Challenges for Growing Corn Silage Suitable for the Dairy Industry in a Northern Climate

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Take Home Messages

- New, early maturing corn hybrids have made corn silage production possible in short-season areas such as the northern prairies.
- To be economically competitive corn has to yield significantly more silage dry matter than barley. The risk in corn silage production is not so much in yield variation, but the high cost of production and the consequences of less than expected yield or milk production.
- To be economically competitive with adapted alternative feedstuffs grow corn silage at higher than conventional plant populations.
- To achieve adequate maturity for ensiling choose corn hybrids that are within 100 corn heat units of those grown for grain. Hybrids rated as later maturing than the resident corn heat unit zone may not have a yield advantage over earlier ones in short-season climates.
- Corn grown in northern short-season environments is not likely to have similar nutritive value for dairy production as that grown in the northern US corn belt unless it can mature to 35% silage dry matter and have well developed kernels.
- Silage percent dry matter of 30 to 35% achieved by frost is not as nutritious as that having high grain content.
- Silage of less than 30% dry matter with low grain content will have a relatively low dry matter intake.

Adaptation Zones for Corn Production

Because corn growth and development is so sensitive to temperature, corn heat unit (CHU) maps can describe the chance of a corn crop reaching maturity or the risk of not reaching maturity. The Canadian mapping system for corn maturity is based on the Ontario CHU, which uses a night time base of 4.4^{0}C and a day time base of 10^{0}C accumulated daily. Corn heat units are summed from a common point in the spring until a killing fall frost. Adaptation zones are map areas with the same number of CHU averaged over many years. Corn hybrids are grouped according to ability to achieve grain maturity within the adaptation zones. The rating of corn hybrids with the CHU system may not have the same accuracy and precision in all regions, particularly in short season areas. The original CHU system designated grain maturity at 40% kernel moisture (Daynard 1978). It follows that some error will occur in predicting time of silage maturity or harvest date.

Grain corn maturity is indicated by the black-layer stage, the point at which plant sugars and water cease to enter the kernel. Grain maturity occurs at different grain moisture contents across CHU zones and tends to occur at higher grain moisture percentages where growing seasons are shorter and cooler (LeDrew et al. 1984). Across the prairie provinces the frost free season is surprisingly uniform, but accumulated CHU tend to decrease in a north-west direction from the Red River Valley in Manitoba on the east to Red Deer, AB on the west due to the negative effects of increasing altitude on daily temperature minimums and maximums. Areas of highest CHU accumulation (approximately 2500 CHU) are in the Carman-Morden-Winkler area in Manitoba and the area surrounding Medicine Hat in Alberta. Until the mid-1970's corn hybrids rated earlier than 2400 CHU were rare; hybrids rated at 2300 CHU became prevalent by 1980 and in the last five years hybrids as early as 2000 CHU have been available, potentially opening up large areas for corn silage production.

Corn Silage Maturity

Corn growth and development can be split into two unequal parts on either side of the silking stage. Vegetative development occurs from planting until silking. Grain development, filling and whole-plant drying occurs after silking. In southern Ontario it takes about 6 weeks from silking to grain maturity, with the first two weeks required for kernel establishment. During kernel establishment grain dry weight and starch accumulation is very slow and whole plant dry matter percentage remains about 20%. The whole plant dries to acceptable levels for ensiling during the mid to latter part of grain filling. The rate of drying is dependent on temperature or CHU accumulation. In the earliest of corn hybrids (2000 CHU) about 1200 to 1300 CHU is required between planting and silking. It is important that silking occurs in July so that the grain filling and drying process can take advantage of the warm mid-summer temperatures. Temperatures decrease rapidly after August 15 in the north-western Prairies. Silking in August may not allow enough time and accumulated CHU to bring the whole plant up to the 25 to 30% dry matter levels required to make silage. In order to achieve maturity levels that can provide competitive silage yields at silage dry matter levels close to 30% corn must be planted in early May or even late April to use all available growing days and CHU.

