RESIDUE MANAGEMENT SYSTEMS IN THE NORTHERN CORN BELT[1]

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In the northern corn belt (Michigan, Wisconsin, and Minnesota) it is very important to minimize negative effects of crop residue (stand establishment and phenology). Soil cover in the row by crop residue (corn, small grain, or soybean residues) should be less than 10% in a strip 6 to 8 inches wide for corn. Mineralization of organic N sources such as legume residues, soil organic matter, and manure is reduced with systems that eliminate full width deep tillage such as ridge till, no till, or shallow spring tillage approaches. Additional applied nitrogen may be neccessary to compensate for tillage effects. Where recommended, the soil nitrate test is more important with these systems. Volatilization losses of urea N sources should also be avoided. It has been demonstrated that a modest amount of row applied P and K (20 to 40 pounds per acre of P_2O_5 and K_2O) is important for corn when grown with these systems on soils developed in glacial loess, till, or outwash, even at high back ground soil test levels.

GÊNERAL DISCUSSION OF CROP RESIDUE EFFECTS ON GROWTH

Imbibition, allelopathy, and soil temperature

The soil environment near the seed (seed bed) is important because it affects germination, emergence, and early growth. The germination rate depends on the rate of absorption of soil moisture by the seed (imbibition) and temperature of the seed zone. Inhibitory chemicals leaching out of crop residues can also be a factor (allelopathy). To minimize this possible problem and to maximize the rate of soil warming it is important to restrict the amount of crop residue left in the row area. This is especially true when a crop follows itself. Soil temperature reductions have been shown to be directly related to the amount of soil cover in the row area. Large amounts of residue in the row can interfere with seed placement and can reduce stand.

The degree to which reduced soil temperatures associated with crop residues affects growth depends on the specific crop. Corn is the

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most sensitive commonly grown crop to soil temperature. The growing point of corn remains below the soil surface until about the 6th leaf stage of growth (6 leaf collars emerged). Up to this time the soil temperature influences both the above and below ground growth. This is one reason when corn is grown after corn it is usually better to opt for a 6 to 8 inch wide relatively clean strip for the row area. Growth delays due to reduced seedbed soil temperature are most noticeable during cold springs, on poorly drained soils, and on north facing slopes. Research at Lancaster, WI. has shown that during short growing seasons when the growing degree days are marginal and little drought stress occurs, corn with over 30% residue cover in the row had increased grain moisture at harvest and decreased yield. In northern Minnesota (300 miles north of Lancaster, WI) soil cover in the row area should be less than 10%.

Soybeans are much less sensitive to crop residue levels than corn. There are several reasons for this. The growing point emerges immediately and is not affected by reduced soil temperatures due to in row residue. If growth is set back because of slower emergence due to in row residue soybeans can compensate later in the season whereas delayed growth of corn persists to maturity. There are also data that show that soybeans take P and K up later in their growth period so temperature affects of residue are less important on nutrient uptake. In a corn-soybean crop sequence less tillage is necessary because the soybeans are less sensitive to soil cover and there is little residue left to affect corn following soybeans.

Small grain will grow at much lower temperatures than corn (32°F vs 55°F for small grain and corn respectively). It is just as important to keep small grain residue out of the seed furrow. The main influence is allelopathic (inhibitory chemicals) and seed soil contact which slows absorption of soil moisture necessary for germination. As with corn, small grain rotated with soybeans eliminates most stand and early growth problems associated with "in furrow" residue with systems that eliminate primary tillage. This is assuming that there is even residue distribution by the combine at harvest.

"In row" crop residue can also affect seed placement. Accurate depth of seed placement is important. Too shallow placement risks reducing stand and delaying emergence under dry conditions while too deep placement delays emergence under cold and wet conditions. Removal of corn residue from the row area with sweeps, rolling fingers, brushes, or clearing discs on conservation tillage planters reduces the variation in depth of seed placement.

STAND ESTABLISHMENT AND EARLY GROWTH

Often when farmers report reduced yields with conservation tillage systems for corn production it is due to reduced stand or delayed growth when corn follows corn and "in row" cover exceeds 30%. Although temperature effects will be similar, residue of a different crop reduces the probability of an allelopathic affect. Soil cover by corn residue has more impact on corn growth on soils with poor internal drainage.

A clean row area is not as important for soybeans.

Following are some data that illustrate these observations.

Corn following Corn

A four year study in Isanti county, Minnesota will be used to illustrate the effect of tillage system on continuous corn production in the northern Midwest (northern WI, MI, and MN). Tillage ranged from Moldboard plowing with secondary tillage to a no till approach. The planter was equipped with 2" fluted coulters mounted ahead of the planter units. In 1990 planter mounted angled concave clearing discs were evaluated in addition to fluted coulters.

The soil at this site is a Typic Albaqualf (Ames fine sandy loam) with **somewhat poor internal drainage**. Corn followed soybeans in 1987 and corn in 1988, 1989 and 1990. There are very few weeds at this site. Tillage effects on soil cover, corn stand, early corn growth, and grain moisture and yield are shown in tables 1-4 respectively.

There was about 25% "in row" cover for the chisel and disc systems vs 70% with the no till system. The conventional planter used in this study equipped with 2" fluted coulters or clearing discs(in 1990) reduced in "row cover" 16% and 32% respectively with no other tillage.

Corn stand was reduced when soil cover by corn residue exceeded 25% and increased as residue levels increased with time in this study. Corn growth was also delayed by an average of one leaf with "in row" cover by corn residue levels exceeding 25%.

Although corn was planted about the same time each year, in 1988 corn had about 4.2 leaves in late May and 3.4 in late June in 1990. This reflects the differences in growing degree days in these two contrasting years. The spring was very warm in 1988 and cool in 1990.

Data that illustrate the effect of soil cover in the row on corn production are graphically presented in figures 1-6. The relationship between the planter seeding rate setting and final stand with moldboard plowing is shown in figure 1. The final corn stand was 10% lower than the planter setting in 1990. For each 1000 plants per acre reduction in stand, grain yields were lowered by 1.8 bushel per acre (figure 2).

The stand loss associated with high levels of soil cover by corn residue in the corn row explains about one third of the reduction in grain yield. The rest is attributable to delayed growth from temperature and allelopathy.

The delay in growth due to soil residue in the row was consistent over a wide range in early spring temperatures (figure 3). The effect of corn residues in the row is less consistent on plant mortality (figure 4). The delayed early corn growth does persist to physiological maturity as suggested by grain moisture levels (figure 5). Whether or not corn development and stand affect yields depends on the year (figure 6). In 1988 (a very warm and dry year) stand loss and delayed early growth did not affect yields. This is contrasted with 1990 (a very cool and wet year) which showed large decreases in yield to be associated with high levels of soil cover by corn residue in the row.

Table 1. The effect of tillage on soil cover by corn residue.

		Tillage				
		No Till[1]		Disc	Chisel	Mldbrd
		FC	CD			
Location		-----------		%	------------	
In Row	1988	75	--	38	33	4
	1989	55	--	16	15	2
	1990	82	52	20	17	8
	Average	**70**		**25**	**22**	**5**
Between	1988	89	--	31	25	3
Row	1989	84	--	24	21	6
	1990	84	73	22	19	8
	Average	**86**		**26**	**22**	**6**

1. FC and CD stand for fluted coulter (2") and clearing discs respectively, mounted on planter units ahead of double disc seed openers.

Table 2. The effect of tillage on corn stand.

		NoTill[1]		Disc	Chisel	Mldbrd	
		FC	CD				
Year	Date	-----1000's plants/A------					Sig.[2]
1987	8/1	22.3	---	26.6	26.3	26.6	.014
1988	6/20	25.5	---	28.1	26.8	28.4	.002
1989	6/5	23.7	---	27.6	27.2	26.3	.020
1990	6/20	17.2	22.9	27.7	26.1	26.6	.001
Average		**22.2**		**27.5**	**26.6**	**27.0**	

1. FC and CD stand for fluted coulter (2") and clearing discs respectively, mounted on planter units ahead of double disc seed openers.
2. Significance values of <.100 indicate that differences in means within the row are due to tillage and not to random variability (corn stand was affected by tillage every year of the study).

Table 3. The effect of tillage on early corn growth.

		Tillage					
		No Till[1]		Disc	Chisel	Moldboard	
		FC	CD				
Year	Date	------	leaves/plant	---------			Sig.[2]
1988	5/27	3.2	--	4.2	4.2	4.3	<.001
1989	6/5	3.9	--	4.9	4.9	5.0	.001
	6/26	6.8	--	7.9	7.9	8.1	<.001
Average		5.4		6.4	6.4	6.6	
1990	6/20	2.3	2.7	3.4	3.4	3.6	<.001
Average		**3.6**		**4.7**	**4.7**	**4.8**	

1. FC and CD stand for fluted coulter (2") and clearing discs respectively, mounted on planter units ahead of double disc seed openers.
2. Significance values of <.100 indicate that differences in means within the row are due to tillage and not to random variability (corn early growth was affected by tillage every year of the study).

Table 4. The effect of tillage on corn yields and moisture[1].

