Effect of Time of Seeding on Emergence and Long-term Survival of Crested Wheatgrass in British Columbia

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Abstract

The study showed that fall was the best time to seed crested wheatgrass *(Agropyron desertorum)* in the dry belt of British Columbia. With fall seedings, if emergence did not take place in the fall, it did so the following spring; there was very little plant kill over winter. Among the spring seedings, germination took place if the soil moisture content was adequate, usually above 10%. Soil moisture content was the most important single factor in determining establishment of seedlings. Late May and June seedings often germinated and died before seedlings became established. Rains in June, July, and August were ineffective in promoting emergence but may have been a factor in assuring establishment of the early-spring seedlings. By 1981, fall seedings no longer retained their advantage but the poor performance of the June seedings was still evident.

The question of the best time to seed crested wheatgrass has been addressed in a number of locations with varying results. In the northern Great Plains of Saskatchewan (Kilcher 1961), crested wheatgrass established well over a wide range of seeding dates although fall seedings tended to be best. Stands seeded in late spring fared poorly. Fall and spring seedings usually established and survived equally well on the Intermountain Valley region of Montana (Gomm 1974). However, in the Intermountain region of Utah (Frischknecht 1951), early fall seedings resulted in higher emergence than those in late fall or spring but because of high mortality on the fall seeded plots, the number of surviving plants was similar for all seeding dates. Superior survival of fall seedings has been observed on big sagebrush-cheatgrass range in southern Idaho (Klomp and Hull 1972), the pinyon-juniper type in Arizona (Lavin et al. 1973), and in ponderosa pine forest in Montana (Gomm 1970).

In some cases spring seeding of crested wheatgrass may prove most reliable. At one trial in central Montana (Gomm 1974) there was no advantage to either spring or fall seedings; yet in another trial at the same location, spring seedings produced superior stands both initially and after 7 years. In the central Great Plains of Colorado, McGinnies (1960a) seeded crested wheatgrass from April to November for 5 years. There was great yearly variation and April was the only seeding month to produce satisfactory stands for each seeding year. Fall seedings were successful providing the seeds did not germinate until spring. McGinnies (1973) later examined spring seeding dates in greater detail and again found great year to year variation. Mid-April seedings proved most reliable for establishment but May seedings also usually performed well.

Success in establishing stands on grassland range seedings in southern British Columbia has been very erratic. The climate of the grasslands is dry and precipitation patterns are irregular. Timing of range seeding, therefore, is crucial to success. It is important to determine the limiting climatic factor in seedling establishment and the conditions under which successful stands can be obtained. The study reported here discusses the success of seed germination and establishment of seedlings of crested wheatgrass relative to weather factors operating in southern British Columbia.

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Methods

Trials to determine the best date to seed crested wheatgrass in grassland ranges in British Columbia were conducted at 4 locations in the Kamloops area. The sites were located in the 3 major grassland zones (van Ryswyk et al. 1966) and one in the ponderosa *(Pinus ponderosa)* savannah. The Tranquille site (395m) was in the big sagebrush *(Artemisia tridentata)* - bluebunch wheatgrass *(Agropyron spicatum)* habitat type (h.t.). The soil, an Orthic Brown Chernozem in the Canadian system of soil classification (Aridic Boroll, U.S. Classification) (Canadian Survey Committee 1978), had a 15-cm layer of fine sandy loam overlaying loam to gravelly sandy loam till with sand lenses. This was the hottest and driest site. West Mara site (640m) was in the ponderosa pine-bluebunch wheatgrass h.t. on an Orthic Brown Chernozem that intergraded to a Dark Brown Chernozem (Typic Boroll) with 30 cm of fine sandy loam to loam lacustrine deposit. Pruden site (700 m) was in the bluebunch wheatgrass - Sandberg bluegrass *(Poa* *sandbergii)* h.t. on a moderately stony Orthic Dark Brown Chernozem with 15 cm of fine sandy loam loess over gravelly sandy loam to loam till. West Mara and Pruden sites had similar climates which were intermediate between the others. East Mara site (853 m) was in the rough fescue *(Festuca scabrella)* - bluebunch wheatgrass h.t. on an Orthic Black Chernozem (Udic Boroll) with 20 cm of fine sandy loam loess over sandy clay loam to loam till. East Mara was the coolest of the sites and had the most favorable moisture regime. The 3-year average April-to-October precipitation for the 4 sites was 104, 117, 130, and 140 mm respectively.

