Crested Wheatgrass Seed Production:
A Literature Review

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I. Introduction

Crested wheatgrass ranks second only to smooth bromegrass in acreage among cultivated grasses in Western Canada. The grass was introduced to North America from Eastern Europe at the beginning of this century, but was not widely cultivated until its use in revegetation programs associated with the drought of the 1930's. Two genera of crested wheatgrass have been identified: Agropyron cristatum (L.) Gaertn. known as the Fairway type and Agropyron desertorum (Fisch.) Schult. called the standard type. The Fairway type is diploid with 14 chromosomes in the cell nuclei and physically is shorter and more leafy than the standard type. It is distinguished by its short, wide seed head, its wide angle of attachment of the seed to the central rachis of the seed head and its pubescence on the upper side of the leaf. The Fairway type also has tip awns on a slightly smaller seed. The two most common varieties of this type are Fairway released in 1932 and Parkway released in 1979.

The standard type is tetraploid with 28 chromosomes in the cell nucleus. This type grows slightly taller than the Fairway type, and has a long, narrow seed head. The seeds are attached to the central rachis at a narrower angle and are slightly larger due to the larger number of chromosomes in the cell nucleus. The leaves of the standard type are not pubescent and the seeds do not usually have tip awns. The seed set of the florets of tetraploid varieties is seldom better than 50% compared to about 70% for the diploid varieties. The common registered varieties of the standard type include Summit, Nordan and Kirk which were released in 1953, 1958, and 1987, respectively.

Pedigreed seed production of crested wheatgrass must follow the guidelines for isolation distances and cropping history. The production field must be inspected prior to harvest and the seed must be inspected in storage after harvest. The seed must meet standards for germination, genetic purity, freedom from disease, and absence of seed of weeds and of other crops. The production of the seed must be pedigreed to be sold as a named variety. The pedigree guarantees to the purchaser the characteristics of the named variety (Bolton, 1985).

There are three classes of pedigreed forage seed production in Canada: Breeder, Foundation, and Certified. Foundation seed is grown from Breeder seed and Certified seed is grown from Foundation seed. The identification tags from the seed bags must be retained for the life of the stand for presentation to the crop inspector.

II. Varieties

Crested wheatgrass seed production has the highest acreage of all grasses grown for seed in Saskatchewan. In 1994, over 1350 hectares of pedigreed crested wheatgrass were grown for seed. The production was split between four varieties, only three of which are registered in Canada. Kirk, Fairway, and Parkway, were grown for seed production in Saskatchewan in 1994 representing 51%, 32%, and 2%, respectively, of the pedigreed crested wheatgrass seed production area. An unregistered variety, Hycrest, was grown on the remaining 15% of the area as contracted production destined for export.

III. Field Selection

A. Adaptation

Crested wheatgrass is a deep-rooted bunch grass which is tolerant of the moisture stress and the low winter temperatures common in the Brown and Dark Brown soil zone (Knowles and Kilcher, 1983). When grown for forage, the standard type is more tolerant of drought, but the Fairway type is better adapted to moist conditions. Crested wheatgrass is not well adapted to saline soils. McKenzie and Najda (1994) found that the diploid variety, Fairway, was more saline tolerant than the tetraploid variety, Kirk. Fairway crested wheatgrass will tolerate spring flooding for only 1-2 weeks as a mature plant (Bolton and McKenzie, 1946) and for 3-5 weeks as a seedling (McKenzie, 1951). Nordan is recommended for the Brown and Dark Brown soil zones only, while Fairway and Parkway are suited to the Dark Brown and Black soil zones and irrigated soils. Kirk is recommended for all dryland soils in Saskatchewan (Tremblay, 1994).

B. Cleanliness

Because the presence of noxious weed seeds will disqualify a seed lot for market as pedigreed seed, the field selected for grass seed production must be free of noxious perennial grassy and broadleaf weeds. A clean weed-free field may be left unattended for several weeks with only minimal weed growth. Special weed concerns for pedigreed crested wheatgrass seed production include wild oats, quackgrass, and other grasses. Because these seeds cannot be separated from the seed of crested wheatgrass, it is imperative to sow this crop for seed production on land which is free of these weeds or to remove these noxious plants from the field by application of appropriate herbicides or roguing. The presence of other weeds is also detrimental to the yield potential of the stand. Heavy weed pressure will weaken and may eliminate the new seedling from the stand (Dodds et. al., 1987).

Prior to seeding the grass, weed control is easily achieved with broad spectrum herbicides and cultivation. Weed control options become severely limited once the crested wheatgrass is sown. The only remaining option for many weeds may be roguing by hand or with a backpack sprayer within the stand which is very time consuming and costly. Achieving this degree of sanitation may require one to two years of planning. Eradication of quack grass is essential prior to seeding any grass. Glyphosate application at 1-2 liters per acre in the fall prior to sowing the grass will control perennial weeds such as quackgrass, Canada thistle, and sow thistle. A fallow or partially fallow field provides opportunity to control several flushes of annual broadleaf and grassy weeds prior to seeding.