	No Till[2]		Disc	Chisel	Mldbrd	
	FC	CD				
Year	---------bu/A-----------					Sig[3]
1987	157	---	166	168	168	.004
1988	146	---	145	147	147	.946
1989	126	---	149	150	147	.001
1990	84	105	137	138	136	<.001
Average	**128**		**149**	**151**	**150**	
	---------% moisture-------					
1987	23.1	---	22.3	21.7	22.0	.006
1988	21.6	---	19.9	19.1	18.9	<.001
1989	18.6	---	16.2	15.6	16.6	.064
1990	25.3	24.0	22.5	22.1	21.6	<.001
Average	**22.2**		**20.2**	**19.6**	**19.8**	

1. Grain was harvested on Oct. 6 1987, Oct. 14, 1988, and Oct. 26, 1989 and Nov. 13, 1990.
2. FC and CD stand for fluted coulter (2") and clearing discs respectively, mounted on planter units ahead of double disc seed openers.
3. Significance values of <.100 indicate that differences in means within the. row are due to tillage and not to random variability (although grain moisture was affected by tillage every year of the study, yields were no affected in 1988).

The data in table 5 show the tillage affect on corn grain yields when grown after corn on soils with **good internal drainage** in southeastern MN. In this part of the Midwest (the contiguous corners of IA, IL, WI, and MN) the convention is a chisel plowing system in conjunction with contour strips and grassed water ways.

In this study soil cover by corn residue in the row was generally less than 30% with the disc and chisel systems; and less than 10% with the ridge till and moldboard systems. Soil cover in the row was greater than 50% with the no till system. On these soils there is a 3 to 8 bushel per acre yield reduction when corn follows corn without tillage and planter mounted tillage tools leave more than 30% cover in the row. This is a much smaller yield reduction than a similar amount of "in row" cover caused on the soil with poor internal drainage (Isanti County example). Other systems resulted in different yields in some years but on average were similar to conventional moldboard or chisel plowing systems.

Both of these studies illustrate that when growing corn after corn it is important to clear the row area of residue. There is a range of conservation tillage approaches (from ridge till to chisel plowing) on soils with good and poor internal drainage that result in equal yields to conventional systems and still provide for adequate erosion control. If corn is grown after corn without tillage and planter mounted tillage tools do not adequate clear the row area yield reductions can range from 8 to 50 bushels per acre on soils with good and poor internal drainage respectively.

Table 5. The effect of tillage on corn grain yields following corn grown on a silt loam soil with good internal drainage.

	Goodhue County, MN[1]							Fillmore County, MN[2]					
	1982	1983	1984	1985	1986	1987	Mean	1985	1986	1987	1988	1989	Mean
Tillage	bu/A												
No-till	134	135	154	141	156	183	**151**	168	204	160	107	145	**157**
Ridge-till	131	146	161	144	162	181	**154**	---	---	---	---	---	---
Chisel	131	138	158	155	161	182	**154**	171	199	171	107	164	**162**
Disc	---	---	---	---	---	---	---	175	206	163	112	160	**163**
Moldboard	---	---	---	---	---	---	---	177	200	167	113	169	**165**
Sig.[3]	NS	S	S	S	NS	NS		S	S	S	NS	S	

1. The soil at this site is a Typic Hapludoll (Mt. Caroll, silt loam).
2. The soil at this site is a Typic Argiudoll (Tama, silt loam). All systems were cultivated with a conventional cultivator.
3. NS = no statistically significant difference between tillage systems, S = significant difference.

Corn grown after Soybeans

When corn is grown after a low residue crop such as soybeans the problems of stand loss and delayed growth with high residue tillage systems are absent or much reduced. The reasons are: 1.) there is about one third as much residue and it decomposes more rapidly, 2.) the allelopathic potential is much reduced (most often documented when the same crop follows itself), and 3.) seed to soil contact is less of a problem due to the fineness of the residue (this assumes adequate distribution by the combine). This is illustrated by several data sets.

The first study presented was conducted on a Cumulic Haplaquoll (Delft clay loam) soil with somewhat poor internal drainage in Meeker County, MN. Soil cover by soybean residue is shown in table 6. There is adequate soil cover to control erosion with the no till and ridge till systems although it was marginal in 1987. Even though soybean yields were only 15 bushels per acre in the drought year of 1988, soil cover in 1989 was still adequate . The soil cover between the row needs to be close to 30% to provide adequate erosion control. Chisel plowing followed by a spring discing did not provide adequate cover for erosion control. When soil cover in the row was 35% under no till conditions early corn growth was delayed by .33 leaves (table 7). The early growth of corn grown with the ridge till system tended to have greater early growth (.08 leaves) than with moldboard plowing.

Average stands were not affected by tillage, however (table 8). In 1987 soil moisture dominated the early growth of corn. The conservation tillage systems resulted in quicker emergence and early growth due to higher levels of soil moisture. The soil was very cloddy with moldboard plowing in the fall followed with a field cultivator in the spring. Average stands had a spread of 500 plants per acre. Stand differences would not be expected to affect yield.

Grain moisture was only affected by tillage one year at this site (1990-table 9). Average grain moisture varied vary little between tillage systems.

Corn yields were affected by tillage in 1990 only (table 10). In this year it was very cool in the early season. It is possible that the delayed growth associated with the no till system was responsible for the 10 bushels per acre yield decline with this system. The yield loss with the ridge till system is likely due to stand loss at cultivation that was not reflected in the stand measurements. Average yields were within five bushels per acre between tillage systems.

Corn yields following soybeans on a well drained soil are shown in table 11. There was no effect of tillage on corn stand establishment or development (data not shown). Tillage affected yields in one year out of six.

Generally corn following soybeans with conservation tillage systems has not resulted in lowered yields with higher levels of "in row" soil cover.

Table 6. The effect of tillage on soil cover by soybean residue at Meeker County, MN (p value <.001 for all years).

	IN-ROW COVER							BETWEEN-ROW COVER						
	1987	1988	1989	1990	1991	1992	Avg.	1987	1988	1989	1990	1991	1992	Avg.
	%													
No till	29.0	66.8	13.3	30.0	10.7	21.1	28.5	24.0	59.5	66.9	58.5	30.7	42.5	47.0
Ridge	20.0	20.8	6.4	12.3	4.0	10.0	12.2	22.0	36.8	47.9	33.0	5.6	24.7	28.3
Chisel	10.0	18.8	5.8	20.0	12.0	6.0	12.1	10.0	14.8	10.9	21.8	11.5	7.5	12.8
Moldboard	3.0	0.8	2.0	3.5	2.0	2.2	2.2	2.0	1.5	2.4	6.0	1.8	2.3	4.4
Date	5/27	6/14	5/11	6/12	6/13	6/17		5/27	6/14	5/11	6/12	6/13	6/17	

Table 7. The effect of tillage on early corn growth, Meeker County, MN.

	1987	1988	1989	1990	1991	1992	Ave.
	leaves/plant						
No till	3.31	6.88	1.45	2.55	----	4.1	3.66
Ridge	3.76	7.47	1.71	2.69	----	4.5	4.02
Chisel	3.25	7.41	2.02	2.61	----	4.4	3.94
Moldboard	3.00	7.54	2.06	2.61	----	4.6	3.96
p value	.001	.007	.004	.097		.019	
Date	5/27	6/14	6/2	6/12		6/19	

Table 8. The effect of tillage on corn stand at Meeker County, MN.

	1987	1988	1989	1990	1991	1992	Ave.
	plants/acre						
No till	37.4	30.5	29.0	29.0	29.2	30.2	30.9
Ridge	37.7	31.6	29.2	29.7	30.3	29.8	31.4
Chisel	36.6	31.4	29.7	30.1	30.6	29.3	31.3
Moldboard	34.3	32.6	29.9	28.6	30.2	29.9	31.0
p value	.092	.647	.631	.351	.452	.804	
Date	5/27	6/14	6/2	6/12	6/17	6/19	

Table 9 Effect of tillage on corn grain moisture, Meeker County, MN.

Year	Mldbd	Chsl	Ridge	NoTil	Sig.
	Tillage				
	-----------%-----------				
1987	21.2	21.5	20.6	19.9	.311
1988	29.9	27.7	27.4	25.5	.680
1989	21.2	21.0	22.1	21.3	.442
1990	22.8	22.1	23.0	25.5	.001
1991	19.3	19.7	18.8	20.7	.396
1992	35.3	34.1	35.2	37.4	.661
Avg.	25.0	24.3	24.5	25.1	

Table 10. Effect of tillage on corn yield following soybeans, Meeker County, MN.

Year	Mldbd	Chsl	Ridge	NoTil	Sig.
	Tillage				
	-------bu/acre-----				
1987	189	187	179	189	.176
1988	46	40	49	43	.179
1989	103	113	103	108	.333
1990	136	134	125	124	.055
1991	106	105	98	92	.375
1992	112	95	110	81	.036
Avg.	115	112	111	106	

Table 11. The effect of tillage on corn grain yields following a soybeans.

