REDUCED CHEMICAL INPUT SYSTEMS FOR IMPROVED WATER QUALITY

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Objective

In recent years there has been increasing concern raised over concentrations of nitrates and pesticides in both surface and ground water within the Great Lakes Basin. Increases of concentration may possibly be associated with the migration of these materials from agricultural lands (Agriculture Canada 1992). While a soil nitrogen test for corn has been developed, most producers determine their rates of nitrogen fertilizer based solely on economic factors, expected yield and the price ratio of nitrogen to corn. Successful farming practices, as measured by high economic yields, are also important environmentally. Crops take up nitrogen derived both from mineralization of soil organic matter and fertilizer sources. Nutrients not taken up by the crop remain potentially available to be lost by leaching or volatilization. Our hypothesis is that matching nitrogen application rates more to crop utilization will result in less opportunity for leaching inorganic nitrogen , no matter what its source to ground water. Eventually, this should lead to reduced nitrate concentrations in ground and surface water.

Certain weed species have developed triazine pesticide tolerance in Ontario. There is also evidence that selective soil bacteria adapt to use applied pesticides as convenient energy sources; such soils are said to have enhanced degradation capability. Annual application of the same pesticide can induce such weed adaptations and changes in soil behaviour. For many years, atrazine has been very widely used across the Great Lakes basin to control broadleaf weeds in corn and recent unpublished research indicates that there exist soil and water bacteria capable of preferentially degrading atrazine. Enhanced atrazine degradation potential in a soil can be identified by monitoring atrazine degradation while monitoring soil thermal and water regimes. A significantly reduced time for disappearance (usually expressed as its half life ($t_{1/2}$), or the time required for the pesticide concentration to decrease to 50% of its initial value) may be indicative of enhanced degradation. In this report, we asses disappearance rates of atrazine, metolachlor and metribuzin at sites representative of the extremes in soils and climates in the lower Great Lakes basin.

Many farmers are using or experimenting with combined chemical and mechanical means of weed control. This study was established to determine whether such combined management practices can reduce the use of herbicides while maintaining the current level of corn yields.

The following management practices were evaluated:

- broadcast vs banded-over-the-row placement of nitrogen.
- broadcast vs band vs slot placement of nitrogen to assess potential for improved plant uptake efficiencies.
- herbicide persistence and movement as affected by soils and climates in the lower Great Lakes Basin (Windsor to Ottawa).
- agronomic benefits of reduced herbicide application by over the row banding with cultivation vs. broadcast herbicide only weed control.
- whether there are any agronomic benefits due to mixing herbicide with 28% UAN solutions (weed and feed effect).

Methodology

Replicated experiments were conducted on coarse and fine textured soils (fig 1) over four years, at a long-season location near Harrow (3500 crop heat units), and over three years at a short-season location at Nepean Ontario (2700 crop heat units). These sites represent the diversity of soils and climates as found in the lower Great Lakes Basin. Corn (*Zea mays* L., Pioneer 3573 in Southwest and Pioneer 3902 in the Eastern Ontario) was grown either continuously or in rotation with soybeans. Eight different nitrogen and herbicide treatments were tested; atrazine plus metolachlor plus metribuzin were surface applied at minimum label rates, either broadcast or banded over the corn row at planting. Interrow cultivation was used to control weeds in treatments where herbicide was band applied over the row. Nitrogen fertilizer, applied at 100 kg-N/ha as a 28% nitrogen solution of urea ammonium nitrate, was broadcast, or banded over the row, or placed in a coulter opened slot 0.2m from, or midway 0.38m between, corn rows.

A complete randomized block design (fig. 1) was used; each plot was 4.6m wide (6x75cm corn rows) by 30m in length. The sites in Southwestern Ontario were located on a Toledo clay loam and Berrien loamy sand, while in Eastern Ontario, Dalhousie silt loam and a Uplands loamy sand were used (Table 1). All sites were tile drained. The sites on the fine textured soils (Toledo and Dalhousie) were managed as a conventional tillage system with fall plowing and spring field cultivation prior to planting. The coarse textured sites (Berrien and Uplands) were managed under a no-till system with a fall or early-spring herbicide burn-down (using glyphosate) followed by planting. All nitrogen fertilizer and herbicide applications were imposed as split plot treatments at planting (Table. 2). Considerable modification and retrofitting of the no till corn planter was required. Cultivation was carried out two or three times between corn emergence and canopy, closure using standard row crop cultivators.