C. Pedigree Requirements

The selected field must have an adequate cropping interval between the seeded crop and a previous crop of the same kind. Crested wheatgrass planted with Breeder seed for Foundation status must be grown on land which did not grow a non-pedigreed crop of crested wheatgrass or a crop of a different variety of crested wheatgrass for any of the preceding five crop seasons. Crested wheatgrass planted with Breeder seed for Foundation status must be grown on land which did not grow the same variety of crested wheatgrass for the previous three crop years. Crested wheatgrass planted with Breeder or Foundation seed for Registered status must be grown on land which did not grow crested wheatgrass during any of the previous three years. Crested wheatgrass planted with Breeder or Foundation seed for Certified status must be grown on land which did not grow crested wheatgrass for the previous two years. Manure or other contaminating material should not be applied to the field prior to seeding or during the productive life of the stand (Canadian Seed Grower's Association, 1994).

` The grower must notify the CSGA in the year of seeding of the pedigree of the seed planted on the production field and the area and previous cropping history of the production field. A field inspection is required each year that a pedigreed seed crop is to be harvested. The inspection should be completed after the crop has headed, but prior to swathing or harvesting. A field sown with Breeder crested wheatgrass seed is eligible for four years of Foundation and four years of Certified seed production. A field sown with Foundation crested wheatgrass seed is eligible for eight years of Certified seed production (Canadian Seed Grower's Association, 1994).

Crested wheatgrass is a cross-pollinated species. To maintain genetic purity and insure that no contaminating pollen has pollinated the seed crop, adequate isolation from other sources of pollen must be observed. For fields larger than 5 acres in size, Foundation, Registered and Certified seed crops must be separated from other bromegrass by at least 300 m, 100 m, and 50 m respectively. Longer isolation distances are required when the field size is less than 5 acres. The requirement for these smaller fields increases to 400 m, 300 m, and 150 m for Foundation, Registered and Certified status, respectively (Canadian Seed Grower's Association, 1994).

Knowles (1974) found that contamination from other sources of pollen was too high with only 46 m isolation in some years. Discarding borders was less effective for reducing contamination in crested wheatgrass than for other grasses. Knowles suggested that the 50 m distance may not be adequate isolation for crested wheatgrass under some conditions.

D. Soil fertility

The soil fertility of the grass seed field should also be evaluated when selecting the field. The easiest time to address phosphorus and potassium fertility problems is prior to sowing the crested wheatgrass. Responses of crested wheatgrass seed yields to applications of phosphorus and potassium are seldom economical once the stand is established. Correction of phosphorus and potassium deficiencies prior to seeding, however, will enhance the growth rate of the seedlings and improve the vigour of the young plants. The rate of fertilizer which may be placed safely in the seed row of forage grasses is minimal. Fields which are deficient in phosphorus and potassium should be fertilized at relatively high rates such as 50 kg P205/ha and 50 kg K20/ha prior to sowing the grass. Nitrogen at a rate of 20-40 kg/ha should also be applied to stubble fields prior to sowing if the field will be sown before June 1. This is required when the field is managed under zero tillage. When sowing crested wheatgrass on fallow or partial fallow, soil reserves of nitrogen will most likely be adequate to carry the grass for the first seed crop. Sulphur levels will be adequate if the field has been adequately fertilized with sulphur for optimum canola production within the last two years. Response of crested wheatgrass to application of micronutrients is uncertain (Stoner and Horton, 1992) . The level of available nutrients, however, is easily checked by submitting a soil sample for analysis.

E. Moisture requirements

Seed yields of grasses vary with moisture conditions; therefore, irrigation or relatively dependable rainfall to supply 35-50 cm of moisture is essential for consistent grass seed yields. Without adequate moisture, seed head formation may be inadequate to justify the harvest of the seed crop. Under dryland conditions, harvest of the grass as forage or pasture may be necessary in drier years to obtain revenue from a grass seed field when it has not set sufficient seed (Atkins and Smith, 1967).

IV. Crop establishment

Crested wheatgrass may be sown with any conventional planting equipment if shallow seeding and adequate packing are achieved. Although air seeder cultivators and hoe drills have successfully established crested wheatgrass, disk drills are the most common seeding implement. Some modifications to conventional equipment will simplify the seeding operation and reduce the risk of poor establishment. The addition of depth control bands to disks and agitators in the seed box relieve many of the difficulties associated with seeding crested wheatgrass. Zero tillage implements have also successfully established crested wheatgrass. A good grass seed drill has the following features:

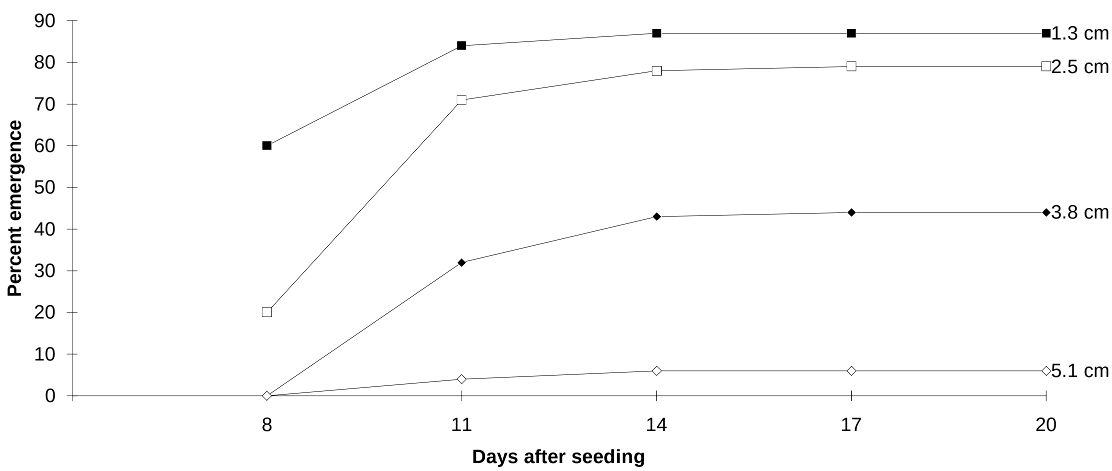
1) a packing wheel ahead of the disk opener to level and firm the soil, (for tilled soil)
2) depth control bands on the disk opener to maintain shallow penetration
3) a trailing packer wheel to ensure good seed to soil contact
4) agitation in the seed box to prevent bridging of seed.

