennial grass species including creeping bentgrass (*Agrostis stolonifera* L.) (Smith and Cattani 1993) (Figure 2) and by Wang et al. (2013) with *Leymus chinensis* (Trin) Tzvel, and Scotton et al. (2015) in a semi-natural grassland setting (*Festuca nigrescens* Lam. – *Agrostis capillaris* L.) and may be important in selection programs.

After selection from the initial introductions in Manitoba, a replicated study using vegetatively propagated genotypes was established in 2015 and first grain was harvested in 2016. A similar, relatively weak response ($r = 0.40$, $p = < 0.05$) of fertile tiller density on seed yield cm^{-2} was found. This relationship was weakest in the first seed production year of the 2011 established trial (Figure 1), so this relationship may strengthen as the trial ages. The correlation coefficient for harvest index (HI) for seven selected individuals in the 2015 established trial versus their across years mean HI for the 2011 established study is $r = 0.84$ ($p = < 0.05$), indicating that some relationships appear to remain stable across time and growth environments.

Other Potential Perennial Crops

There is also potential for other crop development (DeHaan et al. 2016); however, breeding efforts are well behind that of intermediate wheatgrass. For example, we have made collections of both *Helianthus maximiliani* Schrad (Maximilian sunflower) and *Linum lewisii* Pursh (Lewis flax) in Manitoba and preliminary analysis of some quality aspects indicate that there is potential for utilization (Table 4). A USDA assessment of wild germplasm resources in *H. maximiliani* suggests that there is the necessary diversity in seed weight and quality in *H. maximiliani* and other perennial sunflowers for crop development (Seiler 1994; Seiler and Brothers 1999; USDA G.R.I.N. database, 2017). We are currently investigating *H. maximiliani* as a perennial oilseed crop for western Canada (Van Tassel et al. 2014) with genetic diversity being assessed and development of genomic resources using a closely related model species.

Expansion of perennial forage use will be slow. Potential for perennial grain use, in particular Kernza™ is slowly developing as its constituents are being researched (Zhang et al. 2015). As research into its use potential is explored, the potential for perennial grains should expand (Karnowski 2017). Dual usage of perennial grains is a distinct possibility (Bell et al. 2008) and should enhance profitability.

Overview of Forage Seed and Perennial Grain Agronomy Research

Research into forage seed agronomy has found that each crop may have a preferred method of stand renovation for prolonged seed productivity depending upon the region in which they are being grown (e.g. Entz et al. 1994 (timothy); Soroka and Gossen 2005 (Kentucky bluegrass, *Poa pratensis* L.; creeping bentgrass; creeping red fescue, *Festuca rubra* L.); Thompson and Clark 1993 (Kentucky bluegrass); Cattani et al. 1997 (creeping bentgrass); Meints et al. 2001 (creeping red fescue) Havstad 2016 (meadow fescue, *Schedonorus pratensis* (Huds.) P. Beauv., and timothy); Loeppky and Coulman 2001 (meadow brome grass, *Bromus riparius* Rehmman); Fairey and Lekovitch 2001 (creeping red fescue, Kentucky bluegrass and tall fescue (*Schedonorus arundinaceus* (Schreb.) Dumort., nom. cons., formerly *Festuca arundinacea* Schreb (USDA Plants Database)). For example, in timothy, post-harvest renovation methods including burning did not impact seed yield in Manitoba (Entz et al. 1994) whereas burning had a positive impact on seed yield in Norway (Havstad 2016). Fairey and Lefkovitch (2001) stated that at 55°N, post-harvest residue management impacts in the Peace River region were most likely limited by the reduced potential regrowth period after harvest.

In creeping bentgrass (Cattani et al. 1997) and meadow brome grass (Loeppky and Coulman 2001), post-harvest renovation method had a significant impact on fertile tiller density and seed yield. Meints et al. (2001) found that post-harvest residue management was impacted

by cultivar in creeping red fescue in Oregon, with the degree of rhizomatousness being the characteristic associated with the response to renovation. Complete biomass removal, either by fire or mechanical methods allowed for reproductive tiller initiation only in highly rhizomatous cultivars. Zapiola et al. (2006) later reported that field burning of creeping red fescue in Oregon was required to maintain seed production levels over a four-year period. Therefore each crop appears to have its own optimum renovation strategy, which may differ between cultivars and growth environments.

