MANAGEMENT OPTIONS FOR PRODUCERS WHO TRADITIONALLY PLANT BARLEY FOR GRAIN OR FORAGE

by

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ABSTRACT

The objective of the experiment was to evaluate barley management options by varying seed band width, seeding rates, and harvest endpoint under dryland production conditions in Northern Montana. The experimental design was a randomized complete block with a factorial arrangement and was conducted for three years. Treatments consisted of two cultivars (‘Harrington’ and ‘Haybet’), two band widths (125 mm and 193 mm), and three seeding rates (140, 184 and 226 seeds m^{-2}). Year effects were significant. All established plant populations were lower than planned. Band width was confounded with seeding rate. Established plant populations increased from the narrow to the wide band width, any effect attributed to band width appears to be more what would be expected for increasing the seeding rate. Malt quality was never achieved and no treatment combination aided in moving the quality towards an acceptable malt grade of barley. Feed barley production was greatest in 2001 for the lowest seeding rate where as in 2002 and 2003 no difference existed between seeding rates. No beneficial water use patterns were established for any management endpoint or management option. Whole plant DM forage yield favored the highest seeding rate increasing 368 kg over the lowest seeding rate for the early harvest (soft dough) and when the crop matured 7 d longer, DM yield increased by 408 kg over both the lower rates. Nitrate-N was reduced 16 and 19% in the highest seeding rate for the early and late harvest, respectively. Reductions in Nitrate-N exhibited a linear and quadratic response for the early and a linear response for late harvest. With no quadratic affect observed for DM yield and substantially lower established plants m^{-2} than predicted, additional research of seeding rate and band width interactions may be warranted to optimize both forage and grain production. Optimal management strategies for grain production and forage production were different, especially for seeding rate. A producer should decide on how the crop is to be utilized prior to planting of the crop.

PROJECT DESCRIPTION

Barley (*Hordeum vulgare*) is currently second only to wheat production area being grown on over 400,000 hectares, and contributes approximately $90 million in gross revenue to the economy of Montana (Montana Agricultural Statistics, 2006). Although premiums are paid for malt quality barley, the crop is generally grown for grain and utilized as a livestock feed. However, barley planted solely for forage production has been increasing rapidly in recent years (Montana Agricultural Statistics, 2006). One reason that this phenomenon is occurring is diversified producers do not need to purchase additional equipment to use cereals as forages since similar seeding equipment and harvesting techniques can be used as alfalfa (Helsel and Thomas, 1987). Producers rarely evaluate the potential economic benefit of yet another option – that of harvesting barley initially intended for malt or feed grain as hay, rather than letting it ripen as grain once it is determined that meeting malting quality criteria is unlikely given the conditions of the growing season.

Maloney et al., (1999) working with various winter and spring cereals grown in monocultures and as mixes, timed planting so there was two months of growth before a killing frost in the fall. They reported that one benefit of the winter wheat (*Triticum aestivum*) monoculture planted in the fall for forage was that it had the potential to be harvested as grain if markets dictate in late summer, increasing overall profit (flex-harvest). The benefits of winter wheat in Wisconsin (Maloney et al., 1999) in a flex-harvest system were achieved because the winter wheat had higher yields than the other cereals. Although this economic potential was never explored and may not feasibly work in Montana, it illustrates the potential of removing the barley crop as forage rather than harvesting the crop as grain if economic incentives favor the hay. The flex-harvest option may have at least two very beneficial results: 1) increased water availability for subsequent crops through earlier harvest and a corresponding cessation of water use by the current crop, and 2) potential for increased current year profit depending upon markets and operational needs.

By evaluating available stored soil water and precipitation, potential barley grain yield and price, and potential forage production and price, growers could utilize these factors to determine whether barley grain or barley forage would be more beneficial for their current operational needs. By further investigating various cultivars, planting configurations and harvest dates, a grower may be better equipped to make earlier decisions as to whether or not to harvest barley as grain or utilize it as a roughage source in a livestock enterprise. Miller et al. (1993) reported that in Louisiana when grain prices were low, producers grazing both winter triticale and wheat should graze their cattle substantially longer. This extended grazing period reduces the overall eventual grain yield of the combined crop but the producers are marketing the crop as a source of protein and energy with the growing livestock, thereby maximizing return by the crop even though grain yields are impaired by grazing. Miller et al. (1993) concluded that diversifying both the grain and cattle operations to flexible cropping systems may lead to higher economic returns.

Cereal grain yields are attributed to three yield components; spikes per unit area, kernels per spike, and kernel mass (Sprague, 1926). These sequentially determined components collectively determine how much the cereal produces and any change in one or more of the components can generate a change in either direction for overall grain yield. These yield components are affected by various plant and environmental interactions. Adams (1967) felt that the developmental plasticity of the yield components helped maintain yield in various environments, one or more components could compensate for the others, a “buffered yield system”.

It has been generally accepted that grain yields are unaffected by seeding densities, but have been responsive to “arrangements” as long at the populations are not excessively low or high (Brinkman et al., 1979; Briggs, 1975; Finlay et al., 1971). As row spacing decreased from 300 mm to below 180 mm, grain yields generally have increased, however the magnitude has been variable. This variability is potentially related to differences in environment, cultivar, crop (barley or wheat) and population inconsistency (seeds m^{-2} or stand established) inherent in this type of research. This trend of increasing grain yield as row spacing decreases has been attributed by Holliday et al. (1963) to the plant’s ability to make more efficient use of light for photosynthesis earlier in their life and the ability to tiller more profusely.

When discussing plant population, it is vital to understand and consider the expected annual average precipitation, soil type and past and present fertility. All should be balanced to local production areas. Seeding rates should be recommended according to long term environmental conditions in which the crop is going to be grown (McFadden, 1970) and this recommendation will vary from region to region (Miller, 2001). Pant (1979) describes the relationship of yield to population as a competition between plants for necessary resources explaining that a plant can only recruit those resources from a limited area or its immediate vicinity (influence zone). This influence zone is affected by many abiotic and biotic factors.

Barley plant densities have been linked to tiller production (Kirby and Faris, 1970; Kirby and Faris, 1972; and Simmons et al., 1982). Early emerging tillers contribute more to grain yield than do tillers that emerge later and tiller mortality is more prominent at higher plant densities and narrow row arrangements (Simmons et al., 1982). Heavily tillered plants tend to have smaller culms, leaves and heads than neighbors under lower populations (Hamid and Grafius, 1978).

Annual forage barley hay production differs from producing barley for feed grain or malting purposes. Barley planted for forage production should be planted at 25 to 50% higher seeding rates (178 and 288 seeds m^{-2}) than normally seeded for grain (Helsel and Thomas, 1987; Cash et al., 1997) for the potential to increase dry matter yield in the harvested forage. Generally as plant populations have increased, a corresponding reduction of tillers occurred, this has generated higher dry matter (DM) yields and increased fiber content. Although higher fiber contents were usually reported, the forage produced was still of sufficient quality to support normal metabolic requirements for beef cattle (Juskiw et al., 2000a,b).

Barley response to seed band width and seeding rate with modern one pass no-till equipment has not been adequately explored for either grain or forage production. Positive effects on vegetative dry matter production among cereal crops would be expected to be similar or perhaps even greater than that associated with grain production.

It is appropriate to test this hypothesis with malting and hay barley cultivars produced both for grain and forage purposes. In doing so, we will evaluate the potential for growers to make more informed decisions during the growing season as to whether or not a particular barley crop should be harvested for forage or retained for grain production. The objective was to evaluate barley management options by varying seed band width, seeding rate, and harvest endpoint under dryland production conditions.

LITERATURE REVIEW - BARLEY (*Hordeum vulgare L.*):

History

Barley (*Hordeum vulgare L.*) is the fourth-largest crop in acreage to be grown in the world (North Dakota Barley Council, 2003) behind wheat, rice, and corn. Barley is considered by many as the most ancient cultivated grain (Leonard and Martin, 1963) and is presently cultivated in nearly all temperate zones, many subtropical areas and in high altitudes between the Tropic of Cancer and the Tropic of Capricorn (torrid zone) of both hemispheres. As domestication of cereals took place the criteria used for selection was: 1. seed size and weight, 2. local abundance, 3. generation length (annual or perennial), 4. dormancy, 5. ploidy level, 6. harvesting efficacy, and 7. ease of dehusking (Smith, 1995). Original "gatherers" doubtfully understood some of these selection criteria that they were indirectly employing at that time of first domestication. Although using these same criteria, the wheats (*Triticum spp.*) appeared superior to the *Hordeums*. It is however generally accepted that barley was domesticated earlier than wheat (Smith, 1995).

Recently restricted fragment length polymorphism (RFLP) technology was utilized to evaluate and revisit the origin of barley in the Fertile Crescent. The Fertile Crescent is a region of the Middle East. Historically the area arched from the southeastern coast of the Mediterranean Sea around the Syrian Desert north of the Arabian Peninsula to the Persian Gulf. Agricultural settlements in the Fertile Crescent can be dated to c. 8000 BC. Various wild (*Hordeum spontaneum*) and domesticated (*H.*

vulgare) strains found in the archeological sites around the Fertile Crescent were investigated to determine the origin of barley domestication (Badr et al., 2000). The monophyletic (one common ancestor and all of its' descendents) nature of barley domestication was demonstrated based on allelic frequencies at 400 AFLP polymorphic loci studied in 317 'wild' and 57 cultivated lines. The results provided support for the hypothesis that the Israel-Jordon area was the region in which barley was domesticated. These Israel-Jordon wild populations were molecularly more similar than any others to the cultivated gene pool (Badr et al., 2000).

> <u>Monophyletic taxon</u>: A group composed of a collection of organisms, including the most recent common ancestor of all those organisms and all the descendants of that most recent common ancestor. (Abbey, 1997)

It is believed, that Columbus may have introduced barley and wheat seed in the New World on his first voyage; however researchers are certain he returned with barley in 1493 on his second. Barley is also believed to have been brought to the United States by Gosnold around 1602 and Canada (Nova Scotia) shortly thereafter (Leonard and Martin, 1963). Colonists of the new world used the barley primarily for malt production. As colonization continued westward, different types of barley were introduced from Germany, Netherlands, and Spain that were more appropriately suited to inland environments. Local adaptation and breeding was then established in the New World.

Description

Aberg and Weibe (1946) described the genus *Hordeum* as:

> Genus Hordeum: Spike indeterminate, dense, sometimes flattened, with brittle, less frequently tough awns. Rachis tough or brittle. Spikelets in triplets, single flowered but sometimes with rudiments of a second floret. Central florets fertile, sessile or nearly so, lateral florets reduced, fertile, male or sexless, sessile or in on short rachillas. Glumes lanceolate or awnlike. The lemma of the fertile flowers awned, awnleted, awnless, or hooded. The back of the lemma turned from rachis. Rachilla attached to the kernel. Kernel oblong with ventral crease, caryopsis usually adhering to lemma and palea. Annual or perennial plants.

Barley description as outlined by Leonard and Martin (1963): All cultivated barley species have 14 diploid chromosomes. They can be winter or summer annuals. Domesticated barleys are either classified as two or six-rowed barleys. Roots of a barley plant can have a lateral spread between 150 and 300 mm while the depth can reach 900 to 1800 mm. The culm consists of 5 to 7 hollow cylindrical internodes separated by solid swollen joints or nodes at which the leaves arise. The culm length ranges from 203 mm in semi-dwarfs to over 1524 mm tall varieties. The taller varieties are older. Culms can number 3 to 6 when seeded at normal rates and grown under adequate conditions. The leaf sheath is glabrous with a few exceptions of being pubescent. The ligule is short (0.5 to 3.0 mm), truncate and slopes away at both ends. The auricles partially or entirely clasp the stem. The leaf blade is lanceolate-linear, but the upper or flag leaf is curled or rolled in some varieties. The surface of the blade is harsh, usually covered by a white, waxy bloom. The spike has a zigzag rachis from 25.4 to 127 mm and is compressed. With a few exceptions the rachis is hairy. Three spikelets are attached at each of 10 to 30 nodes of the rachis. In six-rowed barleys all three spikelets are fertile; however in two-rowed varieties only the center spikelet is fertile. Each spikelet contains a single floret tended by two linear, flat, pointed glumes. The lemma of the floret is oblanceolate (narrowest at the base and widening towards the center), and at its apex, is drawn out into a stiff awn. The awn may be smooth, rough or even absent; in some cases it may be replaced by a trifurcate appendage called a hood. The palea is obtuse. The rachilla, a continuation of the axis of the spikelet, lies within the crease of the kernels and is covered with hairs. The sexual organs consist of three stamens and a pistil with a single ovule and forked stigma. Two lodicules at the base of the pistil face the lemma, and serve to open the flower by swelling during the pollination. The barley kernel is made up of a caryopsis, lemma, palea and rachilla.

Production and Utilization

Barley can be used in the livestock industry as a feed source for ruminants or non-ruminants, by the malting industry for beverages, and as a food source for human consumption. The majority of the malt barley grown in the United States is produced in North Dakota, Montana, Idaho, Washington and Minnesota (Table 1). Total barley production by state from 2003 to 2005 is presented in Table 2. Land area planted to barley in the United States is represented in Figure 1 (NASS, 2006).

From 1991 through 1999, nearly 89% of the barley planted in Montana was harvested for grain (Montana Agricultural Statistics, 2006). The trend began to change in 2000 when over 31% of the barley planted was harvested as annual forage. In 2001 nearly 53% of the barley planted was harvested for forage. This trend may to some extent be explained by ongoing drought conditions in most of Montana. From 1997 to 2000 barley grain cash receipts were 6.3% (nearly $117 million) of all commodities marketed in Montana. However, in 2001, barley grain receipts were 4.2% and general hay receipts were 5.3%. This trend continues through 2006 as annual forages become more prevalent throughout the state as an emergency, rotational or optimal forage crop.

Table 1. Barley production of approved American Malting Barley Association Inc. varieties, for specific states, regions and nationally, 2000 to 2002, AMBA (2004).

State	Planted 2000	Planted 2001	Planted 2002	Harvested 2001	For Harvest 2002	Planted 2002 % of 2001
	(acres)					
Minnesota	270,000	160,000	210,000	145,000	185,000	131.3%
North Dakota	1,900,000	1,500,000	1,600,000	1,450,000	1,520,000	106.7%
South Dakota	115,000	90,000	60,000	78,000	50,000	66.7%
Three States	2,285,000	1,750,000	1,870,000	1,673,000	1,755,000	106.9%
California	130,000	160,000	110,000	110,000	75,000	68.8%
Colorado	110,000	90,000	100,000	80,000	93,000	111.1%
Idaho	750,000	700,000	710,000	670,000	690,000	101.4%
Montana	1,250,000	1,100,000	1,200,000	720,000	950,000	109.1%
Oregon	150,000	110,000	80,000	100,000	75,000	72.7%
Washington	500,000	430,000	370,000	420,000	360,000	86.0%
Wyoming	105,000	100,000	90,000	85,000	75,000	90.0%
Seven States	2,995,000	2,690,000	2,660,000	2,185,000	2,318,000	98.9%
Other	584,000	527,000	518,000	431,000	426,000	98.3%
Total U.S.	5,864,000	4,967,000	5,048,000	4,289,000	4,499,000	101.6%

Table 2. Total barley average yield ac^{-1} and total production for the highest producing states from 2003 to 2005*.

	Average Yield			Total Production		
State	2003 *Bushels*	2004 *Bushels*	2005[1] *Bushels*	2003 *1,000 Bushels*	2004 *1,000 Bushels*	2005[1] *1,000 Bushels*
AZ	118.0	110.0	100.0	3,540	4,180	3,000
CA	64.0	60.0	63.0	3,712	4,500	3,780
CO	109.0	118.0	130.0	8,938	9,086	7,670
DE	59.0	80.0	81.0	1,239	2,080	2,187
ID	66.0	92.0	87.0	47,520	59,800	52,200
KS	57.0	28.0	42.0	456	336	588
KY	75.0	77.0	83.0	600	616	747
ME	65.0	60.0	60.0	1,755	1,320	1,320
MD	57.0	73.0	86.0	2,052	2,847	3,526
MI	56.0	51.0	47.0	784	612	517
MN	75.0	68.0	43.0	12,750	7,820	3,870
MT	40.0	59.0	56.0	34,000	48,970	39,200
NE[2]	50.0	54.0		200	162	
NV	80.0	105.0	85.0	240	210	170
NJ	45.0	63.0	71.0	135	126	142
NY	50.0	53.0	49.0	650	530	735
NC	56.0	64.0	78.0	784	960	1,482
ND	60.0	62.0	54.0	118,800	91,760	57,240
OH	58.0	50.0	60.0	348	200	300
OR	64.0	73.0	45.0	3,840	4,818	2,025
PA	61.0	62.0	72.0	3,965	3,410	3,384
SD	53.0	63.0	49.0	2,915	3,150	2,303
UT	80.0	86.0	80.0	2,800	3,440	1,920
VA	62.0	74.0	87.0	2,790	2,960	3,915
WA	47.0	70.0	61.0	14,570	17,150	12,505
WI	55.0	55.0	53.0	1,925	1,650	1,590
WY	93.0	94.0	93.0	6,975	7,050	5,580
US	**58.9**	**69.6**	**64.8**	**278,283**	**279,743**	**211,896**

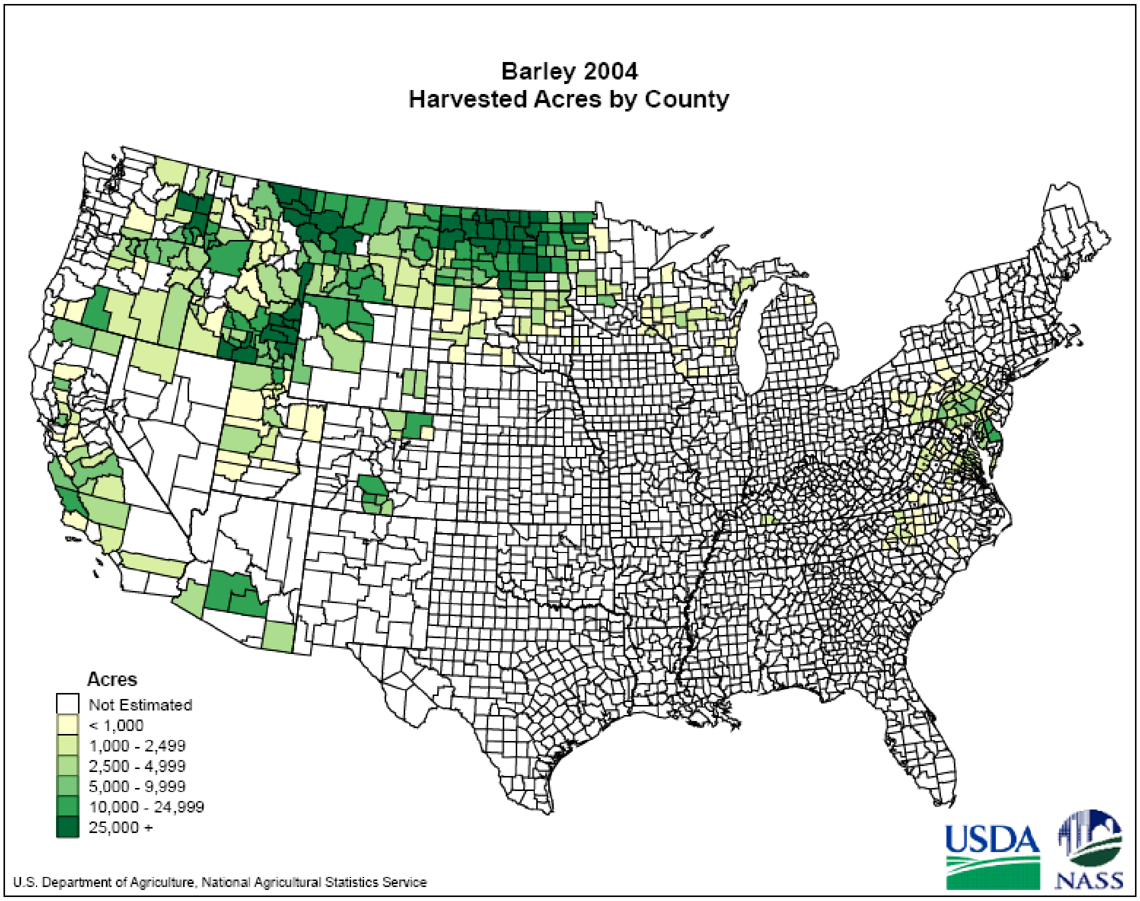
* Source: USDA/NASS (http://www.nass.usda.gov/). NASS, 2006

[1] Updated from "Small Grains 2005 Summary" released September 30, 2005.

[2] Estimates discontinued in 2005.

Since 1996, 'Harrington' (Harvey and Rossnagel, 1984), a two-rowed malt barley developed in Canada, has been the predominant barley grown in Montana (Montana Agricultural Statistics, 2006). Since 2000, 'Haybet' (Hocket et al., 1990), a hooded hay barley cultivar has been the second leading barley produced in Montana ranging from 6.5 to 17% of total barley acreage. In 2006, 'AC Metcalfe' succeeded Haybet as the second most prevalent barley grown in Montana with 17.7% with Haybet dropping slightly to

14.8% of the acres planted. Barley can be classified into three different endpoint uses: malt, feed and forage. Harrington and AC Metcalfe represent varieties that are approved as acceptable ‘malting’ types of barley. Haybet, represents a barley developed exclusively for forage utilization.



U.S. Department of Agriculture, National Agricultural Statistics Service

Figure 1. Production acres planted to barley in Montana and the United States, adapted from **http://www.nass.usda.gov/**. NASS, (2006).

Malting barleys are used in the brewing industry to make malt for different beverages and must meet strict standards dictated by the contracting company. The American Malting Barley Association (AMBA, 2004) recommendations are in Table 3. In the West, the model two-row malt barley is Harrington and the model six-row is

'Morex' (Rassmusson and Wilcoxson, 1979). An objective of most barley breeding programs is the development of improved malting varieties.

Table 3. Basic criteria for malting barley for use in the brewing industry. Adapted from AMBA (2004).

Barley Factors	Two-Row Barley	Six-Row Barley
Plump Kernels (on 6/64)	> 90%	> 80%
Thin Kernels (thru 5/64)	< 3%	< 3%
Germination (4ml 72 hr. GE)	> 98%	> 98%
Protein	11.5-13.0%	11.5-13.5%
Skinned & Broken Kernels	< 5%	< 5%
Malt Factors		
Total Protein	11.3-12.8%	11.3-13.3%
on 7/64 screen	> 70%	> 60%
Measures of Malt Modification		
Beta-Glucan (ppm)	<115	<140
F/C Difference	<1.5	< 1.5
Soluble/Total Protein	42-47%	42-47%
Turbidity (NTU)	< 10	< 10
Viscosity (absolute cp)	< 1.50	< 1.50
Congress Wort		
Soluble Protein	4.9-5.6%	5.2-5.7%
Extract (FG db)	>81.0%	>79.0%
Color (°ASBC)	1.6-2.0	1.8-2.2
Malt Enzymes		
Diastatic Power (°ASBC)	120-160	140-180
Alpha Amylase (DU)	45-80	45-80

Feed barley is approximately 75% of all barley grown in the United States (NASS, 2006). Forage barley is an annual crop either cut for hay (any long forage that has been cured usually by the sun) or silage (anaerobic fermented forage). Annual forages (AF) are traditionally used in rotations with other more valuable crops for two to three years to break disease cycles, as an emergency crop during drought (Undersander,

1992) or to remove the potential of autotoxicity that can occur when alfalfa is replanted into ground where alfalfa was recently grown (Undersander et al., 1991).

Management of the barley crop is strictly dependent upon the endpoint for which the crop is targeted (i.e., annual forage, malt or feed grain). Management options will be discussed further along with how those options may impact various quality or quantity parameters of barley.

The use of cereal AF is becoming widespread in the feedlot areas of Canada, from Medicine Hat west to Lethbridge and north to Calgary, Alberta to Saskatchewan. Vast quantities of silage are generated to be used in beef cattle rations during the finishing phase in beef production. These AF also increase winter feed supplies and grazing opportunities in the Northern Great Plains (Entz et al., 2002). Barley and oat (*Avena sativa*) are commonly the choice in these short-season areas (Jedel and Salmon, 1995). Cool season cereals are rapidly established and the planting and harvesting equipment is similar to alfalfa (Foster, 2004). Short season cereals are adapted to areas that receive less than 2100 heat units a year, where higher heat units are present, corn silage may be the better alternative (Foster, 2004).

