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INDIAN HEAD AGRICULTURAL RESEARCH FOUNDATION

December 2007

Volatile Losses of Surface Applied N: How Substantial are They?

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Taking the Guesswork Out of Estimating the Potential Yield of Canola During the Growing Season

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Background and Objectives

Whether forward marketing grain, deciding whether or not to invest in crop protection, allocating available grain storage, or deciding whether or not they applied enough fertilizer, producers are continually attempting to estimate the potential yields of their crops. The guesswork starts before the crop is in the ground, with most producers using yield goals of some form or

another to determine the fertilizer requirements of their crops.

Yield goals are usually based on a combination of factors such as soil type, previous crop, spring moisture levels and anticipated precipitation, as well as more personal considerations such as aversion to risk and past yield experience. Regardless of how much thought goes into it, yield goals always require a considerable

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amount of speculation and, as such, are generally not very reliable indicators of potential yields that are realized in any given year.

Although factors such as the growing conditions to date, the visual appearance of the crop, and a limited ability to anticipate the conditions of the immediate future tend to enhance the ability of producers to estimate the yields of their crops, such estimates are still quite subjective and often come too late to be of much use in the decision making process.

Optical sensing technology provides a fast and objective method of gathering information from remote surfaces such as crop canopies. Surfaces covered with dense vegetation tend to absorb large quantities of visible light, while reflecting most of the near infrared (NIR) that reaches them. Consequently, visible, primarily red, and NIR bandwidths are commonly measured by sensing equipment and used in vegetation indices to characterize vegetated surfaces such as forest and crop canopies.

Vegetation indexes are defined as numerical values that enhance the spectral reflectance of the plant fractions of a surface while minimizing the effects of interfering factors such as background soil, light intensity, sun angle, senescent vegetation, and atmospheric conditions. The most commonly used index is the normalized difference vegetation index (NDVI). With the introduction of active, ground-based sensing systems such as the GreenSeeker™ (NTech Industries) and the Crop Circle™ (Holland Scientific), the NDVI of crops can now be determined more quickly and with greater ease than previously possible.

A number of physical crop parameters are correlated with NDVI, which include, but are not limited to, above-ground biomass and N uptake (Moges et al. 2004; Freeman et al. 2007). Similarly, NDVI can be effectively used to characterise variability in grain yields for crops including wheat, corn, and soybeans (Ma et al. 2001; Raun et al. 2002; Teal et al. 2006).

However, NDVI changes over the course of the growing season, increasing through vegetative growth, levelling off during the reproduction stages, and decreasing with senescence (Martin et al. 2007). Estimating winter wheat yields, Raun et al. (2002) minimized the effects of normal growth on reflectance by dividing NDVI by the number of days between planting and sensing where it was warm enough for growth. With corn, Teal et al. (2006) tried dividing NDVI by growing degree days (GDD) instead of days from planting, and they found that using GDD lengthened the window over which yields could be predicted and would conceivably allow the model to be applied in other climates.

The objectives of this study were to establish whether or not NDVI can be used to predict potential grain yields of canola and to determine the range of growth stages when yield can be estimated and best methods for minimizing the effects of normal growth during these stages.

Materials and Methods

Field experiments with canola were completed in 2005, 2006, and 2007 at AAFC locations at Brandon, Indian Head, Ottawa, Scott, and Swift Current where the rates of N fertilizer and seed were varied. The six N rates were 0, 22, 44, 89, 134, and 178 lb N ac⁻¹ and the



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seeding rates were approximately 1.2, 2.4, 4.8, and 9.6 lbs ac⁻¹. The purpose of varying N and seed rates was to establish plots with a wide range of potential yields within each site-year. Each plot's NDVI was determined several times throughout each growing season using handheld GreenSeeker™ sensors, and the grain yields of each plot were determined at maturity.

The relationships between the NDVI data and grain yield were determined by calculating the exponential growth equations using SigmaPlot 10 (Systat Software Ltd.) with R² used to determine the relative fit of the correlations. Several potential units were evaluated to standardize NDVI, including days from planting, growing degree days with base temperatures of 0°C (GDD₀) and 5°C (GDD₅), corn heat units (CHU) and physiological days (P-days). P-days is a function relatively complex to calculate, where crop growth increases with increasing temperatures from the minimum (7°C) to the optimum (21°C) temperatures, and it decreases from the optimum to the maximum (30°C).

- ◆ Brandon-05_June 21
- ▼ Brandon-05_June 28
- Brandon-05_June 30
- ◇ Brandon-06_June 19
- ▲ Brandon-06_June 23
- Brandon-06_June 26
- Indian Head-05_June 23
- ▽ Indian Head-05_June 28
- Indian Head-06_June 22
- ◆ Indian Head-06_June 25
- ▲ Indian Head-06_June 28
- Ottawa-05_Jun 10
- Ottawa-06_June 12
- ▼ Ottawa-06_June 16
- Ottawa-06_June 19
- ◆ Ottawa-06_June 23
- ▲ Ottawa-06_June 9
- Swift Current-05_July 4
- Swift Current-05_June 22
- ▼ Swift Current-05_June 27

Fig. 1. Legend for identifying the location and sensing date for each of the points in Figures 2 through 6

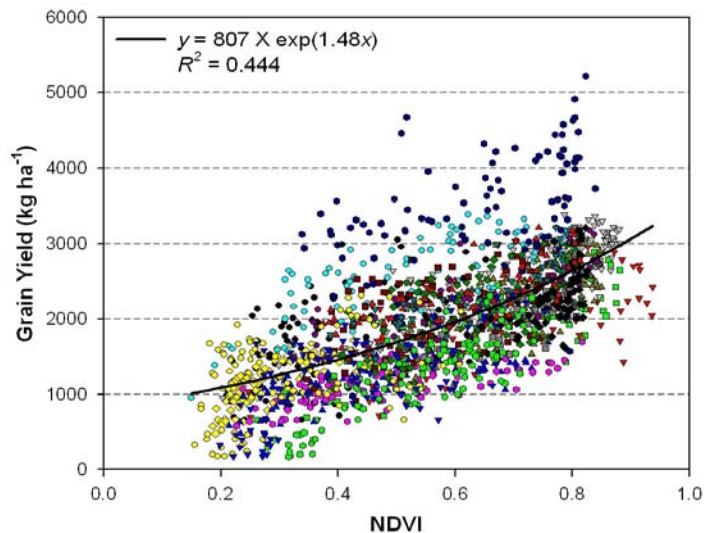


Fig. 2. Correlation between NDVI and grain yield of canola grown at various plant N densities and N rates at various Canadian locations (R²=0.444).

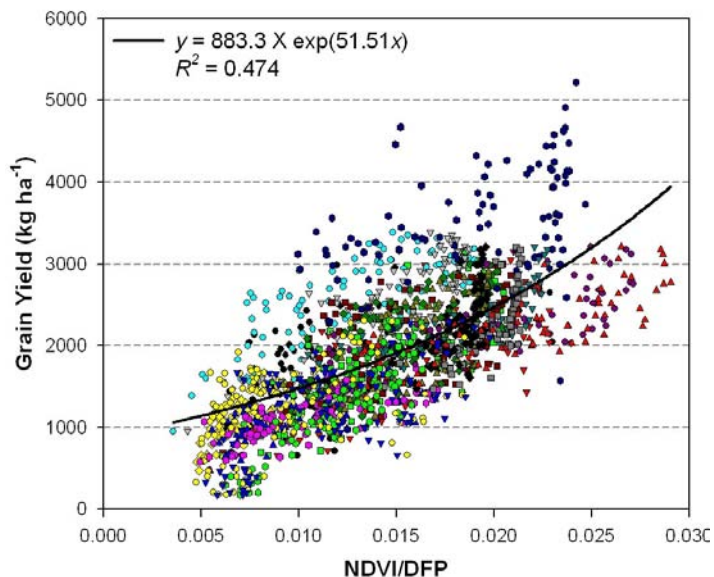


Fig. 3. Correlation between NDVI divided by days from planting and grain yield of canola grown at various plant N densities and N rates at various Canadian locations (R²=0.474).

