SUSTAINABLE AGRICULTURE RESEARCH AND EDUCATION PROGRAM AND AGRICULTURE IN CONCERT WITH THE ENVIRONMENT

FINAL REPORT: September 30, 1992

PROJECT TITLE: Winter Cover Crops for Corn Production in the Northeast: N Balance and Soil Moisture Status.

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ABSTRACT:

Replicated small-plot studies were conducted over a 2-year period at Coastal Plain and Piedmont locations to evaluate the effects of cover crop kill date, corn plant date, and corn FN rates following hairy vetch, cereal rye, and a vetch/rye mixture in a no-tillage corn production system. Factors evaluated included cover crop yield and N production, corn N uptake and yield, soil moisture use efficiency, and soil N status. Results substantiate that vetch can fix most of the N required for high corn yields. When more N is required N responses are greater following vetch than following rye or no cover; this synergistic response appears to be related to more efficient soil water utilization. Research has shown that fall-seeded rye will immobilize more soil N than vetch, thus, reducing the potential for winter nitrate leaching. Data

from these studies support the thesis that vetch/rye mixtures can maximize N production, minimize the potential for N leaching, and optimize corn yields. Cover crop kill dates and corn plant date are critical in terms of N fixation, N recycling, and soil moisture utilization. The ideal kill date will vary with location, soil, and annual climatic pattern but will usually fall between April 20 and May 10 and the best kill date should be what is best for the dominant species in the mixture. Composition of a fall-seeded legume/grass mixture will adjust to the soil N status in that the grass will dominate when the residual N is high while the legume will dominate when the N level is low. This offers good environmental protection while reducing fertilizer N costs to the producer. Shallow ground water samples show lower nitrate concentrations under rye or vetch/rye mixtures, but more study is needed since data are noisy and may reflect previous cropping history.

OBJECTIVES:

1. Determine effects of kill dates of hairy vetch, cereal rye and vetch/rye mixtures, plus no-tillage corn planting dates on nitrogen status of soils and crops, soil moisture availability during corn germination and early growth and shallow ground water quality.

2. Extend field plot research findings to field size research/demonstration program on commercial farms.

3. Develop predictive models to identify viable management alternatives for cover crop use in corn production systems.

PROJECT RESULTS:

A. Precipitation

Precipitation from September 1989 through August 1991 is summarized in Table 1. Fall rainfall was below normal at some time during each fall cover crop establishment period at all locations but satisfactory stands were obtained in all cases. In 1990, spring rainfall was excellent and good spring cover crop growth resulted. There was also adequate soil moisture for good corn germination and early development. June rainfall was below normal and some corn moisture stress resulted but adequate rainfall for the next two months insured good corn yields.

In April, 1991 rainfall was below normal but there was adequate soil moisture in most treatments for corn germination and early growth. However, rainfall from April through mid-July was below normal at the Forage Farm and Beltsville. This resulted in reduced grain yields at both locations while near maximum yields were obtained at Poplar Hill with a more desirable rainfall pattern.

B. Small plot research experiments - Andy Clark, Morris Decker, and Jack Meisinger.

Based on eight plus years of research and experience it was determined that legume cover crops could supply most, in some years all, of the nitrogen (N) needed for maximum corn yields. Small grain covers, such as rye, on the other hand immobilized soil N and additional fertilizer nitrogen (FN) was required to maintain yield goals. Rye was found to be much more effective in recycling unused FN than legumes (Meisinger et al. 1991). Logic suggested that a mixture of annual legumes and grasses could optimize N production and recycling. A 2-year study at Coastal Plain and Piedmont locations was conducted to test this theory. Cereal rye, hairy vetch and a vetch/rye mixture were killed on three different dates at approximately 2-week intervals, starting in late March and continuing through mid-May. Corn was planted no-till about one week after each kill date. Corn was also planted in a no-cover plot at each cover crop kill date. Four rates of FN were topdressed when corn was at the 5-8 leaf growth stage within each species/kill/plant plot.

Table 1. Biweekly (BW) monthly totals and long-term monthly precipitation values from September 1989 through August 1991.

		Location								
		Forage Farm			Beltsville			Poplar Hill		
Month	Days	89-90	90-91	AV*	89-90	90-91	AV*	89-90	90-91	AV*
September	1-15	.03	.13		.00	.19		.69	.15	
	16-30	4.35	1.15		4.25	.85		3.20	.93	
	total	4.38	1.28	4.80	4.25	1.04	3.62	3.89	1.08	3.70
October	1-15	1.33	1.60		1.66	.56		1.35	.38	
	16-31	3.50	3.36		3.37	3.67		2.26	2.05	
	total	4.83	4.96	3.30	5.03	4.23	3.62	3.61	2.43	3.46
November	1-15	.74	2.85		.90	1.66		2.54	1.02	
	16-30	1.70	.40		1.35	.35		1.03	.48	
	total	2.44	3.25	3.42	2.25	2.01	3.36	3.57	1.50	2.83
December	1-15	.57	2.54		.82	1.63		1.39	.47	
	16-31	.73	3.66		.93	3.62		.40	3.24	
	total	1.30	6.20	3.47	1.75	5.25	3.52	1.79	3.71	3.71
January	1-15	1.20	2.78		.97	2.65		1.26	4.32	
	16-31	3.01	.34		2.61	.78		1.75	.59	
	total	4.21	3.12	2.94	3.58	3.43	2.99	3.01	4.91	3.87
February	1-15	1.86	.73		.80	.60		1.72	1.00	
	16-28	.78	.41		.54	.31		.98	.54	
	total	2.64	1.14	2.84	1.34	.91	2.60	2.70	1.54	2.71
March	1-15	.06	1.49		.17	1.48		.39	2.11	
	16-31	2.53	3.93		3.00	4.02		2.64	3.73	
	total	2.59	5.42	3.61	3.17	5.50	3.41	3.03	5.84	3.56
April	1-15	2.74	1.21		2.90	1.03		3.23	.56	
	16-30	1.57	.71		1.70	.60		2.63	2.20	
	total	4.30	1.92	3.45	4.60	1.63	3.34	5.86	2.76	3.39
May	1-15	3.63	1.04		2.24	1.10		2.80	.56	
	16-31	2.39	.89		3.70	1.21		3.82	.71	
	total	6.02	1.93	4.47	6.03	2.31	4.68	6.62	1.27	3.74
June	1-15	1.02	.69		1.39	.17		1.58	.64	
	16-30	.88	1.42		.58	1.14		.41	2.18	
	total	1.90	2.11	3.90	1.97	1.31	3.23	1.99	2.82	3.55
July	1-15	2.57	1.27		4.44	.80		1.08	2.34	
	16-31	1.35	.83		.88	3.09		1.61	3.52	
	total	3.92	2.10	3.81	5.32	3.89	4.34	2.69	5.86	4.59
August	1-15	4.39	1.63		4.47	1.54		4.79	2.35	
	16-31	1.81	1.55		1.38	1.28		.52	2.12	
	total	6.20	3.18	4.80	5.85	2.82	3.93	5.31	4.47	4.89

* Long-term averages: Forage Farm -32 yrs.; Beltsville - 36 yrs.; Poplar Hill - 19 yrs.

1. Cover crop dry matter production and nitrogen contributions

Cover crop topgrowth dry matter production (DM) and nitrogen (N) content are presented in Table 2 for the two-year two-location small plot study. Cover crop growth data were collected in late fall, at spring green-up, and at two-week intervals from early April to early May. Since these studies followed corn with moderate N fertilization, residual soil N was probably low, and N recycling by rye or vetch/rye mixtures was low at the Coastal Plain location (7 to 35 lbs. N/A), and only slightly greater on the higher N-supplying Piedmont soil (21 to 55 lbs. N/A). Cover crops generally had increasingly greater DM production as kill date was delayed, until the latest date (early May), and N content also increased with delay of kill date, until early May, when total N content leveled off. Actual N production was probably still increasing, but leaf loss, especially with vetch, usually resulted in lower N concentration, and subsequently lower total N content was measured.