Cereals used as AF have several characteristics (Stoskopf, 1985): 1. they are generally utilized in one grazing or cutting event, since they usually do not recover like perennials, 2. stand establishment is easier with the large seed, and can be placed in no-till or “rougher” seed beds than smaller seeded perennial crops such as alfalfa, 3. seed is relatively inexpensive with the exception of hybrids such as silage corn varieties, 4. they produce relatively high yields from one cutting, 5. forage quality can be variable, however if properly prepared, the forage is more than adequate for all classes of beef, depending upon the species and time of harvest, it may also be suitable for dairy animals. 6. cereals have a wide range of seeding dates and production time lines to meet any need; winter or spring and cool or warm season AF can be grown. If multiple cuttings are to take place the wheats tends to respond better and recover quicker than the other cereals (Edmisten et al., 1998). Nitrate accumulation is a major concern for cereals that are being used for ruminant feed as forage (Wright and Davison, 1963). This accumulation of nitrates and its toxicity will be discussed later.

Cereal AF quality and quantity has long been investigated under various environments, fertilities and maturity stages at harvest. Cherney and Marten (1982a) conducted a study in which two cultivars each of oats, barley, triticale (*xTriticosecale*) and wheat were grown at two different locations in Minnesota where the forage was harvested at six stages; flag leaf, inflorescence, 7 d, 14 d, 21 d and 28 d post inflorescence. Annual forages follow general trends associated with other forages (Figure 2). Generally as forages mature they increase in acid detergent fiber (ADF), decrease in crude protein (CP) and decrease in in-vitro digestible dry matter (IVDDM, Merchen, 1988). Dry matter yields increased with increasing maturity for all species and appeared linear from the flag leaf to the dough stage, range: 2.9 to 8.6 metric tons ha^{-1}. Barley had the lowest ADF, highest IVDDM and CP when compared to the other species (Cherney and Marten, 1982a; Cherney et al., 1983; Helsel and Thomas, 1987).

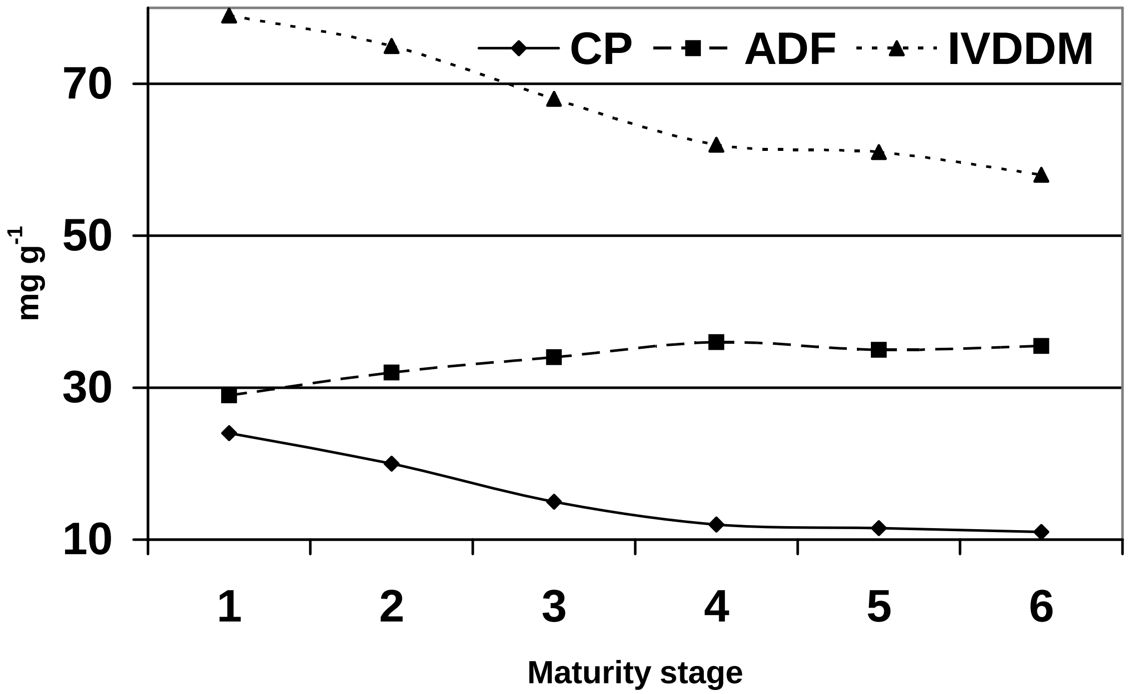


Figure 2. Average forage quality of four cereals (wheat, oat, barley and triticale) as affected response to increasing maturity for in-vitro digestible dry matter (IVDDM), crude protein (CP) and acid detergent fiber (ADF). Maturity stages are: 1) flag leaf, 2) inflorescence, 3) 7 d post, 4) 14 d post, 5) 21 d post and 6) 28 d post inflorescence. Adapted from Cherney and Marten (1982a).

Khorasani et al. (1997) reported a quadratic relationship as maturity increased for fiber levels with cereal forages he used for ensiling. As the crop matured, the leaves and stems became more fibrous (increased in ADF, NDF and acid detergent lignin) and this lower quality was offset at later maturities by an increase in starch content as the heads filled. This dilution effect is seen as more highly digestible starch accumulates in the seed as maturity increases. This decrease in forage quality was linear until grain fill was initiated then developed into a curvilinear relationship during grain fill in a trial conducted with six harvest endpoints for both oat and barley (Cherney et al., 1983; Khorasani et al., 1997). Nitrates dropped rapidly in barley and triticale as maturity increased, however oats tended to retain higher nitrate levels as maturity increased. The process of ensiling decreased nitrate levels by 25 % after 3 months of anaerobic fermentation. Nitrate content did not change from harvest to one month of fermentation. Reduced nitrate level is significant in that ensiling AF's may be an alternative to decrease nitrates without sacrificing quality of the forage to a level that can be fed to ruminants without causing acute toxicity symptoms.

Baron and Kibite (1987) initiated a trial to investigate whole plant yield (WPY), whole plant digestible yield (WPDY), total maximum yield (TMY, defined as when yield within cultivar no longer increased as maturity increased), and in-vitro digestible organic matter (IVDOM) at TMY between eight cultivars of barley. Significant year effects were observed; however it appeared that no cultivar increased in WPY or WPDY after 18 and 23 d post heading in each of the years. The authors recommended selection for taller and later maturing forage barleys to maximize WPY and high leaf content to improve IVDOM.

Plant morphological components including stem, leaf, leaf sheath, and inflorescence (all or some depending upon the study) were dissected and evaluated for forage quality parameters. It was determined that all morphological components followed the same trends as normal forage and maturity response curves in that as maturity increased so did ADF, NDF, ADL and cell wall constituents (Cherney and Marten, 1982b; Cherney et al., 1983 and Sheaffer et al., 1994) regardless of species. Barley tended to have higher percent leaves and retained more leaf DM longer that other species as maturity increased (Edmisten et al., 1998). As grain fill occurs the inflorescence actually increases in quality by dilution of the components with additional starch content.

Yield Component Compensation

Cereal grain yields are attributed to three yield components; spikes per unit area, kernels per spike, and kernel mass (Sprague, 1926). Grafius (1956) described yield potential as a rectangular parallelogram, one side being represented by spikes per unit area (X), the second, kernels per spike (Y), third, kernel weight (Z), the area being the total yield (W). As each is multiplied with the other, a yield is determined. Correlations among X, Y and Z were negative, but it was obvious that any change that could be positive involved a corresponding change in one or all three components.

Grafius (1964) continued with the geometric theory of yield, arguing that in barley these components are sequentially determined, tillering, floral initiation, stem elongation, cessation of tillering, pollination, and grain filling. As competition increases components that are negatively correlated or how each is affected depends upon when stress is imposed on the plant. Variations in yield however are not determined by these but are regulated by the amount of photosynthate or other limiting nutrient availability and distribution (Stoskopf, 1985). Only when total photosynthate is increased will yields increase. The route to increased yield can be from either the carbon source (photosynthesis) or the carbon sinks (seed), but preferably both (Gifford et al., 1984). That is why harvest index (ratio of yield {e.g. seed} to the total biomass at harvest), increasing leaf area without increasing mutual shading (optimum leaf area index via erect leaves) has received so much attention (Stoskopf, 1985). Adams (1967) felt that the developmental plasticity (the ability of a plant to modify and alter its yield as the plant matures) of the yield components could better facilitate and maintain yield if one or more component could compensate for the others, a buffered yield system. The same yield (volume of the cube) but differently shaped.

Interplant competition for nutrients (metabolic pool) may become sufficient to limit resources for the plants and one or all of the components may be impacted. This would lead to the negative correlations seen earlier by Grafius (1956) in oats. Adams (1967) concluded that the environment influenced the components of yield and that negative correlations will be common.

Effects of Water

All plants require some form of water to survive. All metabolically active plant cells require water (Mohr and Schopfer, 1995). As cereals were selected for adaptability cultivars with lower water use requirements were of primary importance (Donald, 1968). Cereal production (yield) and quality are directly related to the plant's ability to use available water (Brown and Carlson, 1990). Barley from a quantitative standpoint is one of the most efficient crops at converting plant available water into grain (Brown and Carlson, 1990). Bauer et al. (1989) attributed this enhanced efficiency to barley maturing 14 days earlier than wheat. This earlier maturity is related to barley having earlier emergence, earlier heading date, and reaching anthesis approximately nine days prior to wheat. This increased water use efficiency early in the plants development stage insures early vigorous shoot development, increasing large numbers of spikes per unit area, a short vegetative duration allows the plant to stabilize yields before the greater stresses of heat and temperature occur later in the season (Loss and Siddique, 1994; Sinebo, 2002). In low rainfall or harsh environments early maturity allows the barley plant to make efficient use of nutrients for early developing yield components that make the most contribution in yield to barley, rather focusing on grain fill (kernel weight) which is the least important component of yield (Hamid and Grafius, 1978; García del Moral et al., 1991). This life cycle may increase water use efficiency in moderate yielding cultivars in water stressed environments, but has been shown to do the opposite in higher yielding cultivars (Sinebo, 2002).

A study conducted in Lincoln, New Zealand illustrated the effects that water stress may potentially play in determining yield and its components in ‘Triumph’ malt barley (Coles et al., 1991). Grain yields were uniformly depressed by increasing drought stress. Grain protein decreased if the moisture stress occurred prior to anthesis, whereas if the moisture stress was imposed after anthesis grain protein was not affected. Early moisture stress reduced kernel number. When moisture stress was imposed in the middle stages of development both kernel number and grain weight were reduced. Stress during the later developmental stages reduced kernel weights. Abiotic stresses not only affect malt production but also decrease yields and increase protein levels in feed barleys (Nass et al., 1975; Coles et al., 1991).

Fertilization Impacts

Since Nobel Peace Prize winner Norman Borlaug initiated the “Green Revolution” by breeding dwarf wheat with erect leaves, crop yields have been increasing (Mann, 1999). Dwarf wheat had stronger stalks which could hold more grain and increased the harvest index by 50%, almost double previous values (Mann, 1997). This more efficient wheat and eventually rice and corn (bred to withstand crowding) did not accomplish the gigantic step in increasing the world’s food reserves alone. The more efficient crops were also accompanied by a dramatic increase in irrigation and fertilizer use. Borlaug is credited as saying “If new high-yielding varieties are the catalyst, fertilizer is the fuel of the green revolution” (Hignett, 1982). Providing additional or needed nutrients to growing crops was not a new concept. Nutrients were now provided by science based information and as industrialization proceeded it allowed better distribution of fertilizer to other parts of the world.

Cereals response to fertilizer has been linked to many physiological aspects leading to increasing some, or at times, all yield components and is related to competition for all nutrients. Phosphorus has been linked to increased number of spikelet per spike and rate of spikelet initiation (Stoskopf, 1985). Increased rates of N have increased nitrate concentrations, N percent in straw, grain, and leaf weight, size, appearance and light interception. Higher yields in response to N were attributed to increases in photosynthesis rate and duration (Gallagher, 1983). Nitrogen application and rates have been shown to alter amino acid levels in barley (El-Negoumy et al., 1982). Increasing fertilization rates (N & P) have been attributed to increased leaf area, spikes m^{-2}, and total biomass of the plant in barley (García del Moral et., 1985). Malt barley has been shown to be detrimentally impacted by N levels exceeding 49 kg n ha^{-1} in Southern Alberta by reducing kernel size (McKenzie et al., 2005).

Research from Montana indicates that yield and quality expectations of the grain must be identified prior to seeding and a soil test must be performed prior to any fertilizer recommendation and subsequent application (Jackson, 2000). Response to N application was highly variable for different traits measured for malt barley. Optimum yields were achieved with N applications of 157 kg ha^{-1} with protein levels can ranging from 11.5 to 12.7%, which are still at levels of acceptable malt quality (Jackson, 2000). Plumpness for high and low levels of fertilizer was acceptable for malt at far lower rates of N applications 129 and 62 kg ha^{-1}, respectively, with higher levels of N application not meeting malt standards.

Phosphorus has been linked to increase drought resistance. Responses of barley to P fertilization were recently evaluated in greenhouse experiments with treatments varying in soil type and moisture regime (Jones et al., 2003). With low water availability and course soils, no whole plant biomass difference was observed when P was provided. However, in low moisture regimes in Amsterdam loam soils, as P was increased to 56 kg ha^{-1}, whole plant biomass increased. The similarity of the high P fertilizer level on low water regimes and the 0 P level in the high water regimes may indicate that P may aid barley to maintain whole plant biomass under drought conditions (Jones et al., 2003). Water use efficiency (plant dry weight/water used) increased by 50% with the addition of

P. Grain yield however was unaffected by treatment and no treatment could meet malt criteria. How this impacts annual forages may be an area of increased research.

Spatial Arrangements

Pant (1979) explains the relationship of yield to population as a competition between plants for necessary resources and that a plant can only recruit these resources from a limited area or its immediate vicinity (influence zone). Lateral roots of barley can spread from 150 to 300 mm. This influence zone is affected by many abiotic (light, temperature, and atmospheric gases) and biotic (produced or caused by living organisms) factors. Pant (1979) illustrated mathematically that grain yields should increase as you arrange plants in a hexagonal arrangement versus a square or rectangular arrangement. Auld et al. (1983) reported that wheat planted (placed) in a mathematically modeled arrangement of either a square or rhomboidal (parallelogram with unequal adjacent sides) arrangement was predicted to give the largest packing fractions of space whether the influence zone of the wheat was plate-like, cylindrical or hemispheric. This arrangement would have the most dramatic effect on yield, dependent on the amount of water available and to a lesser degree on the arrangement of the wheat plants. Rainfall differences in this experiment were thought to alter the size of the “resource of space” available to each plant. Researchers felt that any increase in productivity seen in other experiments was a result of an improved ability to exploit the available “space”. A decrease in “rectangularity” was beneficial to grain yield. Rectangularity refers to the ratio of length to width of a rectangle formed by any two wheat plants in one row with another two in an adjacent row. For example, Hashem et al. (2000) described a planting arrangement with 200 mm between rows and 50 mm between plants within a row will create rectangularity of four, whereas the same rectangularity will be seen in 100 mm rows and 25 mm between plants within a row. A planting arrangement with 400 mm between rows and 25 mm between plants within rows will create rectangularity of 16. This decrease in rectangularity and the correlated yield response commonly illustrated by decreasing row space was predicted and shown by modeling (Fischer and Miles, 1973). By reducing row spacing in cereal crops from 180 mm to 90 mm the rectangularity was reduced from twelve to less than four predicting a 20% increase in yield (Fischer and Miles, 1973).

Grain yields have been somewhat unaffected by seeding densities (populations) but have been responsive to “arrangements” as long at the populations are not excessively low or high (Brinkman et al., 1979; Briggs, 1975; Finlay et al., 1971). Row spacing is the distance from the center of one seed tube outlet to the center of the next seed tube outlet (Figure 3). Generally, as row spacing decreased from 300 mm to below 180 mm, grain yields generally have increased, however the magnitude has been variable. Narrow rows have increased spikes area^{-1} and when plant total biomass was measured it increased proportionally to grain yields primarily attributed to an increased tillering (Brinkman et al., 1979). Potentially this variability is related to differences in environment, cultivar, crop (barley or wheat) and population variability inherent in this type of work. This trend of grain yield increasing as row spacing decreases has been attributed by Holliday (1963) to the plant’s ability to make more efficient use of light in photosynthesis earlier in the growing season and the ability to tiller more profusely. Each individual has greater access to more plant growth factors (light, water and nutrients).

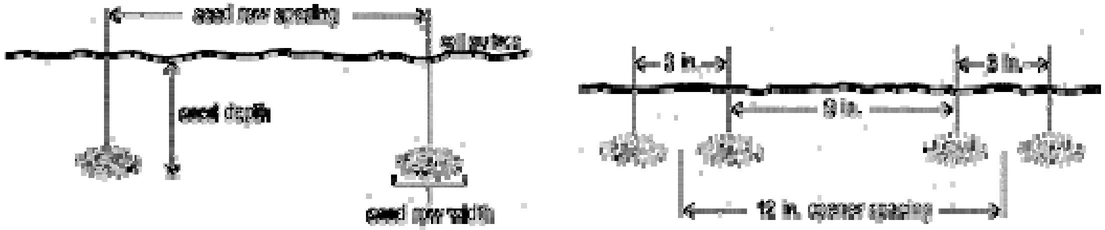


Figure 3. Illustration describing row spacing and seed row width. Shank spacing determines width of opener however with a paired row or wide band adapter to the opener the row width may be modified. Adapted from Zylstra (1998).

The phenomena of increased tillering as row spacing is decreased has been seen with 16 different cultivars of winter wheat in the Midwestern United States where water was not as limiting a resource as in the Western prairies (Marshall and Ohm, 1987). This trend of increased grain yield appears to work best when water is more abundant and not in a limited state, where spikes area^{-1} and kernels spike^{-1} increased. In years when rainfall and ground water were very limited, barley did not show the increases in yield associated with narrow row spacing (Finlay et al., 1971). The same trend in grain yield was reported by Holliday (1963). More within row competition among crop plants in widely spaced rows with the same populations of plants was explained by the lower spikes m^{-2} in winter wheat (Marshall and Ohm, 1987). The increase in spikes in narrower rows was the only yield component affected by the treatments imposed on the winter wheat.

Conversely, in a study conducted near Indian Head, Saskatchewan, Lafond and Derksen (1996) used three row widths and six seeding rates for wheat and barley under a conventional tillage fallow management system. Varying row spacing did not affect spike density, kernels spike^{-1}, seed weight or grain yield for either wheat or barley. No row spacing by seeding rate interaction was observed in either crop. Winter wheat has been shown to be unresponsive to row spacing in a trial investigating seeding depth (25 and 50 mm), seeding rate (30 and 60 kg ha^{-1}), and row spacing (180 and 360 mm) (McLeod et al., 1996).

Recently the idea of increasing yield by decreasing row space or altering rectangularity has been attempted with no-till drills that have the ability to "band" the seed within the main row or produce two distinct "paired" rows within that main row (Figure 3). Within the same population and row space, spreading the seed is thereby increasing average distance between plants through more uniform plant spacing, reducing inter-plant competition (Deibert, 1993). Deibert (1993) reported 32% greater seed yields with increasing banding widths from a band of 75 mm to 300 mm primarily by the increasing spikes m^{-2}. However, this increased band arrangement has also been shown to not affect wheat yields neither increasing spikes plant^{-1} or kernels spike^{-1} (Lafond, 1994; Schillinger et al., 1999; Johnston and Stevenson, 2001).

Plant Population

Seeding rate is defined by the amount of seed planted per unit area. It is an indirect measure of population prior to germination. Seeding rates are developed from germination tests on the seed (pure live seed) and determination of kernel weight to estimate desired plant populations. True plant population can only be determined by doing stand counts after germination and emergence from the soil. The correct seeding rates for crops depend upon the area of production, environment, variety of seed and the intended end use (Miller, 2001). As the plants compete for limited nutrients, yield components, one or all may be changed to stabilize cereal yields. Leonard and Martin (1963) reported the national average planting rate for barley was 27 to 32 kg ha^{-1}. Montana's recommendations for dryland seeding rates for the production of barley for malt and feed grain and an annual forage are 50, 67 and 100 kg ha^{-1}, respectively (Hensleigh et al., 2001). Seeding rates should be recommended on long term environmental conditions in which the crop is to be grown (McFadden, 1970) and will vary from region to region. Production expectations on dryland, or irrigated ground for various end points (malt, feed or forage barley) all influence the recommended plant population (McFadden, 1970). The rationale for different seeding rates is to maximize the yield components that are most critical in meeting that criterion for endpoint quality. Malt barley for example on dry land conditions has the lowest seeding rates. For two-rowed barleys the grain after harvest must have a protein level below 128 mg g^{-1} and plump kernels greater than 90%. Seeding rate recommendations are low so that as the yield components are developed sequentially the last to be determined is kernel weight. Barley kernel weight which is vital for barley grain to meet malt criteria has been shown to be greatest at low plant populations (Lauer, 1991; Jedel and Helm, 1995). In contrast, the recommended rate for forage production is a high seeding rate which benefits total biomass production utilizing the nutrients that are available early metabolizing them for leaves and stems rather than kernel weight (Jedel and Helm, 1995; Juskiw et al., 2000a,b).

All plants and animals live by Liebig's law of minimum, which states, growth potential or yield is limited by the biotic or abiotic feature in shortest supply (Hignett, 1982). The example that is always used is the shortest stave in a barrel determines the amount of water the barrel will hold; as you increase the height of that stave, another stave will allow water to flow out. Although this theorem describes the concept of the most limiting nutrient, the fact that crops or crop ideotypes are locally adapted provide evidence that indicates that no one factor is the sole limiting factor unless extreme conditions are present (Gifford et al., 1984). As competition is altered, either inter-plant or intra-plant, yield components react differently to stabilize yield potentially affecting the different endpoints (malt, feed or forge production).

Fischer and Miles (1973) predicted that simply increasing plant population would do little increase yields. For instance, if the population was increased from 300 plants m^{-2} to 600 plants m^{-2} and if the row space was constant at 18 cm, the rectangularity would actually increase from 8 to 16. The crop would be competing more with itself for required nutrients and the potential of crop yield loss could be increased. The yield curve was described by Willey and Heath (1969) in that seeding rate can alter the yield curve from an asymptotic to a parabolic relationship (Figure 4). Asymptotic relationships are characterized by the yields expanding rapidly within a range of populations. Any subsequent population increase neither increases nor decreases the yield dramatically. Some forage crops may exhibit this type of yield curve.

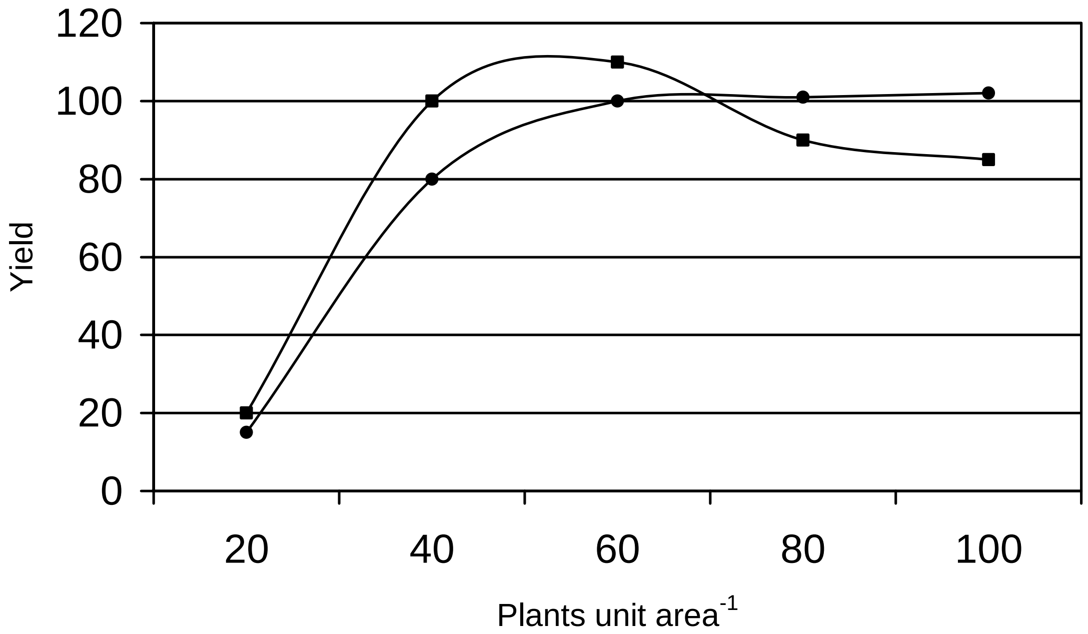


Figure 4. Representation of yield curves for plants exhibiting asymptotic (round markers) and parabolic (square markers) relationships. The x axis represents the plants within a given area (ie. plants m^{-2}) and the y axis is some measure of yield (ie. kg ha^{-1}). Adapted from Willey and Heath (1969).

