NITROGEN RESEARCH ON CORN USING CONSERVATION TILLAGE

Summary of 5 Years

1990 - 1994

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INTRODUCTION

A detailed report has been put out for each year of the project. This brief report is an attempt to summarize the data for the 5 years.

The following are some general comments for each year:

1990 - This was a set-up year.
- There was no tillage variable since the soil was uniformly chisel plowed by the farmer in the fall of 1989 at all sites.

1991 - A tillage variable was set up at all sites. (conventional vs mulch-till at Thamesville & Strathroy; mulch-till vs no-till at Rodney).

1992 - The tillage variable at Thamesville and Strathroy was changed to mulch-till (fa] chisel plow) vs no-till the same as the Rodney site.
- The coulter injection system was changed to inject the UAN solution directly into the soil. In 1990 & 1991 the UAN solution was directed in a stream to hit the slit created by the coulter. It was felt that this system may have accounted for the poor results with the coulter injection system in 1990 & 1991.

1993 & 1994 - No changes made.

PROJECT INFORMATION

PROJECT TITLE: Nitrogen Research With Corn Using Conservation Tillage

INSTITUTION: Ridgetown College of Agricultural Technology
Agronomy Section
Ridgetown, Ontario

PROJECT LEADER: C.K. Stevenson

PROJECT TECHNICIAN: M.C. MacAlpine

STARTING DATE: April, 1990

TERMINATION DATE: March, 1995

FUNDING ORGANIZATIONS: . Ontario Ministry of Agriculture, Food & Rural Affairs (Land Stewardship Program)
Ontario Corn Producers' Association
Pioneer Hi-Bred Limited
Potash and Phosphate Institute of Canada

OBJECTIVES:

1. To compare two tillage systems (mulch-till and no-till) for corn.

2. To evaluate response of corn to rates of nitrogen (N).

3. To compare three sources of N for corn-urea, urea-ammonium nitrate (UAN) solution (28%N) and anhydrous ammonia (AA).

4. To compare various methods and times of applying UAN solution to urea broadcast, and AA knifed in application for corn.

5. To study the interaction effects of the above factors.

EXPERIMENTAL DESIGN: Factorial arrangement in a split plot design.

RESPONSE CRITERIA:

1. Grain yield
2. Moisture content of grain at harvest
3. Broken stalks
4. Barren plants
5. Root lodging
6. Nutrient content of ear leaves at early silking
7. Protein content of grain at harvest
8. N content of plants at harvest
9. N content of soil (0-60 cm)
10. N content of soil (0-120 cm)

INFORMATION ON PROJECT SITES

Location #1

CO-OPERATOR: Greg Devries
R.R. #7, Thamesville
Lot: 4 Conc.: 4 Twp.: Camden County: Kent

SOIL TYPE: Berrien very fine sand (70.4% sand, 18.7% silt, 10.8% clay)

FIELD HISTORY:

1989 - Corn
- Triple superphosphate @ 100 lb/ac} broadcast in fall
- Muriate of potash @ 100 lb/a
- Swine manure @ 10,000 gal/ac in spring
- 11-52-0 @ 125 lb/ac, banded at planting
- UAN solution (28% N) @ 160 kg actual N/ac, broadcast and worked in before planting.

1988 - Soybeans - No fertilizer.

1987 - Corn - Fertilized same as 1989.

Location #2

CO-OPERATOR: Tony Mezenberg
R.R.# 2, Rodney
Lot: 2 & 3 Conc.: 7 Twp.: Aldborough County: Elgin

SOIL TYPE: Berrien loamy fine sand (82.8% sand, 10.0% silt, 7.1% clay)

FIELD HISTORY:

1989 - Corn
- 0-0-42-4.5(Mg)-0.6(B) @250 lb/ac
- 6-28-7-4(Mg)-1.5(Zn) 175 lb/ac at planting
- UAN solution (28% N) @ 100 lb N/ac sprayed on before planting
- UAN solution @ 80 lb N/ac knifed in as a side-dressing

1988 - Soybeans
- 5-10-32-2(Mg)-2(Mn) @ 200 lb/ac

1987 - Corn
- 0-0-42-4.5(Mg) @ 250 lb/ac
- 5-21-16-1.5(Zn) @ 175 lb/ac
- UAN solution @ 100 lb N/ac sprayed on before planting
- UAN solution @ 80 lb N/ac knifed in as a side-dressing

Location #3

CO-OPERATOR: John Henderson
R.R.# 2, Mt. Brydges (farm location - R.R. #1, Strathroy)
Lot: 4 Conc: 8 N Twp.: Lobo County: Middlesex

SOIL TYPE: Tuscola fine sandy loam (68.3% sand, 22.2% silt, 9.5% clay)

FIELD HISTORY:

1989 - Corn
- 70-75 lb K_2O/ac
- 45-50 lb P_2O_5/ac
- 170 lb N/ac

1988 - Corn
- Fertilized same as 1989.

1987 - Corn
- Fertilized same as 1989.

EXPERIMENT OUTLINE

TREATMENTS:

Main Plot:

1. Tillage System (T) - t_1 - Mulch-till (fall chisel plow)
   - t_2 - No-till

   NOTE: there was no tillage variable in the first year of the project (1990); all plots were chisel plowed in the fall of 1989 for the 1990 crop year.

Split Plot:

2. Source, Method and Time of N Application(S)
   - s_1 - Urea, broadcast, preplant
   - s_2 - UAN, sprayed, preplant
   - s_3 - UAN, coulter injected, preplant
   - s_4 - AA, knifed in, preplant
   - s_5 - UAN, spoked wheel injected, side-dress
   - s_6 - UAN, coulter injected, side-dress
   - s_7 - AA, knifed in, side-dress

3. N Rates (N) - n_0 - 0 kg N/ha
   - n_1 - 60 kg N/ha
   - n_2 - 120 kg N/ha
   - n_3 - 180 kg N/ha
   - n_4 - 240 kg N/ha

TOTAL NO. TREATMENTS: 2(7 x 4 + 1 check) = 58

REPLICATIONS: 4

TOTAL NO. PLOTS: 232

PLOT SIZE: main plots - 7.6 m x 88.4 m (25' x 290')
split plots - 7.6 m x 3.1 m (25' x 10')

TRIAL AREA: 61.0 m x 100.6 m = 0.61 ha (not including roadways & borders)
(200' x 330'= 1.52 ac)

129.6 m x 100.6 m = 1.30 ha (including roadways & borders)
(425' x 330'= 3.22 ac)

NO. PROJECT SITES: 3

PLANTING: Corn was planted with a John Deere #7000 Max-emerge plateless planter with 4 rows at 30 inch spacing. The planter was set to plant approximately 40,000 seeds/acre (5.3" spacing in row).

FINAL PLANT POPULATION: Corn was hand thinned to 7.5" spacing within the row = 24 seedlings in each 15' harvest row (28,000 plants/ac or 69,000 plants/ha).

HARVESTING: Harvested the centre 2 rows of plot, each 15' long = 75 sq. ft.
or 1/580.8 ac. or 1/1435.2 ha).

SOIL TEST*:

Location	Requirements			Value					
	N	P_2O_5	K_2O	P	K	pH	Mg	OM	CEC
				----- ppm --------			- ppm -	%	cmol+/k
1	165	0	0	42(VH)	157(VH)	7.0	195(H)	3.84	9.98
2	165	0	0	48(VH)	138(H)	6.5	143(11)	3.87	8.97
3	165	70	50	7.5(L)	96(M)	8.1	69(L)	4.53	16.70

* May 1994

Note: the N requirement is adjusted for an expected yield of 11 t/ha (175 bu/ac) applied as a side-dressing. If N were applied preplant, the total requirement would be 210 kg N/ha.