Vetch/rye mixtures consistently produced more DM than either pure vetch or pure rye, and usually had the most total N, although pure vetch sometimes accumulated more total N due to higher N concentration (i.e., on 5/7/91 at the Coastal Plain, when vetch N content was 172 lbs./A while mixture was 157 lbs./A; or at the Piedmont on 3/19/90, vetch had 97 lbs. N/A and the mixture had 88). Rye generally recycled most of the available N at the Coastal Plain by early April, while at the Piedmont location, rye continued to accumulate N through April.

Both vetch and vetch/rye mixtures maintained C:N ratios below 25:1 for all dates at both locations, while rye C:N ratios were much higher, except for fall and green-up samples (data not shown). This suggests that the use of a mixture of vetch and rye may reduce immobilization of N usually associated with a rye cover crop. Corn grain yields following mixtures were intermediate between pure vetch and pure rye, supporting this hypothesis (see section B-3).

2. Corn N uptake at Poplar Hill

Nitrogen uptake by corn was influenced by cover crop species and management, corn planting date, corn FN rates, and precipitation patterns. In 1991, a more desirable rainfall season, average corn N uptake was 30 lbs higher than in 1990 (Table 3). Lowest N uptake in both years was after rye that was killed early (late March), with corn planted early (early April), and no FN applied to corn. This uptake was significantly lower than for any of the cover kill/corn plant combinations that included hairy vetch. With no FN applied highest corn N uptake was following pure vetch cover. While N uptake increased as kill date was delayed, differences among vetch kill dates were not significant when corn was planted on the same date.

Even though total N in the topgrowth of mixtures was higher than for pure vetch (Table 2), corn N uptake was higher following vetch than after vetch/rye mixtures (Table 3). Corn N uptake was generally highest when vetch or vetch/rye mixtures were killed late but differences between late April and early May were small. This strongly suggests that, in most years, late April killing will maximize N fixation and minimize detrimental soil moisture depletion by the covers allowed to grow late.

3. Corn grain yields at Poplar Hill

Corn grain yields were closely related to corn N uptake values. Average N uptake values were 30 lbs higher in 1991 than in 1990 and grain yields were 34 bushels higher as well (Table 4). In 1990 grain yields ranged from 26 bu/A after early-killed rye and early planted corn with no FN to 171 bu following late April-killed vetch with 160 lbs FN. In the more desirable rainfall year of 1991 yields ranged from 67 bu after the early-killed rye to 200 bu following the vetch/rye mixture with 160 lbs FN. Early-killed vetch and vetch/rye mixtures when corn was planted late

Table 3. Corn N-uptake as affected by cover crop and kill date and by corn fertilizer nitrogen. Poplar Hill[1]

Winter cover kill date (K)	Winter cover Species (S)	Corn plant date (P)	1990 Lbs FN/acre (N) 0	40	80	160	240	AV	1991 Lbs FN/acre (N) 0	40	80	160	240	AV
								- lbs/A -						
1	Rye	1	33	-	55	121	152	90	65	-	155	141	176	134
		3	46	-	143	184	204	144	93	-	155	230	235	182
2	None	1	76	-	102	141	181	138	90	-	130	163	151	133
	Rye	1	53	-	109	167	213	136	71	-	142	150	133	124
		3	62	-	123	156	226	142	84	-	173	222	237	179
	Vetch	1	89	106	142	172	-	127	126	173	194	210	-	176
		3	136	146	140	190	-	153	148	188	201	262	-	200
	Mix	1	89	-	142	155	156	135	103	-	195	210	209	179
		3	94	-	148	215	209	167	132	-	223	289	261	226
3	None	2	68	-	118	171	194	138	75	-	160	192	159	146
	Rye	2	64	-	119	183	186	114	73	-	146	176	203	150
		3	53	-	123	175	198	137	96	-	157	228	242	183
	Vetch	2	116	114	160	223	-	153	149	184	244	213	-	198
		3	114	149	165	206	-	158	179	189	220	252	-	200
	Mix	2	88	-	132	181	213	153	119	-	194	245	223	195
		3	107	-	126	205	207	161	154	-	153	248	207	190
4	None	3	74	-	98	173	181	132	102	-	149	228	219	175
	Vetch	3	133	163	206	174	-	169	181	169	217	232	-	200
	Mix	3	108	-	190	235	194	166	153	-	186	235	224	200
	C.V.%							21.8						13.8

[1]N rates nested within cover/corn plant combinations and cover/corn plant nested within cover kill dates.

LSD (0.05):

	1990	1991
S * K * P over all N rates (column)	25	24
S * K * P within one N rate (column)	50	41
N rates within S and K (one row)	10	8
S * K * P * N interaction (76 values)	50	42

Table 2. Cover crop dry matter and nitrogen production increase as kill date is delayed for pure vetch and vetch/rye mixture, Coastal Plain and Piedmont locations, 1990 and 1991.

	Dry Matter Yield (lbs/A) Kill Date						Topgrowth Nitrogen Content (lbs/A) Kill Date					
Coastal Plain, 1990												
Cover Crop	1/12	3/21	4/13	4/25	5/7	Mean	1/12	3/21	4/13	4/25	5/7	Mean
Rye	421a[1]	1479a	2828ab	3511b	---	2060B	14a	25b	35b	30b	---	26B[1]
Vetch	280a	1748a	2606b	2819c	3475b	2186B	11a	72a	111a	117a	129b	88A
Vetch/Rye	386a	2106a	3331a	5158a	5644a	3325A	14a	66a	102a	120a	156a	92A
Mean	363E[1]	1778D	2922C	3930B	4559A		13D	54C	83B	89B	142A	
Coastal Plain, 1991												
Cover Crop	12/13	3/20	4/10	4/23	5/8	Mean	12/13	3/20	4/10	4/23	5/8	Mean
Rye	221b	1133c	1457c	2079c	----	1235C	7b	17b	20b	22c	---	16B
Vetch	264ab	2639b	2972b	3000b	4481b	2449B	12ab	67a	116a	110b	172a	89A
Vetch/Rye	421a	3236a	3491a	4075a	5558a	3096A	16a	63a	109a	127a	157a	90A
Mean	302D	2336C	2640BC	3051B	5019A		12D	49C	81B	86B	164A	
Piedmont, 1990												
Cover Crop	1/17	3/19	4/9	4/23	5/9	Mean	1/17	3/19	4/9	4/23	5/9	Mean
Rye	888a	1242b	2710b	3262b	----	1928B	21a	27b	55c	45b	---	35B
Vetch	1053a	2724a	2861b	2837b	4242b	2730A	32a	97a	136b	105a	165a	103A
Vetch/Rye	1207a	2793a	4000a	3901a	5175a	3350A	33a	88a	166a	121a	181a	113A
Mean	1049D	2253C	3190B	3383B	4709A	-----	29D	71C	119B	91BC	173A	
Piedmont, 1991												
Cover Crop	12/10	3/21	4/9	4/24	5/7	Mean	12/10	3/21	4/9	4/24	5/7	Mean
Rye	163b	741b	1431c	2604c	----	1340C	9b	15c	24c	37c	---	22C
Vetch	285ab	904b	1834b	3280b	3852b	1914B	6b	26b	62b	124b	119b	66B
Vetch/Rye	469a	1850a	2803a	4910a	5355a	2946A	19a	54a	90a	148a	151a	90A
Mean	306E	1165D	2022C	3598B	4603A		12D	31D	58C	103B	135A	

[1] Means within a column and location followed by the same letter are not different (0.05).
[1] Means across a row followed by the same capital letter are not different (0.05).