Conversely, the parabolic relationship has rapid increases in yield to a peak yield at a certain maximum population and any increase in population there after decreases the yield potential of the crop (Willey and Heath, 1969). This type of yield curve would under most circumstances, be represented by crops that are harvested for their reproductive parts (grains and seeds). The peak of the parabolic yield curve can be quite a range of densities (Carr et al., 2003). Maximum yields are achieved by matching densities to the availability of environmental resources and how many plants m^{-2} (Cuomo et al., 1998).

Barley plant densities have been linked to tiller production, spikes area^{-1} (Kirby and Faris, 1970; Kirby and Faris, 1972; and Simmons et al., 1982). Early emerging tillers contribute more to grain yield than do tillers that emerge later and tiller mortality is more prominent at higher plant densities and narrow row arrangements (Simmons et al., 1982). Heavily tillered plants tend to have smaller culms, leaves and heads (Hamid and Grafius, 1978). Under irrigation near Powell, WY, Lauer (1991) showed higher plant densities (300 vs. 150 m^{-2}) increased kernel plumpness, mass, spikes m^{-2} and kernels spike^{-1}. Fukai et al. (1990) reported increased grain yields with plant densities up to 150 plants m^{-2} with reduced tillering cultivars. They attributed this increase in grain yields to the fact that cultivars which rapidly developed canopy cover and had the highest leaf area also had the higher dry matter production. Plants with more leaf area were more efficient at photosynthesis than those with less leaf area. This increased light inception was essential for grain fill.

In Minnesota using a malt cultivar ‘Excel’ and seeding rates of 48, 72, 95, 191, and 477 kg ha^{-1}, Frank (1993) observed a “crowding effect” with populations of 191 and 477 kg ha^{-1} with those plants producing only one shoot per plant. As seeding rates increased, the plants tended to become more uni-culm in stature and did not tiller. The optimum seeding rate for this trial was 95 kg ha^{-1}. It was their conclusion that although the lower seeding rates increased capacity to tiller, they did not have the photosynthetic capacity of the intermediate (95 kg ha^{-1}) seeding rate. This moderate rate was supported by the work of Green (1990) who reported that seeding rates of 65, 95 125 and 155 kg ha^{-1} had a significant quadratic and linear response. No differences were seen above 95 kg ha^{-1}. Seeding rates higher than 95 kg ha^{-1} were not economically justified because of the increased seed input costs per unit of yield. This is supported by McFadden (1970) who illustrated near Lacome, Alberta that a moderate seeding rate (67 kg ha^{-1}) in their environment was optimum compared to 40 and 94 kg ha^{-1}. In this trial as seeding rates increased, maturity dates were one to two days earlier than those of the lower seeding rates.

In a study conducted near Indian Head, Saskatchewan, Lafond and Derksen (1996) used three row widths and six seeding rates for wheat and barley under a conventional tillage fallow management system. Varying row spacing did not affect spike density, kernels spike^{-1}, seed weight or grain yield for either wheat or barley. No row spacing by seeding rate interaction was observed in either crop. Yield was increased 32 and 14 % for barley and wheat, respectively as seeding rate increased. Yield relationships, as a function of seeding rate, were generally similar for the two crops, but a greater impact of increasing seeding rates was observed in barley (Figure 5).

Recently cultivars of winter wheat have been investigated for their response to seeding rate (30 and 60 kg ha^{-1}), and row spacing (180 and 360 mm) (McLeod et al., 1996). Winter wheat cultivars responded with the same trends reported in barley in that row spacing did not drastically affect yields. Plant populations of these winter wheat cultivars were directly related to the grain yields observed. As in barley, when moisture was a limiting factor, the “seeding rate” rarely affected the grain yields and if it did, it favored the lower planting rates. McLeod et al. (1996) felt the competition threshold was reached as evidenced by the interaction of seeding rate and row spacing. The recommendation for winter wheat planting rates for the semi-arid prairie region of Canada from this research is 60 kg ha^{-1}. Even under moisture stress, yields tended to favor the lower seeding rate. The potential of better yields associated with average or above average moisture and the increase in yields outweighed the lower seeding rates at current seed prices.

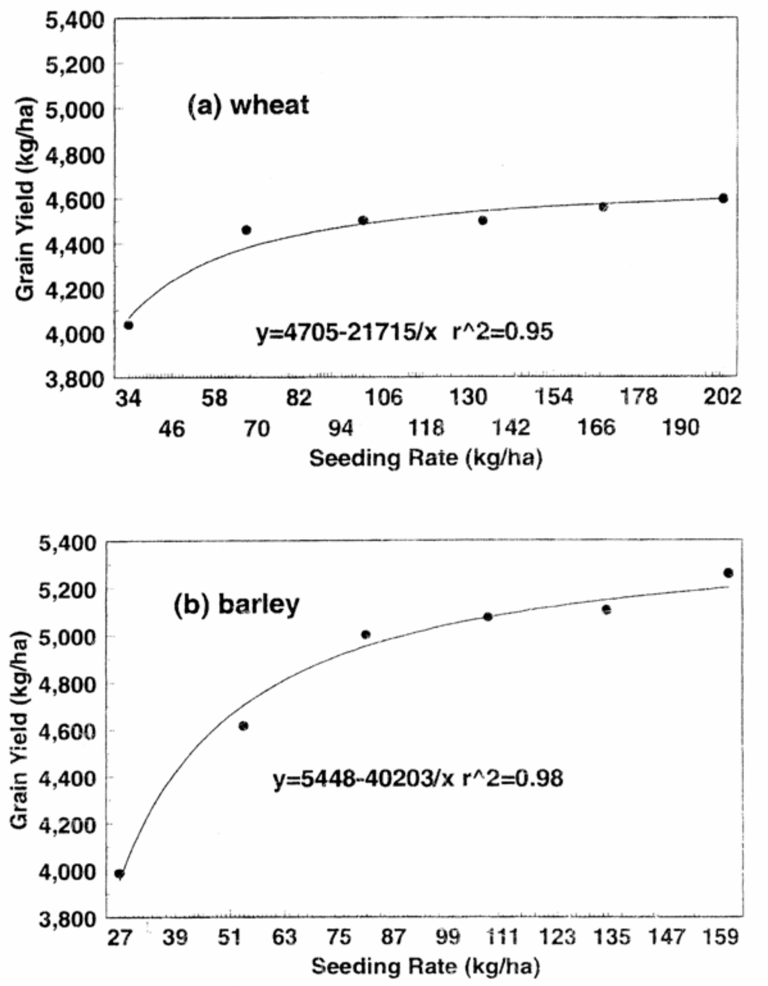


Figure 5. Response of grain yield to seeding rate in (a) spring wheat (‘Biggar’) and (b) barley (‘Harrington’) at Indian Head, SK. Adapted from Lafond and Derksen (1996).

In Lacombe, Alberta, three seeding rates (250, 375 and 500 seeds m^{-2}) were used to evaluate the yield and quality of cereal forages of barley, oat and triticale (Juskiw, 2000a). The authors reported a decrease in the leaf, stem and spike weights $plant^{-1}$ as population increased. This was an expected result as reported earlier and is in agreement with other reports. As the plant population increased, decreased tillering was observed, and despite pronounced effects of plant density on a per plant basis, little effect on the forage or biomass on a land area basis was observed. This reduction of tillers was associated in increased concentrations of acid and neutral detergent fiber possibly related to increased numbers of main stems versus tillers. (Juskiw et al., 2000a)

Nitrate Accumulation and Toxicity

Nitrogen compounds are important for all living organisms. All enzymes are proteins; all amino acids need some form of carbohydrate backbone in which to place the N to form a protein (Meyer et al., 1960). The carbohydrates come from CO_2 fixation created by the plant from photosynthesis. All but approximately 5% of the dry matter in crops is derived from photosynthetic CO_2 assimilation (Xu and Shen, 2002).

Plants can take up and utilize four types of N compounds, nitrate, nitrite, ammonium and organic N compounds (Meyer et al., 1960). The source most readily taken up by plants is nitrate. Upon entering the plant, nitrate has two immediate fates. It will either be stored in a vacuole or reduced. Vacuole accumulation of high nitrate levels may lead to metabolism problems if the forage is fed to ruminants. Nitrate is rapidly reduced either in chloroplasts (primarily in the leaf of cereals; Mickelson et al., 2003) or the plastids in roots. Nitrate is reduced to nitrite by the enzyme nitrate reductase (NR) and occurs in the presence of nicotinamide adenine dinucleotide (NADH) as an energy source to drive the reaction (Crawford, 1995). Important co-enzymes and minerals are molybdenum (Mo) and flavin adenine dinucleotide (FAD). Nitrites are further reduced to ammonia (NH_3) by nitrite reductase (NiR), a toxic compound at high levels; however NH_3 is almost immediately metabolized in the synthesis of amino acids (AA) or other N containing compounds (Meyer et al., 1960). Glutamate provides the initial carbon skeleton in amino acid synthesis (Crawford, 1995).

Nitrates (NO_3^-) can accumulate in plants or be found in water sources, and when consumed at elevated levels ruminants can become ill or even die (Wilson, 1943). Wright and Davison (1964) report the original citation of toxicity in cattle grazing corn stubble in Kansas when several animals died. Levels of KNO_3^- representing levels of nitrates observed in the corn stalks reproduced the effect when test animals were fed at that level; cattle also became ill and died.

Nomenclature for nitrates in plants or animals is varied and to discuss nitrates effectively they must be converted to one common level. Conversions can be seen below. Nitrate nitrogen is the most widely accepted (NO_3^- N) reporting form.

$$1 \text{ nitrate nitrogen } (NO_3^- N) = 4.43\ NO_3^- = 7.22\ KNO_3 = 6.07\ NaNO_3$$

The nitrate ion is not the causative agent in the toxicity seen in ruminants. Nitrate is reduced by the rumen flora to nitrite (NO_2^-) and is the causative agent of the infliction. Absorption of NO_2^- occurs across the rumen and is absorbed by blood. Nitrite is 10 times more toxic than nitrate (Aiello, 2003). Red blood cells are made up of hemoglobin; an iron (Fe) containing compound. The hemoglobin is rapidly oxidized from Fe^{+2} to the ferric (Fe^{+3}) form in the presence of nitrites and methemoglobin is made. The resultant methemoglobin is incapable of carrying oxygen to the lungs and the animal actually suffocates when 70 to 80% of the oxygen carrying capacity of hemoglobin in blood has been converted to methemoglobin (Emerick, 1988).

Associated secondary affects occur in that vasodilatation of smooth muscle tissue occurs when nitrates are present (Aiello, 2003). Acute signs will appear from one to four hours following consumption and death usually will occur in 12 hours or less. Toxicity can be either acute or chronic; levels of toxicity are outlined in Table 4. Symptoms of both are consistent with what would be observed in anoxia (absence of oxygen) in livestock, such as, an increase in heart rate and respiration, labored breathing, muscle tremors and weakness. Inflicted animals may lay on their sides with their mouths open. Membranes of the mouth, nose and eyes become oxygen deficient, and will no longer be pinkish in color and will become darker and the blood will appear to be a brownish (chocolate) color (Emerick, 1988; Aiello, 2003).

Chronic signs of nitrate poisoning in ruminants have included decreased appetite (Davison et al., 1964), weight loss (Wright and Davison, 1963; Hatfield and Smith, 1963), abortion (Davison et al., 1964), Vitamin A deficiency symptoms (Hatfield and Smith, 1963), reduced fertility (Bennet et al., 1968) and reduced milk production (Aiello, 2003). Some or all of the above etiologies have failed to be produced in balanced high energy diets such as in lactating dairy cows fed sub-lethal doses of potassium nitrate sprayed onto their diets (Jones et al., 1966). Symptoms listed above may or may not be present in a chronic poisoning depending upon the animal, adaptation to and levels of nitrate being ingested (Davison et al., 1964).

Table 4. Effect of nitrate concentration on livestock. Adapted from Cash et al. (2002). Note: These guidelines for Montana are more conservative than those published from other states.

Reported on 100% dry matter basis* as:

NO_3-N, ppm	NO_3, ppm	Comment
<350	<1500	Generally safe for all conditions and livestock.
350-1130	1500-5000	Generally safe for non-pregnant livestock. Potentially early-term abortions or reduced performance. Limit use to bred animals to 50% of total ration.
1130-2260	5000-10,000	Limit feed to 25-50% of ration for non-pregnant livestock. DO NOT FEED TO PREGNANT ANIMALS – may cause abortions, weak calves and reduced milk production.
>2260	>10,000	DO NOT FEED. Acute symptoms and death.

*If nitrate content of a feed is reported on an “as is” basis, convert to 100% dry matter basis to compare it to levels in this table. For example, silage at 50% moisture that contains 600 ppm NO3-N on an “as is” basis contains 1200 ppm on 100% dry basis; thus it fits the second group in this table.

Lethal dose where 50% of the animals die (LD50) is the usual chemical poisoning levels reported when discussing toxicology. In cattle, the LD50 has been reported to be approximately 160 to 224 NO_3^-N mg kg^{-1} when fed with or as a roughage source and single dose drench toxicities at 74 NO_3^-N mg kg^{-1} (Wright and Davison, 1964). Emerick (1988) cited levels of single dose toxicity for ruminants on poor quality high forage diets that usually induced death at 75 to 90 NO_3^-N mg kg^{-1} body weight. LD50 is not normally used in discussions; rather the levels that will induce morbidity and toxicity in various units are discussed. These levels are greatly influenced by the animal and whether or not the animal is adapted to high levels of nitrates (Davison et al., 1964). Rumen microflora that have been adapted to higher nitrate feeds may have the ability to withstand higher levels of nitrates than animals that are rapidly changed to, or that consume novel high nitrate feeds (Sokolowski et al., 1960; Alaboudi and Jones, 1985; Laven et al., 2002). Contributing to the toxic dose of nitrates is the level of carbohydrate the animal is consuming. Higher levels of carbohydrates provide for more rapid conversion of nitrite to microbial protein and reduce the amount of nitrite for absorption across the rumen wall (Emerick, 1988). Silages have been reported to release nitrates more rapidly than dry forages in the rumen environment.

Nitrate toxicity is usually not identified until the inflicted animal or animals have died. If identification is made prior to death, the only course of treatment is slow administration of 1% methylene blue solution given intravenously at a level of 4 to 22 mg kg^{-1} body weight or more to reduce the methemoglobin level (Aiello, 2003). Reduced activity level and removal of animal from the nitrate cause is paramount to insure survival of the animal.

All plants must contain some level of nitrate for metabolism to occur. Plant sources include cereals, weeds and vegetables that are accumulators or that have been grown under drought conditions, shading, some form of injury, frost damage, high levels of N in the soil, or improper balance of soil nutrients (Wilson, 1943; Crawford et al., 1961; Undersander et al., 1999). Corn (*Zea mays*) and other grasses have been identified as accumulators under the above situations and have been shown to accumulate the highest levels in the stalk or stem, specifically in the lower portions (Wilson, 1943; Wright and Davison, 1963). Vough et al. (2000) reprinted a table depicting the response of corn to drought. Nitrate-N reported in ppm are ranked as: ears (17), leaves (64), Upper 1/3 stalk (153), Middle 1/3 stalk (803) and lower 1/3 stalk (5524). The whole plant sample was 978 ppm NO_3N. Wilson (1943) reported the same trend, which nitrate accumulated in highly fertilized corn below the ear. Raising the cutting height of the plant at harvest will reduce DM yield but will also reduce the chance of having higher nitrate levels in the plant. Leafy vegetables, rape (*Brassica campestris* L.), Chinese cabbage (*Brassica chinensis* var.) and spinach (*Spinacia oleracea* L.) accumulate the highest level of nitrates in the petiole and stem rather than the leaf and root tissues. Levels of NO_3^-N increased as availability of nitrates to the roots was increased (Chen et al., 2004). Nitrate reductase appeared to plateau at the mid point of nitrate accumulation, apparently indicating a limit to the amount of nitrates the plant can assimilate. Nitrate reductase activity has been decreased due to shading, either self or mutual, with very high populations (Zieserl et al., 1963).

Plant species differ markedly on the amounts of nitrate accumulated; oats > barley > triticale in a trial conducted near Edmonton, Alberta under similar management and harvest maturity levels (Khorasani et al., 1997). Some accumulators include the above listed cereals, sorghum, beet tops and several weeds (Yaremcio, 1991). Grasses (crested wheatgrass and Altai and Russian wild ryegrasses {*Leymus angustus* and *Psathrostachys juncea,* respectively}) under fertilization rates above 200 kg N ha^{-1} accumulate NO_3^-N levels that can be toxic under pasture scenarios (Lawrence et al., 1981).

Retention of nitrates as the plant matures appears to be highest in oats (Khorasani et al., 1997; Westcott et al., 1998) when compared to other cereals. Plants rich in young, succulent, actively growing tissue have elevated levels of nitrates. As plants begin to mature from boot to harvest, nitrate concentrations follow either a linear (oats and triticale) or curvilinear (barley) relationship decreasing nitrates as plant maturity increases (Khorasani et al., 1997). Oats retained higher concentrations of nitrates than triticale which was intermediate and higher than barley. Legumes have also even been shown to accumulate elevated levels of nitrates (Wilson, 1943).

Barley cultivars differ in whole plant forage quality and nitrate-N accumulation. Haybet had lower NDF (55.69 and 61.04 %), ADF (29.00 and 34.49 %), and nitrate-N (0.18 and 0.46%) levels than ‘Westford’ barley (Surber et al., 2001). Both barleys are hooded and are used extensively in Montana as forages. Although all nitrate-N levels in this study were at toxic concentrations to pregnant animals, Haybet could be fed to non-pregnant animals if blended with forages that did not contain nitrate-N with balanced rations and best management practices. Westford barley forages from the trial should not be fed to pregnant animals. As would be predicted by equations for intake and digestibility, the higher quality Haybet should produce better performance when fed to most classes of ruminants (Mertens, 1987). When fed to steers in a 59 d backgrounding trial, Haybet produced better animal performance than the Westford fed steers (Robison et al., 2001).

Barley and oat cultivars have been shown to differ in forage quality (ADF, NDF and N), IVDDM and ISDMD and these differences have been correlated to be under genetic control and heritable (Stuthman and Marten, 1972; Surber et al., 2000; Surber et al., 2001; Mickelson et al., 2003). Heritability levels may allow reasonable progress with focused breeding programs. Globally, increasing annual forage quality has targeted neutral detergent fiber digestibility (NDFD) regardless if the forage contains a grain fraction or not (corn or cereal annual forages; Barrière et al., 2003).

GRAIN PRODUCTION AND YIELD COMPONENTS

Introduction

In Montana, barley is currently second only to wheat for crop area at over 400,000 hectares and constitutes approximately $90 million in gross revenue to the state's economy (Montana Agricultural Statistics, 2006). Although premiums are paid for malt quality barley, the crop is generally grown for grain and utilized as a livestock feed. However, barley planted solely for forage production has been increasing rapidly in recent years (Montana Agricultural Statistics, 2006). One reason that this phenomenon is occurring is diversified producers do not need to purchase additional equipment to use cereals as forages since similar seeding equipment and harvesting techniques can be used as alfalfa (Helsel and Thomas, 1987).

Cereal grain yields are attributed to three yield components; spikes per unit area, kernels per spike, and kernel mass (Sprague, 1926). These sequentially determined components collectively determine how much the cereal produces and any change in one or more of the components can generate a change in either direction for overall grain yield. These yield components are affected by various plant and environmental interactions. Adams (1967) felt that the developmental plasticity of the yield components helped maintain yield in various environments, one or more components could compensate for the others, a “buffered yield system”. Yield components act independently and sequentially as cultural and climatic conditions change to stabilize the yield of cereals (Freeze and Bacon, 1990).

When discussing plant population, it is vital to understand and consider the expected annual precipitation, soil type and past and present fertility. Management inputs should be tailored to local production areas. Seeding rates should be recommended according to long term environmental conditions in which the crop is going to be grown (McFadden, 1970) and this recommendation will vary from region to region (Miller, 2001). Pant (1979) describes the relationship of yield to population as a competition between plants for necessary resources explaining that a plant can only recruit those resources from a limited area or its immediate vicinity (influence zone). This influence zone is potentially affected by a great number of abiotic and biotic factors.

It has been generally accepted that grain yields are unaffected by seeding densities, but have been responsive to “arrangements” as long at the populations are not excessively low or high (Brinkman et al., 1979; Briggs, 1975; Finlay et al., 1971). As row spacing decreased from 300 mm to below 180 mm, grain yields generally increased, however the magnitude was variable. This variability is potentially related to differences in environment, cultivar, crop (barley or wheat) and inconsistent plant densities. This trend of increasing grain yield as row spacing decreases was attributed by Holliday et al. (1963) to the plant’s ability to make more efficient use of light for photosynthesis earlier in their life and the ability to tiller more profusely. There is reduction of intra-specific competition; each individual has greater access to more plant growth factors (light, water and nutrients). Increased yields attributed to this phenomenon is most often observed in non-moisture limiting environments (Marshall and Ohm, 1987), however yields have been shown to be unresponsive to narrow row spacing within the same plant densities in water constrained environments (Finlay et al., 1971).

Barley plant densities have been linked to tiller production (Kirby and Faris, 1970; Kirby and Faris, 1972; Simmons et al., 1982). Early emerging tillers contribute more to grain yield than do tillers that emerge later and tiller mortality is more prominent at higher plant densities and narrow row arrangements (Simmons et al., 1982). Heavily tillered plants tend to have smaller culms, leaves and heads than neighbors under lower populations (Hamid and Grafius, 1978). Increased grain yields were attributed to the fact that cultivars which rapidly developed canopy cover and had the highest leaf area also had the higher dry matter production. Plants with more leaf area were more efficient at photosynthesis than those with less leaf area. This increased light interception is essential for grain fill (Fukai et al., 1990).

Recently modern no-till technologies have been compared to traditional conventional tillage techniques and responses have been similar with yields not being affected by tillage technique or seeding rates. Generally, low seeding rates increased the number of spikes plant^{-1} and the weight of single spikes, but decreased the number of spikes per unit area (Carr et al., 2003; Schillinger, 2005). Modern seeding technologies have not been investigated with locally adapted cultivars. Barley's response to seed band width and varying plant populations have not been adequately explored for grain quality or quantity. The objective of this research was to evaluate the effects of altering seed band width, seeding rate and cultivar on barley yield components and grain yield using modern no-till technologies under dryland production conditions in the Northern Great Plains.

Material and Methods

A spring-established experiment was conducted for three years (2001, 2002 and 2003) at Montana State University, Northern Agricultural Research Center; Hill County southwest of Havre, MT. The soil was a Telstad clay loam, (fine-loamy, mixed Aridic Argiborolls). Plots were established on no-till chemical fallowed two-year old undisturbed stubble using an experimental size 'Concord'[1] air drill (Case IH, 700 State Street Racine, WI 53404 USA). The drill is identical (mechanically) to a commercial size drill, consisting of 10 rows spaced 305 mm apart. The shanks are fitted with 'Farmland' SB1, double-shoot seed and fertilizer boots (Farmland Specialty Products, RR #4, Red Deer, Alberta, T4N54E) equipped either with 102 mm sweeps plus reverse spreaders to restrict the seed band width (narrow); or 254 mm sweeps plus 'SBS2' spreaders (wide) to produce a wider banding pattern. The drill was configured with 'Titan' (Titan International Inc, 2701 Spruce Drive, Quincy, Illinois, 62301) 152 mm square-wall packer wheels to insure proper seed to soil contact. All treatments were seeded 38 mm deep. Fertilizer was distributed as a granular blend during the seeding operation via the backswept knife at a rate of 78 kg ha^{-1} N, 45 kg ha^{-1} P_2O_5 and 28 kg ha^{-1} K_2O. Fertilizer rates were consistent across all years and were determined for historic

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[1] Mention of product names and equipment does not imply endorsement by the authors or Montana State University.

yields of feed barley and recommendations for Montana soils for no net loss of fertility (2365 kg ha^{-1}, Jacobson et al., 2003).

The plots consisted of ten rows and were 15.24 m long and 3.0 m wide. The factorial treatment arrangement consisted of cultivar, band width and seeding rate. Cultivars tested were 'Harrington' (Harvey and Rossnagel, 1984) and 'Haybet' (Hockett et al., 1990). Harrington and Haybet are the number one and two most prevalent cultivars grown in Montana in recent years (Montana Ag Statistics, 2006). Harrington is a malt type cultivar whereas Haybet is used as an annual forage. The band widths evaluated were narrow and wide, as previously described (Fig. 6). Seeding rates of 140, 184 and 226 seeds m^{-2} were used and represent recommended seeding rates for barley intended to be harvested as grain for malt, feed and annual forage, respectively (Hensleigh et al., 2001). Seeding rates were established on a pure live seed basis and 1000 kernel weights. The twelve treatment combinations were arranged in a randomized complete block with six replications.