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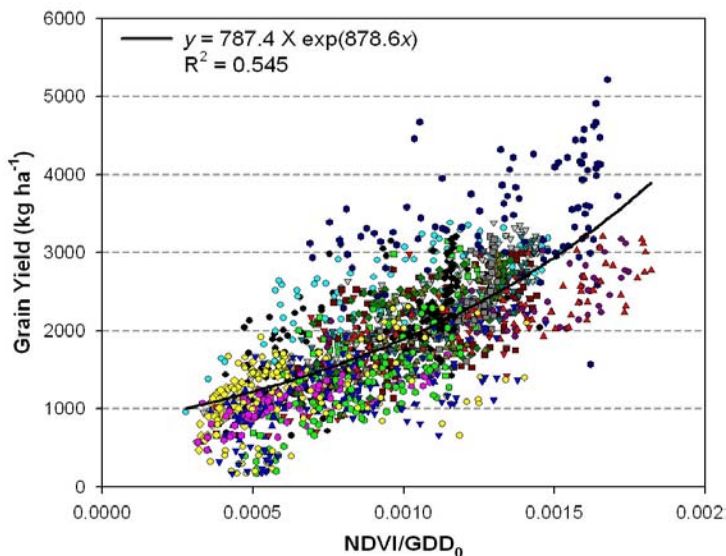


Fig. 4. Correlation between NDVI divided by growing degree days (base temp. 0°C) and grain yield of canola grown at various plant N densities and N rates at various Canadian locations ($R^2=0.545$).

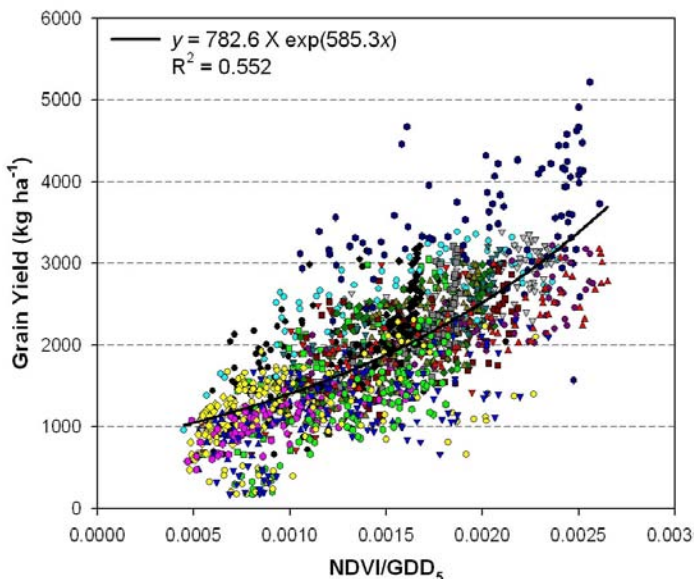


Fig. 5. Correlation between NDVI divided by growing degree days (base temp. 5°C) and grain yield of canola grown at various plant N densities and N rates at various Canadian locations ($R^2=0.552$).

Results

Analysis of the relationship between NDVI and canola yield for individual sensing dates within each site-year revealed either little or no relationship between NDVI and canola yield prior to the 4-5 leaf stage of canola (data not shown). However, the relationship between NDVI and yield generally improved as the crop progressed through the vegetative growth stages, peaked between mid-bolting and 5% flowering, and proceeded to disintegrate when the canola went into full bloom.

Observations from most site-years, collected when the crop was between the 5 leaf stage and about 10% flowering, were compiled for further analysis. The data from Scott in both years and from Swift Current in 2006 was excluded because environmental conditions after sensing substantially reduced yields at these site-years. Hail damaged the plots at Scott in both 2005 and 2006 and hot dry temperatures late in the growing season reduced yields at Scott and Swift Current in 2006. In the end, a total of 1799 NDVI-yield observations were submitted for final analysis.

The figures in this article illustrate the results of the final analysis where the various divisors were evaluated for their effectiveness at standardizing NDVI. The same symbols are used for all of the figures, and Fig. 1 is a legend identifying the location and sensing date for each point. Figs. 2 through 6 illustrate the relationship between NDVI and grain yield when NDVI was divided by each of the potential standardizing units.

Conclusions

Overall, the combination of locations, years, N fertilizer rates and seeding rates resulted in a wide range of both in-season NDVI values and grain yields. Grain yields of the individual plots used in the final analysis ranged from less than 200 kg ha⁻¹ to more than 5000 kg ha⁻¹. Similarly, the NDVI values ranged from less than 0.20 to, in rare instances, more than 0.90. This range of NDVI values and grain yields provided a strong basis for developing an empirical equation to estimate canola yields from in-season NDVI measurements.

When the selected NDVI data that was collected between the 4-5 leaf stage and the start of flowering was combined and plotted against grain yield, the observed

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relationship was reasonably strong ($R^2=0.444$). Dividing NDVI by DFP substantially improved the relationship ($R^2=0.474$), but all of the heat units included performed better than days from planting.

The best correlation observed was between NDVI/ CHU and grain yield ($R^2=0.562$), but GDD performed very similarly, regardless of the base temperature used. Although P-days did not perform quite as well as the other heat units ($R^2=0.528$), it was an improvement over DFP. It is worth mentioning, however, that P-days performed the best in a prior analysis where the data from Swift Current and Scott were included (data not shown). This suggests that the relatively low optimum and maximum temperatures used in P-days were able to better account for reductions in growth at extremely high temperatures than the other heat units. However, because of the complex calculations required to determine P-Days and their somewhat inconsistent performance relative to the other heat units, we would not recommend P-Days as the unit of choice for standardizing NDVI.

The remaining three heat units performed similarly in both of the combined analyses, and GDD_0 , GDD_5 , and CHU were all well-suited for standardizing NDVI measurements for the purpose of estimating canola YP. Although DFP did not perform as well any of the heat units, it was still a substantial improvement over NDVI on its own. Therefore, when past temperatures are not available, dividing NDVI by the number of days between planting and sensing can and should be considered a viable option for improving NDVI based estimates of the potential yield of canola.

Acknowledgements

Major financial aid for this work was provided by AAFC's Environmental Technology Assessment for Agriculture (ETAA) program, the Saskatchewan Canola Development Commission, AAFC, and IHARF. Special thanks to the staff at the Indian Head Research Farm, the Brandon Research Centre, the Central Research Farm at Ottawa, the Scott Research Farm, and the Semi-Arid Research Farm at Swift Current, for their many contributions.

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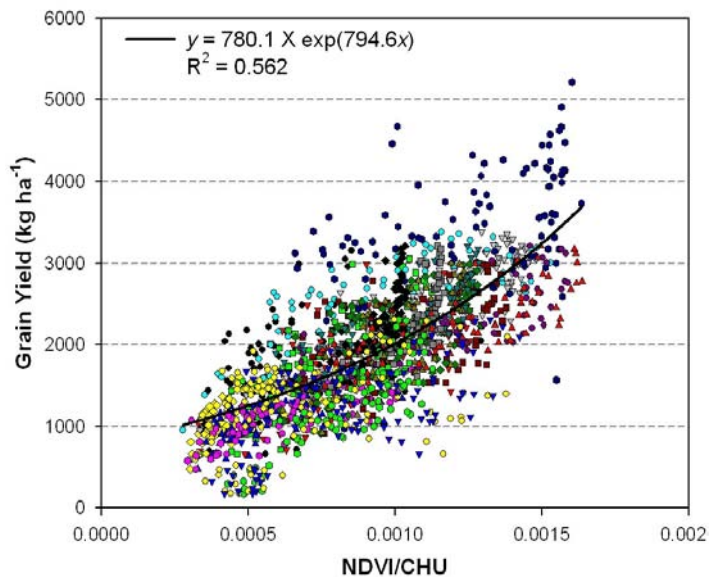


Fig. 6. Correlation between NDVI divided by corn heat units and grain yield of canola grown at various plant N densities and N rates at various Canadian locations ($R^2=0.562$).