Table 4. Corn grain yield as affected by cover crop and kill date plus corn fertilizer nitrogen. Poplar Hill[1]

Winter cover kill date (K)	Species (S)	Corn plant date (P)	1990 Lbs FN/acre (N) 0	1990 40	1990 80	1990 160	1990 240	1990 AV	1991 Lbs FN/acre (N) 0	1991 40	1991 80	1991 160	1991 240	1991 AV
								- bu/A -						
1	Rye	1	26	-	42	75	110	63	69	-	147	133	157	126
		3	59	-	122	151	167	125	82	-	150	163	184	145
2	None	1	85	-	72	100	120	96	85	-	143	152	140	130
	Rye	1	34	-	110	120	140	101	74	-	143	145	141	126
		3	66	-	125	60	174	131	86	-	155	179	194	154
	Vetch	1	75	100	102	94	-	93	132	177	161	158	-	155
		3	141	150	150	149	-	147	160	184	186	191	-	180
	Mix	1	70	-	119	93	122	101	113	-	166	158	165	150
		3	104	-	153	168	166	147	143	-	184	200	192	180
3	None	2	74	-	118	153	149	123	84	-	158	165	157	141
	Rye	2	54	-	109	141	116	88	67	-	155	165	164	138
		3	48	-	123	151	155	119	76	-	169	183	189	153
	Vetch	2	119	130	150	171	-	142	157	170	186	178	-	172
		3	127	157	166	165	-	154	154	177	197	185	-	178
	Mix	2	82	-	131	145	148	127	143	-	159	164	181	162
		3	109	-	140	169	164	146	165	-	167	195	176	178
4	None	3	74	-	114	160	147	124	99	-	156	189	173	159
	Vetch	3	134	160	165	138	-	149	158	163	172	170	-	166
	Mix	3	103	-	159	165	128	131	148	-	140	170	150	152
	C.V.%							15.6						8.6

[1]N rates nested within cover/corn plant combinations and cover/corn plant nested within cover kill dates.

LSD (0.05):	1990	1991
S * K * P over all N rates (column)	31	15
S * K * P within one N rate (column)	37	25
N rates within S and K (one row)	6	4
S * K * P * N interaction (76 values)	41	24

had grain yields similar to late April cover crop kill regardless of corn planting date. These yields were all significantly higher than the no cover treatment regardless of when the corn was planted. This again confirms that a large window exists between mid-April and early May when cover crops can be killed and corn can be successfully planted. This allows flexibility to adjust for the wide-ranging weather patterns that occur from year to year.

4. Corn N uptake and grain yields at the Forage Farm

Corn N uptake (Table 5) and corn grain yield (Table 6) responses for 1990 at the Forage Farm were similar to those obtained at Poplar Hill but were markedly different for 1991 because of severe summer drought. Overall average N uptake was 131 lbs in 1990 and average grain yields were 127 bu/A. In 1991, corn N uptake was 126 lbs/A but grain yields averaged only 93 bu. In 1991 there were significant differences among cover treatment for corn N uptake but for grain yields most differences were not significant. These data clearly point out a long-known fact that drought during corn pollination and grain filling can negate beneficial effects such as legume N fixation and/or improved early soil moisture conservation due to cover crop mulches.

5. Soil Moisture Status as Affected by Cover Crops

Soil moisture was monitored in small plot studies beginning in late March and continuing into August at both locations and for two years of this project. Gravimetric water content to eight inches (20 cm) was measured at each kill date and each corn seeding date, and approximately weekly thereafter. Data from 1991 at the Coastal Plain are presented in Figures 1 and 2, and are representative of results from both locations and years. Figure 1 data represents water content during cover crop growth for several kill date treatments, and Figure 2 continues into the corn growing season for the same treatments. Of greatest agronomic importance in Figure 1 is the lower water content where no cover crop was grown, compared to all cover crop treatments. By the date of corn seeding (5/10), actively growing cover crops had not depleted soil moisture, but rather conserved soil moisture, compared to no cover. Figure 2 shows that the soil moisture advantage of any cover crop mulch continues through all of June, is less apparent during a dry period in July, and then continues through August. Late-killed vetch/rye mixtures, in particular, as well as late rye generally maintained better soil moisture, including during the dry July of 1991 at the Coastal Plain. Data from other locations and years are consistent with the data presented here. At the Piedmont location in 1991, better soil moisture under late-killed covers, as well as early-killed covers compared to no cover, resulted in significantly more corn silage production (data not shown), but since the drought did not break, corn grain yields do not reflect the better soil moisture conditions.

Cover crops in these two years did not compete with corn for soil moisture, but rather, resulted in more favorable soil moisture and better corn response. Late-killed covers often resulted in higher soil moisture than early-killed covers, while the dense mulch provided by vetch or vetch/rye mixture conserved soil moisture better than the more upright canopy of a rye cover crop. Any cover crop was usually better than no cover crop at all, both with respect to soil moisture and to grain or silage yield.

6. Soil Nitrogen Status as Affected by Cover Crops and Nitrogen Fertilization

We have monitored soil NO_3^- and NH_4^+ nitrogen in selected small plot treatments at the early April and late April cover crop kill dates, for the June Pre-Sidedress Nitrogen Test (PSNT), and after corn harvest. Soil samples were taken in 8" increments to two feet, except post-harvest, when they were taken to three feet. Some of these data are summarized in Table 7. Early April soil samples from both locations, and late April samples from the Coastal Plain revealed no differences in soil N regardless of

Table 5. Corn N-uptake as affected by cover crop and kill date and by corn fertilizer nitrogen. Forage Farm[1]

Winter cover kill date (K)	Species (S)	Corn plant date (P)	1990 Lbs FN/acre (N) 0	40	120	180	AV	1991 Lbs FN/acre (N) 0	40	120	180	AV
1	Rye	1	34	71	122	184	103	68	94	123	124	102
		3	53	77	117	164	103	75	74	153	142	111
2	None	1	39	88	153	163	111	95	102	123	123	110
	Rye	1	52	95	120	205	116	73	102	142	138	115
		3	56	77	141	195	110	81	97	146	162	122
	Vetch	1	88	124	178	231	155	94	120	134	142	123
		3	96	114	159	168	134	139	159	166	174	160
	Mix	1	78	99	188	222	147	92	119	132	118	115
		3	86	87	141	178	123	95	122	171	168	140
3	None	2	54	88	148	204	112	99	126	155	147	132
	Rye	2	66	49	-	-	58	76	89	178	164	127
		3	42	67	142	150	100	72	93	146	189	125
	Vetch	2	133	177	200	240	187	131	140	147	115	133
		3	110	144	202	231	171	127	156	156	174	153
	Mix	2	96	128	148	187	136	117	140	166	163	145
		3	120	107	162	184	145	131	145	188	186	162
4	None	3	52	97	136	143	107	92	136	173	144	133
	Vetch	3	145	137	249	258	197	90	140	137	148	132
	Mix	3	123	156	207	246	183	145	138	189	170	160
	C.V.%						17.4					17.9

[1] Cover/corn plant combinations nested within corn kill dates.

LSD (0.05):	1990	1991
S * K * P over all N rates (column)	20	26
S * K * P within one N rates (4 columns)	39	39
N rates within S and K (one row)	8	8
S * K * P * N interaction (76 values)	39	41

Table 6. Corn grain yield as affected by cover crop and kill date plus corn fertilizer nitrogen. Forage Farm[†]

Winter cover kill date (K)	Species (S)	Corn plant date (P)	1990 Lbs FN/acre (N) 0	40	120	180	AV	1991 Lbs FN/acre (N) 0	40	120	180	AV
1	Rye	1	13	48	111	101	70	68	97	95	104	91
		3	61	97	130	168	114	64	62	90	96	78
2	None	1	42	94	138	136	102	85	81	97	101	91
	Rye	1	60	86	114	154	99	64	104	113	97	94
		3	71	96	144	166	114	71	84	73	120	87
	Vetch	1	107	131	145	150	133	70	79	105	100	89
		3	114	142	166	168	147	90	107	94	109	100
	Mix	1	92	121	132	168	128	72	100	88	78	85
		3	100	121	150	176	136	92	95	106	103	99
3	None	2	69	79	158	167	112	96	111	107	102	104
	Rye	2	26	65	-	-	45	76	99	120	115	103
		3	48	74	149	110	95	73	89	111	76	93
	Vetch	2	130	166	191	186	168	100	106	105	106	105
		3	131	186	177	192	172	89	114	88	99	98
	Mix	2	102	141	148	180	139	96	103	109	98	102
		3	127	147	167	177	157	93	91	101	104	97
4	None	3	55	104	149	163	118	71	91	100	80	85
	Vetch	3	162	166	211	212	188	84	90	93	77	86
	Mix	3	145	158	172	211	171	99	104	90	92	96
	C.V.%						15.6					17.6

[†] Cover/corn plant combinations nested within kill dates.