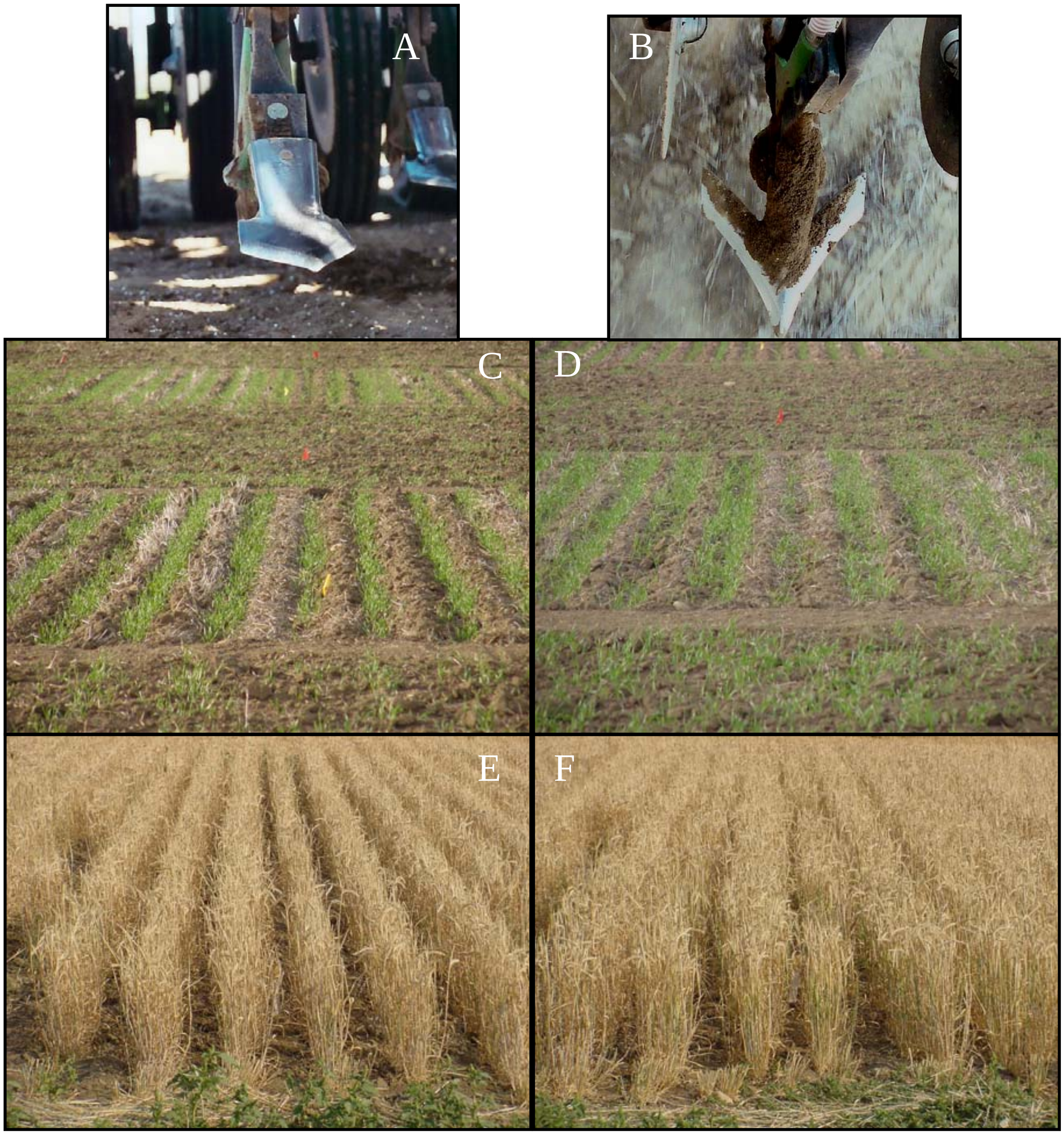

Figure 6. Photos represent illustrations of narrow and wide sweep, spreader and plant configurations. The shanks are fitted with ‘Farmland’ SB1, double-shoot seed and fertilizer boots equipped with 102 mm sweeps plus reverse spreaders (reversed to neck down the seed to simulate traditional narrow hoe or disk drill openers; photo A) and 254 mm sweeps plus ‘SBS2’ spreaders to represent a wider banding pattern utilizing more open space between the row spacing without altering shank spacing (photo B). Photo C and D are early growth photos of narrow and wide band widths produced at median seeding rate to illustrate differing seed placement configuration. Photos E and F are late (pre-harvest) photos of narrow and wide band widths produced at median seeding rate (184 seeds m^{-2}) to illustrate differing seed placement configuration.

Trials were established on May 15, 2001, May 18, 2002 and May 17, 2003. Environmental data for each year are presented in Table 5. Agronomic, soil, and previous crop information is presented in Table 6. Weeds were controlled with post-emergence herbicide applications of bromoxynil (3, 5-dibromo-4-hydroxybenzonitrile) + MCPA {(4-chloro-2-methyphenoxy) acetic acid}).

Table 5. Over winter and monthly growing season precipitation and average temperatures for 2001, 2002 and 2003 trial years at Northern Agricultural Research Center (48° 30' 2" North, 109° 47' 25" West), Havre, MT.

Year	Sept-Apr[†]	May	June	July	August	Total/Mean
			precipitation, mm			
2001	118	11	36	51	9	225
2002	55	45	117	57	62	336
2003	142	49	78	10	14	293
86-year ave[‡]	126	45	65	37	31	304
			temperature, °C			
2001	-0.3	14.7	17.2	22.4	22.2	6.2
2002	0.9	10.1	16.8	22.2	17.5	6.2
2003	1.6	11.8	17.0	23.3	23.5	7.4
86-year ave[‡]	0.4	12.6	17.0	21.0	20.0	6.2

[†] Over winter precipitation preceding the respective growing season.

[‡] Long term, 86 year (1918-2003) precipitation and temperature values.

Stand counts were measured approximately 30 d after seeding (plants m^{-2}) at random locations within rows five and seven using a 914 mm long transect. Biomass samples were hand harvested (910 mm) at random locations within row two of the ten row plot 7 d after the soft dough stage was observed (Zadoks 80 to 83; Zadoks et al, 1974). The biomass measurements do not represent physiological maturity. The heads were separated from the remaining biomass. Samples were dried in a forced air oven at 50°C for 48 hours. The spikes and remaining plant biomass were weighed for plant biomass, spike weight, harvest index (spike weight divided by the whole plant biomass) and to determine the number of spikes m^{-2}. Forage samples were ground to pass a 1 mm screen in a Wiley mill (Arthur H. Thomas Co., Philadelphia, PA) to evaluate dry matter and nitrogen content (AOAC, 2002). Apparent nitrogen uptake for above ground biomass was calculated as whole plant DM yield multiplied by the whole plant above ground nitrogen content.

Table 6. Agronomic, soil and previous crop information for barley banding trial conducted at Northern Agricultural Research Center, Havre, MT†.

	2001	2002	2003
		Agronomic	
Previous year ‡	Chemical Fallow	Chemical Fallow	Chemical Fallow
Previous crop§	Winter Wheat	Spring Barley	Winter Wheat
Planting date	May 15	May 18	May 17
Planting depth, mm	38	38	38
Fertilizer, kg ha^{-1}¶	78-45-28	78-45-28	78-45-28
Herbicide date#	--	June 18	June 14
Grain harvest date	August 28	August 23	August 14
		Soil	
Classification	Aridic Argiborolls	Aridic Argiborolls	Aridic Argiborolls
Texture	Telstad clay loam	Telstad clay loam	Telstad clay loam
OM, %	--	0.9	0.9
pH	--	7.6	8.0
NO_3-N, kg ha^{-1}	--	102	126
Soil Temp at planting			
51 mm Temp, °C	--	18.3	15.0
102 mm Temp, °C	--	15.6	11.1

† Location 48° 30' 2" North, 109° 47' 25" West.

‡ Chemical fallow by glyphosate application as required.

§ Previous crop was two years prior to trial year.

¶ 78 N, 45 P_2O_5 and 28 K_2O kg ha^{-1}. Nutrients required for no net loss of soil fertility for a 2365 kg ha^{-1} feed barley grain yield.

Weeds were controlled with post-emergence herbicide applications of bromoxynil (3,5-dibromo-4-hydroxybenzonitrile) + MCPA {(4-chloro-2-methyphenoxy) acetic acid}).

The crop was combined at harvest maturity with a small plot combine harvesting only the five center rows. Test weight and grain moisture content were obtained for each plot using a Dickey-John Corp. GAC 2100 grain analyzer (Auburn, Ill.). Grain protein was determined via NIR technology for each plot and was adjusted to 120 mg kg^{-1} grain moisture content. After combine harvest, using standing stubble, culm counts and whole plant counts (culms plant^{-1}) were taken at random locations within rows five and seven using a 914 mm long transect. Band width was measured twice within this same transect and averaged for each plot.

Data were analyzed using the GLM procedure in SAS (SAS Inst., 2000). Fixed effects were year, cultivar, band width and seeding rate with rep within year as the random term. The experiments were analyzed across years since error variances were homogeneous. Least squares means were obtained for cultivar, band width and population. When the F-tests indicated a significant ($P < 0.05$) main effect x year interaction, the 'slice' command was used to determine treatment effect within each year. Least squares means are reported with associated standard errors. Planned orthogonal comparisons for plant populations and respective interactions were tested for linear and quadratic responses. In year 2002, blocks 4 and 5 were removed from the data set because of a severe unexplained emergence problem.

Results and Discussion

Climate

Precipitation patterns and temperatures indicated deviation from the 86 year averages in each of the three years (Table 5). In both 2001 and 2003, the September to April precipitation prior to planting was near long term averages and the crop was established into a full profile of moisture. However, in 2002 the overwinter moisture level was 56% below the 86 year average. Crop year 2002 began with a severe moisture deficiency, however the growing season moisture appeared to adequately make up for the initial moisture deficient, with total rainfall for the year being 105% of normal.

Both 2001 and 2003 were characterized as being in a drought for different reasons. In 2001, the May and June rainfall was dramatically lower than long term. In 2001, crops were able to make use of very timely rains prior to heading in early July (25.5 mm) and above normal moisture levels the remainder of the month. During 2003 the weather was characterized as at or above normal moisture levels during germination and the early vegetative growth stage, however from early July through harvest, the temperatures were elevated above long term averages with excessive winds and rainfall was 73% lower than long term averages. The 2003 crop endured severe heat and water stress just prior to heading, throughout anthesis and grain fill. Climactic variability likely created several significant two-way interactions for year by main effect for measured traits. Data are presented within year and across all years for main treatment effects (Tables 8, 9, 10 and 11).

Table 7. P-values from the analysis of variance for spring barley plant growth, yield components and grain measurements as affected by barley cultivar (C), seed band width (B), and seeding rate (R).

		Components									Grain					
Source	df	Plant m $^{-2}$	Head Date	Plant ht mm	Culms m $^{-2}$	Culms plant^{-1}	Biomass kg ha^{-1}	Spike* kg ha^{-1}	SBT[†] m^{-2}	Harvest Index	Yield kg ha^{-}	Moisture mg g^{-1}	Density kg m^{-3}	Plumps mg g^{-1}	Thins mg g^{-1}	Grain N mg g^{-1}
Year (Y)	2	0.0010	0.0001	0.0001	0.0186	0.0001	0.0001	0.0001	0.0005	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Cultivar (C)	1	0.9234	0.0001	0.0001	0.0002	0.0088	0.0513	0.0345	0.0001	0.0043	0.0001	0.0001	0.0001	0.0001	0.0001	0.0213
Band width (B)	1	0.0001	0.5276	0.0506	0.4178	0.0942	0.2395	0.4646	0.0369	0.0008	0.0001	0.0479	0.0044	0.9921	0.3902	0.9577
Rate (R)	2	0.0001	0.7273	0.0650	0.3350	0.0001	0.0530	0.0727	0.0034	0.0001	0.0001	0.1507	0.2717	0.2264	0.5105	0.0009
Linear	1	0.0001	0.8250	0.0406	0.6387	0.0001	0.0157	0.3466	0.0018	0.0001	0.0001	0.0938	0.8043	0.2789	0.6625	0.0015
Quadratic	1	0.9545	0.4441	0.2554	0.1616	0.0117	0.8997	0.0366	0.1894	0.3420	0.2753	0.3214	0.1112	0.1794	0.2833	0.0413
Y x C	2	0.0001	0.0001	0.0001	0.5142	0.0009	0.4464	0.0001	0.0017	0.0094	0.0001	0.0001	0.0001	0.0001	0.0001	0.0386
Y x B	2	0.8107	0.0001	0.4257	0.5576	0.0116	0.1576	0.1525	0.0139	0.0231	0.0007	0.4081	0.0073	0.3198	0.0200	0.0001
C x B	1	0.3878	0.4170	0.4231	0.5271	0.4693	0.9531	0.6024	0.1303	0.0259	0.9321	0.7396	0.7400	0.8746	0.3238	0.1151
Y x R[§]	4	0.0001	0.0771	0.2140	0.2503	0.3767	0.3863	0.8901	0.4146	0.0094	0.0001	0.3167	0.0502	0.0272	0.0047	0.0047
C x R	2	0.2846	0.2423	0.0386	0.8092	0.5140	0.9514	0.5362	0.9362	0.3562	0.0019	0.0446	0.0006	0.2537	0.0469	0.0331
Linear	1	0.3651	0.2698	0.9419	0.5175	0.4422	0.7765	0.8284	0.9826	0.2355	0.0004	0.1992	0.0001	0.1084	0.0153	0.0596
Quadratic	1	0.1930	0.2029	0.0109	0.9627	0.3904	0.8911	0.2747	0.7178	0.4178	0.8708	0.0320	0.6297	0.6892	0.6378	0.0682
B x R	2	0.0001	0.0157	0.9457	0.8952	0.2802	0.3133	0.2355	0.2731	0.4559	0.6338	0.4144	0.2001	0.5792	0.9262	0.7885
Linear	1	0.0001	0.0049	0.7402	0.6503	0.1118	0.1534	0.1197	0.3054	0.2607	0.3700	0.2203	0.4466	0.3219	0.8049	0.5963
Quadratic	1	0.1343	0.0697	0.9715	0.9032	0.9776	0.5974	0.4942	0.2133	0.5818	0.7450	0.6129	0.1046	0.3275	0.7620	0.6601
Y x C x B	2	0.0931	0.0512	0.2235	0.6143	0.9278	0.8604	0.6694	0.5571	0.0142	0.0001	0.4614	0.0788	0.2738	0.1070	0.6590
Y x C x R	4	0.0405	0.0028	0.1922	0.3637	0.0622	0.7397	0.9494	0.6566	0.8927	0.0001	0.0028	0.6434	0.8721	0.6796	0.0218
Y x B x R	4	0.0026	0.1823	0.1406	0.8117	0.0886	0.7007	0.4907	0.0995	0.9382	0.5538	0.3591	0.4602	0.7885	0.8307	0.7705
C x B x R	2	0.1638	0.9758	0.8418	0.9916	0.7130	0.3234	0.6718	0.5793	0.9023	0.7457	0.0746	0.1389	0.2601	0.4322	0.2004
Y x C x B x R	4	0.0296	0.5970	0.5717	0.8576	0.7660	0.0750	0.7286	0.0909	0.3565	0.7397	0.8689	0.8670	0.3245	0.8108	0.6403

* Whole spike weight after dissection of spikes from total biomass.

[†] SBT – Spike bearing tillers determined after dissection of spikes from total biomass.

[§] Data was not collected for plant m^{-2}, culms m^{-2}, culms plant^{-1}, spike kg ha^{-1}, SPT m^{-2} in 2001 and df would be reduced accordingly.

Table 8. Least square means for agronomic, whole plant and grain measurements for barley banding trial conducted at Northern Agricultural Research Center, Havre, MT, for the interaction of three seeding rates (140, 184 and 226 seeds m^{-2}) by band width seed placement relationship; narrow, (NARR) and wide (WIDE). The center five rows of the ten row plots were selected for harvest.

Band width		NARR			WIDE	
Trait	140	184	226	140	184	226
			seed m^{-2}			
Band width, mm	125	126	124	197	188	194
Stand, %	90.6	93.6	94.6	93.3	95.2	96.8
Plants m^{-2}	107^{a}	130^{b}	150^{b}	99^{a}	136^{b}	182^{c}
Heading date	197.2	197.1	197.1	197.1	197.2	197.3
Plant ht, mm	506	495	494	496	487	488
Spike count m^{-2}	471	451	472	477	461	494
Spikes $plant^{-1}$	4.8	3.7	3.3	4.9	3.5	2.8
Biomass kg ha^{-1}	4378	4145	4663	4384	4372	4791
Straw wt, kg ha^{-1}	2524	2466	2509	2489	2629	2792
Head wt, kg ha^{-1}	2433	2108	2358	2271	2272	2558
Spike bearing tillers m^{-2}	430	410	471	430	469	510
Whole plant N, mg g^{-1}	19.3	19.7	19.2	19.1	19.2	18.8
Apparent N uptake, kg ha^{-1}	81	80	85	81	82	87
Grain yield, kg ha^{-1}	1506	1401	1370	1427	1313	1238
Grain moisture, mg g^{-1}	90.5	89.9	90.3	90.2	89.5	89.1
Grain density, kg m^{-3}	580	581	582	579	574	578
Plump kernels, mg g^{-1}	415	419	431	426	409	432
Thin kernels, mg g^{-1}	358	361	352	361	371	359
Grain N, mg g^{-1}	27.8	28.2	28.2	27.7	28.3	28.2

[a, b, c] Within band width seeding rates lacking a common superscript differ ($P < 0.05$).

Table 9. Least square means for agronomic, whole plant and grain measurements for 2001, 2002 and 2003 barley banding trial conducted at Northern Agricultural Research Center, Havre, MT, for narrow (NARR) and wide (WIDE) band width seed placement. The center five rows of the ten row plots were selected for harvest so all opener and packer relationships were the same for all treatments. When the F-tests indicated significant differences ($P < 0.05$) for the main effect x year interaction, the ‘slice’ command was used to determine simple year effects.

Trait	2001		2002		2003		Across all Years	
Band width	NARR	WIDE	NARR	WIDE	NARR	WIDE	NARR	WIDE
Band width, mm	111	178	119	190	145	212	125^{a}	193^{b}
Plants m^{-2}	-	-	145	156	109	122	127^{a}	139^{b}
Heading date	204.1	204.0	192.7^{b}	192.5^{a}	194.7^{a}	195.0^{b}	197.2	197.2
Plant ht, mm	420	407	612	612	464	452	498^{b}	490^{a}
Culm m^{-2}	-	-	425	446	505	508	465	477
Culms plant^{-1}	-	-	3.1	3.2	4.8^{b}	4.3^{a}	3.9^{b}	3.7^{a}
Biomass, kg ha^{-1}	3241	3286	6466	6454	3480	3808	4396	4516
Straw wt, kg ha^{-1}	-	-	3114	3094	1886	2179	2500	2636
Spike wt, kg ha^{-1}	-	-	3237	3168	1362	1572	2299	2371
Spike bearing tillers m^{-2}	-	-	504	498	371^{a}	442^{b}	437	470
Whole plant N, mg g^{-1}	19.3	19.3	16.6	16.0	22.4	21.9	19.4	19.0
Apparent N uptake, kg ha^{-1}	76.0	75.9	103.0	108.8	85.1	80.5	82.0	83.0
Grain yield, kg ha^{-1}	1328^{b}	1102^{a}	2499	2456	448	419	1426	1326
Grain moisture, mg g $^{-1}$	92.8	92.7	105.6	104.4	72.3	71.8	90.2^{b}	89.6^{a}
Grain density, kg m^{-3}	644	646	589^{b}	582^{a}	511^{b}	504^{a}	581^{b}	577^{a}
Plump kernels, mg g $^{-1}$	528	537	668	676	70	53	422	422
Thin kernels, mg g $^{-1}$	177	164	101	99	792^{a}	826^{b}	357	363
Grain N, mg g $^{-1}$	30.1^{a}	30.7^{b}	25.6^{b}	25.0^{a}	28.6	28.6	28.1	28.1

\- Data unavailable.

[a, b] Within year and across years, band widths lacking a common superscript differ ($P < 0.05$).

Table 10. Least square means for agronomic, whole plant and grain measurements for 2001, 2002 and 2003 barley banding trial conducted at Northern Agricultural Research Center, Havre, MT, for three seeding rates (140, 184 and 226 seeds m^{-2}). The center five rows of the ten row plots were selected for harvest so all opener and packer relationships were the same for all treatments. When the F-tests indicated significant differences ($P < 0.05$) for the main effect x year interaction, the 'slice' command was used to determine simple year effects.

Trait	2001			2002			2003			Across all Years		
Seeding Rate[†], seeds m^{-2}	140	184	226	140	184	226	140	184	226	140	184	226
Plants m^{-2}	-	-	-	106^{a}	158^{b}	186^{c}	93^{a}	108^{b}	146^{c}	97^{a}	133^{b}	166^{c}
Heading date	204.0	204.1	204.1	192.8	192.6	192.5	194.8	194.8	195.0	197.2	197.2	197.2
Plant ht, mm	427	404	409	618	615	603	459	454	460	501	491	491
Culm m^{-2}	-	-	-	438	436	432	510	476	534	474	456	483
Culms plant^{-1}	-	-	-	4.2	2.8	2.4	5.5	4.5	3.7	4.8^{c}	3.6^{b}	3.1^{a}
Biomass, kg ha^{-1}	3335	3186	2462	6291	6037	7052	3517	3554	3862	4381^{a}	4258^{a}	4727^{b}
Straw wt, kg ha^{-1}	-	-	-	3046	3102	3162	1966	1992	2139	2506	2884	2617
Spike wt, kg ha^{-1}	-	-	-	3252	3044	3311	1452	1336	1615	2352	2190	2464
Spike bearing tillers m^{-2}	-	-	-	474	501	529	388	378	454	430^{a}	439^{a}	491^{b}
Whole plant N, mg g^{-1}	19.8	19.1	18.9	15.7	17.0	16.1	22.1	22.4	21.9	19.2	19.5	19.0
Apparent N uptake, kg ha^{-1}	65.8	60.2	61.0	98.8	102.2	113.6	77.8	79.4	83.7	80.8	80.6	86.1
Grain yield, kg ha^{-1}	1426^{c}	1201^{b}	1016^{a}	2492	2457	2490	481	413	405	1467^{c}	1357^{b}	1303^{a}
Grain moisture, mg g^{-1}	92.8	92.7	92.7	106.1	104.6	104.2	72.2	71.8	72.2	90.3	89.7	89.7
Grain density, kg m^{-3}	642	645	647	586	582	588	511	506	506	580	578	580
Plump kernels, mg g^{-1}	509^{a}	532^{ab}	557^{b}	675	657	685	78	54	52	420	414	431
Thin kernels, mg g^{-1}	189^{b}	172^{ab}	150^{a}	104	109	89	785^{a}	817^{a}	827^{b}	360	366	355
Grain N, mg g^{-1}	29.8^{a}	30.5^{b}	30.9^{b}	25.1	25.5	25.3	28.5	28.8	28.5	27.8	28.2	28.2

[†] Populations represent recommended rates for harvesting the barley crop for malt, feed and forage production in Northern Montana.

[a, b,c] Within year and across all years seeding rates lacking a common superscript differ ($P < 0.05$).

Table 11. Least square means for agronomic, whole plant and grain measurements for 2001, 2002 and 2003 barley banding trial conducted at Northern Agricultural Research Center, Havre, MT, by year for Harrington (HARR) and Haybet (HAY) barley cultivars. The center five rows of the ten row plots were selected for harvest so all opener and packer relationships were the same for all treatments. When the F-tests indicated significant differences ($P < 0.05$) for the main effect x year interaction, the 'slice' command was used to determine simple year effects.

Trait	2001		2002		2003		Across all Years	
Cultivar	HARR	HAY	HARR	HAY	HARR	HAY	HARR	HAY
Plants m^{-2}	-	-	159^b	141^a	106.7^a	125^b	133.1	132.7
Heading date	204	204	193^b	192^a	196^b	193^a	198^b	196^a
Plant ht, mm	382^a	444^b	580^a	644^b	447^a	469^b	470	519
Culm m^{-2}	-	-	411	460	472	538	442^a	500^b
Culms $plant^{-1}$	-	-	2.8^a	3.5^b	4.6	4.5	3.7^a	4.0^b
Biomass, kg ha^{-1}	3400	3126	6647	6273	3410^a	3879^b	4486	4425
Straw wt, kg ha^{-1}	-	-	2968	3239	1948	2116	2195^a	2391^b
Spike wt, kg ha^{-1}	-	-	3509^b	2896^a	1368	1567	2439^b	2231^a
Spike bearing tillers m^{-2}	-	-	490	512	346^a	467^b	418	489
Whole plant N, mg g^{-1}	19.3	19.2	16.7	15.9	21.9	22.4	19.3	19.1
Apparent N uptake, kg ha^{-1}	65.4	59.3	110.4^b	99.3^a	74.3^a	86.3^b	83.4	81.6
Grain yield, kg ha^{-1}	1252	1177	2779^b	2182^a	446	425	1489^b	1258^a
Grain moisture, mg g^{-1}	93^b	92^a	107^b	103^a	76^b	69^a	92^b	88^a
Grain density, kg m^{-3}	654^b	636^a	610^b	561^a	543^b	472^a	602^b	556^a
Plump kernels, mg g^{-1}	$744.^b$	321^a	848^b	497^a	115^b	7.3^a	569^b	275^a
Thin kernels, mg g^{-1}	93	248	53	148	669	950	272^b	448^a
Grain N, mg g^{-1}	30.0^a	30.7^b	25.3	25.3	28.6	28.7	28.0^a	28.2^b

\- No data available.