Each site was instrumented to measure air temperature, relative humidity, wind speed, rainfall, solar radiation (Environment Canada 1992). Soil water and soil temperature were also monitored using dataloggers and the appropriate sensors at 0.05, 0.20, 0.50, and 1.00 meter depths.

Soils were sampled for nitrogen content three times a year, spring, mid June and post harvest, to a depth of 0.90m by taking cores, 38mm or 45mm in diameter. They were divided into 0.15m sections thick above a depth of 0.6m. Inorganic soil nitrogen was extracted from 10g of fresh soil using 50ml of 2N KCL and a shaking time of 30 minutes. Soil nitrate, nitrite and ammonium were determined using a colorimetric autoanalyzer method (Sheldrick 1984). Soil properties measured included bulk density (Culley and McGovern, 1990), particle size, organic matter content, (Sheldrick, 1990) and hydraulic conductivity (Reynolds 1990).

Herbicide concentrations were monitored in treatments 1,3,5,and 7. Soil was sampled from 15 predetermined locations were taken within each plot to a depth of 0.15 m, on an approximately exponential time base (0,3,7,14,28,56,and 112 days) after application. Composited plot samples were frozen prior to determination of atrazine, desethyl atrazine, metolachlor and metribuzin concentrations. Thawed samples were extracted with methanol and then analyzed using a standard HPLC methods (Tan *et al.,* 1993). Crop growth was monitored through out the season, and visual assessments were made of weed control for each treatment. Yield measurements were made either using a combine and weigh wagons or hand harvesting, subsamples were taken to measure grain moisture and nitrogen content.

Table 1. Selected properties of the Ap horizons of the soils at the experimental sites used to evaluate nitrogen and herbicide placement for corn.

	Organic carbon	Sand	Silt	Clay	Hydraulic conductivity µm sec^{-1}	Bulk density (Mg/m^3)
Site	-------------------%-------------------					
Toledo clay loam	2.18	34.1	38.8	27.1	48	1.44
Berrien loamy sand	1.26	80.6	13.1	6.3	65	1.36
Uplands loamy sand	3.27	85.6	10.8	3.6	68	1.18
Dalhousie silt loam	2.37	33.6	42.3	24.1	51	1.31

Table 2. Treatments to evaluate nitrogen and herbicide placement for corn grow on fine and coarse textured soil at two locations at crop heat unit extremes in Ontario.

Treatment	**Description**	**Nitrogen application method**	**Weed Control**
1	W+F; 28% UAN and herbicide mixed	Broadcast	Broadcast herbicide
2	W+F; 28% UAN and herbicide mixed	0.2m Band over row	Row banded, interrow mechanically cultivated
3	W+F; 28% UAN and herbicide applied separately	Broadcast	Broadcast herbicide only
4	W+F; 28% UAN and herbicide applied separately	0.2m Band over row	Banded herbicide, mechanical cultivation
5	W+F; 28% UAN and herbicide applied separately	slot 0.2m from row	Banded herbicide, mechanical cultivation
6	W+F; 28% UAN and herbicide applied separately	Slot 0.4m from row	Banded herbicide, mechanical cultivation
7	W; no nitrogen fertilizer	No nitrogen	Broadcast herbicide only
8	W; no nitrogen fertilizer	No nitrogen	Banded herbicide, mechanical cultivation

Fig 1. Experimental layout for corn to evaluate nitrogen and herbicide placement and application methods; rotational corn and soybeans reversed annually.

BLOCK 1

	CONTINUOUS CORN		ROTATIONAL CORN		ROTATION AL BEANS	
Guard Rows	Plots 4.6m by 30m Eight treatments	Guard Rows	Plots 4.6m by 30m Eight treatments	Guard Rows		Guard Rows

BLOCK 2

	CONTINUOUS CORN		ROTATIONAL CORN		ROTATION AL BEANS	
Guard Rows	Plots 4.6m by 30m Eight treatments	Guard Rows	Plots 4.6m by 30m Eight treatments	Guard Rows		Guard Rows