The existing vegetation was lightly rototilled during the fall, prior to seeding. Immediately before each sowing the plots were hand cultivated to remove any remaining plants. The plots were seeded to crested wheatgrass, variety Summit, at a rate of 20 kg/ha, which was equivalent to approximately 720 viable seeds per m^2. The seed was covered to a depth of 1.5 to 2 cm, and the plots rolled lightly with a weighted lawn roller. Seeding was done at 2-week intervals starting April 1 to mid June, and again in September and October for a total of 12 treatments. Exclosures were erected at all sites. The trial was repeated for 3 consecutive years. Tranquille and Pruden were started in 1970, and the East and West Mara sites in 1971. At the East Mara site snow cover prevented seeding on the first two dates in 1971 and the first date in 1972. At all sites a randomized block design was used, replicated 4 times, with a plot size of 1.2 × 3.0 m.

Daily air temperatures (Stevenson screen at 1.22 m), soil temperatures (3 cm depth) and weekly precipitation were recorded at all sites. Weekly soil moisture determinations were made on samples from the 2-, 5-, 10-, and 15-cm depth by the gravimetric method. The 2-cm sample was not collected if the surface soil was at air-dry conditions. A composite sample of soil, taken from the 2 cm depth, was collected at each seeding site. Soil water retention curves were developed for each composite to calculate soil water storage capacity of the sites.

Seedlings were counted at 2-week intervals following seeding for the first season and once a year, in late May, until 1975. Also, counts and yields were taken on all plots in 1981. Crested wheatgrass density was determined by counting plants on 4 permanent 0.1-m^2 sub-plots within each plot. The sub-plot counts were totalled and converted to number of plants per square meter. Forage yields were taken on 2 0.5-m samples from each plot. Crested wheatgrass was separated from the remaining vegetation (weeds) and oven-dry weights recorded from each component. Yields from the 2 plots were summed to give yield per square meter. Seedling emergence was used as a measure of germination.

Results and Discussions

Seedling establishment the year after seeding varied greatly among seeding years and sites. Fall seedings, however, produced significantly ($P<.05$) better stands the following spring than did spring seedings when the results from the 4 sites and 3 years were pooled in a Duncan's multiple range test (Table 1). Among the spring seedings, those of mid and late April resulted in the best establishment; earlier or later spring seedings were less successful, particularly those in June. With all fall seedings, if germination and establishment did not take place in the fall, it did so the following spring. In contrast to stands from fall seedings, those from spring seedings did not improve the following spring.

Moisture Effects

Examination of the data indicated that the 2-cm soil moisture measurement was most closely correlated with germination and therefore is the only value reported. Soil moisture is expressed as percent of available water storage capacity (by volume) in addition to percent by weight (Table 2) to allow for direct comparison of the 4 sites.

Soil moisture content was the most important factor affecting germination in the present study. Soil moisture (Table 2) and precipitation (Table 3) patterns varied widely between years and sites. Spring germination took place following snow melt if winter moisture reserves remained until the soil temperature increased sufficiently to permit germination. In some years germination followed rains in May. Spring seedings done after late May could not be depended upon to germinate even at East Mara, where soil moisture was adequate and soil temperatures remained in the 15 to 20° C range until mid-July.

Late June seedings were particularly unsuccessful. An average of 80% of the seedlings which emerged from these seedings during the summer died before fall. In addition to this loss, many seeds never emerged. Hassanyar and Wilson (1979) reported greater susceptibility of seeds to injury at late stages of germination than at the beginning. Presumably in the present study, the moisture supply was sufficient to initiate germination but did not persist long enough for seedling emergence and thus seed mortality resulted.

In our study, precipitation values did not relate as well to germination and establishment as did soil moisture values. Because of weekly sampling, soil moisture values did not always correspond to precipitation which may have fallen anytime during the week. The length of time that precipitation remained effective was dependent upon the precipitation pattern and prevailing temperatures. For example, at Tranquille in 1972, 1.9 cm of rain raised the soil moisture content at 2 cm to 22% in the week of June 12, whereas 2.3 cm in the week of August 21 raised the level to only 12%. Previous week soil moisture contents at the above sites were 4 and 5% respectively. However, the limitations placed on the interpretation of both precipitation and soil moisture data when only weekly values are obtained are recognized.