Tillage	1984	1985	1986	1987	1988	1989	Mean
	Wabasha County[1]						
	--------bu/ac--------						
No-till	154	108	183	181	143	158	**155**
Ridge-till[2]	148	102	185	180	141	160	**153**
Chisel	146	109	185	184	143	172	**157**
disc	154	106	186	180	148	173	**158**
Significance[3]	NS	NS	NS	NS	NS	S	

1. Corn followed sweet clover in 1984 and soybeans in other years and grown on a well drained soil (Fayette, silt loam-Typic hapludalf) soil.
2. The ridge till was cultivated twice and chisel was cultivated once. The no till system was not cultivated. The no till treatment was planted without row clearing equipment on the planter. The row spacing was changed from 38 inches to 30 inches in 1986. Consequently, this is an established year for the ridge-till treatments at this site.
3. NS = no statistically significant difference between tillage systems, S = significant difference.

Soybeans following Corn

Soybeans are much less sensitive to tillage than corn. They can compensate for stand loss due to heavy corn residues in the row area. Plant stands can drop from 160 to 80 thousand plants per acre and only 10% of the yield is lost. Soybeans compensate for cooler soil temperatures by increasing their nodule mass to fix adequate N from the soil atmosphere. Soybeans grown in the northern corn belt have an indeterminate growth habit which means that they can compensate for delayed early growth associated with cooler temperatures later in the season.

The data in tables 12-14 illustrate the tillage effects on soybean growth on a poorly drained soil (corn data from this site is shown in tables 6-10). Soil cover by corn residue is shown in table 12. There is adequate soil cover by corn residue in all conservation tillage systems.

Tillage delayed development of soybeans a maximum of .30 nodes (table 13). In 1988 and 1989 ridge till planted soybeans were likely delayed due to the increased moisture stress in these dry years.

When corn or soybeans are planted onto ridges the amount of the ridge that should be removed should be determined by the amount of soil moisture present at the time of planting and how much is anticipated. More of the ridge can be removed at planting in dry years and less in wet years.

Although early growth was affected by tillage, it did not affect yields in most years (table 14). In 1991 yields were reduced with conservation tillage options. This was not due to stand or weed control. This one year affected the six year average by about 4 bushel per acre.

Table 12. The effect of tillage on soil cover by corn residue at Meeker County, MN (p value <.001 for all years).

	IN-ROW COVER							BETWEEN-ROW COVER						
	1987	1988	1989	1990	1991	1992	Ave.	1987	1988	1989	1990	1991	1992	Ave.
	%													
No till	45.0	73.5	52.6	56.6	55.8	43.7	54.5	43.0	58.8	61.6	55.5	46.0	37.0	50.3
Ridge	35.0	21.8	17.5	9.3	16.3	21.3	20.2	39.0	53.5	40.3	32.8	17.0	35.0	36.3
Chisel	35.0	33.3	22.8	30.2	24.8	16.0	27.0	29.0	23.3	25.1	35.0	17.5	7.7	22.9
Moldboard	8.0	10.5	4.8	4.3	10.5	7.0	7.5	7.0	9.8	4.4	4.5	6.0	4.3	6.0
Date	5/27	6/16	5/22	5/30	6/13	6/17		5/27	6/16	5/22	5/30	6/13	6/17	

Table 13. The effect of tillage on early soybean growth, Meeker County, MN.

	1987	1988	1989	1990	1991	1992	Ave.
	nodes/plant						
No till	2.30	4.11	5.44	2.79	----	3.9	3.71
Ridge	2.40	3.95	5.28	2.90	----	4.3	3.76
Chisel	2.20	4.42	5.73	2.86	----	4.3	3.90
Moldboard	2.43	4.86	5.79	2.94	----	4.0	4.01
p value	.396	.016	.001	.060		.358	
Date	5/27	6/16	7/6	6/12		6/19	

Table 14. Effect of tillage on soybean yield, Meeker County, MN.

	Tillage				
	Mldbd	Chsl	Ridge	NT	Sig.
Year	bu/acre				
1987	52.0	51.0	50.0	51.0	.896
1988	13.6	13.8	13.8	15.2	.367
1989	28.0	29.0	30.0	30.0	.452
1990	49.8	48.9	50.0	42.8	.482
1991	50.9	30.7	37.9	36.7	.003
1992	42.4	35.4	30.4	37.2	.417
Avg.	39.5	34.8	35.4	35.5	

The effect of tillage on soybean yields following corn on a well drained soil is shown in table 15. In some years tillage affected grain yields largely due to weed control differences. On average all but the ridge till grown soybeans had the similar yields. Ridge till soybeans were grown with wide rows (30" and 36"). The other systems in this study had 10" rows. The difference is likely due to an advantage with narrow rows (more efficient light interception).
This is Minnesota data. In the southern Midwest a yield response by soybeans to narrow rows is not likely. Although the row response is common in the northern Midwest it is not entirely consistent. Only the ridge till grown soybeans in the Meeker County, Minnesota study had wide rows (30" vs 8") and in four years there was no difference in grain yields.

In another Minnesota study there was a consistent effect of row spacing on soybean yields at three sites (table 16). Soybeans grown in 10" rows yielded about 10 percent better than those in 30" rows. There are several theories on row spacing response by soybeans. Some maintain that soybean yields are higher when grown in narrow rows due to the earlier crop canopy closure which shades the soil and reduces soil moisture evaporation. Others say that there is less competition between plants (primarily more efficient interception of light) because they are spaced better. If crop residues are effective in reducing soil moisture evaporation, then you would expect less row spacing response with high residue treatments. Since all tillage systems resulted in equal soybean row response, this study suggests that the response by soybeans to narrow rows is more likely due to more efficient interception of light and not better soil moisture conservation due to earlier canopy closure.

Although there was small but statistically significant differences in soybean yields due to tillage at some sites in some years there was no consistent effect of tillage at any site. The range in average soybean grain yield due to tillage over the three sites is .7 bushels per acre. There was a very aggressive weed control program at all sites. Weeds were not a contributing factor to grain yields.

Table 15. The effect of tillage on soybean yields following corn on a Fayette silt loam soil in Wabasha County, Minnesota.

	Tillage				
	NT[1]	RT[2]	Ch	Disc	Signif.[3]
1984	40	35	44	47	S
1985	43	28	34	43	S
1986	43	46	46	43	S
1987	61	57	59	58	NS
1988	41	40	46	45	S
1989	44	39	47	47	S
Average	**45**	**41**	**46**	**47**	

1. The no-till treatment was not cultivated.
2. All tillage treatments had 10 inch rows except for the ridge till system which had 38" rows in 1984 and 1985 and 30 inch rows in 1986 and 1987. Ridge-till soybeans were cultivated twice.
3. NS = no statistically significant difference between tillage systems, S = significant difference.

Table 16a. The effect of row spacing and tillage on soybean yields, Lueschen et al.

	Location								
	Morris[1]		Lamberton[2]		Waseca[1]		Average		
	10"	30"	10"	30"	10"	30"	10"	30"	Overall
Tillage	---------------Bushels per acre								
No till	53.0	47.8	45.9	42.6	48.5	43.8	49.1	44.7	46.9
Spring Disc	51.2	45.8	47.7	43.4	48.6	45.1	49.2	44.8	47.0
Chisel	53.1	47.8	45.4	42.2	48.0	44.5	48.8	44.8	46.8
Moldboard	52.8	46.9	47.4	43.7	48.6	45.6	49.6	45.4	47.5
Ridge		47.5		44.2		44.2		45.3	
Average	**52.5**	**47.1**	**46.6**	**43.0**	**48.5**	**44.8**	**49.2**	**44.9**	

1. Average of four years (1982-1985). 2. Average of three years (1982-1984).

Table 16b. Effect of tillage on soybean yield at Morris, Lamberton, and Waseca (1986-1988), Lueschen et al.

Tillage	Morris	Lmbrtn	Waseca
	--bushels/acre--		
No till	36.7	37.9	41.1
Ridge till	35.5	37.6	38.9
Fall Moldboard	33.5	39.6	42.1
Fall Chisel	35.5	37.5	40.9
Fall Paraplow	35.2	37.4	40.1
(0.05) LSD	2.1	1.3	2.0

Secondary Tillage Effects on Soil Cover

Tillage effects on soil cover by corn residue in the study conducted at Morris, Lamberton, and Waseca, Minnesota are shown in table 17 (yields shown in table 16). The effect of primary and secondary tillage on soil cover by corn residue as well as the tillage associated with the drill is shown in this table. Soybeans were all planted with a no till drill equipped with smooth edged ripple coulters mounted ahead of double disc openers spaced 10" apart. All but every third drill tube was blocked to plant soybeans in 30" rows also. since the coulters were allowed to run in both row spacing treatments the residue measurements presented in table 17 are averaged over row spacing.

Stalks were chopped prior to planting in the spring on the no till plots. There is about a ten percent reduction in soil cover in the no till treatment after planting. The drills used in this study had smooth edged rippled coulters ahead of double disc openers. Fluted coulters would have reduced the cover slightly more.

Stalks were also chopped in the fall prior to chisel or moldboard plowing. In the spring moldboard plow plots were field cultivated once. This operation plus the tillage associated with the drill reduced the average cover very little.

Chisel plowed plots resulted in about 63 percent cover in the spring and after one discing and field cultivation in the spring had 42 percent cover after planting. Starting residue levels in the spring were more variable between sites than after spring tillage and planting.