[a, b] Within year and across all years, cultivars lacking a common superscript differ ($P < 0.05$).

Plant Stand

Plant stand was influence by a significant a four-way interaction for year, cultivar, band width and seeding rate (Table 7). The two-way interaction of band width x seeding rate illustrates the significant difference in the high seeding rate between band widths (Fig. 7). Treatment plant populations (plants m^{-2}) were all substantially (27.6 %) below target populations calculated from pure live seed (Table 8). Target plant populations have been reported for several no-till trials to be substantially lower than predicted by seeding rates (Carr et al., 2003; McKenzie et al., 2005; Schillinger, 2005) where between 60 and 85% of viable live seeds sown became established as plants, in agreement with our trial in which 72 % of the seed sown became established plants. The wide band width configuration exhibited an increase in plants m^{-2} that was targeted with the three seeding rates, however within the narrow seed band width plants m^{-2} was not different for the 226 and the 184 seeds m^{-2} resulting in a band width by rate interaction. Both the narrow and wide band widths had a linear response to seeding rate (Fig. 7).

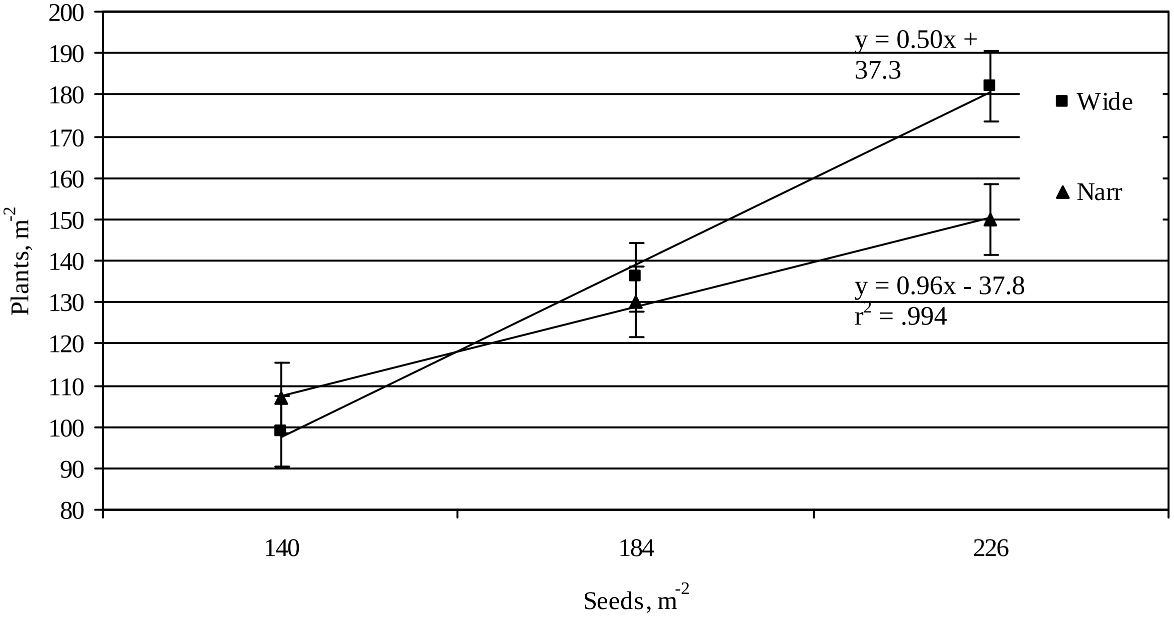

Figure 7. Established plant population (plants m^{-2}) for three seeding rates (140, 184 and 226 seeds m^{-2}) and two band widths, narrow (NARR) and wide (WIDE) for spring a barley banding trial conducted at Northern Agricultural Research Center, Havre, MT, for 2001, 2002 and 2003. Least squares means are reported with the standard error represented by bi-direction error bars.

This interaction may have been caused in this trial by the very narrow fissure created and the wide packer wheel configuration, not allowing proper seed to soil contact at the highest population. As seeding rate increased more seed was packed into the narrow furrow without a direct packing and fissure closing effect as would be seen with a narrow heavy packer wheel. This result of the narrow band width having a reduction of established plants is opposite of that reported by O’Donovan et al., (2005) and McLeod et al., (1996) for barley and wheat, respectively. Unlike the current trial, the wide band width seed placement had lower established plants than the narrow resulting from a narrow packer wheel configuration. The narrow packer wheels were not packing the entire width of the sweep creating the wide band width. Previous research dictated increasing the packer wheel width configuration before this trial was initiated. Apparently in this trial the limitation on the wide pattern (125 vs. 193 mm) was limited by the effective width of the packer wheel 152 mm and the seed spreader since the effective width of the sweep was 254 mm.

Salt toxicity does not appear to be a factor affecting population. If this were the cause of the decreased established plants m^{-2} a corresponding decrease would be expected in all seeding rates. Each of the two lower seeding rates did not exhibit this relationship, apparently in agreement with McKenzie et al., (2005) as they found that the nitrogen source was safely separated below the seed to prevent it from creating a toxic area for the germinating seed. Similar apparent N uptakes among treatments (Table 8 and 9) may indicate that all treatment combinations (band width and seeding rate combinations had equal opportunity to recruit provided nutrients, $P > 0.05$) and did not limit growth of the plant. Applying the fertilizer with the backswept knife below the seed and spreading the plants away from the center of the rows with the wide spreader and large sweep did not impede nutrient availability to the wide arrangement. Barley’s lateral roots can spread from 150 to 300 mm (Pant, 1979). In this trial, with fixed shank spacing (305 mm) and only band width being altered, the barley roots had equal access to fertilizer and light inception for either band width. In this trial and others, as long as fertilizer is not in direct contact or applied very close to the seed creating a toxic environment for the seedling, the newly emerged seedling has easy access to the fertilizer being knifed in 50 mm below the seed (Varvel and Severson, 1987; Clancy et al., 1991).

There was an interaction between cultivar and year resulting in higher plants m^{-2} for Harrington in 2002 and Haybet in 2003 (Table 11). McKenzie (2005) reported differences in two and six-row barley cultivars in response to established plants m^{-2} seeding rates attributing that to vigor among seed lots. When evaluated across years, plant stands of both cultivars increased linearly with increasing seeding rates (Table 7). Cultivars in this trial appeared to react equally across seeding rates, as in previous trials reported by Jedel and Helm (1995).

Yield Components and Grain Yield

The bandwidth by seeding rate interaction for plant stand may have indirectly masked the effects band width may have had on yield components. Band widths resulting from the narrow and wide arrangements were different (Table 9). Within a given seeding rate the seed was distributed in a wider band than the narrow band width, in theory the interplant competition may decrease, potentially allowing the plant to exhibit predicted increases in tillering and spikes m^{-2}. The plant was shorter, tillered less and appeared to mature slightly faster than the narrow band width. When evaluated across years, affects of band width on plant height, culms plant^{-1}, grain yield and grain density (Table 9) were different from literature reports if indeed competition was reduced (Holliday et al., 1963; Marshall and Ohm, 1987) by spreading the seed across a wider area with the same population. It would appear that band width reacted more like what would be expected to increasing interplant competition by increasing from a narrow to wide band width, illustrating what would appear to be a masking affect of band width by the seeding rate imposed on the trial.

Seeding rate altered yield components and grain characteristics (Table 10). When the interaction of year x seeding rate was significant it was in magnitude rather than direction. Plant biomass was increased with increasing seeding rates along with spike bearing tillers m^{-2}. Culms $plant^{-1}$ was decreased linearly (Table 7) as seeding rate increased from 140 to 226 seeds m^{-2}. The reduction of culms m^{-2} seen as seeding rate increased in this trial is in agreement with other data from Minnesota using the malt cultivar ‘Excel’ (Frank, 1993) and data reported from Alberta (Schillinger, 2005) using Baronesse spring barley with seeding rates 120, 200 and 280 seeds m^{-2}. In these trials, spikes m^{-2} was stabilized by this tillering effect and did not change across seeding rates. However in our trial, when plants were dissected and the spike bearing tillers were removed no difference was seen between 140 and 184 seeds m^{-2} which were both lower than the 226 seeds m^{-2} (Table 10).

Grain yield was affected dramatically by year (Table 10). In 2001 grain yields were greatest for the lowest seeding rate and decreased linearly as seeding rate increased. As seeding rates increased interplant competition increased, plump kernels were increased, thin kernels decreased and grain N content increased, in agreement with previous research (Jedel and Helm, 1995). This year was characterized as early drought with substantial moisture shortly after emergence occurred. However in years 2002 and 2003 seeding rate did not affect grain yields. In what was considered an average year

(2002) seeding rated did not impact grain yield or quality. No combination would pass for malting quality due too few plump kernels, too many thin kernels and too high of N content. In 2002 and 2003 higher seeding rates were not justified economically since grain yields did not respond to higher seeding rates. Evaluated across all years the lowest seeding rate increased grain yield over the other higher seeding rates (Table 10). The seeding rates were 30% higher than achieved plant m^{-2} and no quadratic effect was observed for seeding rate perhaps even lower seeding rates may need to be evaluated to better understand this yield component compensation on stabilizing yield as no-till technology is increased in the Northern Great Plains.

Yield components and grain yield were affected by cultivar and significant two-way interactions with cultivar were characterized by changes in magnitude rather than rank (Tables 7 and 11). When evaluated across years Harrington consistently produced shorter, later maturing plants and tended to have a lower capacity to tiller in this trial than Haybet. Yield component and yield characteristics were not dramatically different from long term data comparing Harrington and Haybet, and are consistent with expectations for Harrington being developed for grain production and Haybet for its forage qualities (Hensleigh et al., 2004). In Montana environments Haybet has consistently lower yields, test weight, greater proportion of thin kernels, lower plump kernels, and elevated N content compared to Harringon. In 2003, a very severe drought year Haybet had higher total biomass. Across years no difference was detected in total biomass; however Harrington had higher spike weights with reduced number of spikes m^{-2}.

Conclusions

In the semi-arid Northern Great Plains of Montana using air drill technology, bandwidth (spreading the seed out between the rows) and seeding rates (140, 184, and 226 plant m^{-2}) were altered by different opener and packer wheel configurations. Although research years were highly diverse some generalizations can be made. Malt quality was never achieved and no treatment combination aided in moving the quality towards an acceptable malt grade of barley. Perhaps additional research may be needed to determine if even lower seeding rates would aid in grain fill thereby increasing plump kernels and decreasing the N content.

Feed barley production was greatest in 2001 for the lowest seeding rate where as in 2002 and 2003 seeding rate did not affect yield. In the highly variable environments of Northern Montana dryland planting conditions yields appeared to be better stabilized in lowest seeding rates by a corresponding increase in tillering capacity. From this trial it would appear that for feed grain production the safest approach to optimizing yield, when using an air drill to plant barley, is with lower seeding rates, thereby allowing the plant through nutrient availability and competition to determine the number of spike bearing tillers.

An interaction between the band width and seeding rate treatments masked effects associated with band width and results were more associated with an alteration in seeding rates and established plant populations. Additional research may be warranted in altering the band width of the seed within equal plant populations, so those treatments may benefit by more efficient use of space, light and nutrients decreasing inter-plant competition and altering intra-row relationships.

FORAGE ATTRIBUTES

Introduction

Barley is currently second only to wheat in number of acres of small grain crops grown in Montana. Barley is grown on over 400,000 hectares, and constitutes approximately $90 million in gross revenue to the economy of Montana (Montana Agricultural Statistics, 2006). Although premiums are paid for malt quality barley, the crop is generally grown for grain and utilized as a livestock feed. However, barley planted solely for forage production has been increasing rapidly in recent years (Montana Agricultural Statistics, 2006). One reason that this phenomenon is occurring is diversified producers do not need to purchase additional equipment to use cereals as forages since similar seeding equipment and harvesting techniques can be used as alfalfa (Helsel and Thomas, 1987). Annual forages are traditionally used in rotations with other more valuable crops for two to three years to break disease cycles, as an emergency crop during drought (Undersander, 1992) or to remove the potential of autotoxicity that can occur when alfalfa is replanted into ground where alfalfa was recently grown (Undersander et al., 1991).

The use of cereal annual forages (AF) is becoming widespread in the feedlot areas of Alberta and Saskatchewan, Canada. Cereal annual forages generate vast quantities of silage used in beef cattle rations during the finishing phase in beef production and to increase winter feed supplies and grazing opportunities in the Northern Great Plains (Entz et al., 2002). Barley and oat (*Avena sativa*) are commonly the choice in these short-season areas (Jedel and Salmon, 1995). Short season cereals are adapted to areas that receive less than 2100 heat units a year. Where higher heat units are present, corn silage may be the better alternative (Foster, 2004).

As forages approach maturity, fiber components increase and the digestibility of the forage decreases (Merchen, 1988). Barley had the lowest acid detergent fiber, highest in-vitro dry digestible matter (IVDDM) and highest crude protein (CP) when compared to the other cereal species (Cherney et al., 1983; Helsel and Thomas, 1987). Plant species differed markedly on the amounts of nitrate accumulated; oats > barley > triticale in a trial conducted near Edmonton, Alberta under similar management and harvest maturity levels (Khorasani et al., 1997). Cultivars differ in whole plant forage quality and nitrate-N accumulation. ‘Haybet’ had lower NDF, ADF, and nitrate-N levels than ‘Westford’ barley (Surber et al., 2001). It is recommended to increase plant densities when planting cereals for forage production to increase DM yield (Jedel and Salmon, 1995). Seeding rate increases from 250 to 750 seeds m^{-2}, increased dry matter yield while decreasing weight of leaves, stems and spikes on a per plant basis. However on a land basis little effect upon was observed as seeding rate increased (Juskiw et al., 2000b). As seeding rates increased fiber components and DM at harvest of the forage increased (Juskiw et al., 2000a).

Barley plant densities have been linked to tiller production (Kirby and Faris, 1970; Kirby and Faris, 1972; Simmons et al., 1982). Early emerging tillers contribute more to grain yield than do tillers that emerge later and tiller mortality is more prominent at higher plant densities and narrow row arrangements (Simmons et al., 1982). Heavily tillered plants tend to have smaller culms, leaves and heads than neighbors under lower populations (Hamid and Grafius, 1978). Increased grain yields were attributed to the fact that cultivars which rapidly developed canopy cover and had the highest leaf area also had the higher dry matter production.

Barley's response to seed band width and varying plant populations have not been adequately explored for forage quality or quantity. Air drills are becoming more common in the western states and are a rapid and effective way to plant cereals. The objective of this research was to determine the effects of seed band width and seeding rate on forage yield and quality in two contrasting barley cultivars and if the effects are consistent at two harvest maturities

Materials and Methods

A spring-established experiment was conducted for three years (2001, 2002 and 2003) at Montana State University, Northern Agricultural Research Center; Hill County southwest of Havre, MT. The soil was a Telstad clay loam, (fine-loamy, mixed Aridic Argiborolls). Plots were established on no-till chemical fallowed two-year old undisturbed stubble using an experimental size 'Concord'[2] air drill (Case IH, 700 State Street Racine, WI 53404 USA). The drill is identical (mechanically) to a commercial size drill, consisting of 10 rows spaced 305 mm apart. The shanks are fitted with 'Farmland' SB1, double-shoot seed and fertilizer boots equipped (Farmland Specialty Products, RR #4, Red Deer, Alberta, T4N54E) either with 102 mm sweeps plus reverses

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[2] Mention of product names and equipment does not imply endorsement by the authors or Montana State University.

spreaders to restrict the seed band width (NARR); or 254 mm sweeps plus ‘SBS2’ spreaders (WIDE) to afford a wider banding pattern. The drill was configured with ‘Titan’ (Titan International Inc, 2701 Spruce Drive, Quincy, Illinois, 62301) 152 mm square-wall packer wheels to insure proper seed to soil contact. All treatments were seeded 38 mm deep. Fertilizer was distributed as a granular blend during the seeding operation via the backswept knife at a rate of 78 N, 45 P_2O_5 and 28 K_2O kg ha^{-1}. Fertilizer rates were consistent across all years and were determined for historic yields of feed barley and recommendations for Montana soils and expected yields for no net loss of fertility (2365 kg ha^{-1}, Jacobson et al., 2003).

The plots consisted of ten rows and were 15.24 m long and 3.0 m wide. The factorial treatment arrangement consisted of cultivar, band width and seeding rate. Cultivars tested were ‘Harrington’ (Harvey and Rossnagel, 1984) and ‘Haybet’ (Hockett et al., 1990). Harrington and Haybet are the most prevalent cultivars grown Montana in recent years (Montana Ag Statistics, 2006). Harrington is a malt type cultivar whereas Haybet is used as an annual forage. The band widths evaluated were narrow (NARR) and wide (WIDE), as previously described (Fig. 6). Seeding rates of 140, 184 and 226 seeds m^{-2} were used and represent recommended seeding rates for barley harvested as malt, animal feed and annual forage (Hensleigh et al., 2001). Seeding rates were established on a pure live seed basis and 1000 kernel weights. The twelve treatment combinations were arranged in a randomized complete block with six replications.

Trials were established on May 15, 2001, May 18, 2002 and May 17, 2003. Environmental data for each year is presented in Table 5. Agronomic, soil, and previous crop information is presented in Table 6. Weeds were controlled with post-emergence herbicide applications of bromoxynil (3, 5-dibromo-4-hydroxybenzonitrile) + MCPA {(4-chloro-2-methyphenoxy) acetic acid}).

Stand counts were measured approximately 30 d after seeding (plants m^{-2}) at random locations within rows five and seven using a 914 mm long transect. Plots were hand cut within a 914 mm transect, clipped at furrow height within random locations in row nine of the ten row plot (EARLY) after the soft dough stage was observed (Zadoks 85; Zadoks et al., 1974) and 7 d later a second harvest was taken within the same plot and row in an area that was not harvested for the EARLY sample. The spikes were separated from the remaining biomass. Samples were dried in a forced air oven at 50°C for 48 hours. The spikes and remaining plant biomass were weighed for plant biomass, spike weight, spike count m^{-2} and relative harvest index (spike weight divided by the whole plant biomass). Forage samples were ground to pass a 1 mm screen in a Wiley mill (Arthur H. Thomas Co., Philadelphia, PA) and evaluated for DM, N (AOAC, 2002), ADF and NDF (Van Soest et al., 1991). Forty-eight hour in-situ dry matter disappearance (ISDMD) was estimated by the procedures outlined by Vanzant, et al. (1998), with one modification, all forage samples were ground to pass a 1 mm screen rather than a 2 mm. Although particle size will drastically affect ISDMD levels all samples were treated the same. The estimated ISDMD could be higher than if the samples were ground to pass a 2 mm screen. Duplicate nylon bags (Ankom, Spencerport, NY) were placed in the rumen of two cannulated cows and were removed at 48 hours post insertion. Bags were hand rinsed until cold water ran clear. Bags were dried in a forced air oven at 50° C for 72 hours. All animal care and ISDMD procedures were conducted at the Montana State University Nutrition Lab under conditions approved by MSU animal care and use committee. Apparent nitrogen uptake for above ground biomass was calculated as whole plant DM yields multiplied by the whole plant above ground nitrogen content.

The crop was combined at harvest maturity with a small plot combine harvesting only the five center rows. After combine harvest culm counts and whole plant counts (culms plant^{-1}) were taken at random locations within rows five and seven using a 914 mm long transect. Band width was measured twice within this same transect and averaged for each plot.

Data were analyzed using the GLM procedure in SAS (SAS Inst., 2000). Fixed effects were year, cultivar, band width and seeding rate with rep within year as the random term. The experiments were analyzed across years since error variances were homogeneous. Least squares means were obtained for cultivar, band width and population. When the F-tests indicated a significant ($P < 0.05$) main effect x year interaction, the ‘slice’ command was used to determine treatment effect within each year. Least squares means are reported with associated standard errors. Planned orthogonal comparisons for seeding rates and respective interactions were tested for linear and quadratic responses. In year 2002, blocks 4 and 5 were removed from the data set because of a severe unexplained emergence problem.

Results and Discussion

Climactic conditions were discussed in the previous chapter. Forage yield and quality AVOVA probability values are presented in Table 12. There were few significant three- and four-way interactions ($P < 0.05$). Most interactions are characterized by changes in magnitude rather than direction. Many two way interactions with year are significant, main effects and main effects by year are presented in Tables 13, 14 and 15.

Table 12. P values for analyses of variance for spring barley harvested as an annual forage as affected by barley cultivar (C), seed band width (B), and seeding rate (R).

		Forage harvest, soft dough									
		DM conc.	Plant ht	DM Yield	Spike	DM	ADF	NDF	Total N	Nitrate N	ISDMD
Source	df	g kg^{-1}	mm	kg ha^{-1}				g kg^{-1} dm			
Year (Y)	2	0.0001	0.0001	0.0001	0.0001	0.0020	0.0001	0.0001	0.0001	0.0001	0.0023
Cultivar (C)	1	0.0006	0.0001	0.0513	0.3630	0.0001	0.0001	0.1864	0.6276	0.2936	0.0001
Band width (B)	1	0.2302	0.1813	0.2395	0.6471	0.4229	0.0074	0.9737	0.4556	0.0019	0.0948
Rate (R)	2	0.0001	0.0944	0.0530	0.1753	0.6375	0.7153	0.2247	0.4897	0.0154	0.4538
Linear	1	0.0001	0.0311	0.0157	0.0661	0.9958	0.8323	0.1957	0.3276	0.0589	0.2833
Quadratic	1	0.5605	0.8100	0.8997	0.7559	0.3435	0.4299	0.2512	0.4941	0.0274	0.5141
Y x C	2	0.0001	0.0086	0.4464	0.0001	0.0004	0.0012	0.6901	0.6952	0.1842	0.5103
Y x B	2	0.8588	0.1015	0.1576	0.4419	0.7204	0.0015	0.0820	0.7661	0.4261	0.9104
C x B	1	0.6501	0.6755	0.9531	0.6394	0.8805	0.1196	0.5620	0.5660	0.9295	0.3747
Y x R	4	0.0113	0.6924	0.3863	0.0084	0.3687	0.0371	0.0203	0.2839	0.3750	0.2141
C x R	2	0.8362	0.3714	0.9514	0.1361	0.1837	0.7560	0.1961	0.5398	0.5961	0.3206
Linear	1	0.6864	0.1882	0.7765	0.0470	0.1737	0.9570	0.0789	0.4068	0.4759	0.8587
Quadratic	1	0.6598	0.6205	0.8911	0.8633	0.2138	0.4565	0.6864	0.4611	0.4689	0.1351
B x R	2	0.4532	0.7724	0.3133	0.2195	0.2377	0.0539	0.0542	0.1872	0.4586	0.4499
Linear	1	0.2730	0.4734	0.1534	0.9153	0.1866	0.0165	0.0178	0.6559	0.4451	0.2266
Quadratic	1	0.5383	0.9823	0.5974	0.0827	0.2872	0.8498	0.6496	0.0762	0.3235	0.7189
Y x C x B	2	0.8866	0.2850	0.8604	0.1201	0.7123	0.0001	0.1246	0.3514	0.1951	0.2448
Y x C x R	4	0.9102	0.2243	0.7394	0.8677	0.7306	0.2312	0.8836	0.5094	0.9864	0.6111
Y x B x R	4	0.5802	0.4697	0.7007	0.3787	0.7937	0.1376	0.1956	0.2678	0.7887	0.7699
V x B x R	2	0.1977	0.6195	0.3234	0.7312	0.8062	0.0275	0.6172	0.9496	0.2641	0.0375
Y x C x B x R	4	0.8018	0.1329	0.7500	0.6166	0.0715	0.0423	0.8242	0.4984	0.3151	0.2097
		Forage harvest, 7 d after soft dough									
Year (Y)	2	0.0001	0.0301	0.0001	0.0004	0.0424	0.0412	0.0075	0.0001	0.0001	0.0354
Cultivar (C)	1	0.0001	0.0467	0.6607	0.0001	0.0001	0.0001	0.0001	0.4101	0.2920	0.0001
Band width (B)	1	0.0503	0.5142	0.3764	0.2827	0.5554	0.0150	0.5227	0.1032	0.0002	0.7072
Rate (R)	2	0.0001	0.4534	0.0161	0.0048	0.1671	0.8636	0.2717	0.1605	0.0102	0.0334
Linear	1	0.0001	0.3222	0.0398	0.0070	0.6511	0.8285	0.1075	0.3619	0.0053	0.0531
Quadratic	1	0.0067	0.2860	0.0424	0.0595	0.0666	0.6203	0.9341	0.0924	0.2273	0.0765
Y x C	2	0.0001	0.3403	0.0194	0.0001	0.0009	0.0001	0.0001	0.0791	0.0409	0.0047
Y x B	2	0.3174	0.5586	0.5372	0.3420	0.4194	0.0012	0.3216	0.4891	0.2521	0.4438
C x B	1	0.8848	0.5218	0.1387	0.3070	0.0125	0.0007	0.3403	0.2011	0.6936	0.9066
Y x R	4	0.0907	0.6282	0.1836	0.0553	0.0319	0.8330	0.0912	0.0615	0.0553	0.0131
C x R	2	0.4198	0.3884	0.6455	0.0029	0.0672	0.9733	0.9107	0.5002	0.9042	0.4359
Linear	1	0.1999	0.7475	0.9779	0.0150	0.4948	0.9331	0.6684	0.8652	0.9548	0.5306
Quadratic	1	0.7670	0.3745	0.3505	0.1960	0.0264	0.8284	0.9571	0.2449	0.6567	0.2609
B x R	2	0.1268	0.6185	0.7993	0.7390	0.5339	0.4500	0.8498	0.8307	0.1882	0.5125
Linear	1	0.4326	0.5232	0.7088	0.4500	0.7278	0.2806	0.6236	0.6395	0.8924	0.2509
Quadratic	1	0.0608	0.9108	0.5793	0.8574	0.2877	0.5117	0.7724	0.6980	0.0688	0.3127
Y x C x B	2	0.4944	0.4587	0.7908	0.6703	0.1501	0.0002	0.4189	0.1736	0.0914	0.4984
Y x C x R	4	0.5690	0.6359	0.5421	0.0338	0.3605	0.3466	0.0539	0.8458	0.6679	0.7082
Y x B x R	4	0.5669	0.5198	0.9554	0.4486	0.2560	0.6836	0.7795	0.5918	0.7027	0.5120
V x B x R	2	0.9625	0.5129	0.9519	0.5789	0.1358	0.8677	0.7757	0.3613	0.6386	0.9789
Y x C x B x R	4	0.0418	0.5904	0.6218	0.6436	0.4197	0.2815	0.1212	0.3836	0.9367	0.0599

Table 13. Least square means for forage yield and quality when harvested at the soft dough stage and 7 d after the initial harvest by year for narrow (NARR) and wide (WIDE) band widths. Both forage cuts were taken within row nine. Row nine was selected for harvest so all opener and packer relationships were the same for all treatments. When the F-tests indicated significant differences ($P < 0.05$) for the main effect by year interaction, the 'slice' command was used to determine simple effects. Nutrient values are on DM basis.