Silage yield maximizes before grain yield and maturity, but the time between the two events is not consistent across CHU zones (LeDrew et al. 1984). Corn silage should be at least 25% dry matter for storage in bunker silos and 30% dry matter in tower silos to minimize seepage losses, while obtaining satisfactory fermentation (Daynard 1978). Research in New York and Wisconsin indicates that harvesting of corn silage for dairy operations should optimize around 35% whole plant dry matter (Bal et al.1997; Cox and Cherney 2005). In central Ontario silage yield maximized at 35% dry matter, which coincided with 45% grain moisture when grain-fill was 85 to 90% complete (Daynard and Hunter 1975). However, as the CHU of adaptation zones decrease the dry matter percentage at which silage yield maximizes becomes lower, ranging from 42 to 46% at 3000 CHU to 26 to 31% at 2200 CHU (LeDrew et al. 1984). In the Ontario environment silage yield maximizes about 100 to 200 CHU prior to grain maturity, so a 2400 CHU corn hybrid could be grown for silage in a 2300 CHU zone (Daynard 1978). However, as CHU zones become shorter and cooler the chance of attaining wetter silage (25 to 30% whole-plant dry matter) increases providing a narrow hybrid maturity range that can be grown in the cooler region.

How High Does Yield Have To Be?

Cost of production relative to other alternatives dictates high yield is required. In western Canadian dairy operations corn silage yield has to be high enough so that cost/t of dry matter produced is equal to or lower than the standard alternative, barley silage. We used the Excel spreadsheet method: “Guidelines for estimating barley and corn silage costs” prepared by Blawat et al (2007) to compare costs for expected yields in the Lacombe, AB area. The region is ideal for barley production and marginal for corn production based on average CHU accumulation (1870 CHU). Barley and corn silage total production costs from planting to packing silage were $605/ha ($245/acre) and $874/ha ($353/acre), respectively, assuming non-irrigated dry land production. Among other cost differences the major operating cost differences were seed, fertilizer, herbicide and fuel, which cost $227/ha or $92/acre more for corn than barley. The corn hybrid used was a 2000 CHU (not glyphosate-resistant) type.

Thus, corn has to yield more than barley. We determined a long-term, average barley silage yield at Lacombe, AB, based on 22 years of barley silage data. A long-term, average corn silage yield was determined based on a linear relationship between silage dry matter yield and CHU accumulated from planting until sequential harvests at increasing stages of maturity over 3 years (Figure 1; R^2 = 0.82). Then we predicted corn silage dry matter yields with the relationship (Figure 1) and CHU data (May 12 to first frost) for 30 years that overlapped with the years of barley production. Over the long-term barley silage averaged 8.8 t/ha of dry matter compared to 11.7 t/ha for corn based on CHU data and an assumed corn plant population of 75,000 plants /ha (30,000 plants /acre).

Corn is reputed to be a risky crop to grow, however the variation about the estimated mean yields (CV) was 22 and 19% for barley and corn, respectively. Thus, the risk in silage production for corn is not so much low or variable yield but the high cost of production and the consequences of less than expected yield or milk production. To quantify the risk of not attaining silage yields that would be cost-comparable to barley the 22 years of barley yield and 30 years of corn yield were entered into the @Risk software spreadsheet to develop cumulative probability distributions used to determine probabilities of not achieving certain yield levels in either crop. The risk of producing less than 8.8 t/ha of barley and 11.7 t of corn silage is 50%. While corn yielded more than barley in this comparison the total cost of production on a dry matter basis was $62/t for barley and $67/t for corn. To reduce corn production costs per t to the level of barley, corn must yield approximately 12.5 t/ha of silage dry matter at Lacombe. The chance of corn yielding less silage than 12.5 t/ha at Lacombe is approximately 67% when grown at 75,000 plants /ha. A corn crop grown at 100,000 plants /ha would yield 13 t/ha on average and cost $64/t of corn silage dry matter. The risk of less than 13 t/ha improves to 43% with the higher plant density.