BLOCK 3

	CONTINUOUS CORN		ROTATIONAL CORN		ROTATION AL BEANS	
Guard Rows	Plots 4.6m by 30m Eight treatments	Guard Rows	Plots 4.6m by 30m Eight treatments	Guard Rows		Guard Rows

BLOCK 4

	CONTINUOUS CORN		ROTATIONAL CORN		ROTATION AL BEANS	
Guard Rows	Plots 4.6m by 30m Eight treatments	Guard Rows	Plots 4.6m by 30m Eight treatments	Guard Rows		Guard Rows

Findings

SOIL NITROGEN

Application of nitrogen fertilizer consistently affected inorganic nitrogen soil contents at the June sampling but not after harvest (Table 3). There were considerable differences in soil inorganic nitrogen recoveries between the Southwestern and Eastern Ontario sites. By late June, only about 20% of the applied fertilizer was recovered as soil inorganic nitrogen in the Southwest. Leaching beyond 0.9m was not a factor between planting and June sampling. This contrasts with about 50% fertilizer-N recoveries in June in Eastern Ontario. After harvest at the Southwestern sites, there was little to no difference due to fertilizer applications in soil nitrogen levels. The application of nitrogen fertilizer in the Southwestern sites resulted in about 36 kg-N/ha or 36% more nitrogen being removed in the corn grain than if no nitrogen fertilizer was applied.

The Uplands site contained very high residual soil nitrogen concentrations throughout the experimental period. The field had been cropped to corn from 1986 to 1989 and received liquid manure at a rate equivalent to 350 kg-total N/ha. It was then seeded to wheat (with 300kg total N/ha as liquid manure), under sown to alfalfa. A good stand of alfalfa was chemically killed in 1991 immediately prior to planting corn. After harvest, there was considerably more presumably fertilizer derived nitrogen (about 23 and 15 kg/ha at the Uplands and Dalhousie sites, respectively) available for loss in leachate or by volatilization. At the Uplands site only about 11 kg-N/ha more nitrogen was removed in corn grain due to the application of nitrogen fertilizer that is 84.8 kg-N/ha versus 73.4 kg-N/ha removed in the grain for the 100 kg-N/ha and 0 kg-N/ha fertilizer application treatments respectively.

About 31 kg-N/ha was removed in the corn grain due to nitrogen fertilization of the Dalhousie site. Fertilization with 100kg-N/ha resulted in no residual inorganic nitrogen in the Southwestern soil profiles after harvest. Of considerable interest are the differences in inorganic nitrogen behaviour between the Eastern and Southwestern sites. Based on these data, the agronomic need for higher nitrogen fertilization rates in Southwestern Ontario appears to be justified. There would appear to be little likelihood for enhanced leaching of fertilizer derived nitrate from the Southwestern sites. We should expect losses (by either leaching or volatilization after denitrification) of about 20kg-N/ha due to a 100kg-N/ha fertilization rate from the Eastern Ontario locations.

The results of the Uplands site demonstrated that annual applications of manure and/or alfalfa cropping probably contributed to the soil nitrate pool, as indicated by the observed high levels of nitrate at all sampling times. A spring soil test is potentially important for fields with a legume and/or manure application history. This sort of legume cropping and/or manure application is a very common practice in livestock (cattle)-based production systems.

Table 3. Extracted inorganic nitrogen in the 0.0 - 0.9m soil layer, in late June and post harvest, and nitrogen content in harvested grain corn, averaged over all experimental years.