SPLIT PLOT TREATMENT DETAILS

No.	Treatment Code	Source of N	Method of Application	Time of Application	N* kg/ha
1	11	Urea	Broadcast	Preplant	60
2	12	"	"	"	120
3	13	"	"	"	180
4	14	"	"	"	240
5	21	UAN Sol'n**	Sprayed	"	60
6	22	"	"	"	120
7	23	"	"	"	180
8	24	"	"	"	240
9	31	UAN Sol'n**	Coulter Inject.	"	60
10	32	"	"	"	120
11	33	"	"	"	180
12	34	"	"	"	240
13	41	Anhyd. Ammonia	Knifed In	"	60
14	42	"	"	"	120
15	43	"	"	"	180
16	44	"	"	"	240
17	51	UAN Sol'n**	Spoke Wheel Inj.	Sidedress	60
18	52	"	"	"	120
19	53	"	"	"	180
20	54	"	"	"	240
21	61	UAN Sol'n**	Coulter Inject.	"	60
22	62	"	"	"	120
23	63	"	"	"	180
24	64	"	"	"	240
25	71	Anhyd. Ammonia	Knifed In	"	60
26	72	"	"	"	120
27	73	"	"	"	180
28	74	"	"	"	240
29	00	"	"	"	0

* Rates of additional N; all treatments received 20 kg N, 52 kg P_2O_5 and 52 kg K2O/ha (10-26-26 at 200 kg/ha), banded 5 cm to the side and 5 cm below the seed at planting time.

** 28% N.

METHOD OF APPLICATION:

Urea - broadcast on soil surface and worked in before planting (no-till treatments not worked in).

UAN solution (i) sprayed on soil surface and worked in before planting (no-till treatments not worked in).

(ii) injected 5-10 cm (2-4") deep in slits created by coulters at 76 cm (30") row spacing preplant and side-dressed.

(iii) point injected at 15-18 cm (6-7") spacing and 5-10 cm (24") deep by spoked wheels at 76 cm (30") row spacing, side-dressed.

AA - knifed in 15-20 cm (6-8") deep at 76 cm (30") row spacing, preplant and side-dressed.

TIME OF APPLICATION:

Preplant - applied before planting

Side-dress - applied when corn was approximately 15 cm (6") high.

NITROGEN SOIL SAMPLES

Soil samples (0-60 cm) were taken for nitrate-N analysis from the no-till main plot treatments, split plot treatments #2 (urea broadcast at 120 kg N/ha), #4 (urea broadcast at 240 kg N/ha) and #29 (0 kg N/ha) at 5 dates:

1. early spring (approx. Apr. 15)
   1) before fertilizer application and planting (approx. May 1)
   2) corn emergence (approx. May 15)
   3) early emergence (approx. June 1)
   4) maturity (approx. Oct. 1)

   Samples were taken from 3 depths for each sampling time:
   1) 0-15 cm
   2) 15-30 cm
   3) 30-60 cm

   Deep soil samples (0-120 cm) were also taken for nitrate-N analysis. The same 3 treatments were sampled as for the 0-60 cm samples and sampling was done at date :
   1) early spring (approx. Apr. 15).
   2) late fall (approx. Nov. 1)

   Samples were taken from 4 depths:
   1) 0-30 cm
   2) 30-60 cm
   3) 60-90 cm
   4) 90-120 cm

Literature Review

When urea and materials containing urea like urea-ammonium nitrate solution (UAN) are applied on the soil surface some of the nitrogen can volatilize into the air as ammonia and be lost. Ammonia volatilization is a complex process affected by several interacting chemical and physical factors as well as soil, fertilizer management and environment factors. Estimates of losses vary from 5-20% and higher. Factors affecting the amount of loss include: soil pH, soil cation exchange capacity (CEC), calcium carbonate ($CaCO_3$) content, temperature, drying conditions, rate and method of nitrogen application and crop residues.

Surface applications of urea and UAN are most efficient when they are washed into the soil or applied to soils with a low potential for volatilization (acid pH, high $CaCO_3$ content, high CEC). Other conditions for best performance of surface-applied urea or UAN are cold or dry at the time of application and/or the occurrence of significant precipitation shortly after application. Incorporation of broadcast urea and UAN into the soil will minimize losses.

In a detailed study conducted in Maryland for 3 years and at 4 locations, Bandel et al. (1980) found that ammonium nitrate (AN) was superior to granular or prilled urea and UAN solution in 3 of the 4 cases where potential yields and N responses were relatively high. They concluded that under the conditions which these tests were conducted, for no-tillage, urea or UAN solution should be banded beneath the soil surface.

In a Purdue University study in Indiana, Mengel et al. (1982) found that injecting AA or UAN below the soil surface resulted in consistently higher corn grain yields than applying UAN, AN or urea directly on the soil surface.

Touchton and Hargrove (1982) in a study conducted by the University of Georgia found that corn grain yield results showed the order of efficiency of 3 N sources is generally urea < UAN solution $\leq$ AN.

Howard and Tyler (1989) at the University of Tennessee, found that injecting UAN and urea resulted in significantly higher yield, leaf N concentration and N uptake when compared with broadcast and surface band application methods.

In an Iowa State University study, Blaylock and Cruse (1992) found that corn yields, percentage of N derived from fertilizer, and percentage of fertilizer N recovered were significantly greater with injected UAN than broadcast UAN with ridge-till systems.

A study on irrigated corn using ridge-till in Kansas by Gordon et al. (1992), found that knifed UAN and AA produced 13 bu/ac higher yields than surface broadcasting or dribbling UAN.

Stecker et al. (1993) at the University of Missouri reported that knife injected UAN increased no-till corn yields relative to broadcast and dribble N in 5 of 8 site-years. Yields from knife injected N ranged from 4 to 20% more than dribble, and 5 to 40% more than broadcast.

Stevenson (1993) at the Ridgetown College of Agricultural Technology conducted N research on corn under mulch-tillage, where the soil was fall chisel plowed (8 sites) or spring tandem disced (2 sites). In 5 of the 10 trials AA knifed in application gave a higher yield than urea when both sources were applied preplant. The yield differences ranged from 3-22 bu/ac (12 bu/ac average) in favour of AA compared to urea. The soil texture of the 5 sites ranged from loamy sand to silt loam. In the other 5 trials there was no difference in yield between AA and urea. The soils at these sites are finer in texture ranging from silt loam to clay loam.

RESULTS AND DISCUSSION

Grain Yield

Tillage System

The first year that tillage systems were compared was in 1991. At Thamesville and Strathroy conventional tillage (fall moldboard plow) was compared to mulch-till (fall chisel plow) and there was no significant difference between these two tillage systems at either location (Table 1).

Table 1. Effect of tillage system on corn grain yield, Thamesville and Strathroy, 1991.

Tillage System	Location	
	Thamesville	Strathroy
	- - - bu/ac @ 15.5% moisture - - -	
Moldboard Plow	157.1 a	161.9 a
Mulch-till	160.3 a	157.8 a

Note: data in the same column followed by the same letter are not significantly different at the .05 probability level.

From 1992-1994 at Thamesville and Strathroy, and from 1991-1994 at Rodney, mulch-till (fall chisel plow) was compared to no-till. At Thamesville mulch-till gave a significantly higher yield than no-till in 1 of the 3 years (Table 2).

Table 2. Effect of tillage system on corn grain yield, Thamesville, 1992-1994.

Tillage System	Year			
	1992	1993	1994	Avg.
	- - - bu/ac @ 15.5% moisture - - -			
Mulch-till	149.8 a	147.9 a	148.5 a	148.7
No-till	132.4 b	139.6 a	142.7 a	138.2

Note: data in the same column followed by the same letter are not significantly different at the .05 probability level.

At Rodney mulch-till gave a significantly higher yield than no-till in 3 of the 4 years (Table 3).

Table 3. Effect of tillage system on corn grain yield, Rodney, 1991-1994.

Tillage System	Year				
	1991	1992	1993	1994	Avg.
	---------- bu/ac @ 15.5% moisture ----------				
Mulch-till	156.4 a	151.0 a	144.5 a	164.9 a	154.2
No-Till	144.7 a	129.3 b	134.5 b	146.6 b	138.8

Note: data in the same column followed by the same letter are not significantly different at the .05 probability level.

At Strathroy mulch-till gave a significantly higher yield than no-till in 1 of the 3 years (Table 4).

Table 4. Effect of tillage system on corn grain yield, Strathroy, 1992-1994.

Tillage System	Year			
	1992	1993	1994	Avg.
	---------- bu/ac @ 15.5% moisture ----------			
Mulch-till	111.1a	127.1 a	139.1 a	125.8
No-till	100.8 a	116.2 b	132.0 a	116.3

Note: data in the same column followed by the same letter are not significantly different at the .05 probability level.