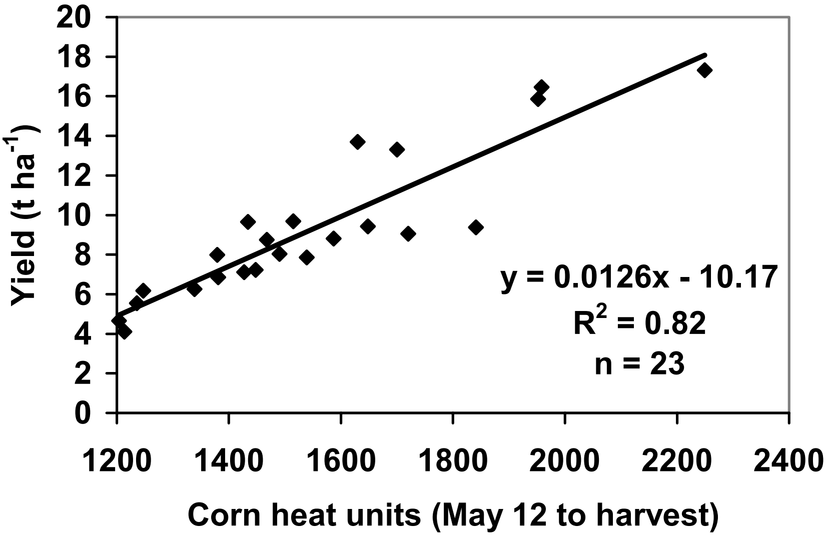

Figure 1. Whole-plant dry matter yield for a 2000 corn heat unit hybrid planted at 100,000 plants /ha, harvested eight times during growth over three years at Lacombe, AB.

Impact of CHU and Hybrid Maturity on Corn Silage Yield

Generally, silage yields increase as CHU zones increase from 2300 to 3000 CHU in Ontario; later hybrids yield more than earlier ones within CHU zones (LeDrew et al. 1984). However, yield differences between early and late hybrids within zones are not always large and the difference between groups is lowest in zones with the lowest of CHU (LeDrew et al. 1984). In our research at Lacombe, Brooks and Bow Island, AB (Table 1) silage yield increased as CHU maturity zone increased, but the early (2000 CHU) and late (2200 CHU) hybrids weren't necessarily significantly different within locations, especially at the coolest location, Lacombe. Obviously, chances of corn silage yield meeting the cost of production criteria improves in higher CHU zones, because yield is higher. Yields of early rated hybrids are likely more consistent from year to year in all zones. In the cool adaptation zones, for example Lacombe (1870 CHU), the late hybrids could not come close enough to potential yield to out yield the early ones. The late hybrids were rated at 330 CHU more than average CHU accumulation for Lacombe and 293 CHU more than actual accumulation (Table 1). At the warmer Bow Island location (2514 CHU) the later hybrids yielded more than the early hybrids as expected. However, their maturity rating (2200) was not later than 2500 CHU.

Table 1. Dry matter yield, percent dry matter, leaf area index and corn heat units from planting until harvest averaged over two years at Lacombe, Brooks and Bow island, AB for two early and two late corn varieties

Hybrids	DM Yield	Percent DM	Leaf Area Index	Corn Heat units	
				Actual Avg[1].	Long Term
	t/ha	%			
			Lacombe		
Early[2]	11.1	31.7	2.5	1907	1860
Late	10.5	21.9	2.9		
			Brooks		
Early	13.5	32.5	2.7	2373	2354
Late	12.8	30.5	2.8		
			Bow Island		
Early	14.2	39.0	2.8	2329	2514
Late	15.4	34.0	3.3		

[1]Average of two years data from planting until date of harvest or killing frost.

[2]Two early and two late corn hybrids rated at 2000 and 2200 CHU, respectively and grown at 75,000 plants /ha (30,000 plants/ha) at standard row spacing.