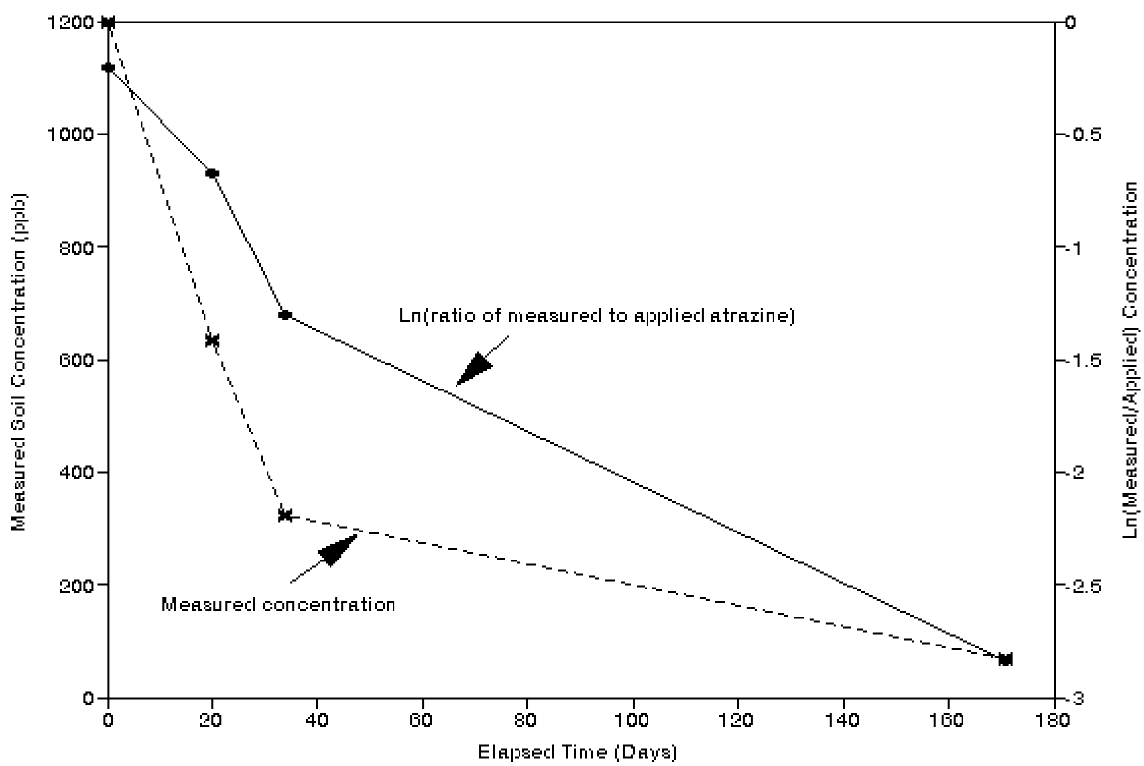
	Soil Nitrogen				Grain Nitrogen*	
	Late June		Post Harvest			
	Nitrogen Fertilization Rate					
	100	0	100	0	100	0
Site	kg-N/ha					
Toledo clay loam	53.4	34.0	19.9	19.3	82.6	36.0
Berrien loamy sand	62.5	25.6	25.6	25.6	55.6	30.6
Uplands loamy sand	136.3	85.2	75.4	52.0	84.8	73.4
Dalhousie silt loam	103.7	48.8	37.0	22.1	94.4	63.1

* assumes average grain corn nitrogen content of 1.4%

Herbicide Disappearance

Soil concentrations of atrazine, atrazine plus the common degradation product desethyl atrazine, metolachlor and metribuzin decreased approximately logarithmically with time. Fig. 2 presents typical results from the 1991 growing season at the Toledo clay loam site. The curvilinear response of soil atrazine concentration with time becomes approximately linear when a log-transformed concentration (soil concentration/concentration at time zero) is used as the ordinate. A linear relationship supports a first order degradation model. All log-transformed soil herbicide concentration data were fitted to the first order model and the time to 50% loss (half life or $t_{1/2}$) was calculated as ln(0.5)/k where k is the slope of the regression line. Time from application was calculated both in terms of days and Growing Degree Days (GDD) above 10°C from the day of application. One GDD is equivalent to about 2.5 crop heat units (CHU).

Fig. 2 Dissipation of atrazine applied to Toledo clay loam in 1991



With the exception of metribuzin, neither herbicide/fertilizer mixing treatments nor year affected herbicide half lives (Table 4). There were clear $t_{1/2}$ differences between sites (Table 5). Atrazine and metolachlor persistences, were considerably longer in Eastern Ontario. This was not the case with metribuzin which appeared to be more long-lived in fine textured soils. Over all sites and years, the average soil temperature at a 0.05m depth was about 19°C during the first $t_{1/2}$ period.