It is not known why mulch-till had a significant yield advantage over no-till at certain site years, especially the Rodney site. The Rodney site had the coarsest texture (Berrien loamy fine sand) and one would expect that no-till would give as high yields as any tillage system.

N Rate

There was a highly significant yield increase from N application at all except the Thamesville site in 1991. Although significant, the yield increase from N application at Thamesville in 1990 was small (Table 5). The small yield increases from N application at Thamesville in 1990 and 1991 is probably due to residual N carryover from liquid swine manure applied in the spring of 1989. Therefore, this site did not provide a satisfactory environment to compare sources, methods and times of N application in 1990 and 1991.

Table 5. Effect of rate of N on corn grain yield, Thamesville, 1990-1994.

N* kg/ha	Year					
	1990	1991	1992	1993	1994	Avg. ('92-'94)
	---------- bu/ac @ 15.5% moisture ----------					
0	160.6	141.7	71.2	93.3	73.0	79.2
60	169.8 b	153.6 b	111.l d	127.3 c	108.4 d	115.6
120	176.6 a	159.3 ab	138.0 c	143.5 b	139.4 c	140.3
180	175.9 a	161.4 a	149.2 b	150.9 a	162.2 b	154.1
240	179.6 a	160.6 a	166.2 a	153.3 a	172.4 a	164.0

* rates of additional N; all treatments received 20 kg N, 52 kg P_2O_5 and 52 kg K_2O/ha banded at planting.

Note: data in the same column followed by the same letter are not significantly different at the .05 probability level.

At Thamesville, grain yields increased up to 240 kg/ha of additional N (260 kg/ha of total N) in both 1992 and 1994, and 180 kg/ha of additional N (200 kg/ha of total N) in 1993.

At Rodney, grain yields increased up to 240 kg/ha of additional N (260 kg/ha of total N) in all years (Table 6). The Rodney site has given the most yield increase from N application in 3 of the 5 years of the project. The soil texture at this site is the coarsest of the 3 sites and therefore more subject to leaching losses of N.

Table 6. Effect of rate of N on corn grain yield, Rodney, 1990-1994.

N* kg/ha	Year					
	1990	1991	1992	1993	1994	Avg.
	---------- bu/ac @ 15.5% moisture ----------					
0	95.3	72.3	69.2	78.1	86.8	80.3
60	130.1 c	114.5c	114.6d	119.7d	125.6d	120.9
120	150.8 b	153.2 b	139.7 c	137.8 c	150.7 c	146.4
180	156.7 b	159.7 b	147.8 b	146.7 b	165.8 b	155.3
240	163.1 a	174.8 a	158.6 a	153.1 a	180.8 a	166.1

* rates of additional N; all treatments received 20 kg N, 52 kg P_2O_5 and 52 kg K_2O/ha banded at planting.

Note: data in the same column followed by the same letter are not significantly different at the .05 probability level.

At Strathroy, grain yields increased up to 120 kg/ha of additional N (140 kg/ha of total N) in 1990 and 1992, 180 kg/ha of additional N (200 kg/ha of total N) in the 1991 and 1993, and 240 kg/ha of additional N (260 kg/ha of total N) in 1994 (Table 7).

Table 7. Effect of rate of N on corn yield, Strathroy, 1990-1994.

N* kg/ha	Year					
	1990	1991	1992	1993	1994	Avg.
	---------- bu/ac @ 15.5% moisture ----------					
0	84.4	98.3	62.5	61.4	66.6	74.7
60	115.1 c	136.0 c	89.7 c	100.8 c	105.6 d	109.4
120	129.8 b	160.8 b	106.4 b	122.9 b	130.1 c	130.0
180	135.0 ab	169.1 a	111.0 b	130.6 a	148.0 b	138.7
240	140.2 a	173.5 a	116.7 a	132.4 a	158.6 a	144.3

* rates of additional N; all treatments received 20 kg N, 52 kg P_2O_5 and 52 kg K_2O/ha banded at planting.

Note: data in the same column followed by the same letter are not significantly different at the 05 probability level.

In general the yield increases from N application were quite large in these trials with 6 of the 15 site-years giving a significant yield increase of 90 bu/ac or greater.

N Source, Method and Time of Application

There was a highly significant yield difference (significant at Rodney `90) among N sources, method and time of application treatments at all site-years except Thamesville in 1990 and 1991, and Strathroy in 1992 and 1993.

Table 8 gives the results at Thamesville. Because of the low yield increases from N application in 1990 and 1991 this did not provide very good conditions for comparing N sources, methods and times of application. In other words if not much N is required for optimum yields the N source, method and time of application used is less critical. The data for 1992-1994 are averaged over 2 tillage systems, mulch-till and no-till. AA side-dress application gave the highest yields, however, the yields were not significantly greater than AA preplant and UAN solution spoke wheel injected or coulter injected side-dress. Comparing the preplant treatments, AA gave significantly higher yields than UAN solution surface broadcast, which gave significantly higher yields than urea surface broadcast. UAN solution coulter injected gave significantly higher yields than UAN solution surface broadcast. In 2 of the 3 years, UAN solution coulter injected gave yields that were not significantly different than AA when both sources were applied preplant. These results indicate that volatilization losses of N are taking place from surface broadcast applications of urea and UAN solution.

Table 8. Effect of N source, method and time of application on corn grain yield, Thamesville, 1992-1994.

Source	Method	Time	Year					
			1990	1991	1992	1993	1994	Avg. (`92-94')
			---------- bu/ac @ 15.5% moisture ----------					
No N			160.6	141.7	71.2	93.3	73.0	79.2
Urea	Broadcast	Preplant	174.4 a	157.6 a	119.2 d	126.0 d	119.4 d	121.5
UAN	Broadcast	Preplant	176.2 a	159.4 a	132.6 c	138.9 c	130.9 c	134.1
UAN	Coulter Injected	Preplant	175.9 a	157.5 a	142.3 b	146.0 b	145.3 b	144.5
AA	Knifed In	Preplant	175.3 a	156.0 a	153.0 a	149.3 ab	151.8 ab	151.4
UAN	Spoke Wheel Injected	Side-dress	176.0 a	162.2 a	146.8 ab	148.3 ab	156.0 ab	150.4
UAN	Coulter Injected	Side-dress	174.0 a	157.5 a	144.5 ab	144.2 bc	157.9 a	148.9
AA	Knifed In	Side-dress	176.6 a	161.0 a	149.5 ab	153.5 a	157.9 a	153.6

Note: data in the same column followed by the same letter are not significantly different at the .05 probability level.

Table 9 gives the results at Rodney. In 1990, the first year of the project, only one tillage system, mulch-till, was used, and the yield differences among treatments were less than the succeeding years. UAN solution spoke wheel injected side-dress gave the highest yield which was significantly higher than all the other treatments except AA (side-dress and preplant). The data for 1991-1994 are averaged over 2 tillage systems, mulch-till and no-till. AA side-dress application gave the highest yields in 2 out of the 4 years, however, the yields were not significantly greater than AA preplant and UAN solution spoke wheel injected side-dress. The yield results with UAN solution coulter injected side-dress were lower than the other side-dress treatments in 1990 and 1991, perhaps because the UAN solution was sprayed from above the soil into the slit created by the coulters. This could have allowed some loss of N because the UAN solution was not completely covered with soil. The coulter injection system was changed in 1992 to release the UAN solution below the soil surface to give more complete soil coverage. Comparing the preplant treatments, AA gave significantly higher yields than urea broadcast. UAN solution surface broadcast gave slightly higher yields (non significant) than urea broadcast. UAN solution coulter injected gave slightly higher yields (non significant) than UAN solution surface broadcast. AA gave slightly higher yields (non significant) than UAN solution coulter injected in 3 of the 4 years. Again the results indicate that volatilization losses of N are taking place from surface broadcast applications of urea and UAN solution.

Table 9. Effect of N source, method and time of application on corn grain yield, Rodney, 1991-1994.