No seedlings emerged when soil moisture content (by weight) was less than 6% and emergence occurred on at least some of the replications when soil moisture exceeded 21%. However emergence was unpredictable when soil moisture content fell in the range of intermediate values between 6 and 21%. For example, at one counting date on the Pruden site when soil moisture was 9.7%, emerged seedlings were present on all replications of one treatment (seeding date) but were absent on all replications of another. Apparently factors other than soil moisture (as measured in this study) were affecting emergence.

Moisture stress frequently has been cited as a major factor impairing crested wheatgrass germination. McGinnies (1960b) found that as moisture stress increased, germination was delayed and the rate was reduced. Nelson et al. (1970) considered moisture the primary cause of differences in seed germination and metabolism since soil moisture fluctuated greatly while soil temperatures remained fairly constant. Drilled seeds experienced delayed ger-

Table 1a. Effect of date of seeding on seeding establishment in the fall of seeding, the spring following seeding, and in 1981; average of 4 sites and 3 years. Values are expressed as the average number of plants per square meter.

	Average of all sites and all years		
Date seeded	Fall	Spring	1981
Apr 1	96*ab*[1,2]	61*ef*[2]	28*abc*[2]
15	136*ab*[2]	97*cde*[2]	33*ab*[2]
29	137*a*	107*cd*	33*ab*
May 13	111*ab*	68*def*	27*abc*
27	115*ab*	70*cdef*	26*abc*
Jun 10	62*bcd*	41*ef*	23*bc*
24	19*cd*	33*f*	17*e*
Sep 1	109*ab*	171*ab*	35*a*
15	70*bc*	171*ab*	33*ab*
29	25*cd*	188*a*	35*a*
Oct 13	0*d*	175*ab*	34*ab*
29	0*d*	127*bc*	29*ab*
Avg	73	109	29

[1]*a-f*Means within columns followed by the same letter are not significantly different by Duncan's multiple range test at $P<0.05$. Absence of a letter indicates lack of significance at $P<0.05$ in the *F* test of the analysis of variance.
[2]Means adjusted for missing seeding dates.

Table 1b. Effect of date of seeding on seeding establishment in the fall of seeding, the spring following seeding and in 1981; on two Orthic Brown Chernozems over 3 years. Values are expressed as the average number of plants per square meter.

	Tranquille								
	Year seeded								
	1970			1971			1972		
	Year counted								
Date seeded	Fall 1970	Spring 1971	Summer 1981	Fall 1971	Spring 1972	Summer 1981	Fall 1972	Spring 1973	Summer 1981
Apr 1	4b[1]	12c	28	83ab	66cd	27	77b	90abc	21
15	4b	11c	26	139a	84c	23	92b	70bcd	21
29	4b	20c	18	126a	83c	18	101ab	64bcd	12
May 13	6b	17c	30	96ab	73c	22	100ab	66bcd	14
27	4b	25c	19	121a	86c	21	129a	71cd	23
Jun 10	4b	21c	28	47bc	27cd	19	107ab	37cd	18
24	11b	40c	28	3c	8d	19	0c	4d	16
Sep 1	151a	234b	34	0c	171b	9	0c	89abc	31
15	8b	240b	26	0c	240a	11	0c	136a	29
29	3b	333a	30	0c	274a	26	0c	143a	18
Oct 13	0b	184b	26	0c	270a	20	0c	124ab	20
29	0b	206b	25	0c	272a	18	0c	61bcd	18
Avg	17	112	27	51	138	19	50	80	20

	West Mara								
	Year seeded								
	1971			1972			1973		
	Year counted								
Date Seeded	Fall 1971	Spring 1972	Summer 1981	Fall 1972	Spring 1973	Summer 1981	Fall 1973	Spring 1974	Summer 1981
Apr 1	159b	70d	29b	148b	113abc	34a	8f	24e	24c
15	155b	70d	32b	189a	56cd	31a	241c	263c	53a
29	189b	75cd	33b	137b	83bc	32a	286b	271c	62a
May 13	266a	103bcd	50a	160ab	86bc	33a	36f	52e	23c
27	271a	137b	50a	142b	84bc	27ab	47f	72e	28bc
Jun 10	154b	73d	38ab	19d	9d	9c	107e	141d	43abc
24	0c	3e	9c	0d	3d	14bc	161d	171d	49a
Sep 1	41c	89bcd	29b	73c	161a	28ab	379a	344ab	63a
15	7c	131b	43ab	6d	133ab	26ab	357a	308bc	53a
29	0c	122bc	41ab	0d	126abc	25ab	226c	371a	58a
Oct 13	0c	208a	35ab	0d	126abc	24ab	0	309bc	50a
29	0c	109bcd	36ab	0d	59cd	16bc	0	173d	47ab
Avg	104	99	35	73	87	25	185	208	46