A firm seedbed is essential for shallow placement of the seed. Packing following the last tillage operation will help to firm the soil. Some grass seed producers roll their fields before seeding to improve control of seeding depth. A rainfall following the final tillage operation will also prepare a firm and moist seedbed for placement of the grass seed.

Crested wheatgrass has a light chaffy seed which will readily bridge in the metering cups of the drill. This bridging causes inconsistent plant stands and missing seed rows. Agitators in the seed tank to disturb the grass seed will prevent bridging of the seed. Filling the seedbox only half full and getting extra help to mix the seed in the seedbox while planting will overcome this difficulty if agitators have not been installed in the seedbox. Using seed coated with a polymer film will improve the flow of the seed in the drill and will protect the user from any seed treatments which may be added to control disease organisms. Another helpful approach is to mix an equal volume of low nitrogen fertilizer (12-51-0), cracked wheat, or cereal grain with the seed. Unused seed should be separated from the fertilizer as soon as possible after seeding is completed. Fertilizer will absorb hygroscopic moisture from the air over time and increase the moisture content of the seed. The increase in moisture content of the seed will decrease its viability. Senter et al. (1975) found that the germination of three grass species was reduced if the seed was in contact with a 20-20-0 blended fertilizer for more than nine days under humid conditions. When the fertilizer was stored with the seeds under dry conditions, no decline in germination of any species was observed after 24 days of storage. The blend contained 57% ammonium nitrate (33.5-0-0), 38% super phosphate (0-46-0), and 5% ammonium phosphate (18-46-0).

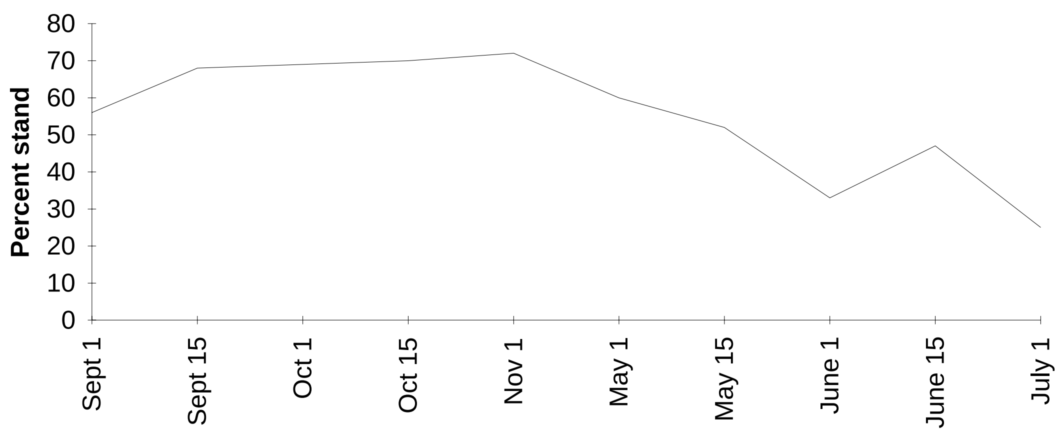
Shallow placement and excellent packing of seed are important to achieve a high percentage of germination and emergence of seedlings. Control of the seeding depth is critical to successful establishment of the crested wheatgrass stand. As the seeding depth increases, the time required for the seedling to emerge from the ground increases and the percentage that emerge decreases (Figure 1).

Figure 1: Effect of seeding depth on rate of emergence of crested wheatgrass seedlings (McKenzie et al., 1946)



The main objective for the establishment year is to produce a vigorous stand of healthy seedlings which have profusely tillered. For sowing on well-prepared fallow or for zero tillage establishment, the best seed yields are often obtained with early spring seedings. McElgunn (1974) showed that Fairway crested wheatgrass is sensitive, however, to planting in cold soils. For a temperature regime which alternates between 2oC and 13oC, the germination rate was only three-quarters as high as for other warmer regimes. Delaying seeding until the minimum temperature has risen above 4oC will improve the germination of crested wheatgrass. The crested wheatgrass seed crop may be sown anytime between early May and mid June, however, without suffering much loss in seed yield when totalled over three seed crops. Although the first seed crop may be reduced slightly with a later seeding date, subsequent crops often yield more seed which compensates for the smaller initial seed crop. Research at Beaverlodge indicates that crested wheatgrass should be sown prior to June 13 for a satisfactory seed yield in the first crop harvest (Elliott, 1972). Based on percent seedling stand of seedings done throughout the year, Kilcher (1961) at Swift Current concluded that crested wheatgrass should be sown anytime from September 1 until freeze-up or from first thaw until May 15 (Figure 2). Late spring seedings produced stands with unacceptable seedling establishment.