Spring disced plots did not have stalks chopped and were disced twice with a light finishing disc (18" diameter discs). The small difference between this treatment and the no till in the spring is due to the spring stalk chopping of the no till plots. The spring disced plots had about eight percent less cover prior to tillage due to standing corn stubble. Two light spring discings reduced cover from 83 to 51 percent cover after planting.

Table 17. The effect of tillage on soil surface cover by corn residue at Morris, Lamberton, and Waseca, MN.

	Location							
	Morris		Lmbrton		Waseca		Average	
Tillage	bfr[1]	aft[1]	bfr	aft	bfr	aft	bfr	aft
	percent soil cover							
No till	84	73	95	80	94	86	91	80
Disc	82	51	83	49	84	54	83	51
Chisel	54	37	74	43	61	45	63	42
Moldboard	17	14	17	15	15	15	16	15

1. Measurements were made before and after spring tillage and planting.

The Unique Effect of Ridges on Residue Distribution

"In row" soil cover by crop residue is affected by the ridges associated with a ridge till system. This is shown in table 18. Before planting there is 53 and 95 percent soil cover in the row with and without ridges respectively. This is the result of settling of crop residues into the valleys over winter when ridges are present.

After planting in row cover was still higher in the strip tillage approach without ridges. These "in row" differences after planting (20% vs 35% for the ridge and no ridge systems respectively) would not be an important factor for soybean production. This difference would be important if corn was to be grown after corn.

Many newer conservation planters (conventional planters with add on tillage tools) require the ridge effect on the spring residue distribution relative to the row to allow residue to flow through the planter effectively.

Table 18. The effect of ridges on soil cover by corn residue before and after planting with a planter equipped with clearing discs.

	Location							
	Morris[1]		Lmbrton[2]		Waseca[1]		Average	
	Bef[3]	aft[4]	Bef	Aft	Bef	Aft	Bef	Aft
Ridges[5]	percent soil cover							
in row	39	12	60	34	60	15	53	20
between	82	61	69	60	81	40	77	54
No Ridges[5]								
in row	--	26	94	42	95	38	95	35
between	86	70	91	68	91	66	89	68

1. Average of four years (1982-1985), n=64.
2. Average of years (1982-1984), n=48.
3. Before planting.
4. After planting with planter equipped with clearing discs.
5. Ridges were either built or not built at cultivation for corn the preceding year with a conservation cultivator.

The corresponding soybean yields for the cover measurements shown in table 18 are shown in table 19. The average yield advantage due to ridges was 1.6 bushels per acre. This yield advantage was probably not due to detrimental affects of in row soil cover by residue. It should also be remembered that in this study soybeans were not cultivated during the growing season. It could be that there was 1.6 bushels per acre loss due to planting in a slight furrow (created by planter mounted clearing discs), from harvest loss due to low pods that weren't accessible by the combine. There does appear to be a slight but consistent yield advantage associated with the ridge. The no till approach was generally as good as the ridge till treatment (table 16). So it appears that the planting in a slight furrow with the no ridge treatment poses a disadvantage rather than an advantage with the ridge treatment.

Table 19. The effect of ridges on soybean yields in southern Minnesota (1982-1985)[1].

	Location			
	Morris[2]	Lmbrton[3]	Waseca[2]	Average
	-------bushels per acre-----------			
Ridges	47.5	44.2	44.2	45.3
No Ridges	45.9	42.7	42.6	43.7
Difference	1.6	1.5	1.6	1.6

1. Ridges for the succeeding corn crop were built after soybean harvest to eliminate the possibility of soybean yield loss due to covering the lower pods.
2. Average of four years (1982-1985), n=64.
3. Average of years (1982-1984), n=48.

SUMMARY-RESIDUE MANAGEMENT

1. Crop residues of corn or small grain in the seed furrow in intimate contact with the seed of the same crop has reduced stands and delayed emergence due to allelopathy and reduced seed to soil contact. In high residue environments planter mounted tillage tools such as rolling fingers, clearing discs, or sweeps should be used to clear the row area of residue.

2. The sensitivity of crops to the effects of crop residues depends on the type and proximity of residue. For this reason a rotation of soybeans and corn or small grain ensures a high probability of success at stand establishment, minimal soil temperature effects, and yields that are equal to those under moldboard plowing.

3. Corn is sensitive to reduced soil temperatures. For this reason a strip about 6 to 8 inches wide should have less than 10% cover by residue in the north central region respectively.

4. Soybeans are very tolerant of crop residue in the row area. Yields have generally not been affected with "in row" cover levels of 70 to 80%.

5. The ridges associated with the ridge till system help concentrate crop residue between the rows.

6 Soybeans are insensitive to tillage or the presence of crop residues on soils with good drainage or in low rainfall years. In the wet years diseases may be a problem on poorly drained soils.

7. In the northern Midwest there has been a fairly consistent yield increase to narrow row soybeans. In the southern part of the Midwest narrow row responses are uncommon.

FERTILIZER MANAGEMENT WITH CONSERVATION TILLAGE SYSTEMS

Success with conservation tillage systems has been partly dependent on fertilizer management. Tillage influences soil physical properties that can change the soil nutrient status as well as the ability of crops to access nutrients. When tillage is reduced to leave crop residues on the soil surface to control erosion the soil may be cooler, wetter, less aerated, and denser.

NITROGEN

Tillage effects on organic N sources

Soil Organic Matter

Crops get part of their nitrogen from mineralization of organic sources of N such as soil organic matter, animal manures, and plant residues from previous years. They also utilize nitrogen which is stored in the soil as nitrate or ammonium. The rest of the nitrogen needed by crops is applied as fertilizer. Tillage can affect the amount of nitrogen mineralized from soil organic matter due to reduced aeration and soil temperature. Full width deep tillage such as chisel plowing or deep discing results in similar soil density as with moldboard plowing. With systems that eliminate primary tillage such as light spring discing, ridge till, or no tillage there is less N mineralized from soil organic matter. These tillage systems may result in a net increase in soil organic matter levels (table 20). This will improve soil structure but also may act as a sink for nitrogen.

Table 20. The effect of eight years of tillage on soil organic matter in the top foot of soil on a Seaton silt loam soil (Typic Hapludalf) in southeastern MN (Moncrief and Olness, upublished data)[1].

	Organic			
	Carbon		Matter	
Tillage	--%--	-T/a-	--%--	-T/a-
No till	1.30a	23.4a	2.24a	40.3a
Chisel	1.16b	19.4b	2.00b	33.4b

1. The no till system was planted with a planter equipped with a two inch fluted coulter and not cultivated. The chisel plowing was done in the spring with a coulter-chisel equipped with 4 inch wide twisted shovels and followed with one finishing pass with a field cultivator.
2. Means within the same column followed by the same letter are not statistically different at $\alpha=.01$.

Another example of tillage effects on soil nitrogen are shown in tables 21 and 22. In this study on a Fargo silty clay soil (Vertic Haplaquoll) with poor internal drainage and 4.1% organic matter, tillage increased the amount of N stored in the soil as nitrate in the spring. Nitrogen was applied based on this test for specific tillage requirements. Barley yields with adequate N resulted in higher yields when grown under conservation tillage options.

The protein concentration and yield of the barley illustrate the interaction between adequate nitrogen and tillage effects. Although tillage did not affect average protein concentration and yield there was an interaction. When adequate nitrogen was applied protein concentration and yield were higher with the chisel and no till systems.

Table 21. The effect of tillage and previous crop on soil test nitrate and barley yields following soybeans on a Vertic Haplaquolls (Fargo silty clay) in northwestern MN, Moncrief et al., 1988.

	Tillage		
Previous Crop	NoTil	Chisl	Moldbd
	-----	lbs/ac[1]	-----
Soybeans	53	55	75
Barley	43	71	99
Average	48	63	87

1. Soil was sampled to a depth of 2 feet in the spring of 1988. The p values for nitrate nitrogen for the main effect of previous crop, tillage, and the tillage by previous crop interaction are: .103, .002, and .034 respectively. system are .103, .002, .034 respectively.

Nitrogen Rate	Tillage		
	NoTil	Chisl	Mldbd
	------	bu/ac	----
0 lbs/ac	51	53	56
30 or 55[2]	62	60	57
Average	57	57	56

2. Nitrogen was applied in the spring of 1988 as broadcast urea. The rate was based on the spring soil nitrate test. The no till and chisel system grown barley received 55 lbs/acre while the moldboard system grown barley received 30 lbs/acre. The p value for the main effects of tillage nitrogen rate, and the interaction are .959, .034, and .222 respectively.

Table 22. The effect of tillage and previous crop on soil test nitrate and barley yields following soybeans on a Fargo silty clay soil (Vertic Haplaquoll) in northwestern MN, Moncrief et al., 1988.

Nitrogen Rate	Tillage			
	NoTil	Chisl	Mldbd	Avg.
	-------	% protein	-------	
0 lbs/ac	12.0	12.3	13.0	12.4
30 or 55[1]	13.5	13.7	13.2	13.5
Average	12.7	13.0	13.1	

1. The p values for % protein for the main effects of tillage, nitrogen rate, and the interaction are .583, .001, and .055 respectively.