Variability in $t_{1/2}$ was surprisingly similar whether time was measured chronologically or "thermally" (GDDs). This was contrary to expectation. Given that metribuzin did not behave like atrazine or metolachlor indicates that the similarity of atrazine response with chronological and thermal time could not be attributed to experimental factors. In fact, $t_{1/2}$ measurements using time and GDDs were highly correlated (Fig.3), and one can be used to estimate the other with little error. Atrazine dissipation at the Uplands site was considerably slower than at the other sites. Atrazine is known to be quite strongly absorbed to organic matter. Given its sandy loam texture and a high organic carbon level, atrazine absorption on organic matter may be reducing disappearance rates at this site.

Amongst others, Walker and Brown (1985), have noted considerable discrepancies between herbicide disappearance rates measured in the field and in the laboratory. Topp and Smith (1994) measured dissipation rates for these chemicals in the laboratory and with field lysimeters. Atrazine, metolachlor and metribuzin $t_{1/2}$ values in a loam soil, adjusted to a soil temperature of 20°C, were 72, 77, and 63 days, respectively. Such dissipation half lives are about twice those reported in this study. Interestingly, they observed field (lysimeter) determined rates of 27 and 41 days for atrazine and metolachlor, respectively. However, they have also reported a very significant laboratory soil water content effect; for example the atrazine half lives decreased by about 0.25 days for each 1% increase in soil water content (expressed as % of saturation) in a loam soil. Collectively, it appears that reliable estimates of the rates at which herbicides disappear in the environment must be measured in the field under appropriate environmental conditions.

Fig.3 Observed valuse and best-fit linear regression relating half lives of herbicide in days and in growing degree days for all sites.

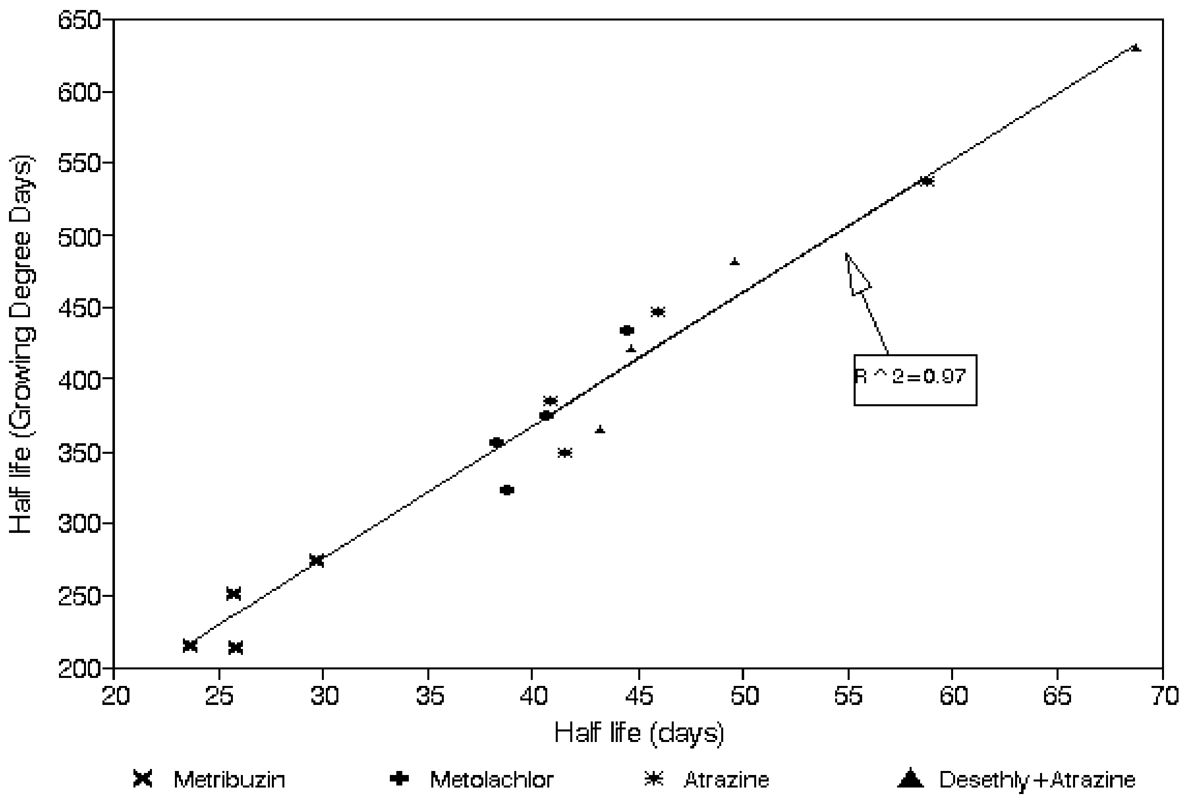


Table 4. Main effect (year, site (soil) and herbicide application method) analysis of variance tables for half lives (t ½) for desethyl atrazine plus atrazine, atrazine, metolachlor and metribuzin expressed in growing degree days above 10°C and days since application, at two sites in Eastern and Southwestern Ontario from 1990 to 1993.