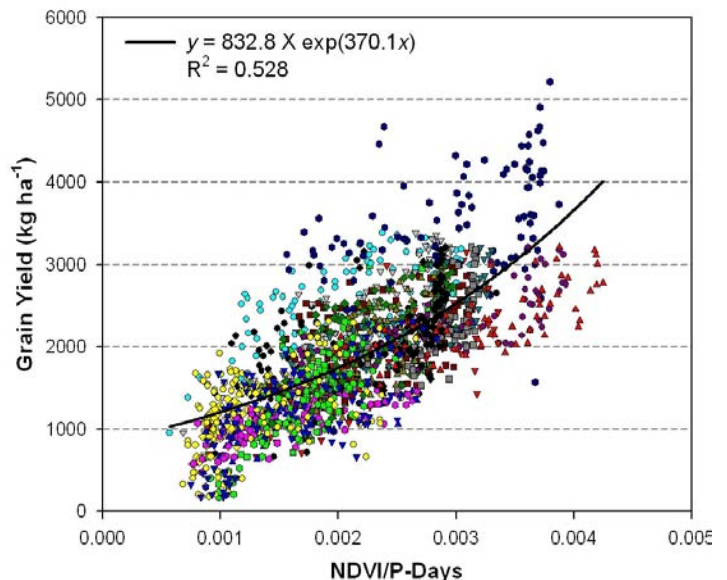


Fig. 7. Correlation between NDVI divided by physiological days and grain yield of canola grown at various plant N densities and N rates at various Canadian locations ($R^2=0.528$).

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2007 Crop Management Field Day



On July 17, IHARF hosted its annual Crop Management Field Day, which featured on-station and off-station tours of AAFC and IHARF projects.

At the on-station tour, there was a lot of interest in the Greenseeker™ technology, which is being used to develop nitrogen management in canola and other crops. The Greenseeker™ is a self-illuminated optical sensor that measures infra-red and near infra-red canopy reflectance and relates those measurements to potential yield. Its sensors can be integrated into a high-clearance sprayer.

The on-station tour also included plots of recropping flax on different stubbles; the progress of niger as a minor

crop; malt barley production; and the development of sulfentrazone rates for several crops. Other projects were noted along the way such as calendula, a crop that is being evaluated for its oil; hemp variety trials; and oat quality trials for Quaker Oats.

The off-station tour contained presentations by University of Saskatchewan researcher, Dr. Jeff Schoenau, on the effects of long-term zero tillage on soil phosphorous; and Dr. Rosalind Bueckert, another U of S researcher, on the effect of long-term zero tillage on lentil production.

The day also featured a presentation to IHARF's 10-year sponsors – Markusson New Holland and New Holland North America. When IHARF began discussing precision farming in 1997, it approached New Holland North America to be a lead sponsor. There was no hesitation on their part as they provided total support to IHARF. With the help of Markusson New Holland, the project received a seeder, tractor, sprayer, swather and combine with yield monitor every year.

In-Crop Applications of Nitrogen: What are the Risks and What are the Benefits to be Gained From this Practice?

By: **G. Lafond (AAFC, Indian Head), W. May (AAFC, Indian Head) and C. Holzapfel (IHARF)**

Worldwide nitrogen is the most limiting and applied nutrient in crop production. Nitrogen also requires a lot of energy for production, and it accounts for the largest portion of total energy required for the production of non-nitrogen fixing crops on the Canadian Prairies.

There is interest in increasing the efficiency of nitrogen fertilizers for environmental and economic reasons. The recent large increase in nitrogen fertilizer prices is making those interests more urgent.

Mismanagement of nitrogen fertilizers can also have important environmental consequences such as surface and ground water contamination with nitrates and emissions of nitrous oxide, a potent greenhouse gas.

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Nitrogen fertility management encompasses four major components - source, placement, timing and rate. Research has demonstrated that there is very little difference between fertilizer forms, provided that they are managed accordingly. Placing the fertilizer in the soil as opposed to on the surface will greatly minimize losses from volatilization and immobilization and enhance overall nitrogen fertilizer recovery. The goal is to ensure that nitrogen is available as close to the time of maximum crop uptake. With cereals this corresponds to the period from the start of elongation to heading with peak uptake during flag leaf extension, and in canola it corresponds to the start of flowering to the end of pod formation.

However, applying nitrogen fertilizers at these critical times and ensuring the availability for crop growth is not always possible for practical reasons because rainfall is required to move the nitrogen fertilizer into the root zone when the nitrogen is surface applied. The more recent no-till production systems on the Canadian Prairies apply all nitrogen fertilizer at the time of seeding either in a side-banded or mid-row banded position. This has been shown to have positive effects on the recovery of applied nitrogen by the crop. The more challenging aspect of nitrogen fertilizer management is deciding on an appropriate rate.

The current nitrogen fertilizer rate recommendations for the Canadian Prairies take into consideration factors such as soil texture, residual soil nitrate levels, soil moisture at seeding, average growing season precipitation, previous

crop grown, crop to be grown, target crop yield, expected commodity prices, and nitrogen fertilizer prices. However, there is much uncertainty with all of these factors due to temporal variations in climatic conditions and spatial variability in soil nutrient levels and inherent fertility.

Nitrogen release from mineralization during the growing season and the major pathways of nitrogen losses (immobilization, volatilization, denitrification and leaching) are also greatly influenced by climatic conditions making their amounts difficult to estimate. Consequently, whatever the chosen rate, much uncertainty exists and rates can easily be either under or overestimated with important economic and environmental consequences in both situations.

There is interest in exploring post-emergent nitrogen applications in annual crops to refine our ability to arrive at more optimal rates of nitrogen fertilizer. Delaying either some or all of the nitrogen fertilizer after crop emergence may allow for a better sense of yield potential and expected growing conditions. With the recent introduction of commercial optical sensors as a nitrogen management tool, it is now possible to estimate crop yield potential early in the growing season in cereals (5-6 leaf stage) and the start to mid-bolting stage of canola and still allow enough time to adjust the rates of nitrogen accordingly.

Studies were conducted to analyze the effectiveness of using different proportions of recommended nitrogen rates at seeding with the balance at different crop growth stages

Table 1. The effects of different proportions of fertilizer nitrogen (%) applied at seeding on grain yield (kg ha⁻¹) in spring wheat. Each value represents the mean of 28 observations.

Fertilizer N at Seeding	Check (no N)	Crop Leaf Stage				Mean
		At Seeding	1-1.5 leaf	3-3.5 leaf	5-5.5 leaf	
–	31.1	–	–	–	–	31.1a
100	–	37.1	–	–	–	37.1b
67	–	–	36.4	36.7	36.9	36.7b
50	–	–	36.6	36.1	35.6	36.1b
33	–	–	36.9	36.4	35.7	36.3b
0	–	–	34.4	36.2	34.7	35.1c
Mean	31.1a	37.1b	36.1b	36.3b	35.7b	

^z Means followed by the same letter are not significantly different at 5% level from the mean where all fertilizer nitrogen was applied at time of seeding.

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Table 2. The effects of different proportions of fertilizer nitrogen (%) applied at seeding on grain protein concentration (%) in spring wheat. Each value represents the mean of 28 observations.