Source	Method	Time	Year					
			1990	1991	1992	1993	1994	Avg. (`91-94')
			---------- bu/ac @ 15.5% moisture ----------					
No N			95.3	72.3	69.2	78.1	86.8	76.6
Urea	Broadcast	Preplant	146.2 b	141.4 cd	130.5 c	132.0 c	142.1 c	136.5
UAN	Broadcast	Preplant	147.7 b	146.5 bed	133.9 bc	133.0 bc	149.5 bc	140.7
UAN	Coulter Injected	Preplant	144.6 b	147.4 bed	142.3 ab	139.4 abc	160.0 ab	147.3
AA	Knifed In	Preplant	152.7 ab	158.5 ab	150.5 a	141.4 ab	158.3 ab	152.2
UAN	Spoke Wheel Injected	Side-dress	158.0 a	154.2 bc	148.0 a	140.8 ab	153.1abc	149.0
UAN	Coulter Injected	Side-dress	148.1 b	136.0 d	138.3 bc	146.3 a	162.0 ab	145.7
AA	Knifed In	Side-dress	153.8 ab	169.8 a	137.8 bc	142.3 a	165.0 a	153.7

Note: data in the same column followed by the same letter are not significantly different at the .05 probability level.

Table 10 gives the results at Strathroy. In 1990, the first year of the project, only one tillage system, mulch-till, was used. UAN solution spoke wheel injected gave significantly higher yields than all the other treatments except AA preplant application. The data for 1991 are averaged over 2 tillage systems - conventional (moldboard plow) and mulch-till (chisel plow). AA side-dress application gave a significantly higher yield than all the other treatments. UAN solution spoke wheel injected preplant and AA preplant gave the next highest yields. Comparing the preplant treatments, AA gave a significantly higher yield than UAN solution coulter injected and urea surface-broadcast. The low yields with UAN solution coulter injected (preplant and side-dress) in 1991 could be due to the fact that the UAN solution was not completely covered with soil which allowed some loss of N. The coulter injection system was changed in 1992 to release the UAN solution below the soil surface to give more complete soil coverage. The data for 19921994 are averaged over 2 tillage systems, mulch-till and no-till. In 1992 and 1993 there were no significant differences among the treatments. Yields were also lower in those 2 years. In 1994 AA side-dress application gave the highest yield, however, the yield was not significantly higher than AA preplant and UAN solution coulter injected (side-dress and preplant) and UAN solution spoke wheel injected side-dress. Comparing the preplant treatments, AA and UAN solution coulter injected gave significantly higher yields than urea and UAN solution surface broadcast. Again this indicates that volatilization losses of N are taking place from surface broadcast applications of UAN solution and urea.

Table 10. Effect of N source, method and time of application on corn grain yield, Strathroy.

Source	Method	Time	Year				
			1990	1991	1992	1993	1994
			---------- bu/ac @ 15.5% moisture ----------				
No N			84.8	98.3	62.5	61.4	66.6
Urea	Broadcast	Preplant	122.8 b	152.4 d	102.9 a	120.4 a	129.2 bc
UAN	Broadcast	Preplant	126.3 b	160.0 bc	107.3 a	116.1 a	122.5 c
UAN	Coulter Injected	Preplant	123.7 b	152.2 d	102.8 a	123.6 a	138.6 a
AA	Knifed In	Preplant	133.1 ab	164.3 b	107.4 a	122.0 a	141.6 a
UAN	Spoke Wheel Injected	Side-dress	140.4 a	163.6 b	106.6 a	122.0 a	133.7 ab
UAN	Coulter Injected	Side-dress	132.9 b	155.3 cd	109.9 a	121.4 a	141.4 a
AA	Knifed In	Side-dress	131.0 b	171.1 a	104.8 a	126.2 a	142.2 a

Note: data in the same column followed by the same letter are not significantly different at the .05 probability level.

Table 11 gives the results for N source, method and time of application averaged over the 8 site-years where mulch-till was compared to no-till and there was a significant difference among N source, method and time of application treatments. The AA and UAN soil injected treatments gave considerably higher yields than UAN and urea surface broadcast.

Table 11. Effect of N source, method and time of application on corn grain yield, 8 site-years, 1991-1994.

Source	Method	Time	Yield bu/ac @l5 5% moisture
No N			76.3
Urea	Broadcast	Preplant	130.0
UAN	Broadcast	Preplant	136.0
UAN	Coulter Injected	Preplant	145.2
AA	Knifed In	Preplant	150.6
UAN	Spoke Wheel Injected	Side-dress	147.6
UAN	Coulter Injected	Side-dress	146.3
AA	Knifed In	Side-dress	152.3

There has been a mulch-till (fall chisel plow) treatment in the experiments in all 5 years of the project. Table 12 gives the yield results for the 11 site-years where there was a significant difference in yield among N source, method and time of application treatments and in trials that gave a large yield increase from N application (Thamesville `90 & `91 excluded). On the average AA side-dress application gave the highest yield, however, the yield was not significantly greater than UAN solution spoke wheel injected side-dress, AA preplant and UAN solution coulter injected preplant. UAN solution coulter injected side-dress gave lower yields than the other side-dress treatments the first 2 years of the project. However, in 1992-1994 after the coulter injection system was changed to inject the UAN directly into the soil, yields of UAN solution coulter injected side-dress were generally equivalent to the other side-dress treatments. Comparing the preplant treatments, AA and UAN solution coulter injected gave the highest yields, which were significantly higher than UAN solution and urea surface broadcast.

Table 12. Effect of N source, method and time of application with mulch-tillage on corn grain yield, 11 site years, 1990-1994.

Source	Method	Time	Site											
			Rod. `90	Str. `90	Rod. `91	Str. `91	Tha. `92	Rod. `92	Tha. `93	Rod. `93	Tha. `94	Rod. `94	Str. `94	Avg.
			bu/ac @ 15.5% moisture											
No N			95.3	84.8	72.3	98.3	71.2	69.2	93.3	78.1	73.0	86.8	66.6	80.8
UR	Broadcast	Preplant	146.2 b	122.8 b	143.5 cde	156.0 bc	126.5 d	142.4 c	132.0 f	139.1 ab	119.4 d	142.1 c	129.2 bc	136.3
UAN	Broadcast	Preplant	147.7 b	126.3 b	156.2 abcd	164.6 ab	137.3 cd	144.8 bc	141.1 def	138.0 ab	130.9 c	149.5 bc	122.5 c	141.8
UAN	Coulter Inject.	Preplant	144.5 b	123.7 b	165.3 a	153.3 c	157.5 a	160.3 a	152.3 abc	150.4 a	145.3 b	160.0 ab	138.6 a	150.1
AA	Knifed In	Preplant	152.7 ab	133.1 ab	161.2 abc	164.2 ab	159.3 a	156.3 ab	155.1 a	143.4 a	151.8 ab	158.3 ab	141.6 a	152.5
UAN	Spoke Wheel Injected	Side-dress	158.0 a	140.4 a	163.4 ab	163.9 ab	160.2 a	161.8 a	151.9 abc	144.1 a	156.0 ab	153.1 abc	133.7 ab	153.3
UAN	Coulter Inject.	Side-dress	148.1 b	132.9 b	136.5 e	157.9 bc	151.1 ab	145.9 bc	148.7 abcd	146.5 a	157.9 a	162.0 ab	141.4 a	148.1
AA	Knifed In	Side-dress	153.8 ab	131.0 b	168.5 a	173.3 a	156.6 a	145.3 bc	154.1 a	146.9 a	157.9 a	165.0 a	142.2 a	154.1
Residue Cover at Planting (%)			-	-	11	20	28	30	40	41	32	32	36	30

MOISTURE CONTENT OF GRAIN

Tillage System

Table 13 gives the results for mulch-till (fall chisel plow) compared to no-till. At both Thamesville and Rodney, no-till generally resulted in a higher moisture content of grain at harvest than mulch-till, although the individual year differences were not always significant. On the average no-till resulted in 1.6% higher moisture content of grain compared to mulch-till, at both Thamesville and Rodney. At Strathroy there was no significant difference in moisture content of grain between the 2 tillage systems in any year.

Table 13. Effect of tillage system on moisture content of grain at harvest, Thamesville, Rodney and Strathroy.