	Half Life							
Sources of Variation	Growing Degree Days above 10°C				Days			
	Desethyl+ Atrazine	Atrazine	Metolachlor	Metribuzin	Desethyl+ Atrazine	Atrazine	Metolachlor	Metribuzin
Year	-	-	-	**	-	-	+	**
Site	**	*	*	**	*	*	-	*
Application method	-	-	-	-	-	-	-	-
R^2	0.342	0.299	0.272	0.498	0.372	0.292	0.278	0.487
Mean	463	421	369	240	50.5	46.0	40.3	26.4
Coeff. of variation(%)	33.5	30.6	22.5	17.9	30.4	28.0	18.4	16.9

+,*,**, denote levels of significance at p= 10, 5 and 1% respectively

Table 5. Half-lives for applied herbicides in both growing degree days (GDD) and time (DAYs) on two soil types in Southwestern Ontario and two in Eastern Ontario.

Site	**GDD's**				**<u>DAY's</u>**			
	Desethyl + Atrazine	Atrazine	Metribuzin	Metolachlor	Desethyl + Atrazine	Atrazine	Metribuzin	Metolachlor
Toledo clay loam	420.9	385.4	274.1	357.0	44.7	40.8	29.7	38.2
Berrien loamy sand	364.3	350.0	213.8	322.4	43.2	41.5	25.8	38.7
Uplands loamy sand	629.8	536.9	215.5	375.2	68.8	58.8	23.6	40.6
Dalhousie silt loam	481.2	446.1	251.0	433.4	49.6	46.0	25.7	44.5
Tukey w* Statistic	197.7	164.1	54.5	115.9	19.6	16.4	5.7	9.4

* means within each column which differ by more than the Tukey *w* statistic are significantly different from each other at p<5%.

YIELDS

Analysis of variance showed significant treatment effects on yield at all sites (Table 6). Corn yields at all sites were consistently about 10% higher when rotated with soybean compared to continuous corn. Statistical significance (p<5%) of corn grown in rotation with soybean was observed only at the Berrien site (Table 7).

Table 6. Analysis of variance for corn yield under various production methods at two sites in Southwestern Ontario and two sites in Eastern Ontario.

Sources of Variation	**SITE**			
	Toledo clay loam	Berrien loamy sand	Dalhousie silt loam	Uplands loamy sand
Year	-	+	-	***
Block	-	-	-	***
Rotation	-	-	-	**
Block x Rotation (Error a)	*	*	-	-
Treatment	**	***	**	+
Rotation x Treatment	-	-	**	-
R^2	0.731**	0.51**	0.47**	0.29**
Means (T/ha)	5.3	3.8	6.5	6.1
Coefficient of variation (%)	24.8	35.7	20.8	26.1

tested using error *a*

\+ significant at the 10%level

* significant at the 5% level

** significant at the 1% level

*** significant at the .1% level

Table 7. Corn-soybean rotation effects on mean corn yield at four sites over four years.

Site	Rotational Corn	Continuous Corn	Tukey's w+ Statistic
	Yield ———t/ha* ———		
Toledo clay loam	6.1	5.9	0.4
Berrien loamy sand	4.6	4.0	0.4
Uplands loamy sand	6.6	6.1	0.5
Dalhousie silt loam	6.9	6.8	0.5

+means within each row which differ by more then Tukey *w* statistic are significantly different at p<5%
* yields adjusted to 15.5% moisture content

Corn yield, obtained using cultivation to control weeds in the interrow, was generally lower compared with broadcast herbicide weed control (Table 8) particularly when the corn was in a corn soybean rotation. Broadcast herbicide resulted in yield that was substantially greater (at p<10%) than herbicide plus cultivation on coarse textured soils. This is consistent with a hypothesis of greater deleterious competition between crops and weeds for available soil water on coarse textured soils which have lower water holding capacities than do fine textured soils. This effect may be further enhanced if damage occurs during cultivation to the crop roots.