Fertilizer N at Seeding	Check (no N)	Crop Leaf Stage				Mean
		At Seeding	1-1.5 leaf	3-3.5 leaf	5-5.5 leaf	
–	14.0	–	–	–	–	14.0a
100	–	14.7	–	–	–	14.7b
67	–	–	14.5	14.7	14.5	14.6b
50	–	–	14.6	14.4	14.3	14.4b
33	–	–	14.5	14.4	14.3	14.4b
0	–	–	14.3	14.5	14.6	14.5b
Mean	14.0a	14.7b	14.5b	14.5b	14.4b	

^Z Means followed by the same letter are not significantly different at 5% level from the mean where all fertilizer nitrogen was applied at time of seeding.

to minimize the risks of yield losses from in-crop nitrogen applications in spring wheat and canola.

The field trials with wheat were conducted at three locations from 2003-2006 and at two locations for canola from 2004-2006. The treatments consisted of applying 100%, 67%, 50%, 33% or 0% of the targeted N rate at seeding and the balance in-crop at the 1.5, 3.5 or 5.5 leaf stages in spring wheat and at the 5-6 leaf stage, the bolting, or start, of the flowering stage in canola.

With spring wheat, applying 33% of the recommended N rate at seeding with the balance in-crop, for all crop stages investigated, resulted in similar yields to when all nitrogen was applied at seeding (Table 1). There was no effect on grain protein (Table 2). With canola, a minimum of 50% of the recommended nitrogen rate was required at seeding and the in-crop application either at or before the bolting phase to give yields equivalent to when all fertilizer was applied at seeding (Table 3).

Consequently, applying either 50% or more of the recommended N at seeding greatly reduces the risks of in-crop N applications and greatly enhances the opportunity of in-crop applications of nitrogen in spring wheat and canola to better match the soil and climatic conditions.

In-crop applications of nitrogen are all about fine-tuning N rates to more effectively match crop needs for N with the current growing conditions. This approach can potentially be enhanced further when combined with a technology like the GreenSeeker™. This optical sensor provides estimates of yield potential early enough in the growing season, and when compared to a non-N limiting strip in the field, it provides a more objective evaluation of whether more nitrogen is required to realize that potential.

The dilemma is deciding on an overall strategy for incorporating in-crop applications of N in a farming operation. Currently in our studies, we are looking at applying either 50% or 66% of the recommended N at seeding and the balance in-crop using the GreenSeeker™.

It may be more practical at a farm level to apply nitrogen according to average grain yields with some adjustments either up or down to allow for spring soil moisture reserves, and then use the non-N limiting strip in the field and compare it to the rest of the field to decide if more N should be applied. A decision can then be made to apply a uniform amount across the field. If a producer purchases a commercial unit for his sprayer, he will have the added advantage of being able to take into consideration spatial variability and adjust the N rates accordingly to make it an even more powerful nitrogen management tool.

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Table 3. The effects of nitrogen management treatments on grain yield of canola. Each value represents the mean of 20 observations.

Fertilizer N at Seeding % of Target Rate	Check (no N)	Crop Leaf Stage			
		At Seeding	5-6 leaf	Start of bolting	Start of Flowering
–	31.4	–	–	–	31.4
100	–	45.9	43.1a ^z	42.2a ^z	39.8a ^z
67	–	–	42.1a	39.3a	36.2b
50	–	–	40.1a	39.3a	36.2b
33	–	–	38.8b	38.6a	35.7b
0	–	–	39.5b	34.7b	32.2b

^z Means within a column followed by the same letter are not significantly different at the 5% from the mean where all the fertilizer was applied at seeding for each crop stage in that same column This is to take into consideration the negative effects of wheel tracks on grain yield. The levels of significance are based on the contrasts from the analysis of variance.

The Tolerance of Foxtail Millet (*Setaria italica* (L.) P. Beauv.) To Combinations of Fluroxypyr, Clopyralid, and MCPA

By: W. May (AAFC, Indian Head), E.N. Johnson (AAFC, Scott), D.J. Ulrich (AAFC, Scott) and G. Lafond (AAFC, Indian Head)

Foxtail millet (*Setaria italica* (L.) P. Beauv., golden German millet, Italian millet) use as a fodder in Saskatchewan is currently increasing, especially for swath grazing. Using foxtail millet in swath grazing can extend the grazing season and reduce the cost of feeding cattle in the winter (McCaughey, et al. 2002; May et al. 2007). For this practice to be successful, inexpensive weed control measures are required.

Foxtail millet's spring growth can be slow under cool conditions, allowing broadleaf weeds to get established and reducing the biomass of the foxtail millet. Currently, only bromoxynil and bentazone (Basagran Forté) are registered for use in Saskatchewan. The weed spectrum of bromoxynil does not control several weeds, including Canada thistle (*Cirsium arvense* (L.) Scop.) and cleavers (*Galium aparine* L.). Bentazone is expensive and requires larger water volumes than growers are willing to use. Thus, improved control options for foxtail millet are required.

Objective

To test the tolerance of foxtail millet to commercially available combinations of bromoxynil, clopyralid, fluroxypyr, and MCPA.

Materials and Methods

Herbicide combinations

- | | | |
|--------------|----|--|
| 1. Untreated | | weed free |
| 2. Buctril M | 1X | 280 g ai/ha MCPA, +
280 g ai/ha bromoxynil |
| 3. Buctril M | 2X | 560 g ai/ha MCPA, +
560 g ai/ha bromoxynil |
| 4. Curtail M | 1X | 560 g ai/ha MCPA, +
100 g ai/ha clopyralid |
| 5. Curtail M | 2X | 1120 g ai/ha MCPA, +
200 g ai/ha clopyralid |
| 6. Trophy | 1X | 562 g ai/ha MCPA +
108 g ai/ha fluroxypyr |
| 7. Trophy | 2X | 1124 g ai/ha MCPA +
216 g ai/ha fluroxypyr |
| 8. Prestige | 1X | 560 g ai/ha MCPA, +
100 g ai/ha clopyralid +
144 g ai/ha fluroxypyr |
| 9. Prestige | 2X | 1120 g ai/ha MCPA, +
200 g ai/ha clopyralid +
288 g ai/ha fluroxypyr |

2X treatments were applied to simulate an overlap with the 1x rate applied twice.

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Locations: Indian Head, SK in 2004, 2005, 2006 and 2007
 Scott, SK in 2006 and 2007

Experimental Design: A randomized complete block design with 4 replicates.

Cultivar: Golden German millet

Crop stage: 2 - 6 leaves

Target Seeding date: June 1

Seeding Rate: 22 kg ha⁻¹

Nitrogen fertilizer: 40 kg ha⁻¹

Phosphorous: 20 kg ha⁻¹

Spray Volume: 111 L ha⁻¹

Spray Pressure: 275

Statistical Analysis

Proc Mixed procedure of SAS (Littell et al., 1996).
 Herbicide treatments were considered fixed; site years were considered random. A Tukey-Kramer mean separation test was used.

Results and Discussion

Crop Injury (Fig. 1)

7-14 days after application

- No treatment exceeded 20% injury.
- Buctril M at the 1X and 2X and Prestige at the 2X rate had higher levels of crop injury than the weed free check.

21-35 days after application

- Prestige at the 2X rate had higher levels of crop injury than the weed free check.

42-56 days after application

- No difference between treatments.