Figure 2: Effect of seeding date on stand establishment of crested wheatgrass (Kilcher, 1961)



Delayed seeding increases the risk of poor emergence if weather conditions are unfavourable. Soil crusting may impede seedling emergence if a heavy rain shower is followed by intense sunshine. Desiccation of emerging seedlings readily occurs if the weather is hot and dry.

Seed production of grasses is higher when no companion crop is sown with the grass seed. The seedlings grow more vigorously during the establishment year and are not stunted by the companion crop. Although the companion crop provides some revenue during the establishment year, the first seed crop of grass is sufficiently reduced to offset the benefit of the companion crop. Buglass (1964) observed that the first seed crop yield of Summit crested wheatgrass increased from 55 kg/ha when wheat was grown as a cover crop to 215 kg/ha without a companion crop. Elliott (1973) found that seed yields of Fairway crested wheatgrass averaged over six harvest years ranged between 85 and 210 kg/ha/year higher when no companion crop was sown (Figure 3). Lawrence (1970) compared seven seed row spacings for wheat undersown with crested wheatgrass. The number of established seedlings per meter of row was not significantly different among the treatments. Although the cover crop decreased the vigour of Summit crested wheatgrass seedlings (Figure 4), seed yields were not adversely affected (Figure 5).

The spacings and placement of the rows relative to the crested wheatgrass also had no significant effect on the grain yield of the cover crop, spring wheat (Figure 6). To minimize the effect of the cover crop on crested wheatgrass, Lawrence (1970) recommended sowing the wheat in rows 60 cm apart at right angles to the crested

Figure 3: Seed yield of Fairway crested wheatgrass seeded with different companion crops (Elliott, 1973)

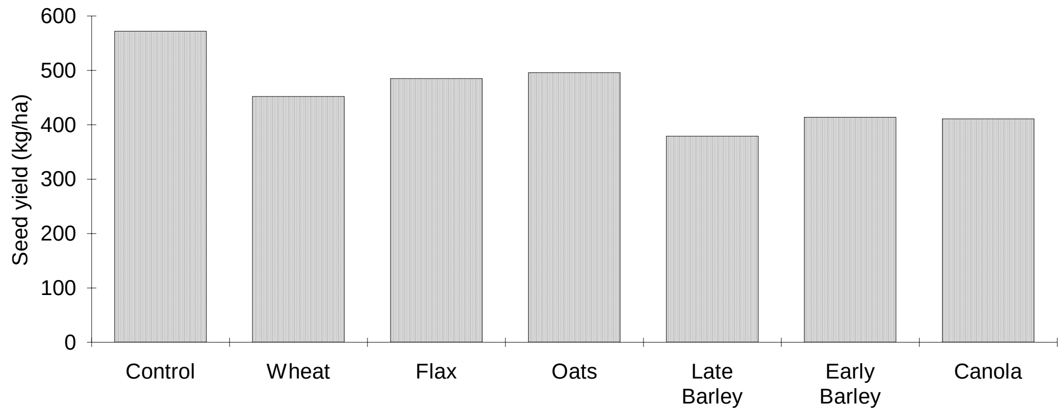
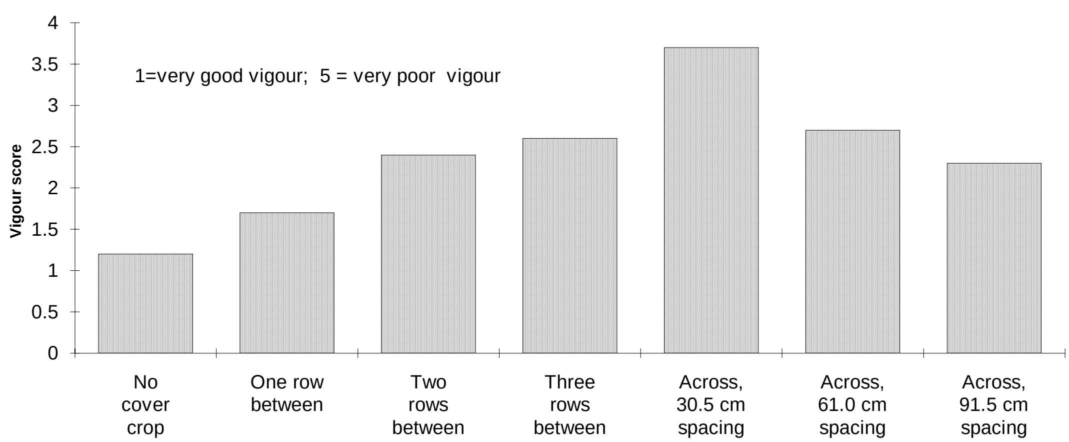


Figure 4: Spring vigour score of Summit crested wheatgrass seedlings sown with spring wheat as a cover crop (Lawrence, 1970)



wheatgrass. The highest wheat cover crop yield corresponded with the lowest spring vigour rating of the crested wheatgrass, but the crested wheatgrass was able to recover from this stress with no significant reduction of seed production.

Row planting of grass seed fields provides a number of benefits. Planting in wider-spaced rows reduces the seed requirements which reduces input costs. The stands can be tilled with a row crop cultivator or gang rototiller to control weeds. Seed yields will be higher, especially as the stand ages. Roguing of the field is more thorough and easier (Patterson et al., 1956). Row production of grass seed under dryland conditions reduces the risk of lower seed yields due to drought (Knowles et al., 1969).