Tillage System	Year				
	1991	1992	1993	1994	Avg.
	---------- % ----------				
			Thamesville		
Mulch-till	-	31.3 b	22.3 a	22.2 a	25.3
No-till	-	33.7 a	23.1 a	24.0 a	26.9
			Rodney		
Mulch-till	14.4 b	31.3 b	20.3 a	21.9 a	22.0
No-till	14.9 a	34.7 a	20.6 a	24.3 a	23.6
			Strathroy		
Mulch-till	-	33.3 a	21.9 a	24.2 a	26.5
No-till	-	33.3 a	22.0 a	25.0 a	26.8

Note: data in the same column followed by the same letter, for a particular location, are not significantly different at the .05 probability level.

N Rate

There was no significant difference in the moisture content of grain due to the rate of N applied at Thamesville (Table 14) and Rodney (Table 15) in 1990 and 1991, and Strathroy (Table 16) in 1990-1992 and 1994. For the other site-years there was a significant difference in grain moisture content among N rates. In general the moisture content decreased with increasing rates of additional N. The largest decrease in grain moisture content occurred when the rate of additional N was increased from 0 to 60 kg/ha, and the second largest decrease occurred when the rate of additional N was increased from 60 to 120 kg/ha.

Table 14. Effect of rate of N on moisture content of grain at harvest, Thamesville.

N* kg/ha	Year					
	1990	1991	1992	1993	1994	Avg.
	---------- % ----------					
0	26.6	17.0	36.1	23.7	25.9	25.9
60	26.4 a	16.4 a	33.1 a	23.2 a	23.7 a	24.6
120	26.1 a	16.1 a	32.5 ab	22.8 ab	23.4 ab	24.2
180	26.4 a	16.4 a	32.5 ab	22.4 b	22.8 bc	24.1
240	25.8 a	16.4 a	31.8 a	22.4 b	22.3 c	23.7

* rates of additional N; all treatments received 20 kg N, 52 kg P_2O_5 and 52 kg K_2O/ha banded at planting.
Note: data in the same column followed by the same letter are not significantly different at the .05 probability level.

Table 15. Effect of rate of N on moisture content of grain at harvest, Rodney.

N* kg/ha	Year					
	1990	1991	1992	1993	1994	Avg.
	---------- % ----------					
0	28.6	16.0	39.0	22.9	25.7	26.4
60	27.7 a	14.8 a	34.4 a	21.0 a	24.1 a	24.4
120	28.0 a	14.6 a	32.3 b	20.5 b	23.1 b	23.7
180	27.3 a	14.4 a	32.5 b	20.2 bc	23.1 b	23.5
240 .	27.5 a	14.7 a	32.9 b	20.0 c	22.1 c	23.4

* rates of additional N; all treatments received 20 kg N, 52 kg P_2O_5 and 52 kg K_2O/ha banded at planting.

Note: data in the same column followed by the same letter are not significantly different at the .05 probability level.

Table 16. Effect of rate of N on moisture content of grain at harvest, Strathroy.

N* kg/ha	Year					
	1990	1991	1992	1993	1994	Avg.
	---------- % ----------					
0	34.7	19.3	36.4	24.7	26.3	28.3
60	30.9 a	18.0 a	33.7 a	22.3 a	25.0 a	26.0
120	28.8 b	18.0 a	32.6 a	21.7 b	24.3 a	25.1
180	28.8 b	18.4 a	33.2 a	22.0 ab	24.5 a	25.4
240	28.0 b	18.3 a	33.5 a	21.8 b	24.5 a	25.2

* rates of additional N; all treatments received 20 kg N, 52 kg P_2O_5 and 52 kg K_2O/ha banded at planting. Note: data in the same column followed by the same letter are not significantly different at the .05 probability level.

N Source, Method and Time of Application

There was a significant difference in grain moisture among the N source, method and time of application among the N source, method and time of application treatments at Thamesville in 1992 and 1994 (Table 17), and Rodney in 1991 and 1992 (Table 18). At Rodney in 1991 and 1992, AA side-dress application of N resulted in the highest moisture content of grain. At Thamesville in 1992 and 1994, the side-dress treatments gave a slightly higher moisture content of grain then the preplant treatments.

Table 17. Effect of N source, method and time of application on moisture content of grain at harvest, Thamesville.

Source	Method	Time	Year			
			1992	1993	1994	Avg.
			---------- % ----------			
No N			36.1	23.7	25.9	28.6
Urea	Broadcast	Preplant	32.3 ab	23.7 a	22.5 cd	26.2
UAN	Broadcast	Preplant	32.1 ab	22.7 a	22.5 d	25.8
UAN	Coulter Inj.	Preplant	31.9 ab	22.6 a	22.8 bcd	25.8
AA	Knifed In	Preplant	31.6 b	22.5 a	22.8 bcd	25.6
UAN	Spoke Wheel Inj.	Side-dress	33.0 a	22.6 a	23.5 ab	26.4
UAN	Coulter Inj.	Side-dress	33.2 a	22.9 a	23.5 abc	26.5
AA	Knifed In	Side-dress	33.1 a	22.8 a	24.0 a	26.6

Note: data in the same column followed by the same letter are not significantly different at the .05 probability level.

Table 18. Effect of N source, method and time of application on moisture content of grain at harvest, Rodney.

Source	Method	Time	Year				
			1991	1992	1993	1994	Avg.
			---------- % ----------				
No N			16.0	39.0	22.9	25.7	25.9
Urea	Broadcast	Preplant	14.4 b	32.0 c	20.5 a	22.8 a	22.4
UAN	Broadcast	Preplant	14.5 b	32.3 c	20.6 a	23.4 a	22.7
UAN	Coulter Inj.	Preplant	14.7 ab	32.2 c	20.5 a	22.6 a	22.5
AA	Knifed In	Preplant	14.6 ab	31.9 c	20.0 a	23.1 a	22.4
UAN	Spoke Wheel Inj.	Side-dress	14.4 b	32.8 c	20.5 a	23.3 a	22.8
UAN	Coulter Inj.	Side-dress	14.8 ab	34.1 b	20.4 a	23.2 a	23.1
AA	Knifed In	Side-dress	15.0 a	35.8 a	20.4 a	23.3 a	23.6

Note: data in the same column followed by the same letter are not significantly different at the .05 probability level.

Table 19. Effect of N source, method and time of application on moisture content of grain at harvest, Strathroy.

Source	Method	Time	Year			
			1992	1993	1994	Avg.
			---------- % ----------			
No N			36.4	24.7	26.3	29.1
Urea	Broadcast	Preplant	32.7 a	22.2 a	24.1 a	26.3
UAN	Broadcast	Preplant	33.2 a	22.1 a	24.6 a	26.6
UAN	Coulter Inj.	Preplant	34.1 a	21.9 a	24.4 a	26.8
AA	Knifed In	Preplant	33.6 a	22.1 a	25.0 a	26.9
UAN	Spoke Wheel Inj.	Side-dress	32.9 a	21.7 a	24.9 a	26.5
UAN	Coulter Inj.	Side-dress	33.1 a	21.9 a	24.5 a	26.5
AA	Knifed In	Side-dress	33.4 a	21.9 a	24.7 a	26.7

Note: data in the same column followed by the same letter are not significantly different at the .05 probability level.

NITROGEN CONTENT OF LEAVES

N Rate

There was a highly significant difference in N content of ear leaves due to the rate of N applied at all site-years. In general as the rate of N was increased the N content of ear leaves was also increased (Tables 20-22). The rate of N for optimum N content of ear leaves varied depending on the site-year, and results were similar to the grain yield results.

Table 20. Effect of rate of N and N content of ear leaves at early silking, Thamesville.

N*	Year					
kg/ha	1990	1991	1992	1993	1994	Avg.
	---------- % N ----------					
0	2.25	1.53	1.58	1.41	1.50	1.65
60	2.56 b	2.03 c	2.20 b	2.06 d	1.69 c	2.11
120	2.62 ab	2.38 b	2.47 ab	2.31 c	2.04 b	2.36
180	2.66 ab	2.46 ab	2.68 a	2.44 b	2.47 a	2.54
240	2.69 a	2.52 a	2.75 a	2.51 a	2.55 a	2.60

* rates of additional N; all treatments received 20 kg N, 52 kg P_2O_5 and 52 kg K_2O/ha banded at planting.