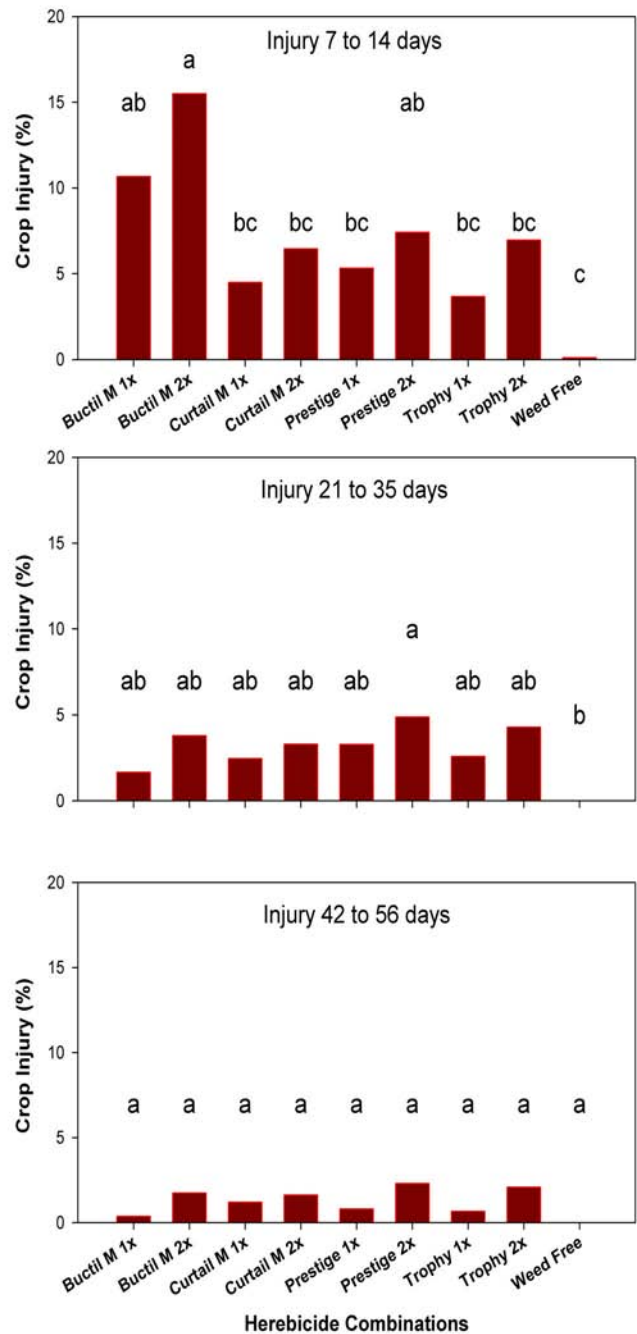


Fig. 1. Observed crop injury to foxtail millet at 7 to 14, 21 to 35, and 42 to 56 days by several herbicide combinations with data combined across site-years.

IHARF Winter Seminar
Weyburn Inn
January 24, 2008

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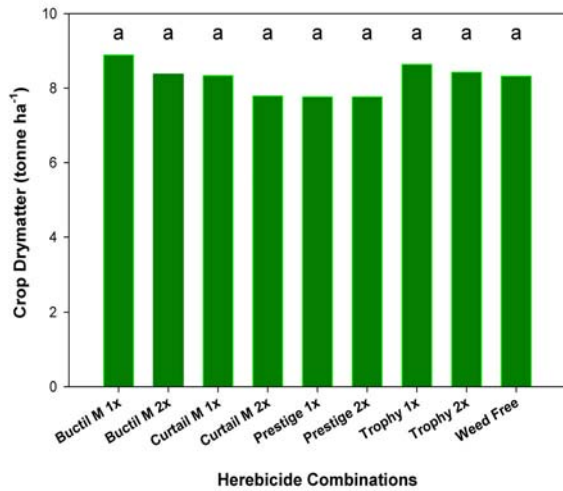


Fig. 2. Crop drymatter of foxtail millet at the end of growing season for different herbicide treatments with data combined across site-years.

Crop Biomass (Fig. 2)

- No difference between treatments.
- Numerically the lowest yielding treatment as Prestige 2X was 7% below the weed free check.

Conclusions

All four herbicide combinations were safe to use on foxtail millet when grown in Saskatchewan and other areas with similar environmental conditions during the growing season.

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Evaluation of Some Small Grain Cereals as Feedstock for Ethanol Production

By: J. McLeod (AAFC, Swift Current) and K. Sosulski (Retired, Saskatchewan Research Council)

Introduction and Literature Review

Traditionally, Canadian cereals were bred for high protein contents, which was desirable in the production of bread and pasta and animal feed. However, high protein contents were accompanied by low concentrations of starch, which made most cereals less desirable for industrial processes (e.g. ethanol production).

Agronomic efforts in recent years have resulted in the release of several high-yielding cultivars of spring wheat, barley and triticale that are low in protein and, therefore, should be high in starch (PRRCG, 1996). However, except in isolated cases, their starch contents are not determined, but reported as the 'total carbohydrates' which are estimated as the difference between 100% and the sum of moisture, protein, crude fibre, fat and ash (CRC Handbook of Processing and Utilization in Agriculture).

In addition to starch and fermentable sugars, the 'total carbohydrates' also contain water-soluble hemicellulose, beta-glucans and pentosans, depending on the grain. Not all 'total carbohydrates' are fermentable and ethanol yields are overestimated when calculated from this parameter in cereal grains.



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The efficiency of ethanol production from grains depends not only on their starch contents, but it is also affected by the presence and concentrations of pentosans of rye, triticale and wheat (Wang et al., 1997) or beta-glucans of barley and oat (Ingledeew et al., 1995). These two components adversely affect process conditions through increases in mash and wort viscosities.

This study was conducted to evaluate and determine the potential of some current and new small grain cultivars as industrial ethanol feedstock.

Materials and Methods

37 cultivars of small grains - 11 spring wheat, eight triticale, six barley and six oat, two winter wheat, two winter triticale, and two winter rye - were grown at seven locations in Western Canada - Winnipeg and Portage la Prairie, MB; Swift Current, Indian Head and Melfort, SK; and Lethbridge and Lacombe, AB. The trials were laid in a randomized complete block design in four replications. At harvest time, a composite sample of each cultivar from each location was prepared for analyses by combining the four replications.

After grinding to reduce particle size to 100 mesh, grain samples were analysed for starch (S) (Budke, 1984; Yellow Springs Instrument Co., 1979); fermentable sugars (FS) (Sosulski and Tarasoff, 1996); beta-glucans (BG) (McCleary and Glennie-Holmes, 1985; McCleary and Nurthern, 1986) and pentosans (P) (Hashimoto and Shogren, 1987). All results are expressed as a percent of the dry matter.

The theoretical ethanol yields (EY) (L tonne⁻¹), reduced to 93% to account for yeast growth, were calculated from grain starch and fermentable sugar contents and expressed on a 12% grain moisture content. In the case of barley and oat, the potential ethanol yields from glucose released from beta-glucans were calculated. In order to present the full fermentation potential for Canada Prairie Spring (CPS) and Canada Western Soft White Spring (CWSWS) wheat, triticale and rye, the theoretical EY from fermenting xylose, released during hydrolysis from pentosans, were also calculated. In this case, the combined efficiencies of hydrolysis and fermentation were assumed to be 72% of theoretical yield.

Table 1. Estimates of Starch, Fermentable Sugars, Pentosans and Potential Ethanol Yields from Wheat Cultivars grown at seven locations in Western Canada from 1993-1996, inclusive.

Wheat Class ¹	Cultivar	Starch (S) (%)	Fermentable Sugars (FS) (%)	Pentosans (P) (%)	EtOH Yield (S + FS) (L. t ⁻¹)	EtOH Yield (P) (L. t ⁻¹)
CWHRS	Grandin	62.8 ± 2.2	0.9 ± 0.8	N/A	368 ± 12	N/A
	Katepwa	62.0 ± 1.8	0.9 ± 0.8	N/A	364 ± 11	N/A
CWAD	Plenty	63.5 ± 2.1	0.8 ± 0.6	N/A	372 ± 12	N/A
CWSWS	AC Reed	64.9 ± 1.7	1.0 ± 0.9	8.8 ± 0.9	381 ± 12	39 ± 4
	CWSWS 109	64.9 ± 2.1	1.2 ± 1.1	9.0 ± 0.7	382 ± 10	40 ± 3
CPS	AC Taber	64.0 ± 2.5	1.2 ± 0.9	9.4 ± 1.6	378 ± 13	42 ± 7
	HY 617	64.9 ± 2.4	1.4 ± 0.9	9.7 ± 1.6	382 ± 14	43 ± 7
	HY 612	64.8 ± 2.4	1.1 ± 0.7	9.9 ± 1.5	381 ± 14	45 ± 7
	AC Karma	64.2 ± 2.0	1.2 ± 0.9	9.4 ± 1.4	378 ± 13	42 ± 6
	Biggar	64.0 ± 2.4	1.2 ± 1.1	10.1 ± 1.9	376 ± 15	45 ± 9
	Genesis	64.0 ± 2.1	1.0 ± 0.9	10.2 ± 1.8	375 ± 12	46 ± 8
CWHRW	Norstar	66.6 ± 3.0	1.1 ± 0.8	N/A	389 ± 16	N/A
	Kestrel	65.7 ± 1.6	0.5 ± 0.3	N/A	383 ± 9	N/A

¹Wheat Class-CWHRS-Canada Western hard red spring; CWAD-Canada Western amber durum; CWSWS-Canada Western soft white spring; CPS-Canada prairie spring; CWHRW-Canada Western hard red winter.
± SD for grain cultivars.

continued on page 13. . .