Swaths are often difficult to pick up from between widely spaced seed rows. Cutting the crop at an angle across the seed rows may alleviate this difficulty. If inter-

Figure 5: Effect of wheat as a cover crop on seed yield of Summit crested wheatgrass (Lawrence, 1970)

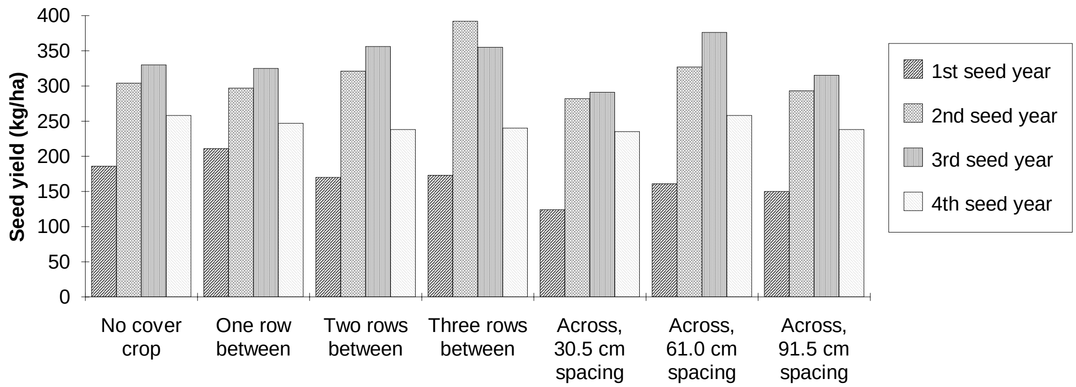
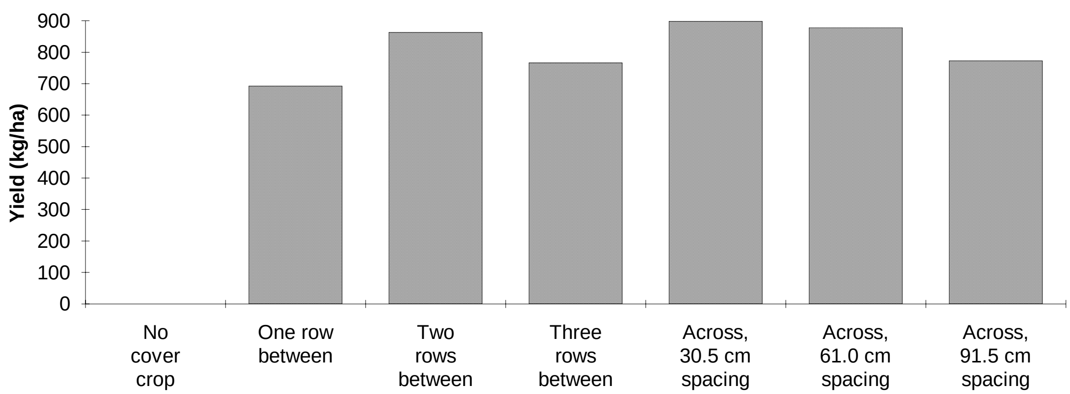


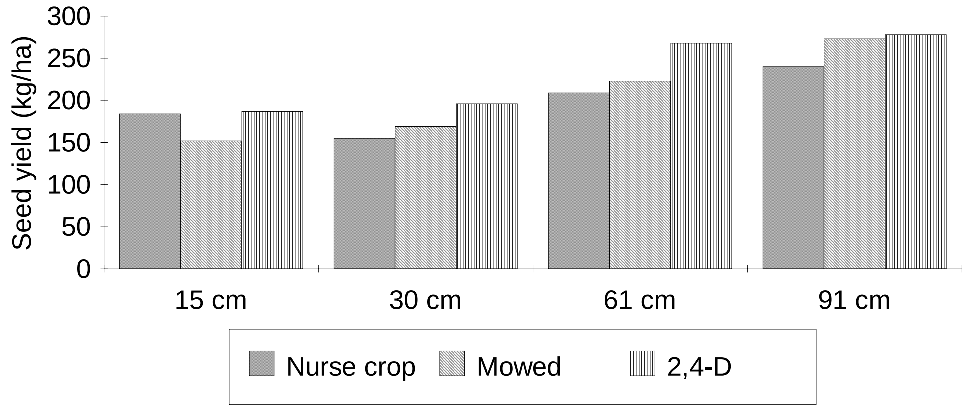
Figure 6: Grain yield of spring wheat when undersown with crested wheatgrass (Lawrence, 1970)



row cultivation is practiced, however, the field becomes too rough to swath the field across the seed rows. Ridges of soil build up adjacent to the row. Picking up a swath from between the soil ridges is difficult and contributes to the deterioration of the combine. One alternative is to straight combine the crop. Another approach is to sow the field with a combination of three or four 30 cm row spacings adjacent to 90 cm row spacing. The narrow-spaced rows provide a level area for placing the windrow and inter-row cultivation is still possible in the wide spacing.