[1]a-f Means within columns followed by the same letter are not significantly different by Duncan's multiple range test at $P<0.05$. Absence of a letter indicates lack of significance at $P<0.05$ in the F test of the analysis of variance.

mination from low soil temperatures when moisture was favourable, but broadcast seeds were probably most influenced by generally unfavourable and rapidly fluctuating soil moisture content (Wilson et al. 1970).

Soil water retention curves in our study revealed widely differing volumes of soil occupied by water at field capacity (1/3 bar) and permanent wilting point (15 bars) at the 4 seeding sites (Table 4). However the available water storage capacity of the sites were remarkably similar.

Temperature Effects

Values and trends of soil and air temperatures followed similar patterns from year to year in contrast to precipitation patterns. In general, temperature did not appear to be limiting except at times when soil moisture was favourable such as late fall and in some cases early spring. High summer temperatures which coincided with low soil moisture contents probably contributed to the lack of germination.

Other studies have demonstrated that crested wheatgrass and other grasses can germinate at low temperatures following prolonged cold treatment (Wilson et al. 1970, Frischknecht 1951). Bleak (1959) noted germination of smooth brome and tall oatgrass in thawed soil and soil under heavy snow cover. It is probable in the present study that seed planted in the fall germinated very early in the spring and became established before the winter moisture reserves were exhausted. In laboratory trials, McGinnies (1960b) obtained slower germination of crested wheatgrass at 10°C than at 20 or 30°C. Ellern and Tadmor (1966), who similarly reported retardation of onset and completion of germination at low temperatures, remarked on the importance of rapid germination and establishment in a drying seedbed. They suggested that low temperatures may delay germination so that seedlings are unable to establish prior to soil moisture depletion. However, Wilson (1973) found that germination was hastened in field trials when seeds experienced periods of low temperatures with adequate moisture. He remarked that seeds planted in fall and early spring make significant gains in germination hastening after the soil thaws while those seeds planted in late spring when soil temperatures are warmer may have inadequate time for seedling growth. Stratification (exposure to cold and moist conditions for a period of time) may have improved germination in the present and other field studies (Frischknecht 1951, Kilcher 1961) where fall seedings of crested wheatgrass (which germinated under cool conditions) proved most successful. Neither of the laboratory studies (McGinnies 1960b; Ellern and Tadmor 1966) indicated seed stratification prior to planting.

Table 1c. Effect of date of seeding on seeding establishment in the fall of seeding, the spring following seeding and in 1981; on a Orthic Dark Brown (Pruden) and Orthic Black (East Mara) Chernozem over 3 years. Values are expressed as the average number of plants per square meter.