LSD (0.05):	1990	1991
S * K * P over all N rates (column)	27	17
S * K * P within one N rates (4 columns)	39	27
N rates within S and K (one row)	7	5
S * K * P * N interaction (76 values)	38	29

Coastal Plain, 1991

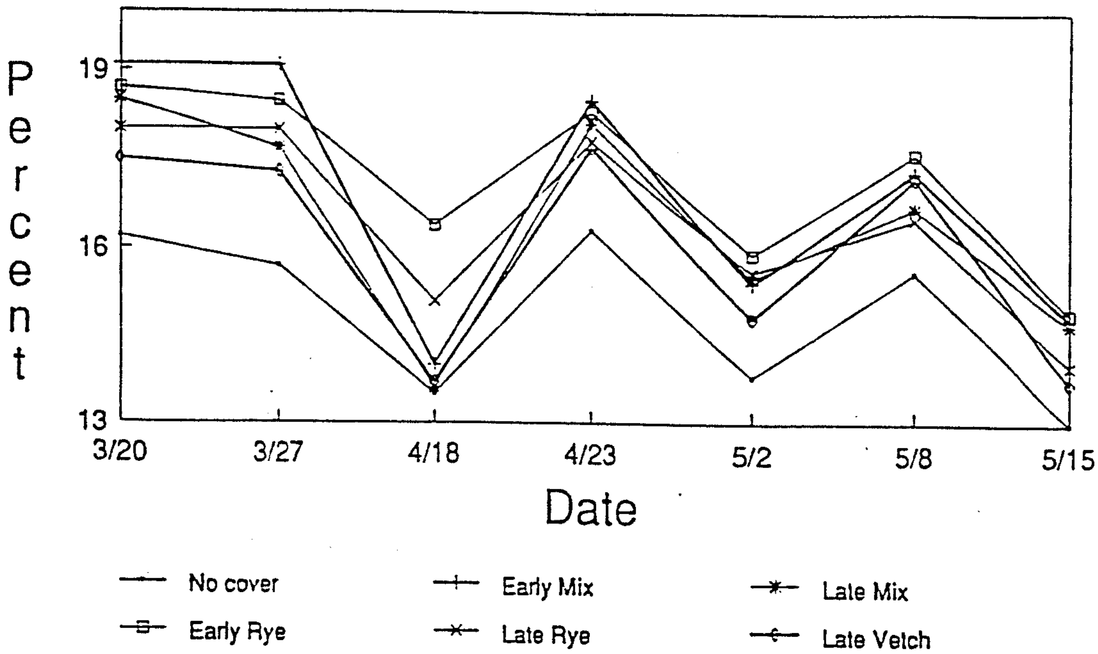

FIGURE 2 Gravimetric water to 20cm
Coastal Plain, 1991

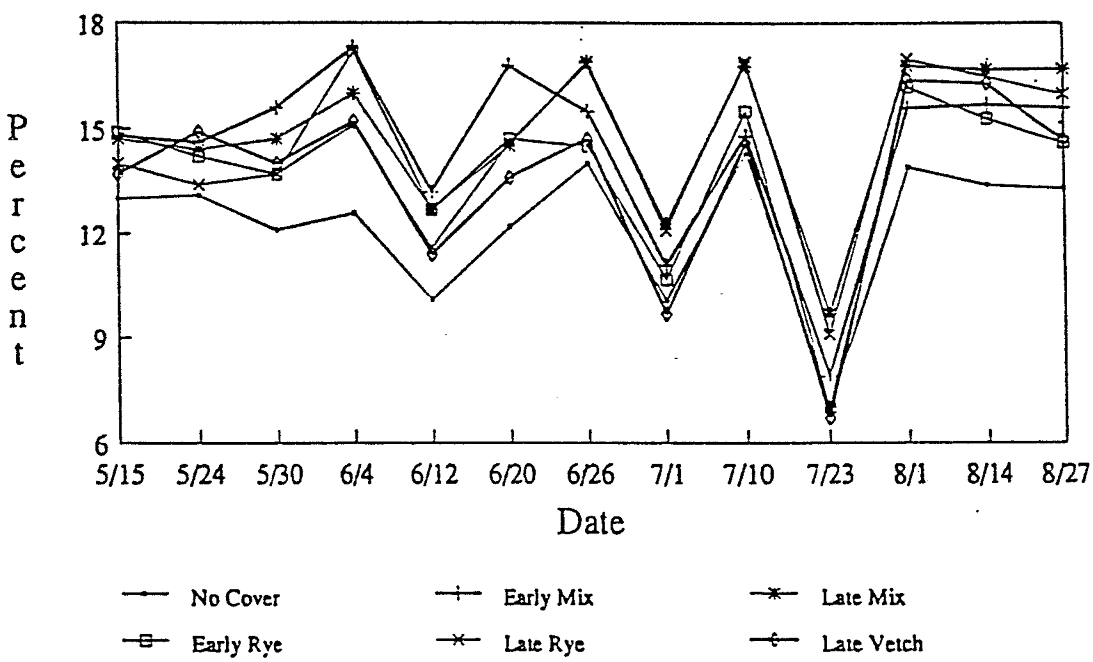

Table 7. April and June soil nitrogen status and subsequent grain yields following selected cover crop treatments in small plot studies at Coastal Plain and Piedmont locations, 1990.[1]

Piedmont

Cover Crop	Kill Date	April NO_3-N	June NO_3-N	June NO_3+NH_4	Grain yield O-N	Grain yield Max	Pounds FN(max)	% Max Yield
		--parts per million--			--bushels--		-pounds-	-percent-
No cover		2.6	4.9	8.9	42	138	120	30
Rye	4/9	2.6	4.0	7.7	71	166	180	43
	4/23	2.6	3.1	7.6	48	149	120	32
Vetch/Rye	4/9	7.8	8.9	12.8	100	176	180	57
	4/23	6.5	9.1	13.8	127	177	180	72
Vetch	4/9	9.8	11.5	15.6	114	168	120	68
	4/23	9.3	13.0	18.1	131	192	180	

Coastal Plain

Cover Crop	Kill Date	April NO_3-N	June NO_3-N	June NO_3+NH_4	Grain yield O-N	Grain yield Max	Pounds FN(max)	% Max Yield
		--parts per million--			--bushels--		-pounds-	-percent-
No cover		1.2	5.1	8.8	73	160	160	46
Rye	4/10	1.6	4.1	7.8	66	174	240	38
	4/25	1.3	3.3	5.2	48	155	240	31
Vetch/Rye	4/10	3.2	6.7	10.8	104	168	160	62
	4/25	2.9	8.5	12.0	109	169	160	64
Vetch	4/10	6.2	11.0	14.8	141	150	40	94
	4/25	2.8	9.5	13.0	127	166	80	77

[1] April samples taken at the late April kill date (4/23 at Piedmont, 4/25 at Coastal Plain)

cover crop treatment, with all soil NO_3^- and NH_4^+ values below 5 ppm. Late April samples from the Piedmont (Table 7) are very low for no cover and rye (2.6 ppm), and slightly higher for vetch/rye mixtures and pure vetch (6-10 ppm). It is not until the June PSNT samples that bigger differences are found. All corn was planted by mid-May, and PSNT tests were taken in mid- to late June on approximately one foot-tall corn. Both NO_3^- and (NO_3^- plus NH_4^+) to one foot are shown, since NH_4^+ may be important where cover crop residues are breaking down. The June NO_3^- for check and rye are still below 5 ppm, while mixtures and pure vetch range from 6-11 ppm. Vetch NO_3^- levels were higher than mixtures, which were higher than check or rye. There are kill date trends towards lower NO_3^-N for late-killed rye (more immobilization, less time to break down), higher NO_3^-N for late-killed vetch (more N production with delay in kill), and higher NO_3^-N for late-killed mix (not enough vetch growth by early date, but more rye). NO_3^- plus NH_4^+ values are higher and may be useful as part of the PSNT for cover crop systems.