Trait	2001		2002		2003		Across all Years	
Band width	NARR	WIDE	NARR	WIDE	NARR	WIDE	NARR	WIDE
Band width, mm	111	178	119	190	145	212	125^{a}	193^{b}
	Early forage harvest, soft dough							
Plant ht, cm	419	411	613	620	469	449	500	493
DM at harvest, g kg^{-1}	349	356	424	426	551	556	441	446
DM Yield, kg[†]	2876	2908	6006	6501	3668	3575	4182	4328
Spike, g kg^{-1}[‡]	307	300	432	442	350	355	363	366
DM, g kg^{-1}	940	940	934	935	934	935	936	937
ADF, g kg^{-1}	253^{a}	269^{b}	266	269	291	289	270^{b}	276^{a}
NDF, g kg^{-1}	476	483	484	485	547	539	502	502
Total N, g kg^{-1}	26.6	26.7	17.2	16.8	23.2	22.7	22.4	22.0
Nitrate-N, g kg^{-1}	0.98	0.84	0.46	0.36	1.68	1.42	1.04^{a}	0.87^{b}
ISDMD, g kg^{-1}	784	789	743	749	768	771	765	770
	Late forage harvest, 7 d post soft dough							
Plant ht, mm	415	503	617	612	475	473	502	529
DM at harvest, g kg^{-1}	418	420	581	589	662	681	553	563
DM Yield, kg[†]	3241	3286	6466	6454	3480	3808	4396	4517
Spike, g kg^{-1}[‡]	450	431	483	487	411	406	448	441
DM, g kg^{-1}	944	943	939	938	944	944	942	942
ADF, g kg^{-1}	266^{a}	285^{b}	260	258	268	270	265^{b}	271^{a}
NDF, g kg^{-1}	502	505	486	482	519	527	502	504
Total N, g kg^{-1}	19.3	19.3	16.6	16.0	22.4	21.9	19.4	19.0
Nitrate-N, g kg^{-1}	0.58	0.50	0.47	0.24	1.63	1.37	0.89^{a}	0.70^{b}
ISDMD, g kg^{-1}	758	766	720	720	775	772	751	752

[a, b] Within year and main effects cultivars lacking a common superscript differ ($P<0.05$).

[†] Whole plant Dm yield.

[‡] Ratio of spike weight to whole plant DM yield.

Table 14. Least square means for forage yield and quality when harvested at the soft dough stage and 7 d after the initial harvest by year for three seeding rates (140, 184 and 226 seeds m^{-2}). Both forage cuts were taken within row nine. Row nine was selected for harvest so all opener and packer relationships were the same for all treatments. When the F-tests indicated significant differences ($P < 0.05$) for the main effect by year interaction, the 'slice' command was used to determine simple effects. Nutrient values are on DM basis.

Trait	2001			2002			2003			Across all Years		
Seeding Rate[†], seeds m^{-2}	140	184	226	140	184	226	140	184	226	140	184	226
	Early forage harvest, soft dough											
Plant Ht, mm	427	414	404	622	619	608	460	460	457	503	498	489
DM at harvest, g kg^{-1}	328^{a}	363^{b}	368^{b}	407^{a}	422^{a}	445^{b}	549	550	560	428^{a}	445^{b}	458^{b}
DM Yield, kg[‡]	2598	3137	2940	6163	615	6460	3436	3525	3902	4066^{a}	4266^{ab}	4434^{b}
Spike, g kg^{-1}[§]	284^{a}	316^{b}	311^{b}	429	431	450	363	345	352	359	363	371
DM, g kg^{-1}	941	940	940	933	934	935	935	933	935	937	936	936
ADF, g kg^{-1}	258	261	265	270	270	262	294^{b}	284^{a}	293^{b}	274	272	273
NDF, g kg^{-1}	481	478	480	491^{b}	488^{b}	474^{a}	545^{b}	534^{a}	549^{b}	506	500	501
Total N, g kg^{-1}	27.2	25.9	26.7	17.0	17.4	16.6	22.7	23.8	22.2	22.4	22.4	21.8
Nitrate-N, g kg^{-1}	1.00	0.90	0.83	0.39	0.52	0.31	1.53	1.70	1.42	0.98^{ab}	1.04^{b}	0.85^{a}
ISDMD, g kg^{-1}	784	779	795	746	749	743	768	769	772	766	766	770
	Late forage harvest, 7 d post soft dough											
Plant Ht, mm	419	558	400	623	616	603	480	479	462	508	551	488
DM at harvest, g kg^{-1}	403	417	436	560	567	627	655	662	698	540^{a}	548^{a}	587^{b}
DM Yield, kg[‡]	3335	3186	3269	6291	6037	7052	3517	3554	3862	4381^{a}	4258^{a}	4727^{b}
Spike, g kg^{-1}[§]	463	442	417	490	469	495	425	398	403	459^{b}	436^{a}	438^{a}
DM, g kg^{-1}	944	944	942	937	939	939	944	944	944	942	942	942
ADF, g kg^{-1}	274	276	277	261	260	256	266	270	270	267	269	268
NDF, g kg^{-1}	496	500	514	487	485	479	517	525	527	500	503	507
Total N, g kg^{-1}	19.8	19.0	18.9	15.7	17.0	16.2	22.1	22.4	21.9	19.2	19.5	19.0
Nitrate-N, g kg^{-1}	0.68	0.47	0.47	0.29	0.51	0.27	1.62	1.54	1.35	0.86^{b}	0.84^{b}	0.69^{a}
ISDMD, g kg^{-1}	766	762	758	712^{a}	710^{a}	739^{b}	772	770	778	750	747	758

[†] Populations represent recommended rates for harvesting the barley crop for malt, feed and forage production in Northern Montana.

[a, b, c] Within year and across all years seeding rates lacking a common superscript differ ($P < 0.05$).

[‡] Whole plant DM yield.

[§] Ratio of spike weight to whole plant DM yield.

Table 15. Least square means for forage yield and quality when harvested at the soft dough stage and 7 d after the initial harvest for Harrington (HARR) and Haybet (HAY) barley cultivars. Both forage cuts were taken within row nine. Row nine was selected for harvest so all opener and packer relationships were the same for all treatments. When the F-tests indicated significant differences ($P < 0.05$) for the main effect by year interaction, the 'slice' command was used to determine simple effects. Nutrient values are on DM basis.

Trait	2001		2002		2003		Across all Years	
Cultivar	HARR	HAY	HARR	HAY	HARR	HAY	HARR	HAY
	Early forage harvest, soft dough							
Plant Ht, cm	378^{a}	452^{b}	584^{a}	650^{b}	439^{a}	479^{b}	467^{a}	527^{b}
DM at harvest, g kg^{-1}	355	350	423	426	532^{a}	574^{b}	437^{a}	450^{b}
DM Yield, kg†	2804	2980	6206	6301	3394	3848	4135^{a}	4376^{b}
Spike, g kg$^{-1\ddagger}$	297	311	460^{b}	413^{a}	344^{a}	362^{b}	367	362
DM, g kg^{-1}	937^{a}	943^{b}	932a	937^{b}	934	935	934^{a}	938^{b}
ADF, g kg^{-1}	251	272	265^{a}	270^{b}	288	292	268^{a}	278^{b}
NDF, g kg^{-1}	477	483	482	487	542	543	500	504
Total N, g kg^{-1}	26.6	26.7	17.1	16.8	23.2	22.7	22.2	22.2
Nitrate-N, g kg^{-1}	0.82	1.00	0.40	0.42	1.57	1.53	0.93	0.98
ISDMD, g kg^{-1}	792	780	753	739	780	759	775^{b}	759^{a}
	Late forage harvest, 7 d post soft dough							
Plant Ht, mm	378	540	582	647	462	486	474^{a}	558^{b}
DM at harvest, g kg^{-1}	417	420	581	589	623^{a}	720^{b}	540^{a}	576^{b}
DM Yield, kg†	3400	3127	5935	6273	3410^{a}	3877^{b}	4488	4426
Spike, g kg$^{-1\ddagger}$	445	436	529^{a}	441^{b}	404	413	460^{b}	430^{a}
DM, g kg^{-1}	942^{a}	945^{b}	936^{a}	940^{b}	944	945	941	943
ADF, g kg^{-1}	261^{a}	290^{b}	248^{a}	270^{b}	268	270	258^{a}	277^{b}
NDF, g kg^{-1}	491^{a}	516^{b}	469^{a}	498^{b}	525	521	495^{a}	512^{b}
Total N, g kg^{-1}	19.4	19.2	16.6	15.8	21.9	22.4	19.4	19.2
Nitrate-N, g kg^{-1}	0.55	0.53	0.38	0.33	1.39^{a}	1.61^{b}	0.77	0.82
ISDMD, g kg^{-1}	767	757	738^{b}	702^{a}	779	768	761^{b}	742^{a}

[a, b] Within year and main effects cultivars lacking a common superscript differ ($P<0.05$).

[†] Whole plant DM yield.

[‡] Ratio of spike weight to whole plant DM yield.

Measured band widths resulting from narrow and wide treatments were different, 125 and 193 mm, respectively (Table 13). Although visible differences were apparent from emergence to maturity among narrow and wide band width treatments (Fig. 6), band width had no effect on forage DM yield, or forage quality parameters for either early or the late harvest ($P > 0.05$; Table 13). Exceptions were ADF and nitrate-N. Nitrate-N was consistently reduced in all years in the wide band width treatment. Nitrate-N for the early harvest was reduced 16% by increasing the band width. Late harvest nitrate-N was reduced 21% by increasing the band width. No literature has been located that has reported the type of response observed in this trial. Spreading the seed across a wider area within a given population may decrease intra-row competition and potentially mutual shading that has been shown to reduce nitrate reductase activity with very high populations (Zieserl et al., 1963). Acid detergent fiber for 2001 was greatest for the wide band width for both harvest endpoints, but ADF was not affected by bandwidth in 2002 and 2003. When evaluated across all years the wide band width ADF concentration was greatest for both harvests; however the relatively small change in ADF seems to be biologically irrelevant when ISDMD was not different; as illustrated when lower ADF forages were fed to lactating dairy cattle (Acosta et al., 1991).

As previously discussed, treatment plant populations (plants m^{-2}) were all substantially reduced (27.6 %) below target populations (Table 8, Fig. 7). Target plant populations have been reported for several no-till trials to be substantially lower than predicted by seeding rates (Carr et al., 2003; McKenzie et al., 2005; Schillinger, 2005) where between 60 and 85% of viable live seeds sown became established as plants, in agreement with our trial in which 72 % of the seed sown became established plants. Both band width configurations exhibited a linear increase in plants m^{-2}. This was targeted with the three seeding rates; however within the narrow seed band width plants m^{-2} was not different for the 226 and the 184 seeds m^{-2} creating a significant band width by seeding rate interaction. This relationship confounded seeding rate and band width. As band width was increased so were the established plants m^{-2} (Fig. 7). Main effects for forage yield and quality for band width appeared to be due to increases in seeding rates and by the resulting increased plants m^{-2}.

Although below desired levels, established plants showed a linear increase as seeding rate increased. Dry matter concentration at harvest increased significantly as seeding rate increased for both 2001 and 2002 for the early harvest(Table 14). When evaluated across all years the highest seeding rate (226 seeds m^{-2}) produced the highest dry matter concentration for both the early and late harvest. This may be an indication that the higher populations had increased competition as indicated by the decrease in tillering (culms $plant^{-1}$, Table 10). The highest seeding rate treatment was further along in maturity than the lower seeding rates even though effort was made to harvest the forage samples at the same soft dough stage for the initial harvest then again 7 d later.

Dry matter yield was greatest for the highest plant population (226 seeds m^{-2}) for both forage harvests (Table 14). No difference was detected in the ratio of spikes to biomass after plant dissection in the early harvest for any seeding rate for 2002 and 2003, however, in 2001 the lowest seeding rate had a lower ratios of spikes than the higher seeding rates. After 7 d of additional grain fill, across all years, the ratio of spikes was greatest for the 140 seeds m^{-2} rate. As reported in the previous chapter when evaluated across all years the lowest seeding rates also favored the greatest grain yields when harvested at maturity. This increasing forage DM yield is in agreement with Jedel and Salmon (1995) that reported DM yield increased as seeding rates were increased from 260 and 390 seeds m^{-2}. However, these results also differ from Juskiw et al., (2000a) who showed little effect of seeding rate on DM yield when used for silages, however the seeding rates were substantially higher than in this trial (250 to 500 seeds m^{-2}). No year by seeding rate interaction for DM yield occurred. This may be indicating that forage yield appears to be less affected by limiting moisture levels that occurred early in the growing season in 2001 and throughout the growing season in 2003. The optimum seeding rates in Northern Montana and similar environments when harvesting spring barley for forage at the soft dough stage are at least 226 seeds m^{-2}. Since no quadratic response of DM forage yield was observed, higher seeding rates may need to be evaluated for annual forage production to determine the upper seeding rate at which DM yield no longer increases and if higher seeding rates can be economically justified by higher forage yields.

Altering the seeding rate affected the harvested forage chemical composition (Table 14). The barley would generally be considered as high quality forage for most classes of beef cattle at both the early and late harvest with the exception of the elevated nitrate-N levels. Although not the thrust of this research when harvest endpoint was placed in the statistical model the early and late harvest endpoint's ($P < 0.05$) chemical composition (NDF remained the same, ADF, N and nitrate-N declined) was altered as predicted by earlier research for maturing annual forages as grain fill occurred for later cuttings (Khorasani et al., 1997).

Fiber components were variable by year for both the early and late cuttings (Table 14). Neutral detergent fiber was greatest for the 140 seeds m^{-2} rate for the early harvest in 2002. In 2003 a severe drought year, both ADF and NDF were lowest for the 184 seeds m^{-2} rate when compared to the other rates, which were not different from each other. Within the early harvest endpoint these minor differences in ADF and NDF are not likely biologically important, in that, within and across years ISDMD did not differ for the early harvest, and when there was a difference as in the late harvest it was so slight that it would appear that the difference was not significant enough to affect animal performance. When annual forages were harvested in the boot or soft dough stage with ADF ranging from 239 to 295 mg g^{-1}, no differences were observed in milk production when fed to lactating dairy cows (Acosta et al., 1991). Dairy cattle actually lost more weight when fed barley forage harvested in the boot stage than when harvested in the soft dough stage. Although the chemical composition favored the boot stage harvested forage, no consistent benefit was observed by harvesting and feeding diary cattle barley harvested in the boot stage (Acosta et al., 1991).

Nitrate-N across all years was reduced 16 and 19% for the 226 seeds m^{-2} when compared with the average of the two lower seeding rates for the early and late harvests, respectively. Observed nitrate-N levels would be considered toxic levels (Cash et al., 2002) and feeding recommendations would be to blend the barley forage with at least a forage source that had very low levels of nitrate-N or no detectable levels to ensure animal performance was not reduced or abortions did not occur in pregnant animals. Nitrate-N levels would need to be reduced to less than 0.350 g kg^{-1} to be considered safe for all classes of livestock (Cash et al., 2002) these reductions in nitrate-n that occurred with the 226 seeds m^{-2} treatment may merit additional investigations. The effects of different seeding rates on forage nitrate-N levels have not been reported extensively in the literature. However, nitrate-N levels for oats have been shown to be unaffected (Southwood et al., 1974) by different seeding rates (67.3, 100.9 and 134.5 kg ha^{-1}).

No seeding rate by cultivar interaction for DM forage yield or quality traits were detected for either early or late harvest endpoint, except for the ratio of spikes g kg^{-1} in the late harvest. This interaction for the late forage harvest may be explained as the beginnings of an increased grain fill and eventual grain yield for Harrington and the 140 seeds m^{-2}. When this treatment combination was allowed to mature and was harvested as grain it produced the greatest grain yields as reported earlier (Table 12). Otherwise it appears that the two cultivars reacted similarly to each other across seeding rates for forage production characteristics.

Cultivar and cultivar by year interactions were significant for forage attributes (Table 15). Generally most interactions were changes in magnitude rather than direction. The one exception is the ratio of spikes to biomass for the early harvest. In 2002, a normal year, Harrington had a higher ratio of spikes to biomass, however in the severe drought year (2003) Haybet was greatest. Generally when evaluated across all the years and both harvest dates Haybet produced taller plants with higher levels of ADF resulting in lower ISDMDs. Haybet produced higher DM yields for the early harvest, but no difference was detected for the late harvest. Forage barleys that have shown to out produce other barleys have been taller in height (Seth and Singh, 1978). Normally annual forages are harvested by the initiation of grain fill to ensure forage that will support high animal intakes and increased performance (Cherney et al., 1983). The late harvest in this trial rarely would be practiced for annual forages. In 2003, characterized as a severe drought year, Haybet had higher DM yields and nitrate-N levels for the late harvest, and no difference for the early harvest.

Conclusions

In the semi-arid Northern Great Plains of Montana using air drill technology, band width (spreading the seed out between the rows) and seeding rates (140, 184, and 226 plant m^{-2}) were altered by different opener and packer wheel configurations. Although year effects were dramatic some generalizations can be made. Band width was confounded with seeding rate in this trail. Plant population increased in the wide band width when compared to the narrow, it appeared that variables to responded more like literature reports for increasing the seeding rate or established plant population than band width.

Whole plant DM yield when barley is harvested as an annual forage was 348 kg ha^{-1} greater for the highest seeding rate (226 seeds m^{-2}) than the lowest seeding rate (140 seeds m^{-2}) for the early harvest taken in the early soft dough stage. When the crop was allowed to mature 7 d longer, the DM yield for the highest seeding rate was 408 kg ha^{-1} over the average DM yield of the 140 and 184 seeds m^{-2} rates.

Although this late harvest is after the normal recommendation for harvesting barley as annual forages, quite often in Montana and the Great Plains nitrate-N levels are at toxic levels so annual forages are left standing in the field to reduce nitrate-N levels prior to harvesting. Although predictable changes to forage have been seen in several trials previously discussed, no information has been generated evaluating the use of air drills to potentially modify competition within the barley crop and if they are consistent across harvest endpoints. Chemical composition of the forage for band width, seeding rate and cultivar were variable across years and treatments. Only nitrate-N seemed to be affected to an extent that is biologically important when feeding beef cattle. Although the nitrate-N was reduced for the wide band width, the established plant population was also increased. The reduction seen was very similar to the observed effect for seeding rate, appearing to illustrate that that band width affects were related more to the increasing population than the band width. No interaction existed between band width and seeding rate for nitrate-N, however both treatments lowered nitrate-N the potential for additive affects of combining treatment combinations may have been observed and may aid on lowering nitrate-N levels.

For the early harvest, nitrate-N levels seen in the trial would indicate recommendations for feeding the forage to non pregnant livestock. If the nitrate-N containing forage is being fed to pregnant animals it would need to be blended with forage that does not contain measurable levels of nitrate-N at least at a ratio of 50:50, infected to non-infected forage. Nitrate-N was reduced 16 and 19 % in the highest seeding rate (226 seeds m^{-2}) when compared with the average of the lower two seeding rates for the early and late harvest, respectively. Reductions in nitrate-N had linear and quadratic relationship for the early harvest and a linear trend for the late harvest (Table 12). With DM yields being greatest on the highest seeding rate and lower established plants m^{-2} than predicted, additional research of the upper limit of seeding rate may be warranted when forage production is the desired endpoint.

SUMMARY

The objective of this trial was to evaluate barley management options by varying seed band width, seeding rate, and harvest endpoint under Montana’s dryland production conditions. The secondary objective was to evaluate the potential of managing the barley crop after it had been planted in a flexible harvest type of system. For example, if the barley crop was planted and one of the endpoints (forage, feed grain or malt crop) targeted appears to be the best economic option, can you effectively change the harvest endpoint as the season progresses based on current environmental or economic information.

No-till farming and direct seeding air drills have allowed producers a larger selection of new opener configurations and increased variability in seed placement. These sweep and opener configurations give the ability to place seed and fertilizer in one pass or to make very wide “paired” row arrangements. Based on these experiments it appears best to target a harvest endpoint prior to planting, rather than deciding what the crop will be used for during the growth cycle. Forage and grain quantity and quality appear to react very differently to seeding rates and band widths.

For barley in this trial, seeding rate affected grain yield and DM forage yield in contrasting fashions. Since no treatment combination approached malt quality, recommendations for feed grain production for Northern Montana using similar air drills and opener configurations would be to plant no higher than 140 seeds m^{-2}. The lack of a quadratic response to seeding rate for grain yield may indicate that even lower seeding rates may be justified in research to determine the lower limit before grain yields or grain quality is affected. Lower seeding rates may potentially be identified where grain fill is optimized thereby lowering N levels and increasing the proportion of plump kernels, aiding the barley producer to meet malting criteria.

When barley forage was harvested either at the soft dough stage or 7 d later the highest seeding rate (226 seeds m^{-2}) significantly increased DM yields. Although chemical composition was variable, differences were slight and would have very small or negligible effects on biological performance when fed to most classes of beef cattle. However, all treatment combinations produced forages that would be considered above toxic levels for nitrate-N for beef cattle. Both early and late harvest nitrate-N levels would indicate the forage be fed to non-pregnant livestock or blended with non-infected forages at a ration of 50:50 (infected to non-infected) if fed to pregnant animals. Although altering seeding rate did not lower nitrate-N levels to a level that could be fed to any class of livestock any reduction in nitrate-N is beneficial. Nitrate-N was reduced 16 and 19% in the highest seeding rate (226 seeds m^{-2}) when compared to the average of the lower two seeding rates for the early and late harvest, respectively. Reductions in nitrate-N reacted in a linear and quadratic manner for the early harvest and in a linear manner for the late harvest with increasing seeding rate. With no quadratic affect observed for either DM yield and substantially lower established plants m^{-2} than predicted, additional research of the upper limit of seeding rate may be warranted. Recommendations for annual forages from barley would be to use higher seeding rates (226 seeds m^{-2}) for both increased DM yields and the potential to reduced nitrate-N.