Table 2: Starch, fermentable sugars, pentosans, and potential ethanol yields from triticale and rye cultivars grown at seven locations in Western Canada from 1993-1996, inclusive.

Grain Crop	Cultivar	Starch (S) (%)	Fermentable Sugars (FS) (%)	Pentosans (P) (%)	EtOHY (S + FS) (L t ⁻¹)	EtOH Yield (P) (L t ⁻¹)
Spring Triticale	Pronghorn	63.6 ± 2.7	1.2 ± 0.9	9.1 ± 0.9	374 ± 15	44 ± 5
	Banjo	63.7 ± 2.6	0.6 ± 0.6	10.0 ± 1.3	372 ± 15	45 ± 6
	AC Certa	63.3 ± 2.7	1.1 ± 0.9	9.5 ± 0.9	372 ± 15	43 ± 4
	Wapiti	63.6 ± 2.6	0.7 ± 0.6	10.1 ± 1.3	372 ± 15	45 ± 6
	Frank	63.2 ± 2.5	0.9 ± 0.6	9.8 ± 1.1	370 ± 15	44 ± 5
	AC Copia	62.9 ± 2.3	0.7 ± 0.6	10.4 ± 1.3	368 ± 14	47 ± 6
	AC Alta	61.6 ± 2.4	1.0 ± 0.8	10.9 ± 1.8	362 ± 15	49 ± 8
	T 114	61.4 ± 2.5	0.7 ± 0.7	10.9 ± 1.3	360 ± 15	49 ± 6
Winter Triticale	Pika	63.9 ± 3.7	0.8 ± 0.7	N/A	371 ± 20	N/A
	Wintri	62.0 ± 2.5	1.0 ± 0.3	N/A	362 ± 13	N/A
Winter Rye	Prima	61.0 ± 3.3	0.6 ± 0.6	N/A	355 ± 17	N/A
	Musketeer	59.1 ± 2.9	1.2 ± 0.6	N/A	345 ± 16	N/A

± SD for grain cultivars.

Results and Discussion

The average starch concentrations in wheat classes were CWHRS wheat (62.4%) < CWAD (63.5%) < CPS wheat (64.3%) < CWSWS wheat (64.9%) < CWHRW wheat (66.2%) (Table 1). The bread-quality CWHRS wheat cultivars were the lowest in starch content among all wheat classes, while the CWHRW cultivars were the highest. CWSWS and CPS wheat were comparable in starch

content, but CWSWS wheat cultivars were lower in pentosans content than CPS. Pentosans are responsible for increases in wort viscosity, so lower pentosans content in wheat should produce less viscous and easier to process worts.

The EY from various wheat cultivars, calculated from starch and fermentable sugar contents, presented in descending order were - CWHRW wheat (386 L t⁻¹) > CWSWS wheat (381 L t⁻¹) > CPS wheat (378 L t⁻¹) > CWAD (372 L t⁻¹) > CWHRS wheat (366 L t⁻¹). Thus, the 3.5% difference in starch concentration between CWHRW and CWHRS wheat translates into a 20 L t⁻¹ difference in EY, which could mean 0.5 million L more ethanol produced by a theoretical plant processing 25,000 tonnes of CWHRW compared to a similar quantity of CWHRS wheat per year.

Assuming that xylose from wheat pentosans could be successfully fermented by either *zymomonas mobilis* (Doelle and Wilkinson, 1993) or the xylose-fermenting transgenic yeast (Ho et al., 1996), the ethanol production from CWSWS and CPS wheats could be increased by 40

and 45 L t⁻¹, respectively. This alone could increase ethanol production of the above theoretical plant by 1.0-1.1 million litres per year.

Triticale cultivars contained an average of 62.9% starch, which makes this grain either comparable to or better than CWHRS wheat and comparable to older cultivars of CPS wheat such as Biggar and Genesis (Table 2). Winter cultivars of triticale were comparable in starch content to the spring cultivars, but were substantially lower than the two winter wheats (Table 1). On average, 372 L of ethanol could be produced per tonne of triticale. An additional 47 L of ethanol per tonne of grain could be produced from the fermentation of the pentosans.

Winter rye cultivars, with an average starch concentration of 60.0%, was lower than CWHRS wheat and triticale cultivars (Tables 1 and 2).

The average starch concentration in the four hulled barley cultivars was 57.7% (Table 3), which was substantially less than the average for other cereal grains (Tables 1 and 2). However, hull-less barley had on average 62.3% starch, making this grain comparable to CWHRS wheat, spring and winter triticale, and winter rye. Thus, ethanol yields calculated for hull-less barley were comparable to those for CWHRS wheat, triticale and rye, and about 30 L t⁻¹ higher than for hulled barley.

However, when the beta-glucans of barley are hydrolysed to glucose and subsequently fermented to ethanol, then the ethanol yields from both types of barley can be

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Table 3: Starch, fermentable sugars, beta-glucans, and potential ethanol yields from barley and oat cultivars grown at seven locations in Western Canada from 1993-1996, inclusive.

Grain Crop	Cultivar	Starch (S) (%)	Fermentable Sugars (FS) (%)	β-Glucan (β-G) (%)	EtOH Yield (S+FS) (L. t ⁻¹)	EtOH Yield (S+FS+βG) (L. t ⁻¹)
Barley	Manley	59.0 ± 1.9	0.8 ± 0.8	4.0 ± 0.5	345 ± 11	369 ± 13
	Virde	57.8 ± 2.4	0.7 ± 0.7	3.9 ± 0.5	338 ± 15	360 ± 16
	Bedford	57.2 ± 2.2	0.9 ± 0.8	4.2 ± 0.6	335 ± 13	360 ± 13
	Brier	56.8 ± 2.0	0.7 ± 0.6	4.2 ± 0.6	333 ± 12	357 ± 12
	CDC Buck	62.8 ± 2.0	1.1 ± 0.8	4.7 ± 0.7	371 ± 13	398 ± 13
	Falcon	61.7 ± 2.4	1.3 ± 1.1	4.0 ± 0.5	361 ± 14	384 ± 14
Oat	Robert	45.2 ± 4.5	1.3 ± 0.9	2.7 ± 0.3	267 ± 29	280 ± 30
	Calibre	45.0 ± 3.9	1.4 ± 0.9	2.7 ± 0.3	266 ± 23	278 ± 17
	Waldern	43.4 ± 4.7	1.7 ± 0.9	2.4 ± 0.4	256 ± 28	263 ± 26
	Cascade	43.3 ± 4.6	1.2 ± 0.9	2.4 ± 0.3	255 ± 29	263 ± 28
	AC Marie	44.1 ± 2.7	1.4 ± 0.9	3.1 ± 0.2	262 ± 18	279 ± 17
	OT 776	40.9 ± 4.0	1.2 ± 0.9	2.3 ± 0.3	240 ± 25	254 ± 25

± SD for grain cultivars.

increased by about 25 L t⁻¹. This makes hulled barley comparable to either CWHRs wheat or triticale, while the hull-less cultivars are comparable to CWHRW wheat.