Note: data in the same column followed by the same letter are not significantly different at the .05 probability level.

Table 21. Effect of rate of N and N content of ear leaves at early silking, Rodney.

N*	Year					
kg/ha	1990	1991	1992	1993	1994	Avg.
	---------- % N ----------					
0	1.90	1.45	1.83	1.58	1.35	1.62
60	2.54 c	1.91 d	2.70 d	2.29 d	1.77 d	2.24
120	2.71 b	2.39 c	3.18 c	2.67 c	2.17 c	2.62
180	2.84 a	2.68 b	3.31 b	2.86 b	2.47 b	2.83
240	2.91 a	2.86 a	3.51 a	3.03 a	2.72 a	3.01

* rates of additional N; all treatments received 20 kg N, 52 kg P_2O_5 and 52 kg K_2O/ha banded at planting.

Note: data in the same column followed by the same letter are not significantly different at the .05 probability level.

Table 22. Effect of rate N on N content of ear leaves at early silking, Strathroy.

N* kg/ha	Year				
	1991	1992	1993	1994	Avg.
	---------- % N ----------				
0	1.58	1.95	1.89	1.15	1.64
60	2.42 c	2.78 c	2.54 c	1.82 d	2.39
120	2.91 b	3.14 b	2.92 b	2.38 c	2.84
180	3.06 b	3.20 b	3.03 a	2.73 b	3.01
240	3.09 a	3.30 a	3.05 a	2.98 a	3.11

* rates of additional N; all treatments received 20 kg N, 52 kg P_2O_5 and 52 kg K_2O/ha banded at planting.

Note: 1) data in the same column followed by the same letter are not significantly different at the .05 probability level.

2) data not collected in 1990.

N Source, Method and Time of Application

There was a highly significant difference in N content of ear leaves among the N source, method and time of application treatments at all site-years. On the average, all the side-dress .treatments and AA preplant had the highest and similar N contents of ear leaves (Tables 23-25). Comparing the preplant treatments at Thamesville and Rodney, AA had higher N contents of ear leaves than UAN solution coulter injected which had higher N contents of ear leaves than UAN solution and urea surface broadcast. Comparing the preplant treatments at Strathroy, AA had a higher N content of ear leaves than the other treatments. Again the results are similar to those for grain yield.

N content of ear leaves is an indicator of the amount of N available to the corn. The lower values for urea and UAN solution surface broadcast compared to UAN solution and AA applied in the soil indicate that losses of N are occurring with surface broadcast applications.

Table 23. Effect of N source, method and time of application on N content of ear leaves at early silking, Thamesville.

Source	Method	Time	Year			
			1992	1993	1994	Avg.
			% N			
No N			1.58	1.41	1.50	1.50
Urea	Broadcast	Preplant	2.19 b	2.08 d	1.93 d	2.07
UAN	Broadcast	Preplant	2.36 ab	2.10 d	2.03 cd	2.16
UAN	Coulter Inj.	Preplant	2.49 ab	2.25 c	2.07 c	2.27
AA	Knifed In	Preplant	2.65 ab	2.52 a	2.32 ab	2.50
UAN	Spoke Wheel Inj.	Side-dress	2.71 a	2.45 a	2.38 a	2.51
UAN	Coulter Inj.	Side-dress	2.71 a	2.35 b	2.22 b	2.43
AA	Knifed In	Side-dress	2.54 ab	2.54 a	2.38 a	2.49

Note: data in the same column followed by the same letter are not significantly different at the .05 probability level.

Table 24. Effect of N source, method and time of application on N content of ear leaves at early silking, Rodney.

Source	Method	Time	Year				
			1991	1992	1993	1994	Avg.
			% N				
No N			1.45	1.83	1.58	1.35	1.55
Urea	Broadcast	Preplant	2.30 cd	2.80 d	2.41 d	2.05 b	2.39
UAN	Broadcast	Preplant	2.14 d	2.96 c	2.50 d	1.98 b	2.40
UAN	Coulter Inj.	Preplant	2.32 c	3.04 c	2.64 c	2.49 a	2.62
AA	Knifed In	Preplant	2.67 ab	3.36 ab	2.78 b	2.36 a	2.79
UAN	Spoke Wheel Inj.	Side-dress	2.61 b	3.48 a	2.83 b	2.32 a	2.81
UAN	Coulter Inj.	Side-dress	2.38 c	3.34 ab	2.98 a	3.34 a	3.01
AA	Knifed In	Side-dress	2.81 a	3.24 b	2.83 b	2.45 a	2.83

Note: data in the same column followed by the same letter are not significantly different at the .05 probability level.

Table 25. Effect of N source, method and time of application on N content of ear leaves at early silking, Strathroy.

Source	Method	Time	Year			
			1992	1993	1994	Avg.
			---------- % N ----------			
No N			1.95	1.89	1.15	1.66
Urea	Broadcast	Preplant	2.98 b	2.77 cd	2.24 c	2.66
UAN	Broadcast	Preplant	3.18 a	2.69 d	2.25 c	2.71
UAN	Coulter Inj.	Preplant	2.96 b	2.80 c	2.42 b	2.73
AA	Knifed In	Preplant	3.16 a	2.99 ab	2.61 ab	2.92
UAN	Spoke Wheel Inj.	Side-dress	3.24 a	3.06 a	2.60 ab	2.97
UAN	Coulter Inj.	Side-dress	3.26 a	2.90 b	2.69 a	2.95
AA	Knifed In	Side-dress	2.96 b	2.99 ab	2.53 ab	2.83

Note: data in the same column followed by the same letter are not significantly different at the .05 probability level.

PROTEIN CONTENT OF GRAIN

N Rate

There was a highly significant difference (significant at Rodney and Strathroy in 199O) in the protein content of grain at harvest at all but the Thamesville location in 199O. In general as the rate of N was increased the protein content of grain was increased up to the highest rate of N used (240 kg/ha of additional N) in 10 out of 15 site-years (Tables 26-28). The results were similar to the grain yield results.

Table 26. Effect of rate of N on protein content of grain at harvest, Thamesville.

N* kg/ha	Year					
	1990	1991	1992	1993	1994	Avg.
	---------- % protein ----------					
0	8.20	8.08	6.38	6.09	6.55	6.34
60	8.40 a	8.05 d	6.59 d	6.92 b	6.13 d	6.55
120	8.80 a	8.52 c	7.05 c	7.12 b	6.75 c	6.97
180	8.80 a	8.96 b	7.44 b	7.54 a	7.46 b	7.48
240	8.80 a	9.19 a	7.76 a	7.60 a	7.81 a	7.72

* rates of additional N; all treatments received 20 kg N, 52 kg P_2O_5 and 52 kg K_2O/ha banded at planting.

Note: data in the same column followed by the same letter are not significantly different at the .05 probability level.

Table 27. Effect of rate of N on protein content of grain at harvest, Rodney.

N* kg/ha	Year					
	1990	1991	1992	1993	1994	Avg.
	---------- % protein ----------					
0	7.4	6.90	6.35	6.56	6.81	6.80
60	7.70 c	7.26 d	7.11 d	7.17 d	6.93 d	7.23
120	8.00 b	8.23 c	7.82 c	7.97 c	7.35 c	7.87
180	8.60 a	9.13 b	8.32 b	8.32 b	7.97 b	8.47
240	8.40 a	9.54 a	8.75 a	8.60 a	8.25 a	8.71

* rates of additional N; all treatments received 20 kg N, 52 kg P_20_5 and 52 kg K_2O/ha banded at planting.

Note: data in the same column followed by the same letter are not significantly different at the .05 probability level.

Table 28. Effect of rate of Non protein content of grain at harvest, Strathroy.

N* kg/ha	Year					
	1990	1991	1992	1993	1994	Avg.
	---------- % protein ----------					
0	8.8	6.68	6.43	6.15	6.23	6.37
60	8.60 b	7.32 d	7.01 d	6.91 c	6.78 d	7.01
120	8.90 a	8.38 c	7.70 c	8.03 b	7.29 c	7.85
180	9.00 a	9.00 b	8.08 b	8.54 a	7.95 b	8.39
240	9.00 a	9.53 a	8.40 a	8.72 a	8.54 a	8.80

* rates of additional N; all treatments received 20 kg N, 52 kg P_2O_5 and 52 kg K_2O/ha banded at planting.