Seed yield potential is also impacted by fertility (Wang et al. 2013), genetics (e.g. Meints et al. 2001; Cattani 2017) and adaptation to the growth environment (e.g. Cattani et al. 2004; Zhang et al. 2017). Perennial forage crops are subject to year to year variability in dry matter yields (Knowles 1987), similar to perennial seed crops and their seed yields (Cattani et al. 2004; Soroka and Gossen 2005; Chastain et al. 2011; Wang et al. 2013; Li et al. 2014). Climatic variability (e.g. precipitation) can greatly impact production (Knowles 1987). This research will be instructive when perennial grains and oilseeds reach production status.

Crop-cycle Components and Seed Yield Impacts

Seed yield in a herbaceous perennial can be seen as a series of developmental stages throughout the yearly growth cycle (Figure 3) (and is based upon work by Heide (1994), Dofing and Knight (1992), Cattani et al. (2004) and Abel et al. (2017) amongst many others). This outline provides a generalized growth and developmental chart of herbaceous iteroparous perennial grasses in particular. Many perennial grasses are determinant in their reproductive efforts unlike legumes such as alfalfa. In legumes, once flowering is initiated, a plant can flower as long as the growth environment allows (Teixeira et al. 2011). All stages of the growth cycle

can be impacted by environmental components including precipitation and temperature (Li et al. 2014).

We will begin with post-harvest tiller growth and development (Figure 3 step1) as this regrowth can set-up the following year's potential seed harvest (see Abel et al. 2017). In a number of species, regrowth after harvest is required for reproductive induction (Heide 1994). For example, in Kentucky bluegrass an individual tiller must attain a prescribed size for primary induction to occur (Thompson and Clark 1993) and an individual tiller may take greater than two years to flower (Sylvester and Reynolds 1999). Renovation method can impact fertile tiller density and seed yield (Loeppky and Coulman 2001). Fairey and Lefkovitch (2001) hypothesized that the length of the regrowth period impacts the success of renovation method. Cattani et al. (1991) found that tiller production in creeping bentgrass in turf appeared to cease after early September. This could explain the variable results found for this species as fall re-growth period is variable (Cattani et al. 2004; Soroka and Gossen 2005). However, there may be environmental stimuli (e.g. frost) that trigger the plant to prepare for winter which influence this and may also lead to the variability of the results. This may also explain the lack of response variability to renovation methods in areas where re-growth potential is not limited by early winters (e.g. Oregon, in Chastain et al. 2011).

With respect to reproductive tiller induction (Figure 3 step 2), Heide (1994) described the transformation from vegetative to reproductive apex in many herbaceous perennial grasses. In western Canada, the meeting of these induction requirements is generally not an issue provided tiller condition restrictions are exceeded (Thompson and Clark 1993).

Reproductive tiller development (Figure 3 step 3) in the spring of the year is also important. Hall et al. (2009) reported that across a number of herbaceous perennial grass

species, that onset of flowering was delayed (day of the year) as distance from the equator increased, however flowering took place at both lower accumulated growing degree days (GDD) and photosynthetic active radiation (PAR). This difference in developmental time (GDD or PAR) may indicate less developmental time for individual inflorescences and thus differentially influence seed yield and yield component compensation between different growing areas.

Flowering and pollination (Figure 3 step 4) can be influenced by environmental factors and genetics. Genetic abnormalities, such as those found in many perennial interspecific hybrids (e.g. perennial cereal rye, Reimann-Philipp 1995), can influence fertilization and seed set. In cross-pollinating species diversity also needs to be maintained for adequate seed set (self-incompatibility issues). Cookson et al. (2009) showed crop nutrient status also plays a role successful seed set. Ergot is a known contaminant in perennial grass seed production and allowances are currently made for ergot presence in pedigree forage seed (Table XI, Schedule I, Canada Seeds Act). Flowering synchronicity is therefore important for reducing empty florets within obligate outcrossing species.

Within an individual stage, especially seed development and maturation (Figure 3 step 5), many factors can interact such that seed yield component compensation takes place (e.g. Adams 1967; Dofing and Knight 1992; Abel et al. 2017). This stage generally can lead to a true interaction between seed yield components. The inter-relationships between components impact the direct effect on seed yield realization. Abel et al. (2017) found that inflorescence size had the largest direct effect on seed yield in perennial ryegrass (*Lolium perenne* L.), which was due in part to its strong relationship with the number of spikelets inflorescence⁻¹. Lodging can also impact the plant's ability to set seed and/or harvest the seed produced and appears to be species dependent (Griffith 2000). Tokatlidis (2014) suggested that breeding for yield component

compensation may be a means to reduce yield variability due to unpredictability of environmental factors. Creissen et al. (2013) indicated that plant level compensation in genotypic mixtures can aid in environmental resiliency with respect to yield. As most of the forage seed and potential perennial grains species have some level of self-incompatibility, intensive breeding of these species will be required to maintain relatively stable yields (e.g. Cattani 2017).