	Pruden								
	Year seeded								
	1970			1971			1972		
	Year counted								
Date seeded	Fall 1970	Spring 1971	Summer 1981	Fall 1971	Spring 1972	Summer 1981	Fall 1972	Spring 1973	Summer 1981
Apr 1	29c[1]	23d	12b	131c	103cd	47a	217a	181a	55ab
15	9c	9d	11b	121c	83d	44a	201a	180a	64a
29	7c	7d	9b	205b	131bcd	51a	102b	141ab	64a
May 13	3c	4d	3b	194b	131bcd	46a	74c	82bc	43bc
27	7c	5d	4b	254a	166ab	54a	73c	48cd	24cd
Jun 10	8c	9d	6b	119c	90d	41a	23d	7d	9d
24	17c	18d	8b	0d	6e	4b	0e	11d	9d
Sep 1	333a	244b	51a	30d	97d	45a	39d	78bc	24cd
15	302b	259b	56a	11d	106cd	41a	0e	96bc	29c
29	18c	323a	48a	0d	122bcd	43a	0e	99bc	31c
Oct 13	0c	286ab	61a	0d	186a	56a	0e	93bc	29c
29	0c	125c	16b	0d	158abc	51a	0e	92bc	31c
Avg	61	109	24	89	115	44	61	92	34
	East Mara								
	Year seeded								
	1971			1972			1973		
	Year counted								
Date seeded	Fall 1971	Spring 1972	Summer 1981	Fall 1972	Spring 1973	Summer 1981	Fall 1973	Spring 1974	Summer 1981
Apr 1	—	—	—	—	—	—	26e	29f	24ef
15	—	—	—	191a	138a	23	129c	141de	46bcd
29	143b	134a	15	202a	133a	36	129c	139de	41bcdef
May 13	224a	128a	20	83c	47b	20	8e	23f	22f
27	108bc	104ab	17	123b	19cd	19	16e	26f	26def
Jun 10	23d	9d	8	68cd	12d	18	36e	54f	35cdef
24	3d	3d	1	0e	6d	11	88cd	123e	39bcdef
Sep 1	59d	86abc	19	51d	119a	23	383a	338a	67a
15	21d	64bc	10	11e	33bcd	13	406a	302ab	55abc
29	0d	51cd	14	0e	43bc	23	203b	246bc	57ab
Oct 13	0d	95abc	16	0e	30bcd	20	0f	190cd	45bcde
29	0d	48cd	21	0e	9d	14	0f	207c	59ab
Avg	58	72	14	66	54	20	119	152	43

[1]a-f Means within columns followed by the same letter are not significantly different by Duncan's multiple range test at $P<0.05$. Absence of a letter indicates lack of significance at $P<0.05$ in the F test of the analysis of variance.

Table 2a. Biweekly percent soil moisture by weight (% by wt) and percent of available water storage capacity (% of AWSC) at 2-cm depth from April to November on two Orthic Brown Chernozems during the years of study.

	Tranquille						West Mara					
	1970		1971		1972		1971		1972		1973	
	% by wt	% of AWSC	% by wt	% of AWSC	% by wt	% of AWSC	% by wt	% of AWSC	% by wt	% of AWSC	% by wt	% of AWSC
Apr 1	—	—	23	49	20	36	—	—	28	73	9	0
15	7	0	11	0	15	7	33	96	20	32	7	0
May 1	7	0	6	0	11	0	13	2	11	0	4	0
15	4	0	5	0	9	0	4	0	7	0	—	0
June 1	—	0	19	27	6	0	15	12	3	0	10	0
15	10	0	13	0	22	43	17	20	27	68	5	0
July 1	7	0	10	0	17	17	11	0	22	45	5	0
15	—	0	8	0	14	2	5	0	13	0	—	0
Aug 1	—	0	—	0	5	0	—	0	4	0	—	0
15	5	0	—	0	4	0	—	0	—	0	—	0
Sep 1	8	0	15	4	6	0	21	39	—	—	4	0
15	9	0	6	0	6	0	5	0	8	0	4	0
Oct 1	6	0	12	0	4	0	12	0	6	0	17	20
15	17	20	8	0	4	0	15	8	3	0	14	5
Nov 1	10	0	7	0	21	41	11	0	23	48	24	55

Table 2b. Biweekly percent soil moisture by weight (% by wt) and percent of available water storage capacity (% of AWSC) at 2 cm depth from April to November on an Orthic Dark Brown (Pruden) and Orthic Black (East Mara) Chernozem during the years of study.

	Pruden						East Mara					
	1970		1971		1972		1971		1972		1973	
	% by wt	% of AWSC	% by wt	% of AWSC	% by wt	% of AWSC	% by wt	% of AWSC	% by wt	% of AWSC	% by wt	% of AWSC
Apr 1	30	95	—	—	—	—	—	—	—	—	47	96
15	17	31	30	95	31	100	—	—	—	—	27	20
May 1	7	0	12	7	20	49	50	100	29	25	14	0
15	6	0	11	0	18	39	24	6	27	20	—	0
June 1	5	0	16	30	3	0	27	20	9	0	26	15
15	8	0	16	30	19	42	29	25	40	66	12	0
July 1	—	0	8	0	16	30	12	0	33	41	10	0
15	—	0	8	0	18	37	11	0	36	55	—	0
Aug 1	—	0	—	0	6	0	—	0	10	0	—	0
15	—	0	—	0	3	0	—	0	4	0	—	0
Sep 1	9	0	17	31	3	0	35	49	33	41	10	0
15	8	0	5	0	6	0	8	0	17	0	10	0
Oct 1	11	0	7	0	5	0	26	15	11	0	26	15
15	17	31	14	19	2	0	29	25	7	0	28	22
Nov 1	12	7	8	0	21	50	18	0	31	33	37	55

Table 3. April to October monthly total precipitation (mm) at the seeding locations during the years of seeding.