Grain yield values without fertilizer nitrogen (FN), maximum grain yield within treatment, and the amount of N required to reach maximum yield are also presented in Table 7. Percent of maximum yield ranges from about 30-45% for check and rye, and 60-95% for mixture and vetch. Only one treatment attained near-maximum yields without FN, and June NO_3^-N was 11.0 ppm (Coastal Plain, vetch kill 4/13, grain yield 141 bu without FN). Responses to FN were good in 1990 at both locations, and we continue to find that synergistic responses to FN following cover crops usually result in higher yields than no cover crop treatment, especially following legumes. Notice that most treatments required 120-240 lbs FN to reach maximum yield, except pure vetch, with 40 to 80 lbs FN resulting in top yields (Coastal Plain). Much of this synergism is due to more favorable soil moisture (Figures 1 & 2) resulting in better N-utilization. This is also evident at the Piedmont, where maximum yield for no cover was only 138 bu, compared to 170-190 bu for vetch or mixture. (See soil moisture section of this report). The June PSNT picks up some of the cover crop N, but much of this N is still in crop residues at that time. Some combination of the PSNT plus an estimate of cover crop contributions to subsequent corn will probably be needed to best estimate fertilizer requirements following legume or legume/grass covers. Fall post-harvest soil samples (not shown) generally show elevated NO_3^-N levels at higher FN rates, usually in the top foot of soil, and little NO_3^-N detectable at FN rates lower than maximum yield. These data clearly show where excess FN has been applied and demonstrate that, under our conditions, little of this NO_3^-N is moving through the profile during the corn season.

7. Use of legume/grass cover crop mixtures for potential recycling of residual fall soil N.

Our data clearly show that total N in the top growth of hairy vetch/cereal rye mixtures is higher than either cover crop species grown alone. It also shows that corn N-uptake and grain yields are intermediate compared to either cover species grown alone. Since rye scavenges residual N and vetch produces biologically fixed N, it can be inferred that cover crop mixtures such as hairy vetch/rye may optimize legume N fixation and residual soil N recycling.

After the 1991 corn harvest at the Piedmont and Coastal Plain locations, strips of rye, hairy vetch, crimson clover, vetch/rye, and crimson/rye were seeded at right angles to the 1991 cover crop strips. No cover crop data were scheduled to be collected but differential responses of rye in these plots to soil residual N were so large by mid-March 1992 that data were obtained on selected plots. Two samples (2 sq. ft.) were taken in each plot. Some of these data are summarized in Table 8. These data are from a single 1991 sub-plot so statistical comparisons are not possible. However differences are large enough that meaningful inferences can be drawn to support our thesis that cover crop legume/grass mixtures will optimize legume N fixation and residual soil N recycling. When soil N is high, the rye component of the mixture increases and rye N-uptake increases. This apparently occurs because of botanical composition changes during the fall and winter period as a result of residual fall soil N levels.

Table 8. The effects of four winter covers and corn FN rates on the recycling of residual soil N by a vetch/rye cover crop mixture following corn.

1990-91 Winter Cover	Corn FN	Corn N uptake	Corn grain yield	Fall soil NO_3	1991-92 Vetch/rye cover harvested March 17, 1992: N Content Vetch	N Content Rye	Rye tiller
	- - lbs/A - -		bu/A	- - - -lbs/A - - - -			2 sq. ft.
Vetch	0	179	154	13	21	19	81
	160	252	185	55	4	57	194
Rye	0	96	76	13	33	11	68
	240	242	189	54	13	18	97
Mixture	0	154	165	15	15	7	45
	240	207	176	62	6	68	266
No cover	0	102	99	16	23	15	104
	240	219	173	76	7	64	207

C. Field-scale research/demonstration studies

Small-plot experiments can be used to evaluate large numbers of plant species and/or treatments. However, such studies do not address many of the production problems facing the farmer. A series of field-scale studies was started in 1988 to look at this problem for selected treatments from our small-plot studies that showed greatest promise.

1. Replicated Field Scale Studies - Andy Clark and Morris Decker

In the fall of 1988, 1989 and 1990 large-scale plantings of different cover crops were made at the Beltsville Facility, Central Maryland Research and Education Center (CMREC). The covers were killed at two dates the following spring and corn was planted no-till. Two to four rates of fertilizer nitrogen (FN) were applied to the corn and grain yields were determined using a 6-row combine each fall. While fall rainfall was below normal in some years, good stands of all cover crops were obtained each fall.

The 1988 seeding was made in a field that was quite variable in topography with scattered small pockets of poor drainage. The soils ranged from loamy sands to fine sandy loams. While good stands were obtained for all covers, crimson and crimson/vetch provided better fall and winter soil erosion protection than hairy vetch or wheat. Three separate contour strips of each cover crop allowed good sampling of soil variability by each. Corn was no-tilled into these strips 22 May and harvested 11 October. Zero and 60 lbs FN were sidedressed when corn was 8-12 inches tall. Normal rainfall during the summer resulted in good corn yields (Table 9). Grain yields following hairy vetch were higher than after wheat but not different than after crimson or crimson/vetch mixture. Higher yields following late killed legumes appeared to be due both to increased legume-N and more efficient moisture conserving mulches. This mulching effect was also observed with late-killed wheat; in contrast to small-plot data, the mulching advantage appeared to be more important than the detrimental effect of N immobilization by the wheat cover. Viewing

Table 9. Corn Grain Yields on Field-Scale, Machine-harvested, Replicated plots - Beltsville.

Winter Covers	Kill[1] Date	1988-89 0-N	1988-89 60-N	1988-89 AV.	1989-90 0-N	1989-90 60-N	1989-90 120-N	1989-90 180-N	1989-90 AV.
				- bu/A -					
None		-	-	-	114	154	156	169	148 a
Wheat	E	45	93	69	75	138	155	-	123
	L	54	116	85	105	140	92	-	112
	AV.	50	104	77 b[2]	90	139	124	-	118 b
Vetch (V)	E	94	110	102	135	159	-	-	147
	L	95	140	118	151	174	-	-	162
	AV.	94	125	110 a	143	166			155 a
Crimson (C)	E	87	123	105	146	156	-	-	151
	L	72	109	90	155	173	-	-	164
	AV.	80	116	98 ab	150	164			158 a
C/V Mix	E	72	110	91	119	159	-	-	139
	L	85	130	108	162	156	-	-	159
	AV.	78	120	99 a	140	158			149
Average	E	74 y	109 x		123 z	155 x			
	L	76 y	124 x		142 y	163 x			
CV%			18.9			14.8			

[1] Early-E 4-17-89 4-23-90
Late-L 5-9-89 5-7-90

[2] Values followed by same letter not different (0.05)

the treatments from the combine vantage point at harvest clearly demonstrated that the vetch cover provided better weed suppression.

The 1989 cover crop field was a relatively level fine sandy loam with less soil variability than the previous year. The preceding crops were wheat/double crop soybeans. Because of heavy deer grazing the beans were too short to combine and substantial N was returned to the soil by the unharvested beans. Rainfall was excellent during the corn season (Table 1) and a grain yield of 114 bu/A was obtained with no crop cover or corn FN (Table 9). Grain yields on this check treatment leveled off between 60 and 120 lbs FN. Since soil moisture was not a problem, grain yields were lower following wheat and were higher following the legume covers. This was true even for crimson that was heavily grazed by deer during most of April; they preferred crimson over vetch or wheat. The highest yields were after vetch or crimson killed late with 60 lbs FN on the corn. There was no corn yield advantage to seeding crimson with vetch. However, as observed the previous year, crimson provides better erosion control than vetch. The synergistic responses due to legume covers and FN were again evident.