Harvest or the ability to harvest the seed set by the crop can also impact seed yield realization (Figure 3 step 6). Elgersma (1988) estimated that up to 50% of seed set may be lost in a perennial ryegrass seed harvest. Selection against seed shattering is a major quest in the attempts to domesticate perennial grains and oilseeds (Lin et al. 2012; Meyer et al. 2012; DeHaan et al. 2016). Interestingly, this process can proceed in the opposite direction, as the loss of the ability to hold onto seed is credited with the development of weedy rice (Kanapeckas et al. 2016).

Timing of harvest and its relationship to seed quality has been investigated. Berdahl and Frank (1998) recommended that windrowing time should be based upon seed moisture for high quality seed in intermediate wheatgrass, crested wheatgrass (*Agropyron desertorum* (Fisch. ex Link) Schult.) and Russian wildrye (*Psathyrostachys juncea* (Fisch.) Nevski). Timing of windrowing based upon these findings could reduce the potential for seed loss during harvest until seed-shattering potential is reduced through breeding efforts. As mentioned above, lodging can also impact harvest (Griffith 2000).

There are many other examples of impacts of events and processes at these stages on seed yield in perennial grasses. As stated previously, environmental conditions can impact a number of these characteristics and throughout the cycle.

Nutrient Availability

Availability of adequate nutrition is important throughout the cycle. Chastain et al. (2014) found spring applied N to increase fertile tiller number in perennial ryegrass while having little to no impact on tall fescue in two of three years of their study. Spring applied N reduced HI in two of three years with perennial ryegrass and in one year with tall fescue (Chastain et al. 2014). Use of a plant growth regulator in these two species without spring applied N had no impact on seed yield or fertile tiller number in most years (Chastain et al. 2014). Wang et al. (2013) applied N in the fall to *L. chinensis* and found higher fertile tiller densities. Fall application of nitrogen was also used as a common treatment in the Chastain et al. (2014) study. Fall application of N is important in most grasses that require a dual induction process for fertile tiller initiation (Heide 1994). Thompson and Clark (1993) found that N fertility applied pre-reproductive induction, led to larger fertile tillers following a simulated winter, and led to larger panicles and greater seed set. Abel et al. (2017) found that larger tillers set more seed.

Perennial forage seed crops face a number of biotic challenges including insects (Butler et al. 2001; May et al. 2003), diseases (Reich et al. 2017), weeds (Moyer and Acharya 2006) and declining yields as stands age (Loeppky and Coulman 2002). These challenges can occur throughout the developmental cycle. Similar impacts are likely to occur in perennial grains and oilseeds as production area increases.

Perennial Grain Agronomy

Research directly related to perennial grain agronomy is lacking, although it is now underway (e.g. Hayes et al. 2016; Jungers et al. 2017). Jungers et al. (2017) found that grain yield was responsive to spring applied N fertility in the first seed production year, but not thereafter. Research on forage seed production can provide instruction as to the parameters that are likely important and therefore provide a starting point for refinements for perennial grain

agronomic packages. For example, Thompson and Clark with Kentucky bluegrass (1993) and Cattani et al. (1997) with creeping bentgrass both found that pre-vernalization (early fall) fertility resulted in greater fertile tillers densities following vernalization and led to higher seed yields (Cattani et al. 1997).

Hayes et al. (2016) looked into the cropping of perennial wheat and intermediate wheatgrass with annual legumes. In general, they found that the legumes could potentially meet the amount of N removed by the crop via N_2 fixation, however the planting design required for legume success reduced grain yields by half. Dick (2016) found that growing intermediate wheatgrass with biennial and perennial legumes in Manitoba increased grain yield only when the area was grazed by sheep in the early fall. Elsewhere we argue that selection for plants able to maintain high seed yields in a third production year will lead to sustainable yields and to a longer stand life Cattani (2017). Cattani et al. (2004) found higher yields in some cultivars of creeping bentgrass in later years, with the most productive lines having higher HI.