	Tranquille				West Mara			
	1970	1971	1972	Avg	1971	1972	1973	Avg
Apr	10	2	6	6	4	10	2	5
May	13	22	16	17	28	14	18	20
Jun	25	33	33	30	36	43	17	32
Jul	4	19	15	13	17	26	8	17
Aug	19	9	24	17	13	32	8	17
Sep	9	8	18	12	9	17	17	14
Oct	16	5	7	9	10	6	16	11
Apr-Oct	96	97	118	104	117	148	86	117
	Pruden				East Mara			
	1970	1971	1972	Avg	1971	1972	1973	Avg
Apr	9	3	6	6	3	9	25	12
May	19	33	25	26	33	24	20	26
Jun	35	32	40	36	39	45	21	35
Jul	3	17	29	16	21	29	12	21
Aug	22	8	22	17	10	32	9	17
Sep	24	10	17	17	13	19	21	18
Oct	13	15	8	12	11	8	15	11
Apr-Oct	125	118	147	130	130	166	124	140

Location Effects

Time and degree of seedling establishment varied greatly from year to year and from site to site, largely because of differences in the climate between locations. Tranquille was the hottest and driest location, while East Mara was the least dry, not only because of higher precipitation but also because of lower evaporation rates resulting from lower temperatures. West Mara and Pruden had similar climates which were intermediate between the others.

In some years the period for successful germination in the year of seeding can be very short (within 2 weeks), especially on the drier drier sites. For example, at Tranquille in 1970, only the September 1 seeding produced a stand during the year of seeding. In 1970, the soil-moisture levels remained low throughout the growing season until 1.3 cm of rain fell in the first week of September. This rain raised the soil moisture level above 10% for 10 days before it dropped again to below 8% by mid-September, where it remained until mid-October. At Pruden, which is 273 m higher in elevation, the same rain shower dropped 1.9 cm of rain and the soil moisture remained between 22 and 11% until mid-October. At this location, germination took place in the September 15 seeding also. The mean soil temperature dropped below 10°C by October 10, preventing further germination.

East Mara was located at the highest elevation of the 4 sites. In 2 of the 3 years snow covered the site on the early seeding dates. Despite the late start for the East Mara site, late-spring seedings were no more successful there than at the lower-elevation sites

Table 4. Water content* at field capacity (0.3 bar) and permanent wilting point (15 bars) and available water capacity* of seeding site soils (1-3 cm depth).

Site	Field capacity	Permanent wilting point	Available water storage capacity
Tranquille	37.5	16.6	20.9
West Mara	37.2	14.3	22.9
Pruden	31.0	10.1	20.9
East Mara	46.1	20.9	25.1

*All values expressed as percent water by volume

Table 5. Effect of date of seeding on crested wheatgrass dry matter yield (g/m^2) in 1981.