Nitrogen Rate	Tillage			
	NoTil	Chisl	Mldbd	Avg.ND
	-lbs.	protein/acre	-----	
0 lbs/ac	256	271	302	276
30 or 55[2]	347	342	312	333
Average	301	306	307	

2. The p value for protein yield for the main effects of tillage, nitrogen rate, and the interaction are: .833, .001, and .029 respectively.

In west central Minnesota, a six year study shows the effect of tillage system on available N to continuous corn (Moncrief et al., 1990; figure 7). This study evaluated the effects of tillage on corn response to a fall applied anhydrous ammonia nitrogen source on a silt loam soil with somewhat poor internal drainage (Pachic Udic Haploboroll- Tara silt loam) and 5.4% organic matter.

Tillage systems that eliminated full width deep primary tillage increase the corn yield N response. Similar to the barley data, at the higher rates of applied N the grain yields were similar.

In the western part of the North Central region where soil nitrate tests are used for N recommendations, it is even more important with conservation tillage systems. In the eastern part of the region, N management is still important for conservation tillage systems.

N from Alfalfa

Tillage also has been shown to have a significant effect on nitrogen response by corn following alfalfa on coarse textured soils. A study at the Staples Irrigation Center in north central Minnesota illustrates this point. The tillage treatments at this site were established in the spring as moldboard plowing, discing with a light finishing disc, and no tillage. The soil at this site is a Verndale sandy loam (Udic Argiboroll). The texture ranges from a loamy sand in the top 20 inches to a coarse sand below this depth. Organic matter is 2.8 percent in the surface 10 inches. There is very little organic matter below this depth. The alfalfa stand in the spring of 1987 and 1990 was a relatively uniform 2.9 and 8.0 crowns/$ft.^2$ respectively. Nitrogen was applied as urea at the eight leaf stage of growth and immediately irrigated with .25 inches of water to minimize any volatilization losses. When urea hydrolizes (combines with water) and is converted to ammonium, ammonia can be lost in an intermediate step as a gas. This will be discussed later.

The first year corn grain response following a three year old stands of alfalfa in 1987 and 1990 are shown in figures 8 and 9 respectively. The response to applied nitrogen is greatest with the no till system. Discing resulted in an intermediate response. There was very little response to applied nitrogen after moldboard plowing. In 1987 early summer temperatures were warmer and more favorable for mineralization than in 1990. These trends were also supported with grain protein data (not shown).

If planting corn into alfalfa with little or no tillage is economically feasible (this would depend on the availability of a conservation planter and the presence of weeds that are inexpensive to kill with herbicides), these data illustrate the need to consider an N rate based on tillage. The nitrogen available from alfalfa residues cannot be estimated with a nitrate test since they are released during the season as decomposition progresses.

N from Manure

The nitrogen in animal manures associated with the urine is primarily urea and uric acid. These are rapidly converted to ammonium after excretion. A good review was published by Steenvoorden in 1989. Nitrogen associated with fecal material is comprised of organic compounds that decompose at varying rates. The mineral nitrogen portion of the manure can be viewed as behaving similar to commercial fertilizer such as urea. The nitrogen associated with the organic portion (fecal material) can be viewed as similar to other organic N sources such as alfalfa and soil organic matter.

The two most likely affects that tillage may have on crop available N from manure is: 1) reduce the risk of volatilization potential of the liquid portion by incorporation and 2) reduce the rate of mineralization of the organic portion due to cooler temperatures. Injected manure almost eliminates the potential for volatilization losses of the ammonium portion of the manure.

The goal should be to incorporate broadcast manure or mix injected manure but still leave adequate cover by crop residues to provide for erosion protection. In a study in southeastern MN the effects of the tillage associated with manure injection and chisel plowing on soil cover and yields are shown in tables 23 through 25. The nutrient content of the manure in this study was quite consistent from year to year.

Manure and fertilizer N sources were applied every year. Manure was also applied every other year. Manure was injected about 6 to 8 " deep with a 3,250 gallon applicator equipped with 6" sweeps. The two tillage systems evaluated were: 1.) no other tillage other than that associated with spring manure injection (in years with application), and 2.) spring chisel plowing followed by a field cultivator.

The tillage associated with manure injection plus additional chisel plowing and a field cultivation resulted in adequate soil cover for erosion control when yield levels were maximized (annual manure or fertilizer application, table 23). When yield levels were lowered by applying manure every other year (one half the recommended N rate), chisel plowing followed by field cultivation did not allow enough soil cover for erosion control.

The tillage effect on mineralization of soil organic matter and release of N is reflected in the check plot yields (67 and 87 bushels per acre for the no till and chisel systems respectively). Tillage influences on soil organic matter and organic nitrogen from manure are illustrated in the year after manure application grain yields (121 and 130 bushels per acre for the no till and chisel systems respectively).

Table 23. Nutrient content of liquid dairy manure from an anaerobic pit below a barn 1983-90, (Joshi et al., 1991).

Nutrients Applied (lbs/ac @9500 gal/ac)		
Ammonium	143	(urine)
Organic	115	(feces)
Total N	258	
Anhydrous	180	
P_2O_5	128	
K_2O	216	

Table 24. The effect of tillage on soil cover by corn residue (Joshi et al., 1991).

	No Till		chisel	
	-------%		-------	
Annual	In	Btn	In	Btn
Fertilizer	52	69	19	32
Manure	28	38	24	32
Biennial Manure				
Yr. of Appl.	21	29	16	23
Yr. After	50	61	20	26
Check	30	55	19	23

Table 25. The effect of tillage and time on corn grain yields following liquid dairy manure application (Johsi et al., 1991).

	Tillage			
	No Till		Chisel	
Annual	b/a	% mx	b/a	% mx
Fertilizer	149	97	153	100
Manure	153	100	153	100
Biennial Manure				
Yr. of Appl.	146	95	147	96
Yr. After	121	79	130	85
None	66	43	87	57

N from Fertilizer

One of the major concerns when managing commercial fertilizer N sources is to prevent volatilization losses from urea N sources. The risk of volatilization losses with urea sources of fertilizer is illustrated well by a study conducted in central MN on a irrigated loamy sand soil (Hubbard loamy sand, Udorthentic Haploboroll) by Malzer (figure 10). In this study a 28% urea-ammonium nitrate solution was broadcast on the surface, dribbled in a surface band, or injected behind a knife. As the level of corn residue increases the corn grain yield decreases reflecting N losses. When the solution was injected crop residue had a much smaller influence on grain yields. Dribbling the solution on the soil surface decreased the surface area of contact and improved grain yields.

If an ammonium nitrate-urea solutions are used as an N source it should be incorporated or injected below crop residues. Often times farmers will apply this fertilizer source during cultivation incorporating it with soil to prevent volatilization losses. A ridge till system provides an opportunity for incorporation at planting and cultivation.

A study conducted on a clay loam soil in southern MN illustrates this (table 26). In this study fertilizer was applied just before planting or during ridge building in a ridge till system for continuous corn. The strategy was to incorporate urea sources of fertilizer with soil during the planting operation or cultivation. The decline in grain yields with time shows that each year was dryer than the one before. The advantage of preplant over sidedress N was greater with dry conditions. This is the result of application of N sources that would become ammonium (a relatively immobile source of N) and remain at a shallow depth where root and microbial activity is limited in a dry year. This is also supported by the performance of anhydrous ammonia which is placed deeper (more moist soil) and the urea-ammonium nitrate solution which is one quarter nitrate (a more mobile source of N) in the dryer years. Preplant nitrogen was superior regardless of N source.

Table 26. The effect of nitrogen source and time of application on continuous corn yields with a ridge till system on a Webster clay loam soil (Typic Haplaquoll) at Waseca, MN (Randall, et al., 1982-84).

	1981		1982		1983		Average	
Nitrogen Source	Pre-Plant	Side Dress	Pre-Plant	Side Dress	Pre-Plant	Side Dress	Pre-Plant	Side Dress
Urea-Ammonium	bushels per acre							
Nitrate Solution	171	168	162	155	101	76	145	133
Urea	174	168	167	148	97	70	146	129
Anhydrous Ammonia	175	169	166	162	98	92	146	141
Average	173	168	165	155	99	79	155	134

When using conservation tillage systems anhydrous ammonia has been the most consistent source of N. This is because increased probability of losses due to: leaching (remains ammonium in soil longer, a positively charged ion held by soil), immobilization (is placed below crop residues), and denitrification (remains ammonium longer) are reduced.

P AND K

Availability

Availability of soil P and K is dependent on both soil and plant factors. Physical soil properties such as temperature, moisture, and aeration, and the spatial distribution of P and K can affect their corp availability. Plant properties such as root distribution, root metabolism (effects on active uptake), and nutrient requirements can also affect P and K availability. Tillage affects many of these interacting soil and plant properties. For example, lower soil moisture could provide a beneficial effect. What is the net effect of changes due to tillage? A review in the midwest can be found by Moncrief, et al., 1986.