We are currently looking at post-harvest agronomic practices including the impact of timing of fertility and residue management on sustained productivity in intermediate wheatgrass. This work may have ties to other areas of potential use including stock-piled grazing of production stands (Bell et al. 2008) to increase its value and to potentially reduce fertility inputs (Dick 2016). Table 5 shows a forage quality comparison of stockpiled intermediate wheatgrass between two renovation treatments. The first treatment was clipping to 5 cm and 60 kg ha^{-1} actual N applied in late August; and the second a straight combined area with a similar nitrogen treatment. This data indicates that there is potential for dual usage, especially on renovated stands. Holman et al. (2007) reported that grazing by cattle in Kentucky bluegrass replicated the seed yields achieved with field burning. The forage value reported by Holman et al. (2007) also

indicated grazing potential with Kentucky bluegrass, although it was grazed in late summer in the western US and had 140 kg N ha⁻¹ applied after grazing. A number of researchers are currently looking at grazing potential in intermediate wheatgrass (S. Culman, Ohio State University, personal communication).

Other issues that may become important will include the potential for reduced perennality as harvest index increases (Zhang and Jiang 2000; Smaje 2015; González-Paleo et al. 2016), the continuity of productivity (Cattani 2017) and pest infestations as area planted increases.

Conclusions

Forage use will increase if animal production is increased. Forage seed production is therefore limited by the animal production industry. Perennial grains however, can bring the benefits of perennial land cover to production agriculture. Perennial grains are not expected to replace current crop production, however they can provide many of the benefits to cropping systems that perennial forages and forage seed production currently provide. While intermediate wheatgrass is approaching commercialization, much more work on the agronomics of production and market development are needed. Current agronomic research results on forage seed production will be instructive in the development of agronomic practices to sustain perennial grain yields over the life of a stand. Given the impact of growth environment on seed productivity, each production area will need to refine the broad principles that are uncovered via research. Much of this will be facilitated by getting seed into producer's hands and allowing them to fine tune the production systems.

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List of Figures:

Figure 1. Seedhead density versus seed yield cm^{-2} for TLI and GRIN accessions for 2012-2014 at Carman, MB.

Figure 2. Seedhead density versus seed yield ha^{-1} for creeping bentgrass renovation study across all renovation treatments at Arborg MB in 1989 (from Smith and Cattani 1993, Table 4).

Figure 3. Generalized yearly developmental cycle of herbaceous perennial grasses after first seed harvest.

Table 1. Growing degree days (GDD) (base temperature 0°C) and monthly precipitation (ppt) (mm) from April, September and October 2012-2016 at Carman MB

Year	April		September		October	
	GDD	ppt (mm)	GDD	ppt	GDD	ppt
2012	65.7	18.5	422.4	64.7	138.9	84.5
2013	26.6	12.7	451.5	84.5	166.1	13.2
2014	84.3	40.1	392.2	46.6	223.7	6.0
2015	184.4	17.5	474.3	42.0	223.0	37.3
2016	128.9	55.3	422.4	64.7	207.3	36.5
Long-term mean ^a	148.0	29.5	393.4	51.8	173.1	44.4

^a gdd – 20 year mean (1991-2010) and ppt - 30 year mean (1981-2010)

Table 2. Forage and turfgrass seed production in hectares for Canada between 2005 and 2016 (Data taken from D. Wong, 2016).

Year	Forage and turfgrass species (hectares grown)								Total
	ALF ^a	BRG	CLV	FES	RYG	TIM	WHG	BFT	
2005	24,627	5,492	2,210	11,828	11,632	13,648	4,303	n/a	73,740
2006	23,635	4,393	2,582	9,211	16,602	13,880	3,146	n/a	73,448
2007	25,443	5,178	2,162	8,209	12,214	15,151	3,654	n/a	72,012
2008	23,090	4,999	1,694	9,361	10,151	15,542	3,498	n/a	68,336
2009	19,894	4,029	1,669	7,214	7,874	13,590	2,756	n/a	57,026
2010	20,585	3,114	1,293	5,849	11,373	10,706	3,074	1,677	57,670
2011	17,934	2,604	1,457	4,218	9,743	10,532	2,557	2,027	51,073
2012	19,205	2,079	1,573	4,401	7,474	13,360	2,141	2,960	53,193
2013	20,610	2,261	1,719	4,872	6,299	15,209	1,561	3,012	55,542
2014	22,792	2,174	1,009	4,140	6,359	15,267	2,007	1,582	55,331
2015	28,315	2,301	2,343	5,868	10,057	17,710	2,041	1,055	69,690
2016	32,885	3,995	2,471	7,637	10,273	17,097	2,580	853	77,790
Mean Yr ⁻¹	23251	3552	1848	6901	10004	14308	2777	1097	63738

^a ALF – alfalfa, BRG – brome-grasses, CLV – clovers, FES – fescues, RYG – ryegrasses, TIM – timothy, WHG – wheatgrasses and BFT – birdsfoot trefoil.