Year seeded	Tranquille			West Mara		
Date seeded	1970	1971	1972	1971	1972	1973
Apr 1	41.2	41.5*abc*[1]	56.0*ab*	31.8	39.0*ab*	40.9
15	41.9	40.6*abc*	53.9*abc*	42.7	52.7*a*	60.2
29	34.1	49.9*ab*	70.9*a*	48.2	49.4*a*	77.6
May 13	43.0	52.5*a*	45.4*bc*	45.3	54.6*a*	50.5
27	46.7	49.0*ab*	48.1*abc*	52.6	47.9*a*	47.2
Jun 10	30.7	42.7*abc*	57.7*ab*	50.3	18.2*b*	55.9
24	40.0	31.6*abcd*	31.5*c*	16.3	12.1*b*	58.8
Sep 1	49.5	16.4*d*	41.5*bc*	43.1	57.9*a*	70.3
15	48.6	26.5*cd*	52.6*abc*	38.6	53.8*a*	61.8
29	42.7	47.0*abc*	37.2*bc*	38.5	54.5*a*	57.9
Oct 13	39.5	44.0*abc*	44.0*bc*	45.5	65.7*a*	60.6
29	40.4	29.6*bcd*	52.7*abc*	51.3	66.2*a*	53.3
Avg	41.5	39.3	49.3	42.1	47.7	57.9
Year seeded	**Pruden**			**East Mara**		
Date seeded	**1970**	**1971**	**1972**	**1971**	**1972**	**1973**
Apr 1	38.9*cde*	56.2	52.9	—	—	67.0
15	45.4*bcd*	58.7	52.6	—	46.1	84.1
29	20.8*ef*	72.3	68.4	46.2	50.7	68.7
May 13	12.9*f*	48.6	63.0	37.8	25.2	85.5
27	11.7*f*	69.2	60.0	35.5	51.8	50.0
Jun 10	26.8*def*	60.5	31.0	12.3	19.1	92.4
24	28.1*def*	32.9	29.7	19.2	26.7	84.7
Sep 1	63.9*ab*	57.2	54.1	57.2	66.6	93.0
15	52.0*bc*	47.1	66.6	35.1	51.5	83.5
29	61.0*ab*	68.0	71.7	61.7	49.9	68.2
Oct 13	74.8*a*	62.5	50.3	21.6	40.7	102.0
29	46.9*bcd*	61.9	51.5	51.3	35.9	84.1
Avg.	40.3	57.9	54.3	37.8	42.2	80.2

[1]*a-f* Means within columns followed by the same letter are not significantly different by Duncan's multiple range test at $P<0.05$. Absence of a letter indicates lack of significance at $P<0.05$ in the *F* test of the analysis of variance.

since the soil moisture level dropped about as quickly in early summer as it did at the other sites. In 1972, the April 15 and 27 seedings appeared to respond to rains in late May. In 1971, the late spring seedings germinated quickly, but many seedlings died in late July and August. Similar results were obtained the same year with the late-spring seedings at other locations.

Subsequent Year Effect

Nine to 12 years after seeding, crested wheatgrass populations continued to vary among seeding sites and years. When the 1981 counts were pooled, the advantage of fall versus spring seeding virtually had disappeared since the initial counts, but the populations of the mid-June seedings remained low (Table 1). Yields likewise indicated a disadvantage in many of the June seedings (Table 5). Most populations declined from the initial counts, the exceptions being plants with low starting densities which either remained constant or improved. The 1981 weed yields had very limited interpretive value because of the great variation among plots. There was a tendency for an inverse relationship between weed and crested wheatgrass yield so that total plot yields were often relatively consistent among dates within a seeding year.

At the Tranquille site (driest), crested wheatgrass populations apparently reached equilibrium for each year of seeding. Analysis of yields indicated minor differences among dates in the 1971 and 1972 seedings, but there were no sharp distinctions.

Counts differed significantly among dates at West Mara. Plant populations tended to remain low on those stands with poor initial establishment but plots which originally differed with moderate or good early establishment showed no difference by 1981. Despite count differences among seeding dates, there is no statistical difference in yields except for the 1972 seedings. Low crested wheatgrass productivity for the June 1972 seedings will likely continue as these plots now support moderate to dense stands of big sagebrush, pasture sage *(Artemisia frigida)*, and bluebunch wheatgrass.

Analysis of the Pruden counts also indicated differences among treatment dates. All seeding years shared low mid-June seeding counts but otherwise the years were dissimilar. Early spring seeded plots were favoured over fall seeded in the 1972 seeding, while the reverse was true for the 1970 seeding. There was no difference between fall and spring dates in the 1971 seeding. Diffuse knapweed *(Centaurea diffusa)* has invaded the Pruden site since completion of the seedings. It has become well established where crested wheatgrass density is low but strong wheatgrass populations have impeded knapweed invasion.

East Mara populations have declined greatly from the initial counts, likely as a result of intense competition from Kentucky bluegrass *(Poa pratensis)* and other perennial grasses. No statistical count differences were detected for the 1971 and 1972 seedings, although the average plant densities varied widely among dates. The lack of significance likely resulted from great variation between replicates. Fall seeded plots continued to be favored in the 1973 seeding. The initial advantage enjoyed by the fall 1973 seedings, of germinating in a moist spring following a drought year, is still evident. There was no statistical difference in 1981 crested wheatgrass yields among dates for any of the 3 years, although the 1971 and 1972 June seeding yields appeared low. Again, great variation between plots may have masked seeding date differences.

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