In contrast to the first two years, low 1991 summer rainfall (Table 1) resulted in severe corn yield reductions. From April 1 through August a deficit of 7.61 inches was recorded. The soil was a droughty loamy sand and corn was under severe moisture stress by mid-July. The moisture stress on corn was most severe on the no-cover and early-killed rye and least severe on the early-killed vetch/rye mixture and late-killed vetch. Both water use by the growing covers and water conservation by the killed cover mulches were involved. Just before 2.8 inches of rain fell 24-27 July, corn in the no-cover and rye plots had shed most of its pollen but no silks had emerged. In contrast, silks were emerged and pollen was being shed in the vetch and vetch/rye mixture plots. After these rains silks in all plots emerged and pollen was wind blown so that most plants were pollinated. However, August was hot and rainfall was more than an inch below normal and grain filling was greatly restricted. The drought effects were less harsh on the treatments with vetch included but there simply was not enough soil moisture for normal grain yields (Table 10). Grain yields ranged from 33 bu/A following crimson killed early with no FN added to 106 bu/A following the vetch/rye mixture killed early with 60 lbs FN applied to the corn. The early-killed vetch/rye mixture simply used less of the limited spring moisture and the heavy, uniform mulch conserved more of it for the corn crop. The beneficial mulching effects are clearly evident by comparing grain yields following vetch and the vetch/rye mixture. Early-killed vetch did not provide sufficient mulch to conserve soil moisture and the late-killed vetch simply used too much before it was killed. The same thing is illustrated by the 9-bu increase obtained when rye was killed late rather than early; this occurred in spite of the fact that more soil N was immobilized by the late-killed rye. Soil moisture was the limiting factor - not nitrogen.

Table 10. Corn grain yields on replicated field-scale plots Beltsville, 1990-91

Winter	Early		Late	
Covers	O-N	60-N	O-N	60-N
		- bu/A -		
None	-	-	50e-h	90abc
Rye	42gh*	68b-g	55d-h	77a-f
Vetch	57d-h	46fgh	64c-h	69b-g
Crimson	33h	44gh	79a-e	98ab
Rye/vetch	72b-g	106a	96ab	89abc
Rye/crimson	70b-g	48fgh	84a-d	96ab

CV = 27.3%
* values followed by the same letter are not different (0.05).

2. Unreplicated strips on commercial grain farms

a. Calvin Serman Farm

The field was a sandy loam. Crimson clover and cereal rye were seeded after 1989 corn harvest. Each cover was killed early - or late-April and within each kill date FN rates were zero, 80, and 120 lbs/A. These treatments were repeated on the same field strips in the 1990-91 cover crop/corn season.

More desirable rainfall in 1991 resulted in higher corn grain yields (Table 11). At zero and 80 lbs N/A, early killed crimson resulted in higher grain yields even though more N was fixed by the late-killed crimson. While slower mineralization rates of the more mature crimson played a role in reduced grain yields, soil moisture depletion appeared to be more critical. In support of this thesis, grain yields were higher following late-killed rye. The beneficial effects of higher mulch levels were especially evident in the 1990 corn season. On sandy soils, moisture depletion by the cover crop can negate the advantage of more N-fixation if allowed to grow too long.

b. Norman Brittingham Farm

The soil was a sandy silt loam with a higher organic matter level. Irrigation was applied as needed based on tensiometer readings. Hairy vetch was seeded each year after corn harvest. One field received poultry manure in 1989 and the other did not. Half of each field was killed early and the other half was killed late with zero and 80 lbs FN applied to each strip. Highest yields were obtained on the poultry-manured field (Table 12). With no manure or FN applied, better yields were obtained when vetch was killed late; this advantage was more pronounced in 1991. Killing the vetch late on the manured field and applying FN produced the highest yield in 1991. This agrees with our small plot data in that a good vetch mulch improved FN responses. For example, yields on the manured treatment with no FN added were 16 bushels higher than the no-cover check and with 80 lbs FN the yield advantage was 25 bushels. In 1990, yields were the same for no-tillage and conventional plantings.

Both cooperating producers recognized the advantage legume cover crops provide by supplying fixed N and improved soil moisture conservation by any cover crop that provided a surface mulch that lasts into the summer. Early fall seeding of cover crops is essential for maximum winter soil protection and legume-N fixation and can compete with timely harvest of corn and soybeans. Legume cover crops fix maximum N if allowed to grow late but this late growth can deplete soil moisture. Killing the crop at the optimum time requires additional planning and the operation must compete with other spring operations. For these reasons, both producers were reluctant to incorporate cover crops into all of their fields.

D. Factors affecting mineralization of covers

1. Cover Crop Incubation Studies - Bruce James and Mwaffak Taib

A laboratory incubation experiment was conducted to determine the kinetics of N mineralization in soil that received cover crop residues and to compare them with other N sources such as poultry and dairy manures. The experiment used soils taken from both conventional and no-tillage check plots which had not received nitrogen for more than three years. The cover crop plant materials consisted of hairy vetch and rye plants (not including roots) grown at the Poplar Hill Farm in 1990. The plant materials were oven-dried, ground to pass 2 mm sieve and either mixed with

Table 11. Corn grain yields following winter cover crops killed at different dates with different nitrogen rates on corn. Unreplicated field-scale strips, Calvin Serman Farm.

Winter Cover		Corn Harvest Year								
		1990			1991			Average		
Species	Kill date	0[1]	80	120	0	80	120	0	80	120
Rye	E[2]	72	105	91	101	-	119	86	-	105
	L	66	-	111	107	-	126	86	-	118
	AV.	67	105	101	104	-	122	86	-	112
Crimson	E	83	116	115	114	126	121	98	121	118
	L	70	93	110	110	117	122	90	105	116
	AV.	76	104	113	112	122	122	94	113	117

[1]lbs N applied to corn
[2]E = 4-9-90 & 4-10-91; L = 5-2-90 & 4-22-91

Table 12. Corn grain following hairy vetch killed at two dates with two nitrogen rates on corn. Unreplicated field-scale strips, Norman Brittingham Farm.

Winter cover	Corn harvest year	Cover kill date	Chicken Manure (1989)					
			No		Yes		Average	
			0[1]	80	0	80	0	80
Vetch (No-till)	1990	E[2]	115	147	138	144	126	146
		L	121	113	126	127	124	120
	1991	E	123	168	160	166	142	167
		L	137	150	154	171	146	160
Vetch (Disked-L)	1990	E	-	-	125	-		125
No cover (No-till)	1991	L	-	-	138	146		142

[1]lbs N applied to corn
[2]E = 4-13-90 & 4-8-91; L = 5-7-90 & 4-24-91

the soil or added onto the surface. Soil samples with or without N treatment were then incubated at 25°C and leached with 0.01 M $CaCl_2$ after 0, 7, 14, 21, 28, 35, 42, 56 and 70 days of incubation. The concentration of nitrate in the leachate was determined by ion chromatography and taken as a measure for N mineralization in the soil.

Results indicated that higher nitrate concentrations were obtained when the rye or hairy vetch was surface applied than when they were incorporated into the soil. Moreover, when the rye was incorporated in the soil, it caused a flush in microbial activities which resulted in immobilization of the nitrate already in the soil incubation. The results will be useful in determining the best kill date for the cover crop and the expected levels of N available to the corn crop during the growing season under various agronomic practices and different methods of N management.

2. Litter Bag Studies - Ray Weil and Susan Davis

In the summer of 1991 two years of field work for the study of cover crop decomposition and N release dynamics were completed. Laboratory analyses for all soil samples from the two seasons have been completed, but analysis of the data is not complete at this time. Cover crop plant samples from 1990 have been analyzed in the lab, and analysis of cover crop samples from 1991 are nearly completed at present. Corn plants, collected throughout the season in 1991 remain to be processed and analyzed for total carbon and nitrogen. Thorough data analysis and interpretation of the two years of data remain to be completed.