As adaptation zones become cooler reductions in dry matter yield are expected because of environmental effects on growth rate of the warm season crop and because the whole-plant yield will maximize earlier in relation to grain development (Daynard 1978). In areas that are on the edge of corn adaptation zones the CHU system for grain maturity may not be accurate enough. A 2000 CHU hybrid grown at Lacombe (average CHU of 1870) and harvested from silking until frost continued to increase in yield after 2000 CHU from planting, but only achieved 30% whole-plant dry matter at 1950 CHU and kernel moisture of 53% after 2200 CHU (Figure 1 and Table 2). In 2005 the CHU accumulation was 1650, about 350 CHU less (Figure 1) than the hybrid rating (2000 CHU), causing silage to be too wet for bunker silo storage, low yield, and cost of production higher than desired. Daynard (1978) estimated that 300 to 400 CHU are required between 25% dry matter and grain maturity in areas less than 2200 CHU. This would mean that a 2300 CHU hybrid should reach 25% dry matter after 2000 CHU have accumulated. However, at Lacombe a 2000 CHU hybrid reached only 19% silage dry matter by 1700 CHU (Table 2). Daynard's estimate of 100 – 200 CHU between 25 and 30% dry matter appears to be on target. Thus in this very cool environment hybrid maturity choice has to be very conservative to arrive at appropriate silage dry matter percentage and grain development for high quality silage.

Table 2. Estimated dry matter yield, actual nutritive value, milk yield index and estimated cost of dry matter production for a 2000 corn heat unit corn hybrid, planted at 100,000 plants /ha and harvested sequentially before and after frost at Lacombe AB compared to corn silage produced in New York State

		Yield Estimated at CHU[1]					
		1700	1840	1950	2200	Post Frost	[2]New York State
P. of fewer CHU[3]		0.17	0.43	0.67	0.97		
DM	%	19	24	30	29	36	35
Kernel Moist.	%	----	71	53	53	50	--
DM Yield	t/ha	11.5	13.0	14.4	17.6	17.6	15.1
NDF[4]	%	51	51	50	46	45	42
NDFD[4]	%	67	67	69	64	56	63
IVTD[4]	%	83	83	84	84	84	85
Protein[4]	%	9.1	9.2	8.2	8.0	6.9	7.2
Starch[4]	%	2.9	6.7	12.4	18.7	23.9	27
Milk/t[5]	L/t	1196	1315	1491	1665	1598	1588
Milk/ha[5]	L/ha	13679	18972	21318	26047	25013	24252
COP/t DM[6]	$/t	79	70	64	53	53	--

[1]Corn yield is predicted for 1700 to 2200 CHU based on linear relationship (Figure 1) of three years of data. Post frost corn data is actual data from 2006.

[2]New York example after Cox, W.J. and Cherney, J.H. (2005).

[3] Probabilities of fewer corn heat units determined from the normal distribution of the last 30 years of CHU accumulation at Lacombe, AB using the @Risk software.

[4]Corn quality is from actual CHU accumulation at harvest during 2006; NDFD (neutral detergent fibre digestibility) is 48h digestion: IVTD (in vitro true digestibility).

[5]Milk Index (i.e. Milk/t and Milk/ha) after Schwab, E.C. and Shaver, R.D. (2001).

[6]COP – cost of production/t dry matter after Blawat et al (2007).

Impact of Plant Density and Row Spacing on Silage Yield

As plant breeders select earlier silking corn hybrids to attain early grain maturity, plant size and capacity to intercept sunlight at conventional plant densities has been sacrificed. The leaf area index (LAI) of corn after silking is too low to intercept all available sunlight. An LAI of 2.0 to 2.7 (Table 1) intercepts about 75% of full sunlight; the higher the LAI is at an optimum plant density the higher the yield. Recently we (Baron et al. 2006) found that population densities of 100,000 plants /ha (40,000 plants/acre) or greater were necessary to maximize silage yield under central Alberta conditions. However, there are no broad recommendations for plant population densities for all regions and environments because it is dependent on factors such as soil moisture, soil fertility, hybrid, time of planting and harvest. In earlier research Baron et al (1987) found that whole-plant yield was maximized consistently at 75,000 plants/ha at sites having CHU typical of the southern prairie provinces.

A small (2 to 8%) increase in silage yield may be obtained by growing corn in narrower than conventional row spacing (e.g. 30 to 50 vs. 76 cm). This cropping technique may improve efficiency of light interception of corn grown in northern latitudes. We (Baron et al. 2006) found that on average silage yield was improved by 4% when grown in a 38-cm compared to 76-cm row spacing. By contrast increasing plant density from 75,000 to 125,000 plant density increased yield by 12%. However, we observed that one hybrid yielded 22% more when planted in narrow row spacing and at 100,000 plants /ha than in standard row spacing and 75,000 plants ha. This indicates that silage yield may be improved by using a combination of hybrid, row spacing and population.