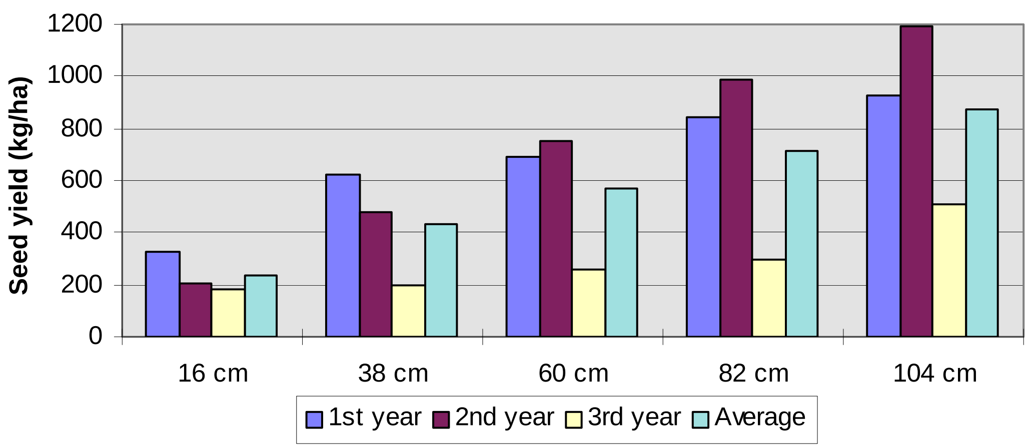
The seed yields of crested wheatgrass sown at four row spacings were determined at Saskatoon for four years (Figure 7). Seed yields were higher with 61 or 91 cm rows

Figure 7: Effect of row spacing and method of establishment on seed yields of Fairway crested wheatgrass (Knowles, 1961)



than for narrower row spacings. Canode (1968) at Pullman, Washington found that the seed yield of the variety Nordan was about 75 kg/ha higher when grown at a row spacing of 60 cm as compared to 30 or 90 cm. McGinnies (1971) found that seed yields of Nordan crested wheatgrass averaged over five seed production years were higher when the crop was sown at a row spacing of 61 cm than at 15, 30, or 46 cm. Fairway and Summit crested wheatgrass were sown at Scott, Saskatchewan with row spacings of 30 and 91 cm (Crowle, 1966). Based on the five-year average seed yields, the wider row spacing yielded 160-220 kg more seed/ha on both dryland and irrigated trials. Darwent et al.(1987) found that the seed yield increased as the the row spacing widened from 16 cm up to 104 cm (Table 1). Under dryland conditions, widening the row spacing was as effective as

Figure 8: Effect of row spacing on seed yield of Fairway crested wheatgrass (Darwent et al., 1987)



increasing the nitrogen fertility. When the field is irrigated, however, nitrogen is more efficient at increasing seed yield than widening the row spacing. The higher yield potential requires more nitrogen than is readily supplied by the soil.

The sowing rate for grasses is somewhat arbitrary depending on the suitability of the soil for seed germination. Because weather is an important factor in the success of a seeding, the safe approach is to seed at a higher rate than is suitable for ideal conditions. It is wise to plan for loss of up to 80% of the seedlings. The goal is to sow enough seed to achieve a satisfactory stand without too much inter-plant competition. Seedlings which are vigourously tillering, however, will produce a higher seed yield. Sowing at a higher seeding rate increases the inter-plant competition and reduces the vigour of the seedlings. Button et al. (1993) recommend a seeding rate of 3.3 kg/ha with a 60 cm row spacing or 4.4 kg/ha with a 30 cm row spacing. Knowles et al. (1969) suggest sowing 40-65 seeds per meter of seed row when sowing bromegrass. This principle also applies to other grasses. When another material is mixed with the seed to eliminate bridging of the seed, this method eliminates much of the uncertainty in determining the drill setting. With a 60 cm row spacing, one hectare (10,000 m2) would contain 16,667 meters of seed row. Since one kilogram of the Fairway type of crested wheatgrass contains 480,000 seeds (1 lb = 218,000 seeds), the rate ranges between 1.4 - 2.3 kg/ha (1.2 - 2.0 lb/ac). With a 30 cm row spacing, the recommended seeding rate ranges from 2.8 - 4.6 kg/ha (2.4 - 4.0 lb/ac). Using this approach, it is easy to calibrate the drill by seeding over a sheet of plywood or a pad of concrete and counting the seeds sown over a measured distance.

The calculations for the standard type of crested wheatgrass follow the same pattern. Recommended seeding rates for the different types of crested wheatgrass are summarized in the following table:

Table 1: Recommended seeding rates for crested wheatgrass seed production

Crested Wheatgrass	Fairway type		Standard type	
Seeds / lb	218,000	163,000		
Seeds / kg	480,000	360,000		
	lb/ac	kg/ha	lb/ac	kg/ha
30 cm row spacing	2.4 - 4.0	2.8 - 4.5	3.2 - 5.3	3.7 - 6.0
60 cm row spacing	1.2 - 2.0	1.4 - 2.3	1.6 - 2.7	1.8 - 3.0
90 cm row spacing	0.8 - 1.3	0.9 - 1.5	1.1 - 1.8	1.2 - 2.0

The injury to germinating seedlings from fertilizer occurs from two sources: the dissolved salts and the ammonium content. Fertilizers which are readily soluble in water are more hazardous than less soluble forms. Nitrogen sources which liberate ammonium are more hazardous than nitrate sources. Ammonium phosphate is relatively safe because the fertilizer dissolves more slowly when it comes in contact with moisture. The ammonium content of ammonium phosphate is only 10-12% of the weight of the fertilizer.