There are three primary objectives of the decomposition study: 1) to characterize the decomposition of cover crop material as affected by the stage of development or date of kill of the cover crop species (hairy vetch (Vicia villosa), rye (Secale cereale), and a mixture of the two); 2) to determine the effect of the method used to kill the cover crop on the decomposition of the cover crop litter in the field; 3) to measure the corn N uptake to determine if the N release of the cover crop parallels the period of logarithmic corn growth.

Litter-bag studies were done in 1990 and 1991 at Central Maryland Research and Education Center, Clarksville. In 1990, a portion of the study of kill method effects on decomposition was done at the Clagett Farm research and education facility of the Chesapeake Bay Foundation located in Upper Marlboro, Maryland. To quantify the litter and retain it in the field 30 * 30 cm nylon mesh bags with 1 mm square mesh opening containing a known amount of freshly killed cover crop litter were pinned to the ground in their respective plots into which corn was subsequently planted. The dry matter content of the fresh tissue was determined and used to represent the dry matter content of all of the samples in that replication of the treatment.

Because the tissue does not remain clean in the field, and the amount of soil contamination will vary from bag to bag a correction factor for soil contamination must be used. There are several ways in which this can be done. Many published litter bag studies, and the preliminary figure presented here, use a correction factor for soil contamination which assumes that the ash component of the tissue placed in the bag remains there throughout the season. While this is a good assumption early in the season, it is not valid later in the season after rain and microbial activity have removed K, Mg, Ca, Mn, Fe, and other mineral components from the plant tissue. An improved correction was developed and confirmed in the literature. This approach calculates the tissue remaining by the following equation which was derived by solving three simultaneous equations describing the ash content of the three materials, clean tissue, soil, and bag contents:

$$W^{w} = W_t\,[(A_s - A_c)/(A_s - A_t)]$$

where W_w is the weight of the tissue remaining, W_t is the weight of tissue placed in the bag, A_s is the percent ash of the soil, A_c is the percent ash of the dirty bag contents, and A_t is the percent ash of the clean tissue.

The rate of tissue decomposition throughout the season (expressed as tissue dry weight remaining in bag/tissue dry weight added) can be described by a variety of equations. Of particular note are the first order decay curves of the form $y = a(e^{x \cdot day})$. This equation has frequently been used to describe the decay of many types of materials. The data in 1990 in the date of kill study (Figures 3 and 4) indicate that a modification of this decay model with two exponential components fits the data and accounts for nearly all of the variability (late kill, mixed species $r^2 = 0.999$). This two component model represents the two pools of carbon substrates present in the plant tissue. Microbes are simultaneously degrading readily decomposable sugars, starches, and proteins, and the more resistant compounds such as lignin, cellulose, and hemicellulose.

The effect of the method of kill in the decomposition of the cover crop litter is small, but initially the herbicide killed material decomposes more quickly than the mowed material. Later in the season this difference in decomposition becomes insignificant. It remains to be determined how the method of kill affects the rate of N release.

3. Relationship between cover crop nitrogen partitioning and its subsequent release - James F. Holderbaum

Although rate and extent of cover crop herbage degradation and N release have been described, little information is available on factors controlling these processes. Studies, described here, were conducted to ascertain relationships between the form and distribution of cover crop N and rate/extent of cover crop N release.

Cover crops of cereal rye (*Secale cereale* L.) and hairy vetch (*Vicia villosa* Roth) and a rye-vetch mixture were characterized in replicated field studies in 1990 and 1991. The cover crops were established in the fall of the previous year (late September-early October) and sampled in the following spring. Herbage was collected just prior to herbicide application at 3 stages of maturity. Cover crop herbage was separated into rye leaf blade, sheath, stem, and inflorescence and vetch leaflet, petiole, and stem components. Following herbicide application, rye and vetch cover crop residues were sampled at 2-week intervals for approximately 14 weeks and subsequently separated into their respective components as previously described. All components were frozen and freezed dried, and weighed for determination of each component's contribution to total herbage mass within cover crop types. Each sample component from pre- and post-herbicide application sampling dates was analyzed for total nitrogen and carbon concentration, nitrogen associated with cell wall constituents (neutral detergent fiber method), and water soluble nitrogen (defined here as hot water extraction).

Overall, results were similar for both years and are described below in general terms. Rye N concentration prior to herbicide application typically ranged from 6.5 to 49.4 g kg^1, depending on plant part and sampling date (maturity). The C:N ratio of rye plant parts ranged from 8 to 66 and was also dependent on stage of maturity. Differences observed in C:N ratios between plant parts was primarily a function of differences in N content rather than differences in C content. Rye leaf blade nitrogen as a percentage of total nitrogen (NTN) typically decreased from approximately 60% for the first sampling date to 25% for the last sampling date. Rye stem NTN increased on average from 9 to 26% with advancing maturity. Overall, vetch N concentration was higher for leaflets