Increasing corn population will increase cost of production because of a higher seeding rate. Does the extra yield offset the extra costs? Most producers use plant densities of about 75,000 plants/ha. Increasing density to 100,000 plants/ha would cost an extra $44/ha ($18/acre). A 2000 CHU corn hybrid planted at 100,000 plants/ha in narrow rows yielded 14.1t/ha dry matter (average of 2005, 2006 and 2007), resulting in cost of dry matter production of $59/t. Barley in the same trial averaged 9.7 t/ha for a cost of dry matter production of $56/t. These yields are higher than the long-term expectations shown earlier. Placed in the perspective of the long-term probability functions presented earlier, risk of yields less than 14.1 t/ha for corn and 9.7 t/ha for barley are 62 and 67%, respectively. In this case the odds favour corn.

Nutritive Value and Potential Milk Production

Effects of dry matter percentage and grain content on silage nutritive value have been contentious issues related to ruminant performance and corn silage feeding. In short-season locations below 2200 CHU it may not be possible to increase silage dry matter above 25%, reliably, with significant grain (Daynard 1978) or starch accumulation. Reviews by Daynard (1978) and Fisher and Fairey (1979) summarized information related to feeding immature corn silage in North America and Europe. Over the decade of the 70's and 80's short season corn silage was grown at population densities as high as 150,000 to 200,000 plants/ha in Europe. Corn silage, with low grain contents, was ensiled, stored and fed at silage dry matter percentages of less than 30%. However, Daynard (1978) concluded that reductions in dry matter intake would occur beginning in the range of 25 to 30% dry matter. Later Coors et al (1997) demonstrated the relationship between increasing grain content and reduction in neutral detergent fiber (NDF) and slight increases in *in vitro* true digestibility (IVDT) between 30 and 40% dry matter. Bal et al.

(1997) related starch content and digestibility in corn silage to milk yield that maximized close to 35% silage dry matter. Oba and Allen (1999) showed that improvements in NDF digestibility significantly improved intake and milk yield. The more recent research has shown that large positive changes in nutritive value that maximize milk yield occur between 30 and 35% corn silage dry matter and that silage that is less than 30% dry matter level is of lower quality in terms of milk production. Nutritive value estimates of NDF, NDF digestibility (NDFD) and percent starch have been included in spreadsheet software (e.g. Milk 2000 and amended versions) that can provide single term indices to evaluate corn hybrids and agronomic and feeding practices for potential milk production (Schwab and Shaver 2001; Cox and Cherney 2005). Unfortunately very little western Canadian corn and small grain silage information exists that is suitable for this type of software. Further, we don't know how applicable the software is to Canadian applications.

Generally, as corn matures stover decreases in cell wall digestibility, while highly digestible starch accumulates in the grain. Stover NDF content increases due to loss of sugars to the grain during the grain-filling period and to increasing lignin concentration. These offsetting factors result in whole-plant digestibility remaining more or less constant (Daynard 1978). While whole-plant in vitro true digestibility does not seem affected over a range of 25 to 40% dry matter, the accumulating grain tends to reduce whole-plant NDF, but this occurs most rapidly from 30 to 40% dry matter, which is in the last half of the grain-filling period. Starch accumulation in the grain increased by 1.2 times from 31 to 35% silage dry matter in Wisconsin (Bal et al. 1997) and 1.6 times from 29% to 35% dry matter in New York (Cox and Cherney 2005) areas of corn adaptation. Starch digestibility ranged from 92 to 94% from early dough to the 2/3 milk line stage and then decreased in the study of Bal et al. (1997). The reduction in starch digestibility in the last stages of grain filling may be due to hard kernels passing through the digestive tract. Generally, milk yield has optimized at close to 35% dry matter whether determined in actual trials (Bal et al 1997) or using the milk yield indices, MILK 2000 (Cox and Cherney 2005).