The quantity of fertilizer which is safely placed in the seed row with the grass seed is dependent on a number of factors. The texture and organic matter content of the soil are the two most important factors which limit the risk of injury. The moisture content of the soil at seeding time, the proximity of precipitation to the seeding operation, the spacing between rows, and the width of the seed row itself are the remaining considerations. Soils with a high content of organic matter and clay have a lower risk for fertilizer injury to grass seedlings. A soil with a moisture content near field capacity is less likely to have fertilizer injury. Rainfall immediately after seeding will replenish the moisture content of the soil and remove fertilizer salts from the vicinity of the grass seeds. As the spacing between the rows widen, the amount of fertilizer next to the seeds will increase if the application rate per unit area remains the same. A narrow width of the seed row itself will place more fertilizer in close contact with the seed than a wider seed row. The general guideline for forage seeds is for no nitrogen, potassium, or sulphur fertilizers placed in the seed row. Application of phosphate fertilizer up to 10 kg P205/ha is generally safe if the preceding principles are kept in mind.

V. Crop Management

Herbicide registrations for the control of weeds during the seedling year provide a wide array of options for control of annual grassy and broadleaf weeds. The most difficult grassy weeds to control include quackgrass, downy brome, green foxtail, and Persian darnel. Control measures for annual grasses during the seed production year would reduce the requirement for roguing. The adjacent chart lists currently registered treatments (Table 2).

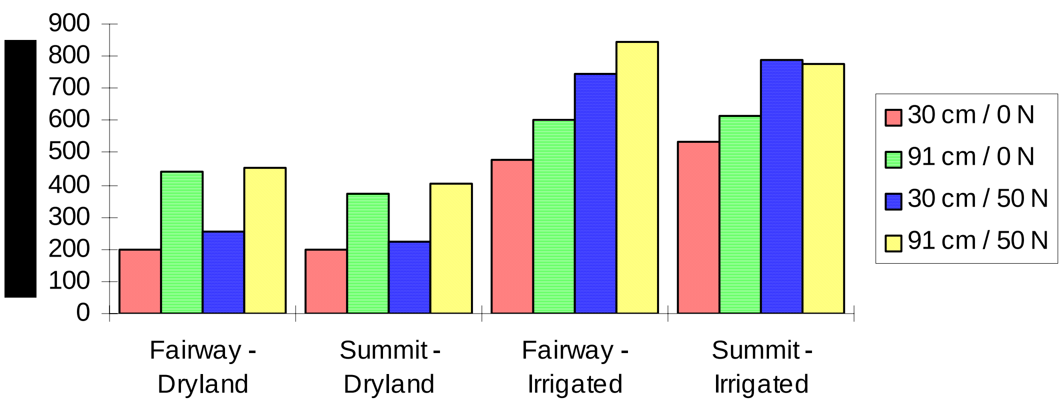
Clipping or mowing is another effective strategy for controlling annual weeds. The weeds should be mowed as required to prevent them from setting seed. When the soil is not disturbed, most weed seeds do not germinate. After the grass crop becomes established, few weeds will germinate in the seed production years.

Field roguing is a requirement for production of quality grass seed for the Canadian market. Chaffy grasses such as crested wheatgrass have no tolerance for primary noxious weeds such as quackgrass, Canada thistle, cleavers, and wild mustard. Cleavers seeds are extremely difficult to remove from the finer grasses such as Kentucky bluegrass. Unthreshed wild mustard seeds are often retained in the beak which impossible to clean out of a chaffy grass sample. Wild oats, Persian darnel, scentless chamomile, shepherd's purse, stickseed, and stinkweed are secondary noxious weeds which are limited to 1 and 2 seeds in 25 g for Canada Registered No. 1 and No. 2 grades respectively. Once the window of application for herbicides has passed, any of these weeds which appear in the stand must be eradicated before the field is inspected. Although downy brome is not listed as a noxious weed, some customers will not purchase seed containing this weed. The weedy plants may be uprooted manually by hoe or hand-pulling. Roundup is an effective herbicide for controlling perennial weeds in grass seed
Table 2: Herbicides registered for use on crested wheatgrass

stands, but it must be applied by spot treatment directly on the target weeds to prevent injury to the grass seed crop.

The seed yield of both Fairway and Summit crested wheatgrass responded strongly to irrigation (Crowle, 1966). The grasses were irrigated three to five times during the growing season to supply a total of 55-65 cm of annual precipitation. With adequate nitrogen fertility, seed yields were doubled by the application of the irrigation water (Figure 9).

Figure 9: Influence of row spacing, nitrogen fertility and irrigation on seed yield of crested wheatgrass (Crowle, 1966)



VI. Disease and Insect Problems

Ergot, the fungus Claviceps purpurea, will infect cross pollinated grasses such as crested wheatgrass. Tetraploid varieties seem more susceptible than diploid varieties (Stever, 1994). The first symptom of ergot infection is the collection of a sticky honeydew on the surface of infected florets. The deposit contains the spores of the disease. The fungus continues to grow within one or more of the infected florets to form a hard, purplish black ergot body in place of a seed. Often the ergot body or sclerotium is conspicuous because it is black and much larger than the seed it replaces. Ergot-affected heads produce few viable seeds. Ergot tends to be spread from infected grasses along field margins. The disease is most prevalent during years when the soil surface is moist during the spring and early summer and when showers prevail during the flowering period of the grass. Moisture stimulates the germination of sclerotia and the release of the infecting spores. Wet cool weather also prolongs pollination which increases the likelihood of infection of florets by spores. Fertilized ovaries are resistant to ergot infection. Muhle (1971; cited by Labruyere, 1980) considers the rejection of contaminated seed as the major economic loss from this disease in grass seed production. Seed treatments are ineffective in control of ergot (Seaman, 1980). Sanitation and use of ergot-free seed are the best control measures. Mowing the field edges just prior to heading reduces the risk of ergot infection. Deep ploughing and post-harvest burning will reduce the survival of viable sclerotia (Labruyere, 1980). If the outside edge of the field is infected, this portion should be harvested and kept separate from the remainder of the seed. Sclerotia can be separated from the other seed by flotation in a 20% salt solution. The sclerotia float on the surface and are easily skimmed off. This seed would then require a subsequent washing and drying. Storing the infected seed for three or more years will also reduce the number of viable sclerotia. The Canada Seed Act allows only 1.5% sclerotia in No. 1 seed and 3% in No. 2 seed (Seaman, 1980).