Many researchers have documented the vertical stratification of immobile nutrient such as P and K with conservation tillage. Most researchers in areas of adequate rainfall report no difference in availability of P due to tillage. The most common explanation given to account for availability of stratified P in the upper soil is an increase in root activity in this region due to higher moisture content. It seems logical, however, that if the surface soil dried out and the roots became inactive that the nutrients in the dried soil would not be available the plant. This may pose a problem in the drier areas of the midwest on soils with low subsoil P.

The literature is more evenly split on tillage effects on K availability. Some find conservation tillage systems result in K being more available, some less, and some no difference. In the North Central corn belt researchers have found K availability reduced with residue management systems that eliminate full width deep tillage.

Tillage induced K availability is illustrated in a study in southern WI on a soil developed in loess in figure 11 (Moncrief, 1981). Three years are summarized in this figure. In this study row applied K at less than 15 pounds K_2O per acre almost entirely eliminated the reduced availability by corn. The advantage to starter K was greater at lower back ground soil test K levels for all tillage systems. The corn response was higher with the residue mangement systems however. All the lines are converging at a high soil test K level with a banded K application. These data illustrate the yield penalty of operating at lower soil test levels with residue mangement systems, especially without the banded application.

Since this research, tillage induced K deficiencies have been found on soils developed in glacial outwash (Moncrief et al., 1988) and glacial till with high back ground soil test levels (Moncrief, et al., 1990). In most cases it has been demonstrated that the tillage induced K deficiency can be eliminated with modest amounts of banded K near the row (10 to 20 lbs K_2O/acre). On fine textured soils with poor internal drainage most farmers have opted for a fall applied band with systems that do not disturb the row. Corn is then planted over the band in the spring.

It appears that the reduction in availability is directly related to the energy expended in tillage (Moncrief et al., 1990; figure 12). In this study in southeastern Minnesota five tillage systems were evaluated in a corn-soybean rotation. The soil test K is 140 pmm. The tissue K level is linearly related to the amount of energy required for tillage over the two year crop sequence.

The tillage was dependent on the previous crop. In the two points labled moldboard/chisel and chisel/no till tillage was more intense than following corn than soybeans. In the corn year, the continuous no till (bottom, left of the graph) and the chisel/no till are both no till. The chisel plowing in the previous year (following corn for soybeans) affected the ear leaf K levels.

The paraplow treatment which required the highest amount of fuel did not result in increased K availability. It appears that the energy expended below the plow layer is much less efficient at loosening the soil.

This study illustrates the relationship of tillage intensity on K availability to corn and the effect of tillage memory over more than "this years" program.

Interpretation of Soil Test P and K

When applied P and k are not uniformly mixed within the top 6-8 inches of soil, special considerations are necessary when interpreting soil tests. Generally broadcast P and K applications when mixed with a smaller volume of soil by tillage result in a higher increase in soil test than with moldboard plowing. There is a gradient in soil test decreasing from the surface. Chisel plowing and disc systems result in a fairly steep vertical gradient. If the upper region of the soil is moist enough of the time to permit plant exploitation of soil P and K, conservation tillage is a benefit with respect to recovery of these nutrients. Most soils will fix either P or K (sometimes both). For this reason a banded application is by far the most efficient on these soils.

A unique problem with interpretation is encountered with a ridge till system. During cultivation to build ridges soil P and k are moved into the rows. During planting the ridge is scalped and thrown between the rows. When and where does one soil sample with this system? If samples are taken between the row after ridging soil test P and K values are misleadingly low. If the row area is sampled they are high. Essentially one would be sampling the top three inches twice (three inches of soil moved into the ridge and three inches of below). Sampling between the row is actually the 3-9 inch layer. Results from a sampling study in south central MN is shown in table 27 for soil P. Large differences due to position relative to the row are apparent after ridging. After planting but before ridging there is not much variability. Based on these data it would appear that the best time to sample with a ridge till system is after planting but before ridging. If soil sampling cannot be done at this time then it is suggested that the samples be taken half way up the ridge.

Table 27. The effect of ridging and planting on the distribution of soil P and K with a ridge till system (Randall, 1983).

	After Planting		After Ridging			After Planting		After Ridging	
	--phosphorus ppm--					--potassium ppm--			
Depth	In	Btw	In	Btw	Depth	In	Btw	In	Btw
0-2"	49	40	68	33	0-2"	337	341	295	241
2-4"	22	24	42	19	2-4"	190	221	216	157
4-6"	13	17	20	13	4-6"	151	150	154	125
6-9"	8	10	12	7	6-9"	124	139	118	115

LIMING

Low soil pH can limit nutrient availability, rhizobium activity of legumes, and effectiveness of triazine herbicides (atrazine, simazine, and metribuzin). If broadcast applications of ammoniacle sources of N (urea, ammonium nitrate, and ammonium sulfate) are used in tillage systems that offer little incorporation, the surface soil pH can be reduced. Research has shown that corn will respond with surface lime applications under no till conditions in a humid climate similar to the eastern tier of states in the midwest. In the western tier of states in the midwest liming is not a problem since most of the soils are calcareous.

Alfalfa is the most sensitive common crop to soil pH. Soil pH levels should be maintained close to neutrality (7).

Lime should be applied well ahead of alfalfa in the crop sequence since reaction time may be increased under conservation tillage conditions.

SUMMARY-FERTILITY

1. If a system that eliminates primary tillage (no till, ridge till, light spring discing) is used following alfalfa or clover on sandy excessively well drained soilsp; decrease the legume N credits by 25%. If these systems are used on fine textured soils credits should be the same as conventional systems.

2. If a system that eliminates primary tillage (no till, ridge till, light spring discing or field cultivation) is used, when evaluating the amount of N available from organic manure sources (fecal material) in subsequent years after application decease the credit by 25%.

3. If corn or small grain is following corn or small grain and a spring soil nitrate test is not available increase the N rate over current recommendations 25% and 15% for no till and ridge till respectively.

4. If corn or small grain is following a low residue crop such as soybeans, sunflowers, or sunflowers, use recommendations developed under moldboard plowing tillage systems regardless of tillage used.

5. If a full width, deep tillage system is used such as chisel plowing or deep discing, use current N recommendations for moldboard plowing systems regardless of the crop sequence.

6. Incorporate urea N sources within 2 to 3 days after application. Incorporation can be accomplished with cultivation in ridge till systems.

7. Row applied P and K is necessary for corn. The benefits to fertilizer applied with the planter increase as residue levels increase and tillage decreases.

8. In drier areas ($\leq$ 20" per year) place the starter fertilizer as deep as possible (2-4 inches).

9. Continue to take soil samples from 0-6 inches deep for P and K analysis.

10. If a ridge till system is used, take soil samples after planting but before cultivation. For other times of the year sample half way up the ridge.

11. Take a sample from 0-3 inches for pH determination if there has been a history of surface applied N and triazine herbicides are to be used.

12. When alfalfa is rotated with corn apply lime in the corn years to allow more reaction time. If rainfall is $\geq$ 30" per year incorporation and complete soil mixing is not necessary for adequate soil reaction.

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Fig. 1 Relationship between planter setting and final stand at Isanti County, 1990.

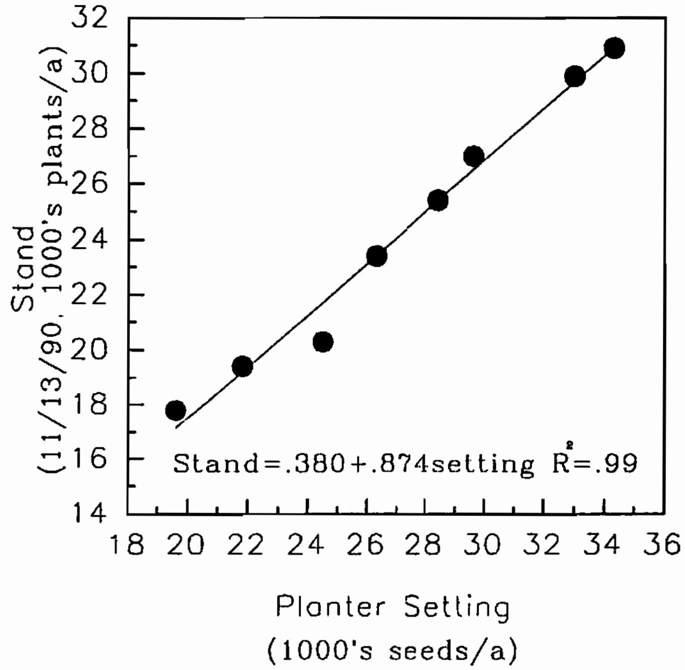


Fig. 2 Relationship between measured stand and yield at Isanti County, 1990.