Table 8. Mean corn yield, 1990-1993, as affected by banded herbicide application with interrow cultivation versus overall spraying at four sites in Ontario.

Site	Continuous Corn		Rotational Corn		Tukey's *w*+ Statistic
	Cultivated	Noncultivated	Cultivated	Noncultivated	
	——— t/ha* ———		——— t/ha* ———		
Toledo clay loam	5.9	5.8	6.4	6.5	1
Berrien loamy sand	4	3.9	4.4	5.1	1
Uplands loamy sand	5.9	6.4	6.5	6.9	1.2
Dalhousie silt loam	7.1	6.7	6.6	6.6	1.3

+means within each row which differ by more then Tukey *w* statistic are significantly different at p<5%
*yields adjusted to 15.5% moisture content

There was a significant reduction (p<10%) in yield on the Toledo soils, when herbicides were mixed with the nitrogen fertilizer (Table 9). A similar, but not significant benefit of separate applications of the chemicals was observed at two other sites. We had hypothesized that application of herbicides mixed in the fertilizer solution, which has a specific gravity 25% greater than water, would result in enhanced performance due to reduced drift. Observation does not support our hypothesis, but it may be important to note that the mixing of herbicide with nitrogen fertilizer could save a pass over the field and the slight yield difference could be offset by this time saving.

Table 9. Mean corn yield as a result of surface applying nitrogen versus by mixing herbicide with nitrogen fertilizer.

Site	Mixed	Unmixed	Tukey *w*+ Statistic
	——T/ha——		
Toledo clay loam	5.7	6.3	0.7
Berrien loamy sand	4.1	4.4	0.7
Uplands loamy sand	6.4	6.3	0.9
Dalhousie silt loam	6.6	6.9	0.9

[+] means within each row which differ by more then Tukey *w* statistic are significantly different at p<5%

Study Conclusions

Atrazine, metolachlor and metribuzin, used at minimum label rates, provided reasonable weed control, and appeared to be degraded to very low soil concentrations by harvest time. There was some indication of more rapid degradation of atrazine in Southwestern Ontario, than in Eastern Ontario. Increased (enhanced) degradation, was not a factor in these experiments. Replacement of herbicides with interrow cultivation depressed yields on coarse textured soils. There was no agronomic weed control benefit associated with mixing herbicides into the 28% N fertilizer solution but neither was it detrimental.

The agronomically beneficial corn-soybean rotation yield effect (about 10%) was confirmed. Application of 100 kg-N/ha at planting increased soil inorganic nitrogen content in mid-June less in Southwestern Ontario than in Eastern Ontario. After-harvest residual soil nitrogen content, due to nitrogen fertilizer applied at 100 kg-N/ha, was negligible in Southwestern Ontario. At the Eastern Ontario sites, about 20% of the applied N remained available for loss after harvest. These results imply that higher rates of nitrogen may be agronomically appropriate in Southwestern Ontario, and they would not, materially affect ground water contamination risk. Manure and legume derived nitrogen sources of nitrogen can materially affect soil inorganic N levels; care should be exercised in determining economic and environmentally responsible rates of nitrogen fertilizer in fields with such histories. Use of the nitrogen soil test may be very appropriate for the management of manured fields.

New technologies and benefits:

There is a substantial potential for the use of combined methods (cultivation plus herbicide) of weed control on fine textured soils. Detrimental economic risks, probably due to reduced weed control or root damage or possibly loss of available water, appear to be greater on coarse textured soils, where competition for soil water is often more severe.

There appears to be both economic and environmental justification for greater nitrogen application rates in Southwestern Ontario. While our results indicated that there may be somewhat more rapid degradation of atrazine in Southwestern Ontario than in Eastern Ontario, it was not a concern. The field-measured degradation rates of atrazine, metolachlor and metribuzin, while in line with literature values, were quite different from those measured in the laboratory using similar disturbed soils.

Gaps/needs for future research:

1) The uptake and utilization of soil nitrogen is still a poorly understood process; in particular when manure is used as a nitrogen source and forage crops are part of the crop rotation.

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