Oat cultivars had the lowest concentrations of starch among cereal grains, with only 43% to 46% of dry matter (Table 3). Thus, the yields of ethanol from six oat cultivars were very low, with the average value being only 257 L t⁻¹. Oat cultivars were also low in beta-glucans, as compared to barley, thus their hydrolysis and fermentation would increase ethanol yields by only 12 L t⁻¹. Thus, oats are a less suitable feed stock for ethanol production.

Conclusions

The suitability of small grains for ethanol production, in descending order, are hull-less barley and CWHRW wheat > CPS and SWS wheat > CWAD, spring and winter triticale, and hull-less barley > HRS wheat and winter rye > barley > oats. Among individual cultivars, those most suitable for ethanol production are CDC Buck (hull-less barley) and Norstar (HRW wheat) > Kestrel (HRW wheat), SWS 109 and HY 617 (CPS wheat) > T 124 (spring triticale), HY 612 (CPS wheat) and AC Reed (SWS wheat).

This project identified grains and grain varieties that are most suitable for ethanol production due to their high starch content. Based on this information, the ethanol industry in Canada can make informed decisions regarding their grain purchases.

Acknowledgments

Research funding was provided by the federal government's Greenhouse Gas Initiative of the departmental Green Plan through the Ethanol Program Advisory Committee.

Determination of starch, beta-glucan, fermentable sugars and pentosans contents and estimates of EY were provided by contracts with the Saskatchewan Research Council. Field trials were grown in cooperation with Dr. D.F. Salmon, AAFRD, Lacombe, AB; Dr. J.B. Thomas, AAFC, Lethbridge, AB; Mr. C.L. Vera, AAFC, Melfort, SK; Mr. D.T. Gehl, AAFC, Indian Head, SK; and Dr. R.I.H. McKenzie, AAFC, Winnipeg, MB. With appreciation to Ms. J.F. Payne for her expert technical assistance in data analysis.



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Volatile Losses of Surface Applied N: How Substantial are They?

By: C. Holzapfel (IHARF), G. Lafond (AAFC, Indian Head), R. Irvine (AAFC, Brandon), D. James (AAFC, Swift Current), M. Morrison (AAFC, Ottawa) and W. May (AAFC, Indian Head)

Background and Objectives

Although most nitrogen (N) fertilizer in the Canadian Prairies is applied either at or before the time of seeding, certain situations may warrant in-crop applications of N. However, when they wish to do so, producers have limited options for applying N to established crops.

Although it is possible to apply post-emergent (PE) N in the soil with either little or no damage to the crop using specialized equipment such as spoke-wheel applicators or coulter banders, such equipment is costly and has no other utility besides in-crop N applications. Furthermore, research completed at Indian Head and Scott has shown that the potential agronomic benefits associated with placing PE N in the soil are probably not sufficient to justify investing in the necessary equipment (Holzapfel et al. 2007).

Since most operations already utilize a high-clearance sprayer, equipping the sprayer with specialized dribble-banding nozzles and using it to apply N is a relatively inexpensive option for liquid products such as UAN. For granular sources such as urea, though, broadcasting is often still the most practical application method available.

The obvious problem with applying N fertilizer to the soil surface is that it leaves the N vulnerable to volatile losses. Volatilization occurs when soil ammonium (NH_4^+) is converted to ammonia (NH_3), which is a gas at normal temperatures and pressures (consider anhydrous ammonia fertilizer), and lost to the free atmosphere. Once the NH_4^+ has been converted to nitrate (NO_3^-), it is no longer susceptible to volatilization, which is why ammonium-nitrate has traditionally been the preferred source for established forage crops and winter cereals.

Only the urea fraction of the N in the ammonium nitrate, which amounts to 50% of the total N, can be volatilized. Half of the actual N contained in UAN solutions comes from urea, while the remainder is from ammonium nitrate.

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As a result, 25% of the N in UAN solutions is not volatile. For this reason, slightly lower losses can be expected from surface applied UAN in comparison to urea; although the same would probably not be true for polymer coated products such as ESN fertilizer (Agrium) or those containing chemical inhibitors such as Super-Urea (Agrotain International). However, these latter fertilizer options can be in limited supply and are more expensive than traditional sources of N.

The objectives of this study are to quantify the amounts of N lost as NH₃ from in-crop, surface applications of UAN, and urea relative to urea banded at seeding under varying environmental conditions. An increased understanding of the extent to which volatile losses can be expected will enable producers to make well-informed decisions with respect to the appropriate forms and rates of PE N.

Field Experiments

Field experiments were completed at AAFC locations at Indian Head, Swift Current, and Brandon during the 2005, 2006, and 2007 growing seasons. Similar experiments were completed at Ottawa, but they are not discussed in this article. The quantity of NH₃ emitted from the soil was measured following applications of fertilizer N to spring wheat at various times in the growing season. The following N management treatments were included:

1. Check – no fertilizer N applied.
2. Split Application (UAN) – a portion of the fertilizer N was applied at seeding, and the remainder was applied as UAN to the soil surface at various times during the growing season.
3. Split Application (urea) – a portion of the fertilizer N was applied as urea at seeding and the remainder as urea was applied to the soil surface at various times during the growing season (treatment included at Swift Current only).
4. All N applied at seeding – 100% of fertilizer N as soil-placed urea.

The sizes of the experiments were kept small, with each experiment consisting of four adjacent plots and each plot representing a different treatment, in order to minimize the effects of spatial variability.

Four NH₃ chambers were placed in each plot after seeding and prior to applying the PE N. The chambers were white PVC tubes 20 cm long and 15 cm in diameter and were placed 3-5 cm into the soil. A foam disk impregnated in an acidic solution was inserted inside the chamber to absorb

NH₃N from the soil, while a second disc closed the top of the chamber to “scrub out” any NH₃N generated outside the chamber. Permitting air exchange between the chamber and the surrounding’s atmosphere minimized micro-climate effects, but did not eliminate them. A plastic canopy was placed above each chamber assembly to shield the discs from rain (Fig. 1).



Fig. 1. Chambers used to measure NH₃ emissions from surface applied N fertilizer.

For the measurements completed just after seeding, the chambers at Indian Head and Swift Current were placed directly over the fertilizer bands. At Brandon, urea was buried by hand approximately 2.5 cm below the soil surface. PE N was applied directly into the chambers to ensure accurate rates and that the actual quantities of N fertilizer applied varied (Table 1). We applied PE N at various times throughout the growing season, targeting the 3.5 leaf and flag leaf stages at Indian Head and Brandon and the 5 leaf stage, the flag leaf stage, and anthesis (data not shown) at Swift Current.

Table 1. Quantities of N fertilizer applied at all site-years.

Site	Year	N Seed ^z	N PE ^y	N Total ^x
		kg N ha ⁻¹		
Indian Head	2005	20	11	31
	2006	43	47	90
Swift Current	2005	30	15	45
	2006	45	22.5	67.5
Brandon	2005	47	23	70
	2006	47	23	70

^zUrea banded in-soil at seeding

^yUAN or urea surface applied directly into chambers

^xTotal quantity of N applied in fertilized treatments

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For simplicity, all emissions of NH₃ are expressed as the percentage of applied fertilizer N lost as NH₃. Background emission levels, estimated from the unfertilized checks, were accounted for in the N fertilizer loss calculations.

Results and Discussion

As expected, essentially no NH₃ was lost from the urea applied at seeding in either year at both Indian Head and Swift Current (Fig. 2). At these two sites, emissions from the fertilized treatments were always very close to the unfertilized checks. However, for reasons which are not entirely certain, nearly 5 kg N ha⁻¹ of fertilizer N was lost from the soil-placed urea at Brandon which amounted to just under 9% of the fertilizer N applied.