Established plant populations were different for the narrow and wide band widths. However, in this trial wide band width increased established plant numbers which was beneficial for both forage DM yield and reduction in nitrate-N. No interaction existed between band width and seeding rate for nitrate-N, indicating that additive affects of combining treatment combinations may be occurring lowering nitrate-N. Recommendations should include using a wide sweep and packer configuration since no adverse affect was observed at least to our highest seeding rate. Although this trial was ineffective in maintaining established plant populations for each band width. The topic may merit additional research since very little work has been shown on the affects of altering band width a management option that barley producers may select.

Cultivars (Harrington and Haybet) appeared to react similarly across years to the treatments imposed on them in this trial. Until a "dual purpose" – hooded or awnless cultivar is developed that can produce grain yields and quality that are equal to or above locally adapted awned cultivars, it would be best to match harvest endpoint with the best locally adapted cultivar to meet harvest endpoint needs. Haybet is a hooded barley which should prevent sore mouths and eye irritations compared to an awned variety when fed as dry hay to cattle. If forage harvest is not the goal then the highest or most stable yielding grain variety for the region should be employed.

No conclusions can be made about the original hypothesis about the effects of banding the seed within given established populations. The hypothesis was that some combination of those treatments may be shown to be beneficial by more efficient use of space, light and nutrients. Under the extreme environmental differences exhibited by this trial forage yield and grain yield were opposite for optimum production, making a flexible harvest seem unfeasible. Rather than trying to manage the barley crop while it is growing, it would appear the best option would be to identify the endpoint and use best management practices for that endpoint, as outlined above. Producers should evaluate established plant populations they are obtaining with their current production practices in relation to seeding rates. Air drills have consistently over several studies produced stands significantly lower than was desired. As producers alter opener configurations they should attempt to determine the best plant stand for optimal yields for their desired harvest endpoint and their geographic region.

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APPENDICES

APPENDIX A: GRANT PROPOSAL (AS PRESENTED TO THE AGENCY)

Increasing Yield and Management Options for Producers who Traditionally Plant Barley Acres for Grain or Forage Production by Varying Seed Band Width, Planting Rates and Harvest Endpoint

Grant Proposal Submitted to:
Montana Board of Research and Commercialization Technology

Darrin Boss and Gregg Carlson
Northern Agricultural Research Center

Project Proposal

Early growth photos of narrow and wide band widths produced at median population density to illustrate differing seed placement configuration.

Late (pre-harvest) photos of narrow and wide band widths produced at median population density to illustrate differing seed placement configuration.

Project Description

Producers are asking researchers to develop strategies that improve options for dryland barley production where rainfall levels vary from year to year. Barley is currently second only to wheat in number of acres of small grain crops grown at 1.25 million acres, and constitutes approximately $ 90 million in gross revenue to the economy of Montana.

Barley planted solely for forage production has been increasing rapidly in recent years (Montana Agricultural Statistics, 1999, 2000, 2001). However, producers rarely evaluate the potential economic benefit of yet another option – that of harvesting barley initially intended for grain as hay rather than letting it go to grain fruition once it is determined that under certain given conditions meeting malting quality criteria is unlikely. This option may have at least two very beneficial results for Montana producers: 1.) Increased water availability for subsequent crops through earlier harvest and a corresponding cessation of water use by the current crop, and 2.) Potential for increased current year profit depending upon markets and operational needs.

By evaluating available stored soil water and precipitation, potential barley grain yield and price, and potential forage production and price, growers could use these factors to determine whether barley grain or barley forage would be more beneficial in their current operation. By further investigating various cultivars, planting configurations and harvest dates, a grower may be better equipped to make earlier decisions as to whether or not to take barley to yield as grain or utilize it as a roughage source in a livestock enterprise.

It has been documented (Stougaard and Carlson, personal communication) that spring wheat yield increases with increasing seed band widths and planting rates, due to a reduction in intra-specific crop competition. Such seed placement and rate manipulations have also resulted in reduced weed competition and associated increases in crop protein content with spring wheat.

Barley response to seed band width has not been explored for either grain or forage production. Positive effects on vegetative dry matter production among cereal crops would be expected to be similar or perhaps even greater than that associated with grain production. It is appropriate to test this hypothesis with malting and hay barley cultivars produced both for grain and forage purposes. In doing so, we could evaluate the potential for growers to make more informed decisions during the growing season as to whether or not a particular barley crop should be harvested for forage or retained for harvest as grain. Additional information could be gleaned as to optimum population densities and placement configurations for varied end uses of barley under given climatic conditions.

Objective: To evaluate barley management options by varying seed band width, population densities, and harvest endpoint under dryland production conditions.

Background

Producers are asking researchers to develop strategies that improve options for dryland barley production where rainfall levels vary from year to year. Barley is currently second only to wheat in number of acres of small grain crops grown at 1.25 million acres, and constitutes approximately $ 90 million in gross revenue to the economy of Montana. Although production of barley meeting malt quality criteria is successful less than half the time under dryland cropping conditions, growers commonly plant malting industry-approved cultivars that can potentially be open marketed for malt at a price significantly higher than that for feed barley. Thus, enhanced profit is realized when climatic conditions result in production that meets malting criteria. If malting criteria is not achieved, the barley is sold at a lesser price as feed grain or is used on-farm as livestock feed.

However, producers rarely evaluate the potential economic benefit of yet another option – that of harvesting the crop for hay rather than letting it go to grain fruition once it is determined that meeting malting quality criteria is unlikely. Dr. Dennis Cash (Montana State University, Forage Extension Specialist) documented, after reviewing yields and prices of barley grain sales for the past twenty years using Montana Agricultural Statistics, that producers with the ability to harvest their barley as a hay crop could have potentially achieved a better return per acre by cutting the crop for forage and utilizing that forage for cattle feed rather than taking the crop to grain. This evaluation was based on actual grain yields and prices compared with expected forage yields and prices. The evaluation featured no economic overheads or variable equipment costs associated with either grain or forage harvest operations. Haying a barley crop originally planted for grain may have at least two very beneficial results for Montana producers: 1.) Increased water availability for subsequent crops through earlier harvest and a corresponding cessation of water use by the current crop, and 2.) Potential for increased current year profit depending upon markets and operational needs.

By evaluating available stored soil water and precipitation, potential barley grain yield and price, and potential forage production and price, growers could determine whether barley grain or barley forage would be more beneficial in their current operation. By further investigating various cultivars, planting configurations and harvest dates, growers may be better equipped to make earlier decisions as to whether or not to take barley to yield as grain or utilize it as a roughage source in a livestock enterprise on a year by year basis. This would increase a Montana producer’s ability to evaluate and make both proactive and reactionary management decisions to any environmental conditions, price advantages or other factors that may arise affecting their original production goals. By planning and reacting to trends and conditions as they happen and having the tools to make informed decisions the producer can quickly take advantage of rapidly changing opportunities to add value to a crop already planted or to optimize profits.

It has been documented (Stougaard and Carlson, unpublished data) that spring wheat yield increases with increasing seed band widths and planting rates (plant densities), due to a reduction in intra-specific crop competition. Such seed placement and rate manipulations have also resulted in reduced weed competition and associated increases in crop protein content. However, barley response to seed band width has not been explored for either grain or forage production. Positive effects on vegetative dry matter production among cereal crops would be expected to be similar or perhaps even greater than that associated with grain production. Results from the spring wheat band width work showed Leaf Area Index and biomass increased with increasing seed band widths. Similar results would seemingly also be exhibited with barley grown under narrow and wide band width configurations.

It is appropriate to test this hypothesis with malting and hay barley cultivars produced both for seed and forage purposes. Forage yields of barleys that were selected and bred for grain production are traditionally lower than barleys selected for strictly forage production. However, these yield relationships should be re-investigated under different management regimes and seeding configurations.

Forage barley acres have been increasing steadily in recent years (Montana Agricultural Statistics, 1999, 2000, 2001). Montana State University has begun intensifying research and breeding efforts focusing on forage quality and nitrogen mobilization to identify variation in nitrate accumulation in the barley forage. Major Quantitative Trait Loci (QTL) for nitrogen, nitrate, non-nitrate and in situ dry matter disappearance (ISDMD) were reported in Lewis / Karl RIL lines and in another experiment using a Steptoe/Morex di-hybred cross population (Surber et al., 2001 and 2000). Substantial genetic variation existed in these traits and the authors felt progress could be made in breeding programs focusing on forage barleys. But, management options and how they interact with other modes of nitrogen remobilization has yet to be investigated. Molecular markers associated with ISDMD, nitrogen, NO_3-nitrogen, and non-NO_3 nitrogen traits were found on Chromosome 2, 3, 4, and 6 (Surber, 2001). Previously, QTL controlling variation in grain ISDMD was found only on Chromosome 4 (Gibson, 1994). Variation existing in QTL control within grain ISDMD provides evidence to challenge if other management factors associated with forage ISDMD, NO_3-nitrogen, and non-NO_3 nitrogen or feed quality features may provide additional or different regulatory factors under different management options. This design would begin to answer how different population densities, band widths and varieties react to different management options. If by employing different management options, the nitrate levels alone could be lowered from a toxic level to a level that could be blended with non-nitrate hay or to a level not requiring blending, it could mean adding increased value to a crop otherwise useless or of a substantially lower price than hay containing high levels of nitrate.

In response to producer requests for new strategies and options for dryland barley production where rainfall levels vary from year to year, a prediction model could eventually be developed wherein malting barley and feed grain prices, barley hay price, and projected grain and forage production under given available soil water scenarios coupled with precipitation probabilities could be utilized to determine the most appropriate barley crop management decision within a growing season. Allowing the Montana producer to react and make management decisions rapidly under varying environmental conditions and changing local markets, potentially adds value to a crop already under widespread production in the state.

Procedures

The project will evaluate representative cultivars of two general types of barley; 1.) Dual-purpose grain barley (feed or malt) and 2.) Awnless hay barley. Barley cultivars will be: `Harrington' (a popular Canadian two-row dual purpose barley) and `Haybet' (representing the popular awnless "hay type" barley) both widely grown in Montana Triangle area. Harrington represents the most widely seeded barley cultivar totaling 500,200 acres (45.5 %). Haybet the second most common cultivar being grown constitutes 10.2% (112,600 acres) of the barley acres in Montana (Montana Agricultural Statistics, 2001). Forage barley acres have been increasing steadily in recent years (Montana Agricultural Statistics, 1999, 2000, 2001). These forage barleys are used primarily for rotational advantages in cropping systems and are subsequently fed to livestock (Surber et al., 2001).

Each cultivar will be planted at three uniform population densities (representing equivalents of appropriate planting rates for malt barley, feed barley and hay barley). Average recommended dryland planting rates for Montana District 5 for malt, feed, and hay barley are 35-45 lbs/ac (10-13 seeds/ft^2), 45-60 lbs/ac (13-17 seeds/ft^2, and 67-90 lbs/ac (20-26 seeds/ft^2) respectively (Hensleigh et al., 2001). Plant counts will be taken after emergence to determine actual plant densities achieved.

The cultivars and density combinations will be planted in two seed band width configurations (narrow and wide) utilizing a research-scale Concord air drill system (Figure 1). Narrow and wide seed band widths will be achieved utilizing `Farmland' SB1, double-shoot seed and fertilizer boots equipped with 4-inch sweeps plus reverse spreaders and 10-inch sweeps plus SBS2 spreaders, respectively (Figure 2). `Titan' 6-inch square-wall packers will be utilized for both seed band width configurations.

Figure 1. Research-scale Concord air drill system equipped with computerized variable rate technology. Individual plot observations will consist of 10, 50-foot rows on fixed 12-inch row spacing.

Figure 2. Examples of band width configurations. The photo on the left represents the narrow banding configuration; right hand photo represents the wide band configuration. Both pictures were taken shortly before harvesting the plots for grain, and reveal canopy closure and row definition differences between the two placement configurations.

Individual plots will consist of 10, 50-foot rows on fixed 12-inch row spacing. The entire trial, including 72 observation plots at 500ft^2 each plus appropriate air drill maneuvering alleys, will occupy 2.66 acres direct seeded on chemical fallow utilizing a factorial arrangement of treatments in a randomized complete block design with six replications. The plots will be established under dryland conditions at Northern Agricultural Research Center in a no-till cropping system on clean chemical fallow and will be fertilized in accordance with the amount of available water and subsequent target crop yield as if the crop were to be harvested for grain (Brown and Carlson, 1990).

Figure 3. Example of plot layout after harvesting selected rows for grain.

Uniform portions of pre-selected rows within each plot will be utilized for separate forage and grain harvest operations. Separate harvests for forage will be conducted at two stages of crop development. The initial forage harvest will be collected after heading (milk stage) with a subsequent forage harvest at the early soft dough stage of development. Such harvests will be conducted at times appropriate for each individual “Variety x Band Width x Planting Rate” treatment. The initial harvest will simulate an optimum cutting time from a “hay barley” management standpoint while the latter forage harvest date will simulate the latest a decision should be made by the producer not to retain the crop for grain production but instead utilize it as forage before further forage quality is lost. All plots will further be harvested for grain at combine maturity. By uniform row assignment for sub-sampling, each individual plot will accommodate both forage harvests and the grain harvest. To minimize any non-treatment variability that is sometimes inherent among rows, even with identical opener and packer configurations; the same drill rows in each plot will be utilized consistently for each data sub-sampling to include early forage, late forage and grain sub-sampling. The ten rows in each plot will be utilized as outlined in Table 1.

Materials harvested for forage will be analyzed for dry Matter (DM) yields, acid detergent fiber (ADF), neutral detergent fiber (NDF), total digestible nutrients (TDN), crude protein (CP), relative feed value (RFV), Nitrate (NO3), head to stem/leaf weight ratio. Materials harvested for grain will be analyzed for yield, test weight, kernel weight, plump percent, thin percent, and protein to represent the value and quality of the crop had it been allowed to go to feed grain or malt production. Water utilization is a vital component to how the band width and population densities react to the management regimes imposed. Water use and availability will be monitored using neutron probe technology throughout the trial.

Table 1. Operation and response variable allocations for replicated ten-row air drill plots established per treatment combination (variety x seed band width x planting rate).

Row	Operation and Response Variable Data Collected
1	Outside row, left standing as a guard row for intraplot and interplot effects
2	Row cut for early forage harvest
3	Left standing as a guard row for adjacent intraplot grain harvest rows
4	One of four rows cut for grain harvest
5	One of four rows cut for grain harvest
6	One of four rows cut for grain harvest
7	One of four rows cut for grain harvest
8	Left standing as a guard row for adjacent intraplot grain harvest rows
9	Row cut for late forage harvest
10	Outside row, left standing as a guard row for intraplot and interplot effects

Economic values can be placed on each endpoint commodity (early hay, late hay, feed barley and malt barley) and can be used to evaluate which decision would be the most economical in a particular year and moisture regime.

Preliminary Results – Initial Year (2001)

The following section is a short discussion of the initial year results. A USDA Special Grant funded the initial year: (Drs. Blake and Bowman) *Barley Feed for Rangeland Cattle* and will be represented in part of the matching funds under the Budget section of the proposal. This is only an example of data being collected and includes only one year of data under severe water stress conditions.

The first year of the trial was established at Northern Agricultural Research Center (NE1/4 Section 32, Township 32N, Range 15E) on a Telstad Clay Loam soil. The trial was direct seeded (May 21, 2001) no-till into chemical fallow using a 'Concord' air drill system (Figure 1) with 70#N, 40# P_2O_5, 25# K_2O fertilizer via granular blend and double-shoot seed and fertilizer placement configurations. The fertilization rate was calculated based on Brown and Carlson's (1990) equation for estimation of potential grain yields based on stored soil water and probable rainfall occurring during the growing season.

Drought conditions at the station were severe throughout the 2001-growing season. Only 1.29 inches of precipitation was received from April 1, 2001 to planting on May 21, 2001 with only 0.83 inches recorded in individual events occurring over 0.10 inches. Total rainfall from crop establishment to grain harvest (August 28, 2001) was only 3.05 inches in events greater than 0.10 inches. Approximately one-third of the growing season rainfall fell in one event July 13, 2001 (0.91 inches). Topsoil moisture at planting was very marginal and successful establishment for all spring crops at NARC was credited primarily to no-till planting. Crop year precipitation was 72% of normal. Growing season temperatures were 108% of normal with 44 days over 90^oF compared to 26.3 days average for 1916-2001. Wind was relentless at 110% of normal with new all-time monthly peak velocity records set during both May and July. Spring barley yields in nearby uniform variety trials at Havre in 2001 were 43% of the long-term average for the station. Given the extreme weather conditions we were very encouraged by the differences exhibited this year and are very anxious to explore the potential results for another two years.

The data was analyzed using the GLM procedure of SAS (2000) with the main effects separated with the LSD function. There were no statistically significant two- or three-way-interactions, thus only the main effects are reported here.

Cultivar Differences: Harrington vs. Haybet

Forage yield adjusted to a 10% moisture level did not differ for cultivar. However, CP, (ADF), (TDN), (RFV) and (NO3) were of higher quality for Harrington than Haybet for each cutting (Table 2). Early cutting for most variables resulted in higher quality than the late cutting. However, late cutting did provide higher forage yields and lower NO3 levels. Nitrate levels have been documented to decline with increasing days after the milk stage has been reached (Cash et. al., 1993).

There was no difference in Leaf Area Index and Canopy for either cultivar. Grain yield was not different for cultivar; however, plant height and test weight were higher for Harrington than Haybet.

Table 2. Cultivar comparison for traits measured for Early and Late cutting, Leaf Area Index, Canopy Cover and Grain parameters.

Trait	Harrington	Haybet	LSD (P=0.05)	
Early Cutting - July 23, 2001				
Yield, lbs/ac 10% moisture	2782	2956	289	ND
CP, %	16.6	16.7	1.26	ND
ADF, %	25.1	27.2	0.88	**
NDF, %	48.2	47.7	0.73	ND
TDN, %	73.9	69.3	0.97	**
RFV, %	135.6	130.7	2.68	**
Nitrate, %	0.36	0.44	0.04	**
Late Cutting - August 6, 2001				
Yield, lbs/ac 10% moisture	3373	3101	337	ND
CP, %	12.1	12.0	0.37	ND
ADF, %	26.1	29.0	1.20	**
NDF, %	49.1	51.6	1.24	**
TDN, %	70.5	67.4	1.24	**
RFV, %	130.4	120.2	4.46	**
Nitrate, %	0.24	0.24	0.04	ND
Leaf Area Index	0.61	0.67	0.07	ND
Canopy Cover	0.64	0.60	0.04	ND
Grain Parameters - Harvested August 28, 2001				
Height, cm	38.2	44.4	1.28	**
Yield, bu/acre	23.3	21.9	2.09	ND
Test Weight, lbs/bu	50.8	49.4	0.31	**

ND = No difference

** Main effects within rows differ.

Band width Differences: Narrow vs. Wide

Narrow and Wide band widths achieved with the different opener configurations were 4.4 and 7.0 inches, respectively. Narrow band width produced higher quality forage than did the wide band width (Table 3). Again the earlier cutting appeared to be of higher forage quality than the late cutting, however, the yields increased for the late cutting. Although the yields were not different between band widths the Leaf Area Index and the canopy closure were greater for the wide band width when compared with the narrow configuration. This trend is in agreement with Stougaard and Carlson (unpublished data) with spring wheat. However, at harvest biomass was different for the spring wheat. Grain yield and plant height were greater for the wide band width, agreeing with the spring wheat yields being higher for the wider band widths.

Table 3. Band width comparison for traits measured for Early and Late cutting, Leaf Area Index, Canopy Cover and Grain parameters.

	Narrow	Wide	LSD	
Trait	4.4 inches*	7 inches*	(P=0.05)	
Early Cutting - July 23, 2002				
Yield, lbs/ac 10% moisture	2853	2885	288.7	ND
CP, %	16.6	16.7	1.26	ND
ADF, %	25.3	26.9	0.88	**
NDF, %	47.6	48.3	0.73	ND
TDN, %	72.5	70.8	0.97	**
RFV, %	135.5	130.8	2.68	**
Nitrate, %	0.43	0.37	0.04	**
Late Cutting - August 6, 2001				
Yield, lbs/ac 10% moisture	3215	3260	336.6	ND
CP, %	12.0	12.0	0.37	ND
ADF, %	26.6	28.4	1.15	**
NDF, %	50.2	50.5	1.24	ND
TDN, %	70.0	68.0	1.25	**
RFV, %	126.9	123.6	4.46	ND
Nitrate, %	0.26	0.22	0.04	**
Leaf Area Index	0.68	0.60	0.07	**
Canopy	0.59	0.65	0.04	**
Grain Parameters - Harvested August 28, 2001				
Height, cm	42.0	40.7	1.28	**
Yield, bu/acre	24.7	20.5	2.08	**
Test Weight, lbs/bu	50.0	50.2	0.31	ND

* Band width measure before grain harvest. Statistical difference (LSD<0.05 = 0.46)

ND = No difference

** Main effects within rows differ.

Population Rates: Malt vs. Feed vs. Forage

Population rate did affect yield weights that were adjusted to a 10% moisture level. Nitrate levels were decreased for both cuttings by increasing population densities (Table 3) and accordingly the Nitrate in the late forage cutting parallels the crude protein in the grain. All grain parameters were affected dramatically by population rate and appeared to follow normal water use patterns when moisture is in limited supply.

Summary: Initial Results - 2001

The initial results are encouraging given the weather conditions. It would appear there should be meaningful differences in various measured traits in normal rainfall years. Three years of data would be a minimum to build a database on management options involved with producing barley and developing proactive options for the producer to use while a crop is in the field. Low moisture years provide a good beginning reference point in the analysis of management decisions. These preliminary data indicate there is potential for positive economic impacts in Montana with the development of optional management strategies for dryland barley production.

Table 4. Population Rate comparison for traits measured for Early and Late cutting, Leaf Area Index, Canopy Cover and Grain parameters. Average recommended dryland planting rates for Montana District 5 for malt, feed, and hay barley are 35-45 lbs/ac (10-13 seeds/ft^2), 45-60 lbs/ac (13-17 seeds/ft^2, and 67-90 lbs/ac (20-26 seeds/ft^2) respectively.

Trait	Malt-40#	Feed-60#	Forage-80#	LSD (P=0.05)	
Early Cutting - July 23, 2002					
Yield, lbs/ac 10% moisture	2577^{a}	3113^{b}	2917^{ab}	354	**
CP, %	17.1	16.3	16.7	1.54	ND
ADF, %	25.8	26.1	26.5	1.08	ND
NDF, %	48.1	47.8	48.0	0.90	ND
TDN, %	72.0	71.7	71.3	1.18	ND
RFV, %	133.1	133.8	132.6	3.28	ND
Nitrate, %	0.44^{a}	0.40_{ab}	0.37^{b}	0.05	**
Late Cutting - August 6, 2001					
Yield, lbs/ac 10% moisture	3310	3160	3243	412.3	ND
CP, %	12.4^{a}	11.9^{b}	11.9^{b}	0.45	**
ADF, %	27.4	27.6	27.7	1.41	ND
NDF, %	49.6^{a}	50.1^{ab}	51.5^{b}	1.52	**
TDN, %	69.1	68.9	68.8	1.52	ND
RFV, %	127.6	125.9	122.3	5.46	ND
Nitrate, %	0.30^{a}	0.21^{b}	0.21^{b}	0.04	**
Leaf Area Index	0.62	0.62	0.67	0.09	ND
Canopy	0.63	0.62	0.61	0.05	ND
Grain Parameters - Harvested August 28, 2001					
Height, cm	42.7^{a}	40.4^{b}	40.9^{b}	1.56	**
Yield, bu/acre	26.5^{a}	22.4^{b}	18.9^{c}	2.56	**
Test Weight, lbs/bu	49.9^{a}	50.1^{ab}	50.3^{a}	0.38	**

** Main effects within rows with different superscripts differ.

ND = No difference

Results of External Review

Dr. Patrick Carr, North Dakota State University reviewed the proposal. See Appendix I.

Required Facilities and Equipment

The research will be conducted at Northern Agricultural Research Center (NARC), Havre, Montana. Ample chemical fallow farm ground has been designated for the project for the next two years. The research-scale Concord air drill system (Figure 1) has been equipped with variable rate technology and all components for planting the project have been procured. Narrow and wide seed band widths will be achieved utilizing `Farmland' SB1, double-shoot seed and fertilizer boots equipped with 4-inch sweeps plus reverse spreaders and 10-inch sweeps plus SBS2 spreaders, respectively (Figure 2). `Titan' 6-inch square-wall packers will be utilized for both seed band width configurations. This piece of equipment is one of a very few research scale air drills in the country capable of performing this type of research. Funding to procure in-ground hardware and for neutron probe work is requested in the budget. The actual probe will be borrowed from another project.