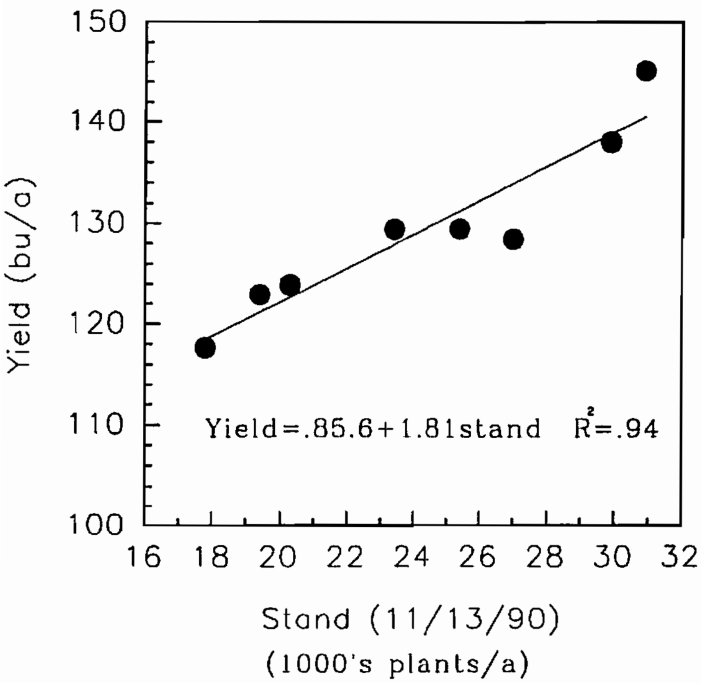


Fig. 3 The effect of soil cover in the row by corn residue on early growth at Isanti County

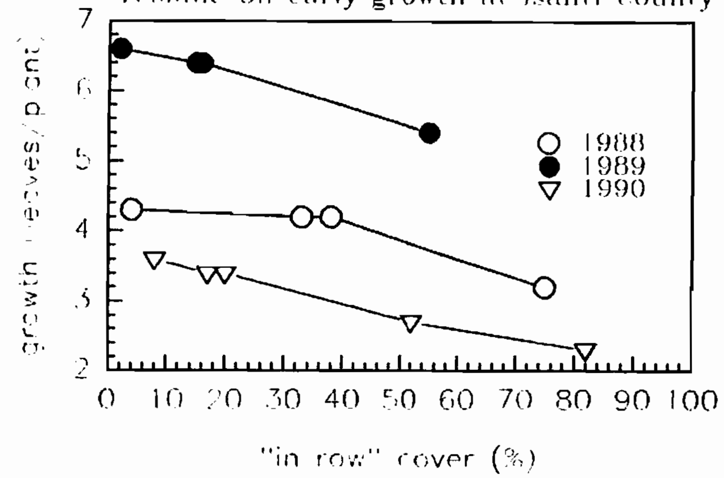


Fig. 4 The effect of soil cover in the row by corn residue on stand establishment.

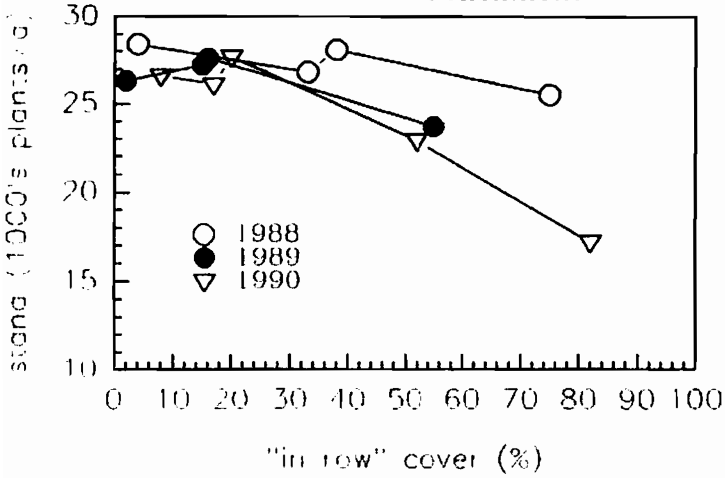


Fig. 5 The effect of soil cover in the row by corn residue on grain moisture at harvest.

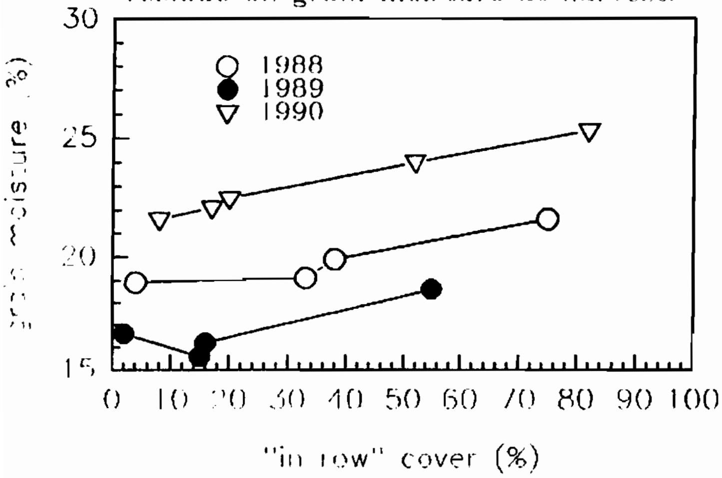


Fig. 6 The effect of soil cover in the row by corn residue on grain yields, Isanti County.

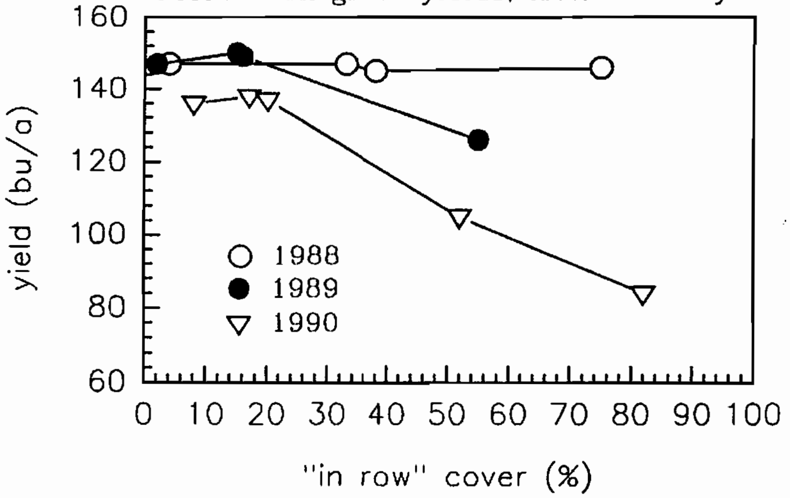


Figure 7. The effect of tillage on the N response by corn 1984–1989. Morris, MN (Moncrief et al. 1990).

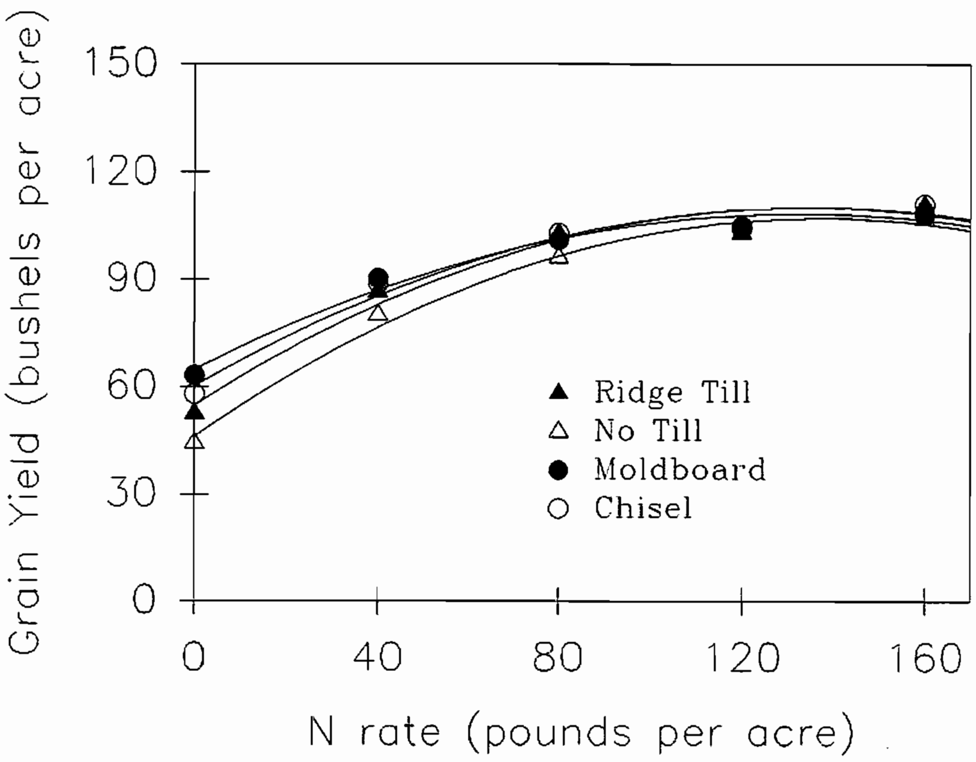


Figure 8. The effect of tillage system on N response by corn, Staples, MN, 1987. Moncrie. et al., 1988).