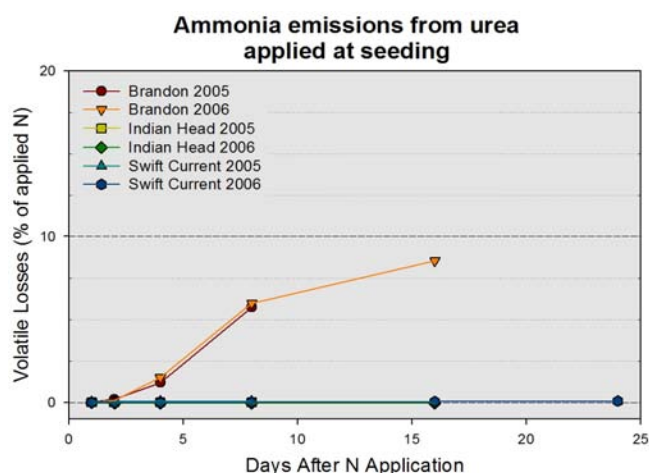


Fig. 2. Ammonia emissions from soil-placed urea within 24 days of application.

Volatilization from in-soil placed urea is rare, but can occur under certain circumstances. The soil at Brandon has a higher pH than the soil at either Indian Head or Swift Current, which would theoretically result in more NH₃, as opposed to NH₄⁺, existing in the soil solution. However, on its own, this is not likely sufficient to explain the high losses from soil-placed urea observed at Brandon.

A more probable explanation for the observed losses at Brandon is that the urea was not adequately sealed beneath a layer of soil, perhaps due to the mixing of fertilizer with the soil at the surface while burying the urea. In reality, such situations are not uncommon, especially when crops are seeded into excessively wet, clay soils. For banded fertilizer to be effectively protected from volatile losses, it is essential that the band be completely covered with soil and firmly packed.

When either UAN or urea was applied to the soil surface early in the growing season (3.5-5 leaves) a certain amount of N was always lost. Ammonia emissions started to increase in the fertilized treatments within 48 hours of application in all cases except Swift Current in 2005, where emissions were delayed to some point between 48-96 hours of application. The reason for the delay is that urea must be hydrolyzed by the urease enzyme into NH₃ before it can be emitted.

The total observed losses ranged from about 1% to 12% of the applied N (Fig. 3). The highest losses occurred at Indian Head and Brandon in 2006, and it is uncertain how high the losses at Indian Head in 2005 would have climbed had we continued to measure past eight days. In contrast, the lowest losses were at Swift Current, where the cumulative losses actually appear to decrease from eight days after application onward.

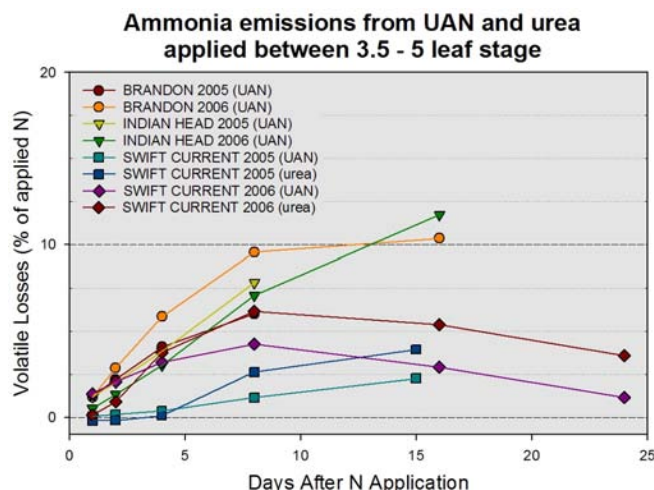


Fig. 3. Ammonia emissions from surface-applied urea and UAN within 24 days of application.

Although it is misleading to think of cumulative losses as decreasing, the reason that they appear to do so is that the total emissions between eight and 24 days after application were higher in the check than they were in the fertilized treatments. Notice that the patterns of losses for UAN and urea at Swift Current are virtually identical and that losses from the UAN are consistently lower than from urea.

When UAN and urea were surface-applied to wheat plots late in the growing season, the same overall trends were observed as for the earlier PE applications. In both years at Brandon and in 2005 at Indian Head, NH₃ emissions from the newly fertilized plots substantially increased 24 hours after application.

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The highest losses amounted to just less than 10% of the applied N at Indian Head in 2006 where conditions were hot and dry (Fig. 4). Hot, dry conditions result in net evaporation of soil moisture, which draws water upwards through the soil profile and increases the concentration of N in the solution (Al-Kanani et al. 1991). Such conditions can potentially result in a renewed supply of N at the soil surface and increased volatile losses.

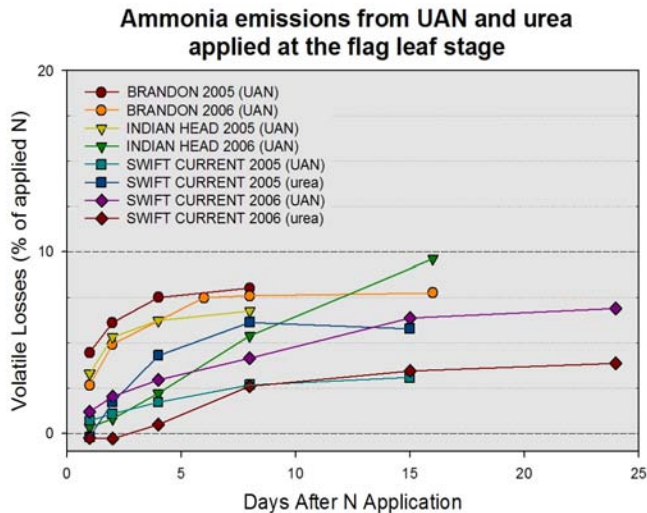


Fig. 4. Ammonia emissions from surface-applied urea and UAN within 24 days of application.

On the other hand, precipitation events after surface applications of N wash the N into the soil and can reduce losses substantially if they occur soon after application (Whitehead and Raistrick 1991). As observed with the earlier PE N applications, the lowest losses generally occurred at Swift Current and volatile losses from surface-applied UAN were proportionately lower than from urea.

Conclusions

Overall, our results support the assertion that placing ammoniacal fertilizers beneath the soil surface is the most effective method for minimizing volatile losses of N. However, in situations where this is not possible, such as when applying N to established crops, N fertilizer can generally be surface-applied without losing too much N as NH_3 . Our results indicate that losses from UAN will seldom exceed 10% of the applied N and will often be less than 5%.

Furthermore, there is probable reason to believe that the actual losses observed in reality would be lower than those measured in this study. Recall that our chambers were covered to prevent rainfall from washing NH_3 from the

discs. If this same rainfall were allowed to enter the chambers, it would also wash any NH_3 or urea downward into the soil, where it is reasonably protected from volatile losses.

In addition, the surface of the soil inside the chambers is largely sheltered from the outside environment and, if it is wet, remained so for longer periods of time than would be expected in nature. Under normal circumstances, the top few centimetres of soil often dry out relatively quickly upon becoming wet, creating somewhat of a protective barrier between the soil solution and the free atmosphere and limiting losses of dissolved NH_3 . As such, our estimated losses likely err on the conservative side, and in practice losses of 10% would probably only occur under the least favourable environmental conditions.

Although fertilizers protected by either polymer coats or chemical inhibitors may be better suited to PE N applications than either UAN or urea, they are also more expensive than traditional products and their effectiveness was beyond the scope of this study. In any case, a certain amount of volatile loss is expected from surface applications of either UAN or urea, and they should be considered when either calculating rates or deciding whether or not to apply PE N.

Acknowledgements

The work for this study is funded by AAFC's Environmental Technology Assessment for Agriculture (ETAA) program. Additional thanks to the AAFC staff at the various locations for their contributions.

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