Northern Agricultural Research Center has ample lab space and grinding equipment to process routine research samples. However, a barcode scanner, GAC grain test weight and moisture analyzer, analytical balance (accurate to 0.001) and a Pentium type computer with hard copy printing ability is requested in the proposal budget section to facilitate processing greater numbers of samples and to more accurately and efficiently determine forage component ratios.

Performance Benchmarks and Target Dates

2001

The initial investigation year has been completed and data analysis has been performed and is presented in this proposal. Planning for 2002 planting regimes and project protocol is complete with partial funding available through NARC-designated and USDA special grant funds.

Our funding request begins with crop year 2002. 2001 is included in this section for illustration of matching funds already procured.

2002

Funding is being requested for two funding years (7/1/2002 to 6/30/2003 {2002 crop year} and 7/1/2003 to 6/30/2004 {2003 crop year}). The 2002 trial will be established in the spring with NARC designated account funds already received from the USDA special grant. Target harvest dates for grain and forage will be dependent upon development of the crop. Data analysis and lab procedures will be completed the end of the crop year 2002.

2003

February will be targeted to complete second year data analysis, two-year data analysis and project review. Third year trial establishment will take place in the spring of 2003. Target harvest dates for grain and forage will be dependent upon development of the crop. Data analysis and lab procedures will be completed the end of the crop year 2003.

2004

A final project report would be completed by June 30, 2004.

Budget

Funding is being requested for two funding years (7/1/2002 to 6/30/2003 {2002 crop year} and 7/1/2003 to 6/30/2004 {2003 crop year}). Funding will be supported by NARC designated account funds and monies already received from the USDA Special Grant – *Barley Feed for Rangeland Cattle*. Initial year funding from that grant totaled $16,225.00 including a Research Associates salary and benefits (NARC designated funds) and is included in matching funds section of this proposal.

With a trial of this scale labor becomes a large portion of the funding required, since two forage harvests, grain harvest, and extensive lab work is involved. Salary requests are for two summer employees for each of the two years ($6.10 / hr for 12 weeks each year). Matching funds include Research Associate salary and benefits being paid from the USDA Grant for 25 % time for each of the funding request years plus monies from the USDA grant to perform the initial year research.

Repair and maintenance costs include farming equipment and lab equipment, further including expendable equipment associated with establishing and managing the trial. Travel costs are for two principal investigators to attend Agronomy and or Animal Science meetings to present research results. Communication costs are page costs for publication and any expenses associated with popularizing and distributing the results to producers in the state.

Contracted laboratory services include all forage samples analyzed for proximate analysis, nitrate and grain measurements. There will be 144 and 72 forage and grain samples, respectively, each year. It has become more efficient and economical to contract these services rather than purchasing the equipment to perform the analyses required.

Rent includes a portion of lease expenses associated with a 125 hp tractor to handle the ‘Concord’ air drill for trial establishment. Also included are land and equipment charges required to perform research activities of this size.

Equipment items necessary for this type of research that were purchased via non-state funded entities are: Air drill modification (Northern Ag Services - $6000.00), Raven variable rate controller, seed and fertilizer flow monitoring devices (NARC-Agronomy designated account {$2777.00} and Montana Wheat and Barley Association {$5730.00}) and ‘Titan’ 6 inch packer wheels to achieve proper seed – soil contact when banding the seed at the wider widths required (Industry; $900). Funding is requested for an automated grain analyzing system for the seed lab at Northern Agricultural Research Center including a GAC grain sample analyzer, computer to run and record data, barcode scanner, printer, analytical balance and handheld computer for field record collection and organization.

Just as the initial year of this project was funded from another source; this proposal, if funded will increase Northern Agricultural Research Centers visibility and infrastructure thus making the Center better able to attract additional funding from other sources for continuation of this type of work or possibly other large scale applied annual forage investigations. Using the added lab equipment as a potential match for other funding sources should further assist Northern Agricultural Research Center and the Principal Investigators in attracting additional grant dollars toward helping Montana's producers add value to their commodities and expand management tools available to address changes in market opportunities.

Total Project Budget

Budget Item	R&C Funds	Matching	Other	Total
Salaries	11712	27145		$38,857.00
Payroll Benefits	2810	6430		$9,240.00
Repair and Maintenance	1500	750		$2,250.00
Travel	2500			$2,500.00
Communications - Publication Costs	2000	500		$2,500.00
Contracted Services	10080	2500		$12,580.00
Rent - Tractor, land use fee, sprayer	2400			$2,400.00
Supplies and Materials	3500	400		$2,800.00
Equipment				
GAC - Grain analyzer	4275			
Sample Bar code Scanner	400			
Pentium Computer linked to GAC	1000			
Printer for GAC	250			
Analytical balance	4000			
Air Drill flow monitors		2430		
Raven variable rate controller		6077		
"Titan" 6 inch Packer Wheels*		900		
Concord air drill components*		6000		
Handheld Computer - IPAQ	899			
Equipment Total				$27,331.00
Total	$47,326.00	$53,132.00	$0.00	$100,458.00

* Denotes Equipment Grant from Private Industry

Source of Matching Funds	Amount Applied to Proposal
USDA Special Grant	$6,225.00
USDA Funded Salaries	$31,500.00
Carlson Designated Account	$2,777.00
Equipment*	$12,630.00
	$0.00
Total	$53,132.00

* Industry Grants and Montana Wheat and Barley Committee

2002 Project Budget

Budget Item	R&C Funds	Matching	Other	Total
Salaries	5856	13573		$19,429.00
Payroll Benefits	1405	3215		$4,620.00
Repair and Maintenance	750	375		$1,125.00
Travel				$0.00
Communications - Publication Costs				$0.00
Contracted Services	5040	1250		$6,290.00
Rent - Tractor, land use fee, sprayer	1200			$1,200.00
Supplies and Materials	2300	200		$1,400.00
Equipment				
GAC - Grain analyzer	4275			
Sample Bar code Scanner	400			
Pentium Computer linked to GAC	1000			
Printer for GAC	250			
Analytical balance	4000			
Air Drill flow monitors		2430		
Raven variable rate controller		6077		
"Titan" 6 inch Packer Wheels*		900		
Concord air drill components*		6000		
Handheld Computer - IPAQ	899			
Equipment Total				$27,331.00
Total	$27,375.00	$34,020.00	$0.00	$61,395.00

* Denotes Equipment Grant from Private Industry

2003 Project Budget

Budget Item	R&C Funds	Matching	Other	Total
Salaries	5856	13572		$19,428.00
Payroll Benefits	1405	3215		$4,620.00
Repair and Maintenance	750	375		$1,125.00
Travel	2500			$2,500.00
Communications - Publication Costs	2000	500		$2,500.00
Contracted Services	5040	1250		$6,290.00
Rent - Tractor, land use fee, sprayer	1200			$1,200.00
Supplies and Materials	1200	200		$1,400.00
Total	$19,951.00	$19,112.00	$0.00	$39,063.00

Darrin L. Boss

Education

B.S.	The Ohio State University, Columbus, Zoology/Wildlife Biology, 1990.
B.S.	The Ohio State University, Columbus, Animal Science, 1992.
M.S.	Montana State University, Bozeman, Beef Cattle Nutrition, 1994.
Ph.D.	Candidate, Montana State University, Bozeman, Program Initiated Fall 2001.

Professional Experience

1995 – Present:	Research Associate, Northern Agricultural Research Center, Montana State University
1994 – 1995	Research Associate, Montana State University, Bozeman, Animal and Range Department
1992 – 1994	Research and Teaching Assistant, Montana State University, Bozeman, Animal and Range Department

Selected Publications

Anderson, D. C., D. D. Kress, D. W. Bailey, D. L. Boss and K. C. Davis. 2001. Evaluation of F1 crosses from Angus, Charolais, Salers, Piedmontese, Tarentaise, and Hereford sires. II: Feedlot and carcass traits. Proc. West. Sec. Amer. Soc. Anim. Sci. 52.

Boss, D. L., D. D. Kress, D. . Anderson, D. W. Bailey and K. C. Davis. 2001. Evaluation of F1 crosses from Angus, Charolais, Salers, Piedmontese, Tarentaise and Herefords. I: Calf performance and heifer development. Proc. West. Sec. Amer. Soc. Anim Sci. 52:

Boss, D. L. and J. G. P. Bowman, L.M.M. Surber, D.C. Anderson, and T.K. Blake. 1999. Feeding value of two Lewis and Baronesse recombinant inbred barley lines. Proc. West. Sect. Am. Soc. An. Sci. 50.

Bowman, J.G.P., B.F. Sowell, D.L. Boss, and H. Sherwood. 1999. Infulence of liquid supplement delivery method on forage and supplement intake by grazing beef cows. Anim. Feed Sci. Technol. 78:273-285.

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Davis, K. C., D. D. Kress,, D. C. Anderson, and D. L. Boss. 1998. Influence of selection for greater yearling weight and smaller birth weight on scrotal circumference and age at puberty for purebred hereford cattle. Proc. West. Sec. Am. Soc. An. Sci. 49.

Bailey, D. W., D. D. Kress, D. C. Anderson, D. L. Boss and K. C. Davis. 1998. Relationship between grazing distribution patterns and performance of beef cows. J. Anim. Sci. 76:supp 1.

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Boss, D. L. and J. G. P. Bowman. 1996. Barley varieties for finishing steers: II. Ruminal characteristics, and rate, site and extent of digestion. J. Anim. Sci. 74:1973-1981.

Gregg R. Carlson

Education

B.S., Montana State University, Bozeman 1969, major: Animal Science, Ag Production

M.S., Montana State University, Bozeman 1982, major: Agronomy
Thesis: Seed and Embryo Size Relationships with Seedling and Mature Plant Performance in Barley

Professional Experience

01/89-Present: Associate Professor, Research Agronomist, Montana State University, Northern Agricultural Research Center, Havre, MT. 100% Research Appointment.

09/81-12/88: Assistant Professor, Research Agronomist, Montana State University, Northern Agricultural Research Center, Havre, MT. 100% Research Appointment.

01/79-08/81: Instructor, Extension Agent Chair, Montana State University, Hill County Extension Service, Havre, MT. 100% Extension Appointment.

09/77-12/78: Instructor, Educational Leave, Montana State University, Plant & Soil Sciences Department, Bozeman, MT.

03/73-08/77: Instructor, Extension Agent Chair, Montana State University, Hill County Extension Service, Havre, MT. 100% Extension Appointment.

03/70-02/73: Instructor, Extension Agent Chair, Montana State University, Liberty County Extension Service, Chester, MT. 100% Extension Appointment.

10/69-02/70: Personnel Records Specialist, Military Leave, U.S. Army Reserve, BCT/AIT, Fort Ord, CA.

Selected Publications

Holen, D.L., P.L. Bruckner, J.M. Martin, G.R. Carlson, D.M. Wichman, and J.E. Berg. 2001. Response of winter wheat to simulated stand reduction. Agron. J. 93:364-370.

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Commercialization Plan

Producers are asking researchers to develop ways to increase their potential profits by adding value to crops that are environmentally adapted to the variable growing conditions in Montana. Developing improved management tools will allow the producer to plan for the best but be prepared to adapt to environmental or market changes. Certain crops are already adapted and presently constitute a large portion of the Montana agricultural economy. Producers need different management options to take advantage of small windows of opportunity arising when markets fluctuate or when differing environmental conditions exist. This project is not intended to promote replacement of traditional barley growing practices, but to evaluate the potential for increasing the value of a crop producers already grow very well in Montana. With barley grown on 1.25 million acres in Montana alone, the potential is high for even very small increases in profits to generate a great deal of additional revenue.

Public talks and seminars following completion of the project will be used as the conduit to introduce and inform producers about the various options and potential benefits or pitfalls associated with various management practices and environmental conditions that may be encountered. Results will be published in scientific journals and will be popularized for dissemination to Montana producers. As air drill technology becomes more widely utilized it is important for the research community to anticipate producer needs for information allowing them to adapt the technology to their best advantage for increasing production profit. Adding value to a crop that the producers of Montana are very comfortable growing would allow them to quickly adopt new technologies and management options.

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External review conducted by Dr. Patrick Carr, North Dakota State University. Comments are below.

Dr. Patrick Carr:

04 March 2002

To: Montana Board of Research and Commercialization

From: Patrick Carr, PhD.
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RE: Grant Application Entitled:
Increasing Yield and Management Options for Producers who Traditionally Plant Barley Acres for Grain or Forage Production by Varying Seed Band Width, Planting Rates and Harvest Endpoint by D. Boss and G. Carlson

Summary: I have reviewed the grant proposal submitted by Boss and Carlson. The proposed research would generate information that could have and immediate (positive) economic impact of Montana producers. There is no alternative source of information available to the work proposed by the authors of the proposal. The experimental design that will be used is acceptable. The proposal justifies serious consideration for funding, particularly given its strong practical application to improving the economics of dryland farming in Montana.

APPENDIX B: WATER USE

Water use and water use efficiency estimated by neutron probe technology of barley (Harrington or Haybet) seeded in wide or narrow band widths at three seeding rates (140, 184 and 226 seeds m^{-2}) when harvested as annual forage or grain production in Northern Montana.

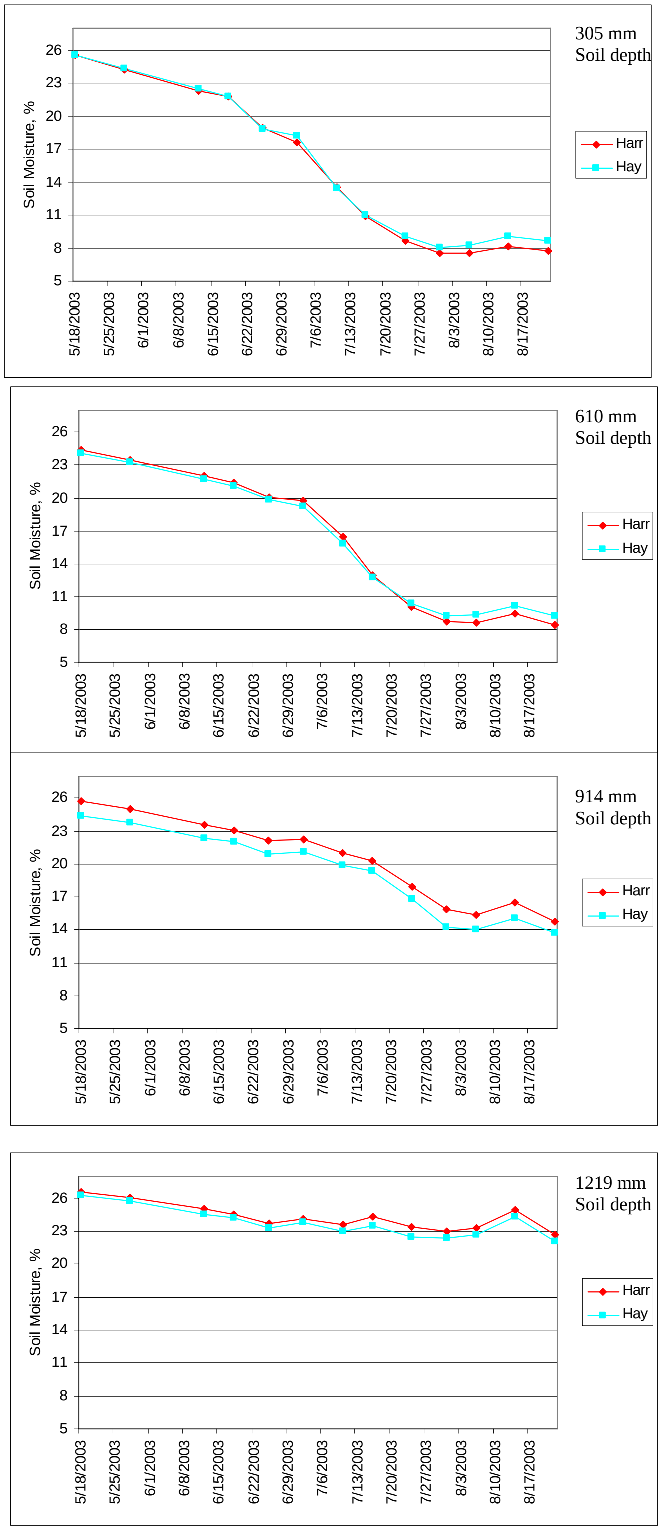

Figure. Soil moisture levels for Harrington (HARR) and Haybet (HAY) barley cultivars for 305, 610, 914, 1219 mm deep sampling depths. Neutron probe access tubes were placed between rows 5 and 6 in reps 2, 3 and 5. Main effects (Harrington and Haybet) did not differ (P > 0.05).

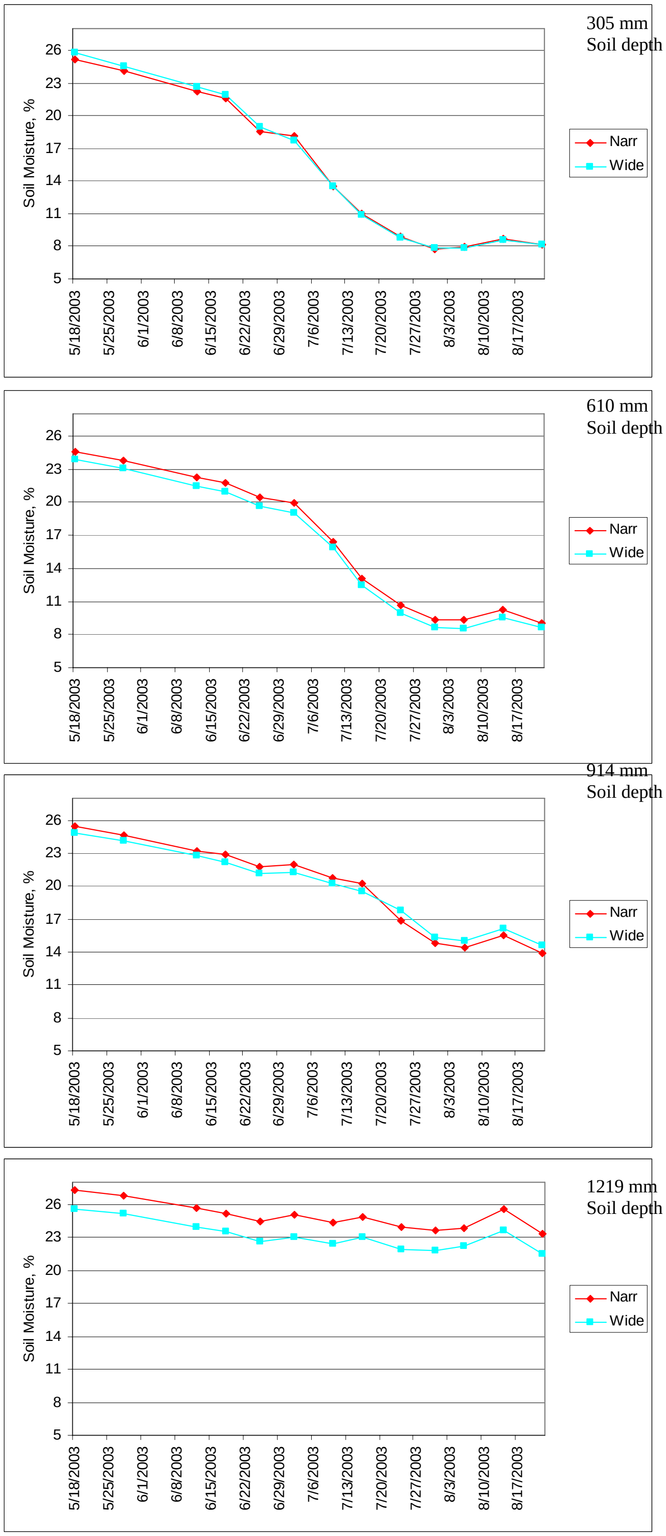

Figure. Soil moisture levels for narrow (NARR) and wide (WIDE) treatments for 305, 610, 914, 1219 mm deep sampling depths. Neutron probe access tubes were placed between rows 5 and 6 in reps 2, 3 and 5. Main effects (NARR and WIDE) did not differ ($P > 0.05$).

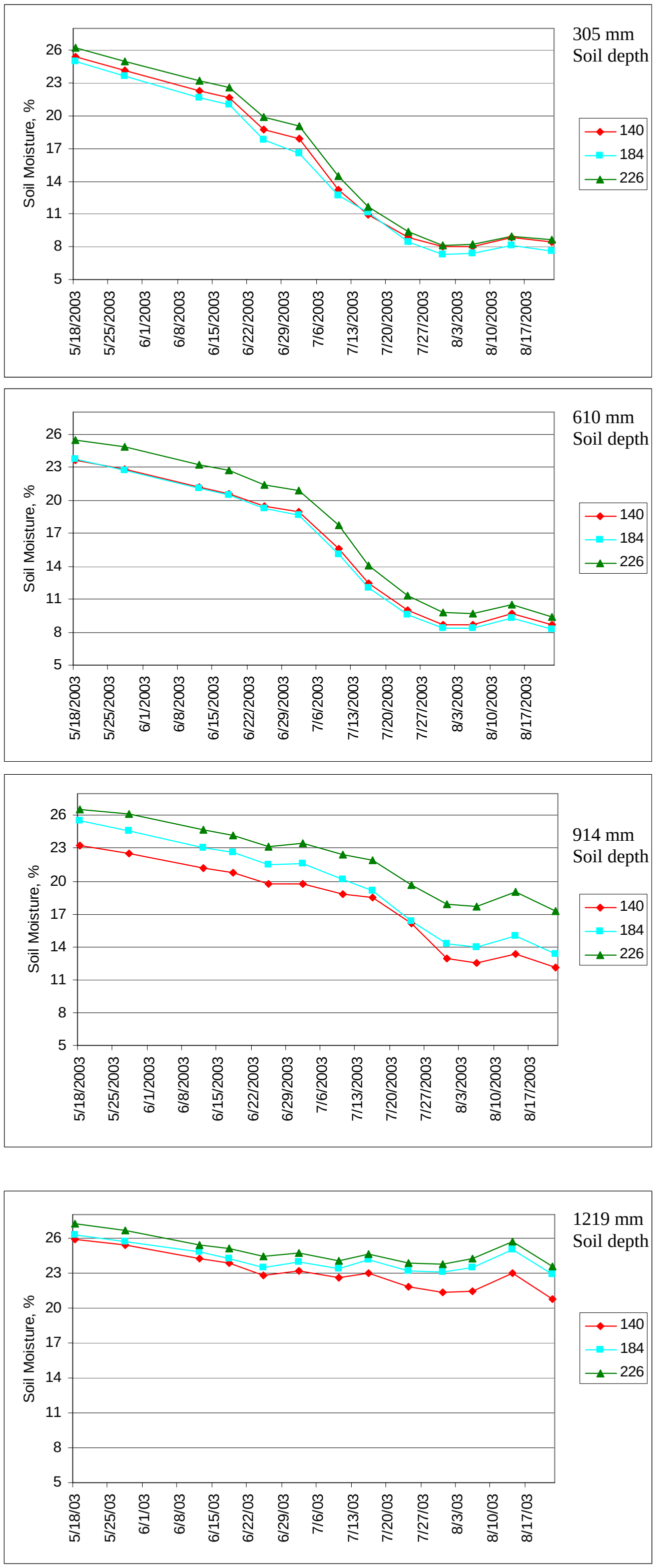

Figure. Soil moisture levels for three populations (140, 184 and 226 seeds m^{-2}) for 305, 610, 914, 1219 mm deep sampling depths. Neutron probe access tubes were placed between rows 5 and 6 in reps 2, 3 and 5. Main effects (140, 184 and 226 seeds m^{-2}) did not differ ($P > 0.05$).

Table 1. Water use efficiency (defined as the moisture level consumed from the entire 1220 mm profile from the beginning of the neutron probe measurements to harvest endpoint) for main effects.

Water Use Efficiency[†]	Variety			P =
	Harrington	Haybet		
Early cut, soft dough[‡]	36.7	40.7		0.2627
Late cut, 7 d later	39.6	41.3		0.7022
Grain harvest	92.9	88.5		0.4819
	Band width			
	Narrow	Wide		
Early cut, soft dough[‡]	37.3	40.1		0.4350
Late cut, 7 d later	39.0	41.8		0.5704
Grain harvest	92.9	89.9		0.5556
	Seeding rate, seeds m^{-2}			
	140	184	226	
Early cut, soft dough[‡]	39.1	38.0	39.0	0.9642
Late cut, 7 d later	34.2	39.6	47.3	0.0986
Grain harvest	97.3	87.0	88.4	0.5109

[†] Water use efficiency,
Forage harvest, kg ha^{-1} mm^{-1}.
Grain harvest, g ha^{-1} mm^{-1}.

[‡] Zadoks 80 to 83 (Zadoks et al, 1974).