We summarized data (Table 2) for a 2000 CHU hybrid grown at Lacombe, AB from 1700 to 2200 CHU. The most probable corn silage yield and nutritive values for the area are represented by the columns headed by 1840 and 1950 CHU as the average CHU for Lacombe is 1870. At these harvest stages corn silage ranges from 24 to 30% dry matter. Thus nutritive value and milk yield/t as indicated by Milk 2000 (Schwab and Shaver 2001) estimates are less than those observed in US literature for mature corn silage (Cox and Cherney 2005), also shown in Table 2. While NDF digestibility for Lacombe corn silage at 1840 CHU is relatively high, compared to the US data, starch content is only 25%, NDF content is 9 units higher and milk yield/t is 83% of the Cox and Cherney (2005) data collected in New York (Table 2). Occasionally corn silage nutritive value at Lacombe will be both lower and higher as indicated by data under 1700 and 2200 CHU columns, respectively. Nutritive value for corn grown in areas of higher CHU accumulation than Lacombe should be closer to that of the northern US, but depends on corn silage containing well developed grain, which is a challenge. Choosing hybrids that are close to the maturity recommended for grain for each CHU adaptation zone may be necessary.

Impact of Frost on Yield and Nutritive value of Corn Silage

Corn is sensitive to frost, although cooler than average weather resulting in inadequate CHU accumulation (Table 2) or even hail may be a similar or greater economic risk to corn and other crops. Because cost of corn production is relatively high, the consequence of drastic weather is serious. Late spring frosts, early fall frosts and frosts prior to attainment of 30% whole-plant dry matter are the likely frost-damaging scenarios. The latter scenario will happen inevitably to corn silage producers in short season areas.

Spring frosts are occasionally a problem in all corn-growing areas including the U.S. corn-belt because of the emphasis on early planting. Spring frosts can result in loss of total fields or just spots. Generally, if the frost is light and before the six-leaf stage the crop can be salvaged. The seedling growing point remains below the soil surface until the six leaf stage. This protects the corn from death. If weather conditions are good then the corn crop will likely recover and the spring frost has little impact on yield. In Alberta the six leaf stage will not likely occur until sometime in June, so chances of a spring frost at or after the 6-leaf stage are low. Because the season is short re-seeding with corn may not be an option. Late frosts can reduce potential yield substantially. A frost during the latter part of August after 1700 CHU at Lacombe would decrease silage dry matter production by 10 to 20%, increase cost of feed production by $5 to $15/t and potential milk production by 120 to 300 L/t (Table 2). The reduced milk production is due to lack of grain in the silage.

Producers often use frost as a means of reducing silage moisture or increasing percent dry matter so that corn silage can be ensiled. If the choice is between growing a late hybrid, dependent on frost to reach 30% dry matter and using a variety that reaches 30% dry matter due to maturing grain, choose the latter. The simple reduction of moisture content in standing corn will not replace the beneficial effects of grain to nutritive value. Reduction of grain content will result in lower nutritive value and less milk/t. The effect of frost per se on nutritive value is somewhat case specific. Loss of water from the vegetative part of the plant will increase silage dry matter percentage about 10%. The higher the grain content in the silage, the lower the impact as frozen grain will not dry as fast as frozen immature vegetative corn. Corn frozen at 35% dry matter, which contains grain, has a higher nutritive value than corn frozen at 20% dry matter with corn at the blister stage. Dry, brittle highly vegetative immature corn may lose anywhere from 10 to 40% of its yield depending on weather conditions after the frost. Thus the sooner corn can be ensiled after frost the better.

■ Conclusions

Defining corn maturity suitable for dairy production in a short-season region is necessary. Corn heat unit maps provide an indication of corn hybrid maturity requirements, but may not be precise enough in cool short-season environments. Corn has to yield more silage dry matter than barley to be cost-competitive. This is more probable as the long-term average CHU accumulation for various regions increase. The risk in corn silage production is not so much in yield variation, but the high cost of production and the consequences of less than expected yield or milk production. In order to increase corn silage yield within CHU zones corn should be planted at higher than conventional populations. Corn silage of less than 30% dry matter is likely to have a lower nutritive value for milk production than silage that has matured to 35% dry matter prior to frost and has well developed kernels. Achieving 35% dry matter levels for silage by waiting for immature corn to freeze will not produce silage of the same nutritive value as unfrozen corn with the same dry matter content and well developed kernels.

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