Note: data in the same column followed by the same letter are not significantly different at the .05 probability level.

N Source, Method and Time of Application

There was a highly significant difference in protein content of grain among the N source, method and time of application treatments at all site-years. On the average all the side-dress treatments and AA preplant had the highest and similar protein contents of grain (Tables 29-31). Comparing the preplant treatments at Thamesville and Strathroy, AA and UAN solution coulter injected gave similar protein contents of grain which were significantly higher than UAN solution and urea surface broadcast. Comparing the preplant treatments at Rodney, AA had a higher protein content of grain than UAN solution coulter injected which had a higher protein content of grain than UAN solution and urea surface broadcast. Again the results were similar to those for grain yield. Protein content of grain, like N content of ear leaves, is an indicator of the amount of N available to the corn. The lower values for urea and UAN solution surface broadcast compared to UAN solution and AA applied in the soil indicate that losses of N are occurring with surface broadcast applications.

Table 29. Effect of N source, method and time of application on protein content of grain at harvest, Thamesville.

Source	Method	Time	Year			
			1992	1993	1994	Avg.
			---------- % protein ----------			
No. N			6.38	6.09	6.55	6.34
Urea	Broadcast	Preplant	6.83 b	7.09 bc	6.42 c	6.78
UAN	Broadcast	Preplant	7.13 a	6.96 c	6.45 c	.6.85
UAN	Coulter Inj.	Preplant	7.31 a	7.32 ab	6.87 b	7.17
AA	Knifed In	Preplant	7.30 a	7.51 a	7.11 b	7.31
UAN	Spoke Wheel Inj.	Side-dress	7.22 a	7.48 a	7.00 b	7.23
UAN	Coulter Inj.	Side-dress	7.31 a	7.07 bc	7.63 a	7.34
AA	Knifed In	Side-dress	7.37 a	7.64 a	7.79 a	7.60

Note: data in the same column followed by the same letter are not significantly different at the .05 probability level.

Table 30. Effect of N source, method and time of application on protein content of grain at harvest, Rodney.

Source	Method	Time	Year				
			1991	1992	1993	1994	Avg.
			---------- % protein ----------				
No. N			6.90	6.35	6.56	6.81	6.66
Urea	Broadcast	Preplant	7.93 d	7.38 e	7.76 b	7.35 bc	7.61
UAN	Broadcast	Preplant	8.20 c	7.63 d	7.62 b	7.22 c	7.67
UAN	Coulter Inj.	Preplant	8.42 c	7.86 c	7.86 b	7.63 ab	7.94
AA	Knifed In	Preplant	8.88 b	8.53 a	8.16 a	7.71 a	8.32
UAN	Spoke Wheel Inj.	Side-dress	8.73 b	8.22 b	8.15 a	7.92 a	8.26
UAN	Coulter Inj.	Side-dress	8.28 c	8.21 b	8.37 a	7.73 a	8.15
AA	Knifed In	Side-dress	9.33 a	8.18 b	8.18 a	7.81 a	8.38

Note: data in the same column followed by the same letter are not significantly different at the .05 probability level.

Table 31. Effect of N source, method and time of application on protein content of grain at harvest, Strathroy.

Source	Method	Time	Year			
			1992	1993	1994	Avg.
			---------- % protein ----------			
No. N			6.43	6.15	6.23	6.27
Urea	Broadcast	Preplant	7.50 b	7.72 c	7.32 bc	7.51
UAN	Broadcast	Preplant	7.56 b	7.52 c	6.95 c	7.34
UAN	Coulter Inj.	Preplant	7.67 a	8.09 ab	7.84 a	7.87
AA	Knifed In	Preplant	8.06 a	8.32 a	7.90 a	8.09
UAN	Spoke Wheel Inj.	Side-dress	8.02 a	8.37 a	7.60 ab	8.00
UAN	Coulter Inj.	Side-dress	8.03 a	7.99 b	7.97 a	8.00
AA	Knifed In	Side-dress	7.73 b	8.34 a	7.90 a	7.99

Note: data in the same column followed by the same letter are not significantly different at the .05 probability level.

N UPTAKE BY PLANTS

Tables 32-34 give a comparison between N applied and N taken up by plants. Where only 20 kg N/ha was applied (no additional N) there was considerably more N taken up than was applied (on the average, 103, 70 and 54 kg N/ha at Thamesville, Rodney and Strathroy, respectively).

At the medium rate of N (140 kg N/ha), which is sufficient only for an approximate yield of 5.5 t/ha (88 bu/ac), there was more N taken up than was applied (on the average, 40, 37 and 20 kg N/ha at Thamesville, Rodney and Strathroy, respectively).

At the very high rate of N (260 kg N/ha), which excessive for highest economic yields in Southwestern Ontario, there was less N taken up than was applied (on the average 32, 28 and 60 kg N/ha at Thamesville, Rodney and Strathroy, respectively). This excess N that was applied and not taken up is subject to loss by leaching and/or denitrification before the next growing season.

Table 32. Comparison of N applied vs N uptake, Thamesville.

Year	N Applied (kg/ha)*		
	20	140	260
	---------- N uptake (kg/ha)** ----------		
1991	136	203	237
1992	134	201	255
1993	116	164	192
1994	105	150	225
Avg.	123	180	228

* total rate of N applied including 20 kg/ha of starter N applied at planting.

** mean uptake by whole plants.

Table 33. Comparison of N applied vs N uptake, Rodney.

Year	N Applied (kg/ha)*		
	20	140	260
	---------- N uptake (kg/ha)** a)** ----------		
1991	75	188	258
1992	67	140	202
1993	139	184	190
1994	79	194	276
Avg.	90	177	232

* total rate of N applied including 20 kg/ha of starter N applied at planting.

** mean uptake by whole plants.

Table 34. Comparison of N applied vs N uptake, Strathroy.

Year	N Applied (kg/ha)*		
	20	140	260
	---------- N uptake (kg/ha)** ----------		
1991	95	204	238
1992	69	123	166
1993	66	150	166
1994	64	162	231
Avg.	74	160	200

* total rate of N applied including 20 kg/ha of starter N applied at planting.

** mean uptake by whole plants.

N Content of Soil (0-60 cm)

There was a highly significant difference in the NO_3-N content of the soil (0-60 cm) due to the date of sampling at all 3 locations in all 4 years. At Thamesville, on the average the NO3-N content of the soil increased up to the third sampling date, dropped slightly by the fourth sampling date and then dropped significantly by the last sampling date (Table 35). At Rodney and Strathroy, on the average the NO_3-N content of the soil increased up to the fourth sampling date, then dropped significantly by the last sampling date (Tables 36 & 37). The dramatic reduction in the NO_3-N content of the soil by the last sampling date is probably due to both N uptake by the corn and leaching of N beyond the 0-60 cm depth caused by summer rainfall.

Table 35. Effect of date of sampling on nitrate-N content of soil (0-60 cm), Thamesville.

Date of Sampling	Year				
	1991	1992	1993	1994	Avg.
	---------- NO_3-N ---------- (kg/ha)				
April	25.1 c	31.4 b	35.0 b	31.5 c	30.8
May (early)	62.7 b	41.6 b	40.6 b	30.4 c	43.8
May (late)	119.5 a	91.6 a	118.7 a	113.0 a	110.7
June	96.3 a	88.5 a	121.0 a	85.6 b	97.9
Sept. - Oct.	108.1 a	19.3 b	18.6 b	15.9 d	40.5

Note: data in the same column followed by the same letter are not significantly different at the .05 probability level.

Table 36. Effect of date of sampling on nitrate-N content of soil (0-60 cm), Rodney.

Date of Sampling	Year				
	1991	1992	1993	1994	Avg.
	---------- NO_3-N ---------- (kg/ha)				
April	26.7 b	14.4 d	21.5 c	32.4 c	23.8
May (early)	28.8 b	31.7 c	23.5 c	24.6 c	27.2
May (late)	42.2 a	50.8 b	58.4 b	106.3 a	64.4
June	43.0 a	138.1 a	107.8 a	87.3 b	94.1
Sept. - Oct.	26.8 b	9.1 d	17.8 c	20.6 c	18.6

Note: data in the same column followed by the same letter are not significantly different at the .05 probability level.