VII. Harvest

Grasses need about 30 days after flowering for the seeds to develop. Hot, dry weather shortens the ripening period while cool, moist conditions will delay seed maturity (Tober, 1988). Grasses grown under irrigation or moister conditions have a higher ash content which increases the likelihood of shattering (Najda et al., 1994). The ripening process begins at the top of the seed head and proceeds down the stem. Seeds at the top of the head may begin to shatter while those at the bottom are only starting to fill seed. Frequent inspection of the field is necessary to determine when the maximum yield of seed will be harvested. Under warm, dry weather, grasses will advance in maturity from medium dough to initial seed shatter in as few as 3-4 days.

The appropriate harvesting approach depends on the seed size, plant height, maturity, shattering traits, seed head abundance, seed fill, and moisture content. Conventional harvest equipment is suitable for most grasses. Crested wheatgrass is preferably harvested by swathing and combining after 5-7 days when the seed has dried. Because the crop is not prone to lodging, direct combining is also a common method of harvesting this crop (Tober, 1988). Tetraploid varieties are more suited to direct combining than diploid varieties because the tetraploid varieties are less prone to shattering. Crested wheatgrass is ready to swath in late July or early August. The crop should be swathed when the moisture content of the head is between 35-40% (Elliott, 1972). This corresponds to the medium to hard dough stage. This stage occurs when firm thumb nail pressure is needed to imprint the seed. The seed heads will be brown, but the stems will still be green. If the seed shatters when striking the seed head firmly against the palm of the hand, the crop is ready to swath. Swathing early in the morning or in the evening when the air humidity is higher will reduce shattering losses. If the heads are laid in the center of the swath instead of to the side, some of the shattered seeds will be retained on the top of the swath.

Under good drying conditions, the crop will be ready to combine in 5-7 days after swathing. Initial combine settings recommended for crested wheatgrass are a cylinder speed of 850 rpm and a concave clearance of 1/16". The fan speed is generally set between 400-500 rpm with the sliding covers over the exterior fan housing fully open. Because of the potential for contamination and the value of grass seed, thoroughly clean the combine before harvesting grass seed. Maintain an even flow of material into the combine. Grass seed crops often require a slower forward speed than conventional crops. Slower combining speeds improve the seed separation from the chaff and straw and greatly reduce losses over the straw walkers and sieves (Najda et al., 1994). For crested wheatgrass, the concave setting should be adjusted to minimize straw breakage so that the sieves do not become clogged. A properly adjusted concave will just break up the head into separate seeds. The spikelets must also be broken up to permit separation of the seeds.

Hermann and Hermann (1939) evaluated the effect of maturity of diploid crested wheatgrass on the germination of the seed. Seed harvested during the pre-milk stage did not germinate. For seed harvested from the soft dough to hard dough stages, germination rates increased as the storage period increased. The length of storage period required to reach maximum germination decreased as the harvested seed became more mature. Ripe seed reached the maximum germination percentage after only two weeks of storage. The early dough stage of seed development was the earliest maturity from which seed with acceptable germination percentage (> 80%) was harvested, but 5 weeks of storage were required to reach this level of germination. Seed harvested at a more mature stage germinated more quickly and emerged from a deeper seeding depth. Vigorous seedlings were obtained only from seed harvested from the hard dough to the slight shatter stage of development.

The seed can be stored safely in open storage up to one year when the moisture content is 10-12%. Mold growth and insect damage may still occur at this moisture content. The safe moisture content for open storage of grasses for longer periods is 8-10% (Harrington, 1960).

VIII. Post Harvest Management

Crowle (1966) increased the seed yield of Fairway crested wheatgrass by 250 kg/ha and the seed yield of Summit crested wheatgrass by 180 kg/ha when 56 kg N/ha was broadcast during the first two weeks of September. Buglass (1964) found that annual late fall applications of 75 kg N/ha in the form of 33.5-0-0 produced 22 more kg seed/ha when the fertilizer was drilled into the soil as compared to broadcasting the fertilizer. Seed yield increases from the application of the nitrogen were higher for narrow row spacings than for wider row spacings.

Burning of crop residues will also increase seed yields compared to removal of the straw. Canode and Law (1978) observed an increase of 80 kg seed/ha when the straw was burned compared to mechanical removal of the straw. Removal of the stubble and straw with a field chopper reduced grass seed yields relative to the mechanical removal of the straw by 75 kg/ha. Burning at temperatures greater than 500oC controlled downy brome in the seed field. Knowles (1968) conducted a test to determine if spring burning of crested wheatgrass was beneficial for a seed stand. An early spring that year allowed him to burn the seed field on April 9. The early spring burn increased the seed yield of the fourth seed crop from 205 to 280 kg/ha.

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