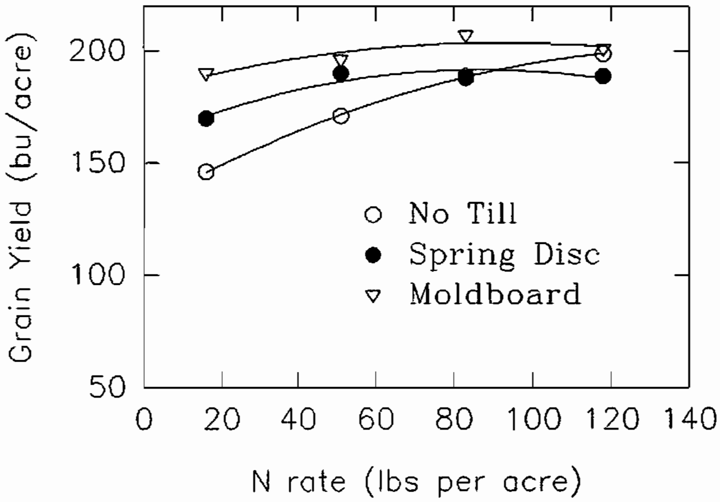


Figure 9. The effect of tillage system on N response by corn, Staples, MN, 1990, Moncrief, et al., 1991).

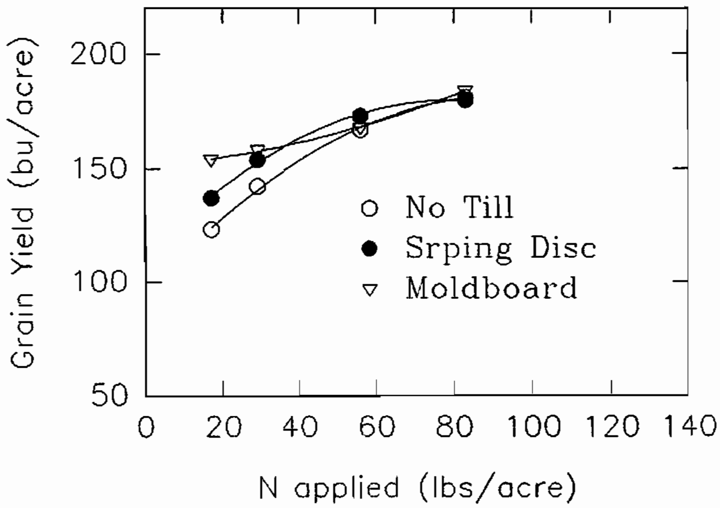


Figure 10. The effect of soil cover with crop residue and method of urea-ammonium nitrate solution application on corn grain yields (Malzer, et al., 1985).

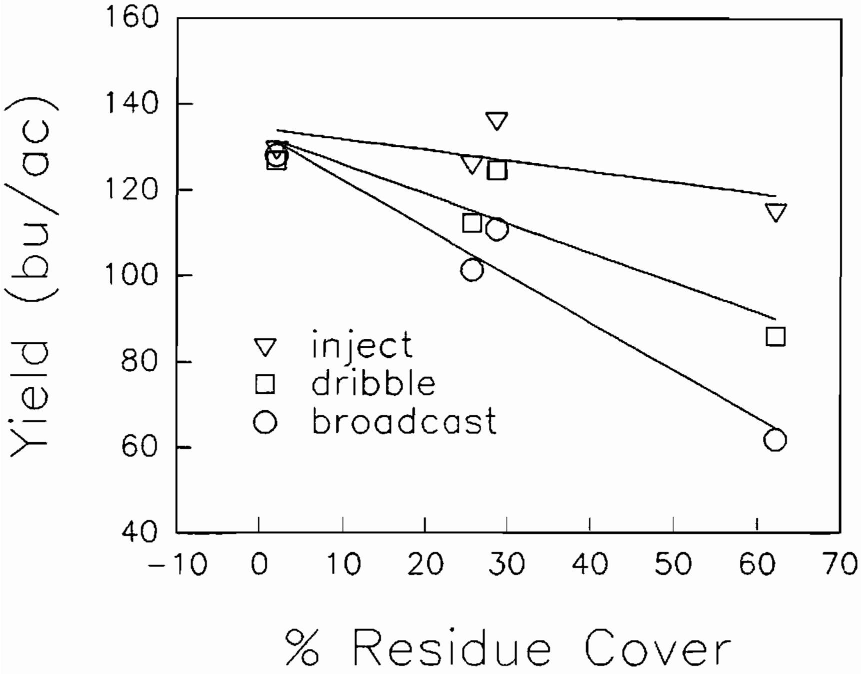


Figure 11. The effect of tillage on corn response to row applied K and soil test K (tillage labels are positioned where starter–no starter lines converge) Moncrief, 1981.

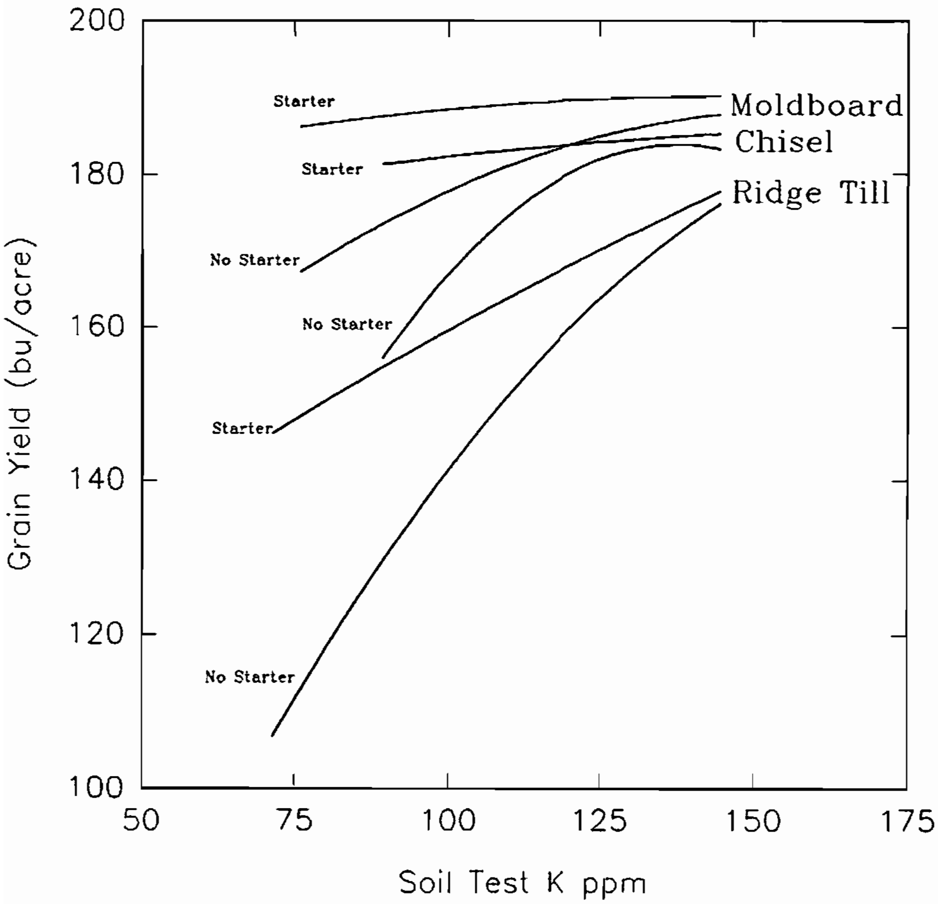
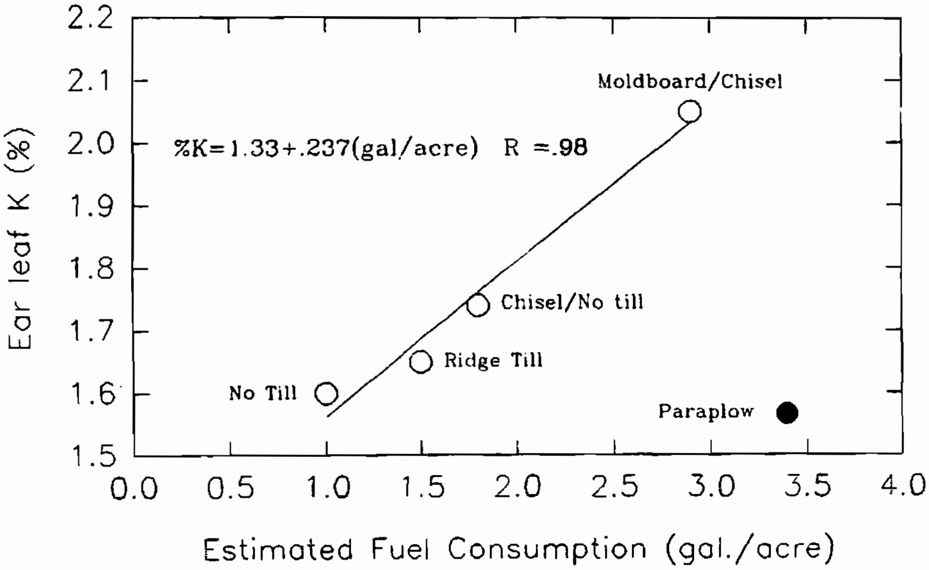


Figure 12. The relationship between the energy associated with tillage system and ear leaf K concentration (Moncrief et al., 1990).



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