Table 3: Ranking of estimated production costs per hectare of common annual and perennial crops in Manitoba for 2016 (MbAg, 2016).

Annual crops	Seed cost	Fertilizer	Herbicide	Fungicide	Insecticide	Fuel	Total	Rank
<i>Canola^a</i>	\$52.25	\$78.99	\$13.13	\$36.25	\$4.73	\$16.43	\$201.78	11
<i>Spring wheat</i>	\$22.00	\$61.23	\$26.21	\$21.31	\$0.00	\$20.05	\$150.80	8
<i>Soybean</i>	\$94.38	\$11.35	\$14.67	\$0.00	\$0.00	\$15.37	\$135.77	5
Oats	\$18.13	\$48.57	\$9.50	\$10.13	\$0.00	\$23.33	\$109.66	3
Grain corn	\$78.30	\$94.42	\$18.17	\$0.00	\$0.00	\$23.65	\$214.54	12
Winter wheat	\$20.00	\$66.14	\$13.83	\$21.31	\$0.00	\$21.71	\$142.99	6
Forage seed	Seed cost ^b							
<i>Alfalfa</i>	\$24.24	\$24.84	\$49.00	\$36.00	\$14.00	\$9.77	\$157.85	10
<i>Timothy</i>	\$21.97	\$64.21	\$10.00	\$0.00	\$3.00	\$9.34	\$108.52	2
Red Clover	\$99.40	\$24.84	\$20.00	\$0.00	\$0.00	\$8.21	\$152.45	9
Meadow fescue	\$26.28	\$64.21	\$10.00	\$0.00	\$3.00	\$10.18	\$113.67	4
Birdsfoot trefoil	\$22.88	\$24.84	\$20.00	\$17.00	\$14.00	\$9.18	\$107.90	1
<i>Tall fescue</i>	\$31.55	\$64.21	\$23.00	\$17.00	\$3.00	\$11.55	\$150.31	7

^a Italicised crops are the currently highest production area crops of annual and perennial seed crops.

^b Seed cost for forage seed crops calculated as (Seed + nurse crop costs – nurse crop revenue).

Table 4. Seed quality characteristics for *Linum lewisii* and *Helianthus maximilianii* as compared to annual crop relatives.

Species	Fat Content in seed (%)	Fatty acid concentrations in %							
		polyunsaturated			mono- unsaturated	unsaturated			Protein (%)
		LNA ^a (%)	LA (%)	LNA+ LA (%)	OLE (%)	STE (%)	PAL (%)	Total (%)	
<i>Linum lewisii</i>	27.2	59.9	17.3	77.2	15.8	1.7	3.1	4.8	27.6
Flax ^b	35	57	16	73	18	4	5	9	23
Sunflowers									
<i>Helianthus maximiliani</i> ^c	-	0.02	69.3	69.3	22.4	2.5	4.7	7.2	18.8
<i>Helianthus maximiliani</i> ^d	31.1	-	77.4	77.4	13.5	2.8	5.0	7.8	-
<i>H. annuus</i> ^e	41.1	-	64.1	64.1	27.4	2.5	5.2	7.7	-

^a LNA = linolenic acid , LA = linoleic acid, STE = stearic acid, OLE = oleic acid, PAL = palmitic acid.

^b Flax council of Canada (2017)

^c University of Manitoba

^d Seiler and Brothers (1999)

^e Seiler (1986)

Table 5. Forage quality (on a dry matter basis) on December 15, 2016 of renovated (clipped and fertilized) versus straight combined intermediate wheatgrass.

	Crude Protein	%NDF ^a	%ADF	%TDN	ME Mcal kg ⁻¹	%nitrates	RFV
Renovated	11.66	51.26	26.64	70.18	2.57	0.21	124
Straight combined stubble	11.00	63.59	40.78	55.07	2.02	0.29	84

^a NDF = neutral detergent fibre, ADF = acid detergent fibre, TDN = total digestible nutrients, ME = metabolizable energy, RFV = relative feed value

For Review Only

Figure 1.

Figure 2.

Figure 3.