Table 37. Effect of date of sampling on nitrate-N content of soil (0-60 cm), Strathroy.

Date of Sampling	Year				
	1991	1992	1993	1994	Avg.
	---------- NO_3-N ---------- (kg/ha)				
April	-	15.5 d	22.3 cd	23.5 c	20.4
May (early)	133.5 ab	34.5 c	33.2 c	33.2 c	58.6
May (late)	92.7 b	125.2 a	87.1 b	105.8 b	102.7
June	185.4 a	106.5 b	139.1 a	127.9 a	139.7
Sept. - Oct.	32.5 c	12.5 d	12.9 d	18.3 c	19.1

Note: data in the same column followed by the same letter are not significantly different at the .05 probability level.

There was a highly significant difference in the NO_3-N content of the soil (0-60 cm) due to the rate of N applied at all 3 locations in all 4 years. On the average the NO_3-N content of the soil increased up to the 240 kg/ha rate of additional N (Tables 38-40).

Table 38. Effect of N rate on the nitrate-N content of soil (0-60 cm), Thamesville.

N* kg/ha	Year				
	1991	1992	1993	1994	Avg.
	---------- NO_3-N ---------- (kg/ha)				
0	54.4 b	32.6 b	43.5 c	34.7 b	41.3
120	97.3 a	50.5 b	71.8 b	63.0 a	70.7
240	95.3 a	80.3 a	85.1 a	68.1 a	82.2

* rates of additional N applied as urea preplant (mulch-till in `91, no-till in `92-'94); all treatments received 20 kg N/ha banded at planting.

Note: data in the same column followed by the same letter are not significantly different at the .05 probability level.

Table 39. Effect of N rate on the nitrate-N content of soil (0-60 cm), Rodney.

N* kg/ha	Year				
	1991	1992	1993	1994	Avg.
	---------- NO_3-N ---------- (kg/ha)				
0	24.4 b	26.1 b	29.6 c	30.7 b	27.7
120	35.5 a	56.3 a	48.2 b	66.7 a	51.7
240	40.5 a	64.0 a	59.5 a	65.4 a	57.4

* rates of additional N applied as urea preplant (no-till in `91-'94); all treatments received 20 kg N/ha banded at planting.

Note: data in the same column followed by the same letter are not significantly different at the 05 probability level.

Table 40. Effect of N rate on the nitrate-N content of soil (0-60 cm), Strathroy.

N* kg/ha	Year				
	1991	1992	1993	1994	Avg.
	---------- NO_3-N ---------- (kg/ha)				
0	68.9 b	31.4 c	32.1 c	35.0 b	41.9
120	90.7 b	61.9 b	56.7 b	66.8 a	69.0
240	173.5 a	83.3 a	88.0 a	83.6 a	107.1

* rates of additional N applied as urea preplant (mulch-till in `91, no-till in `92-'94); all treatments received 20 kg N/ha banded at planting.

Note: data in the same column followed by the same letter are not significantly different at the .05 probability level.

N CONTENT OF SOIL (0-120 cm)

There was no significant difference in the NO_3-N content of the soil (0-120 cm) due to the rate of N applied except at Thamesville in 1991 (Tables 41-43). This would indicate that the applied N is not leaching beyond the 0-60 cm depth.

Table 41. Effect of N rate on the nitrate-N content of soil (0-120 cm), Thamesville.

N* kg/ha	Year				
	1991	1992	1993	1994	Avg.
	---------- NO_3-N ---------- (kg/ha)				
0	51.7 c	54.0 a	50.8 a	48.4 a	51.2
120	72.8 b	60.5 a	52.2 a	49.0 a	58.6
240	105.6 a	68.5 a	55.4 a	47.7 a	69.3

* rates of additional N applied as urea preplant (mulch-till in `91, no-till in `92-'94); all treatments received 20 kg N/ha banded at planting.

Note: data in the same column followed by the same letter are not significantly different at the .05 probability level.

Table 42. Effect of N rate on the nitrate-N content of soil (0-120 cm), Rodney.

N* kg/ha	Year				
	1991	1992	1993	1994	Avg.
	---------- NO_3-N ---------- (kg/ha)				
0	29.5 a	12.6 a	45.0 a	47.4 a	33.6
120	36.8 a	16.3 a	38.8 a	37.7 a	32.4
240	36.0 a	14.1 a	44.4 a	44.8 a	34.8

* rates of additional N applied as urea preplant (no-till in `91-'94); all treatments received 20 kg N/ha banded at planting.

Note: data in the same column followed by the same letter are not significantly different at the .05 probability level.

Table 43. Effect of N rate on the nitrate-N content of soil (0-120 cm), Strathroy.

N* kg/ha	Year				
	1991	1992	1993	1994	Avg.
	---------- NO_3-N ---------- (kg/ha)				
0	72.8 a	45.3 a	40.8 a	29.7 a	47.2
120	69.9 a	39.6 a	40.0 a	40.4 a	47.4
240	75.1 a	44.5 a	46.9 a	46.4 a	53.2

* rates of additional N applied as urea preplant (mulch-till in `91, no-till in `92-'94); all treatments received 20 kg N/ha banded at planting.

Note: data in the same column followed by the same letter are not significantly different at the .05 probability level.

SUMMARY AND CONCLUSIONS

Yield

Mulch-till gave a significantly higher yield than no-till at 5 of 10 site-years. It is not known why mulch-till gave a higher yield than no-till at these sites. The soil texture at all 3 sites is coarse (68% or > sand) therefore, one would expect that no-till would give as high yields as much-till.

There were large yield increases from N application at all but the Thamesville site in 1990 and 1991. At 6 of the 15 site-years there was a significant yield increase of 90 bu/ac or greater. At 13 of the 15 site-years there was a significant yield increase of 55 bu/ac or greater. Disregarding the first 2 years at the Thamesville site, the rate of N that gave optimum yield was either 180 or 240 kg/ha of additional N (200 or 260 kg/ha of total N). The small yield increase from N application at Thamesville in 1990 and 1992 was probably due to residual N carryover from liquid swine manure applied in 1989.

There was a highly significant yield difference among N source, method and time of application treatments at 8 out 10 site-years where mulch-till was compared to no-till. The AA and UAN solution soil injected treatments gave considerably higher yields than UAN solution and urea surface broadcast. The lower yields with urea and UAN solution surface broadcast applications are attributed to volatilization losses of N as ammonia (NH_3) when urea is hydrolyzed to ammonium (NH_4^+) shortly after application. Factors that may have contributed to volatilization losses of NH_3 at these sites include - high (alkaline) soil pH, low soil CEC, warm temperatures, moist soil, good drying conditions (windy and low humidity) and the presence of considerably amounts of crop residue. With mulch-till, N losses from urea and UAN solution surface broadcast applications can be reduced by immediate incorporation with soil tillage. However, yields may still be slightly lower than AA and UAN solution soil injected. With no-till, urea and UAN solution should not be surface broadcast, but should be injected into the soil. It should be pointed out that while these results occurred at these 3 sites over the 5 years of the project, different results could occur under different conditions. For example on medium and fine textured soils with higher CEC's, and/or soil pH's that are acidic in reaction, and/or conventional tillage systems which leave less crop residues on the soil surface, volatilization losses from surface broadcast application of urea and UAN solution may be reduced and yields from surface applications may be equivalent to soil injected applications of AA and UAN solution.

N Content of Leaves

In general as the rate of N was increased the N content of ear leaves increased. The rate of N for optimum N content of leaves varied depending on the site-year, and results were similar to the grain yield results.

On the average, all the side-dress treatments and AA preplant had the highest and similar N contents of ear leaves, while urea and UAN solution surface broadcast had the lowest N contents of leaves. Again the results were similar to those for grain yield.

Protein Content of Grain

In general as the rate of N was increased the protein content of grain was increased up to the highest rate of N used. The results were similar to the grain yield results.

On the average, all the side-dress treatments and AA preplant had the highest and similar protein contents of grain, while urea and UAN solution surface broadcast had the lowest protein contents of grain. Again the results were similar to those for grain yield.

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