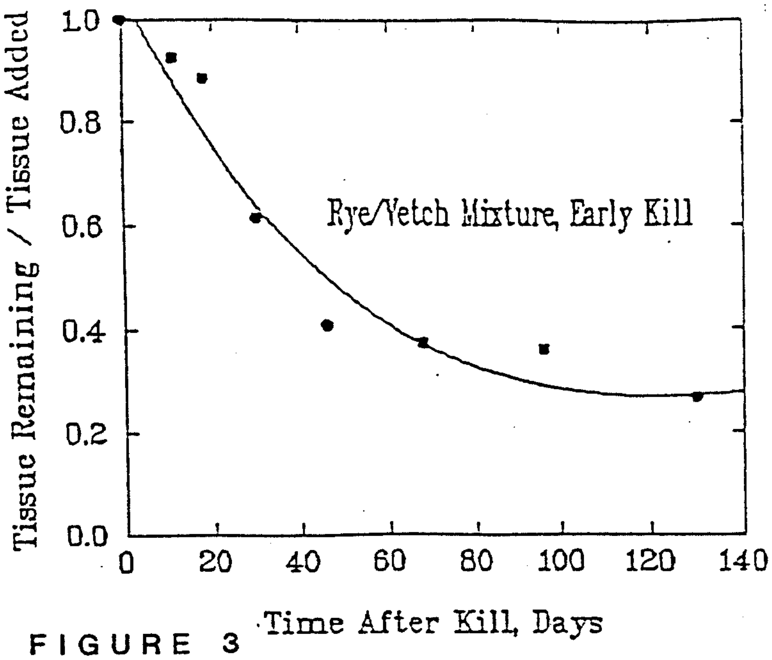

FIGURE 3

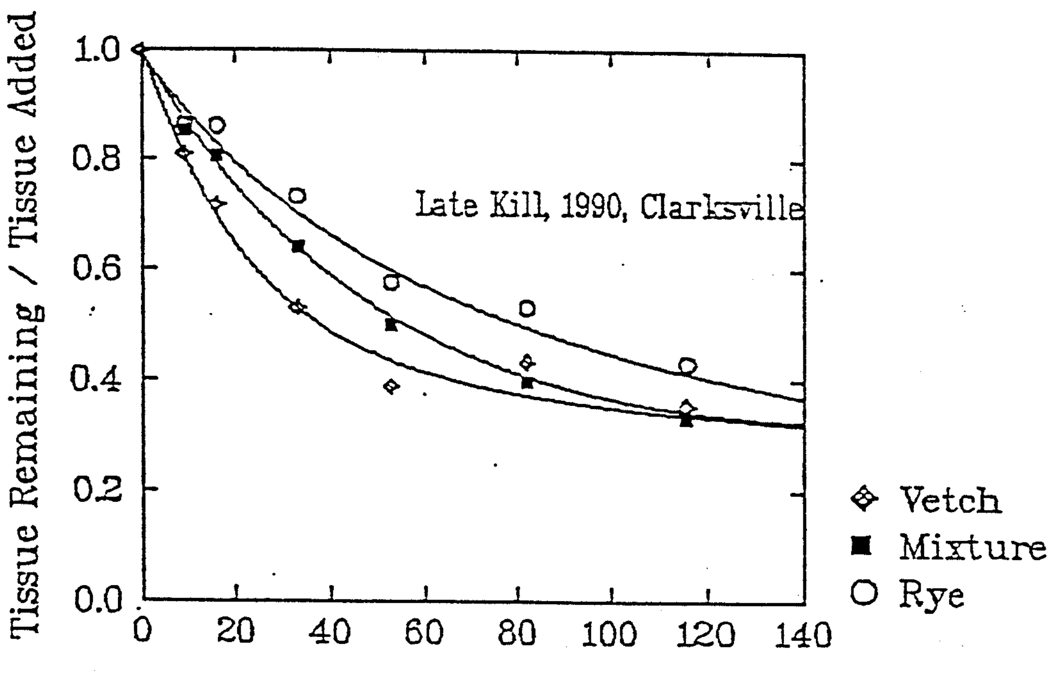

FIGURE 4

(approximately 65.0 g kg^{-1}) than for petioles (32.0) or stem (31.2) and accounted for, on average, 64% of the total nitrogen in vetch herbage. Unlike rye, stage of maturity had little influence on the nitrogen concentration of vetch components or the relative contribution of individual plant components to total plant nitrogen.

Characterizing plant nitrogen in terms of hot water solubility and association with cell wall constituents revealed considerable variation between plant parts, as well as between species, in the character of plant nitrogen. Cell wall nitrogen in rye accounted for between 12 and 19% of total plant nitrogen whereas cell wall nitrogen in vetch constituted only 3 to 8% of the total nitrogen in vetch. As with nitrogen concentration, the range in cell wall nitrogen as a percentage of total plant nitrogen reflects differences among plant parts.

The quantitative assessment of nitrogen in the hairy vetch cover crop was complicated by the initiation of decomposition of the vetch cover crop (particularly at the base of the canopy) prior to herbicide application. Decomposition was usually observed by the second sampling date. When present, the decomposing portion of the canopy was collected in total and analyzed as a separate component of the cover crop canopy. The low N concentration that was observed in this component (relative to N concentration in the leaflet, petiole and stem component) suggested that a significant portion of N in the decomposing herbage was being released prior to herbicide application. The significance of premature decomposition of a hairy vetch cover crop to overall nitrogen contribution to the subsequent crop warrants further investigation.

Following herbicide application, leaf dry matter and nitrogen concentration in both rye and vetch decreased at a faster rate than any other component over time. Vetch leaflets had completely disappeared within 3 weeks from the time of herbicide application, regardless of stage of maturity. Vetch stem material, however, was still discernable 12 weeks after herbicide application. Similar results were observed with rye, however, unlike vetch stems which rapidly came in contact with the soil, rye stem and sheath residues remained upright and not in contact with the soil for more than 14 weeks following herbicide application.

These studies provided valuable information regarding the nature and spatial distribution of nitrogen in both cereal rye and hairy vetch cover crops both prior to and following herbicide application. Further refinements in the methodologies used in conducting detailed characterizations and assessments of cover crop nitrogen would likely enhance the information that studies of this nature can provide.

E. Water Quality Study - J. J. Meisinger

The water quality phase of this project was begun in 1990 with the objective of determining the effect of fertilizer N rates and winter cover crops on NO_3-N concentrations of shallow groundwater on Maryland's Eastern Shore.

In 1990 two inch PVC wells were installed into the shallow unconfined aquifer (water table 6-8' deep) below large (45' X 50') continuous no-till corn plots which received fertilizer N rates of 0, 80, 160, or 320 lbs N/ac. Corn grain yields were measured annually and after corn harvest winter cover crop treatments were established which consisted of: rye, hairy vetch, rye-hairy vetch mixture, or a no-cover control. Well water samples were collected periodically during 1990-1992 by pumping the wells three times and then withdrawing an analytical sample which was analyzed for NO_3-N by ion chromatography.

1. Corn Grain Yield

The corn grain yield data show significant response to fertilizer N up to 160 lb N/ac without a cover crop in 1990 and in 1991 (Table 13). The cover crop treatments were begun in the fall of 1990 and cover crop effects on 1991 corn grain yields (Table 13) show that rye reduced corn N availability about 30 lbs N/ac while hairy vetch supplied the equivalent of about 85 lbs of fertilizer N/ac. The rye-hairy vetch mixture produced yields intermediate between the pure cover crop stands with an apparent fertilizer N equivalent of about 25 lbs N/ac. These data are entirely consistent with yield results obtained in other sections of this project and with previous results reported by Holderbaum et al. (1990); Mitchell and Teel (1977); and Ebelhar et al. (1984). The yield reductions observed with cover crops following 320 lb N/ac were due to low corn populations, which resulted from high levels of cover crop residue causing poor seed-soil contact.

Table 13. Average corn grain yields (bu/ac @ 15.5%) at the Poplar Hill water quality site for various fertilizer N rates and cover crop treatments in 1990 and 1991.

Fertilizer N Applied	Cover Crop Treatment and Year				
	No-Cover		Rye	Vetch	Rye & Vetch
lb N/ac	1990	1991	1991	1991	1991
	bu/ac				
0	78	66	39	118	80
80	117	113	107	133	117
160	138	134	125	129	126
320	143	134	102	-	106
LSD (0.05)	13	15	15	15	15

2. Shallow Ground Water Status

The water quality data contain mixed results, with both distinct and indistinct features included. The nitrate-N concentrations collected in 1990-1991 averaged 9.9 ppm and contained no significant differences between treatments. Apparently these data reflect drainage from the prior management when the site was cropped uniformly for four years to a rotation of corn and winter wheat with double-crop soybean and was fertilized with 120 lb N/ac annually. In 1991-1992 the surface N treatments began to impact the water quality with average nitrate-N concentrations of: 7.5 ppm for N deficient plots (check plots and 80 lbs N/ac plots) and 9.5 ppm for the 160 lb N/ac plots. The 320 lb N/ac plots without a cover crop averaged about 15.5 ppm nitrate-N while the plots with a rye or rye-vetch cover crop averaged about 10.5 ppm, with no significant differences among covers. There was a general lack of statistical significance among all treatments which is attributed to: i) a large variation among plots, CV's ranged from 35 to 110 % with typical values being 55 %, and ii) the fact that 1991 was the first full year of treatments. Nevertheless, the data do exhibit some of the expected changes in water quality - except that the magnitude and consistency of these changes is less than anticipated.

It is likely that the shallow groundwater nitrate-N concentration is a rather conservative parameter, which changes slowly over time in response to changes in surface management. For example, other research in the Eastern Shore (Brinsfield & Staver, 1991) reported a two-year lag between the first use of cover crops and a corresponding change in nitrate-N concentration in shallow groundwater. Thus, it is likely that the above lack of statistical significance and high variability merely reflect the fact that the site is in a transitional phase. Continued patient study will be required to determine the final impact of current fertilizer N use and cover crop management practices on nitrate concentrations in shallow groundwater.

F. Dissemination of Research Findings

Research on the use of legume cover crops in no-tillage corn production for Maryland was begun in 1982. Producer interest continues to increase as more research findings are publicized through Research/Extension Field Days, producer field tours, etc. Numerous producer requests for cover crop information prompted publication of Agronomy Mimeo 34 "Winter annual cover crops for Maryland corn production systems". Informal meetings have been held with Maryland Department of Agriculture, U.S. Soil Conservation Service, Maryland Cooperative Extension Service on cover crop use. The following is a list of scheduled cover crop related meetings in which we have participated since 1989:

1. Research/Extension Field Days at Research & Education Centers
   a. Poplar Hill Research Facility 1989, 1990, 1991 & 1992
   b. Western Maryland Research & Education Center 1991
   c. Wye Research & Education Center 1989 and 1991
   d. Central Maryland R & E Center (Beltsville) 1991
   e. Central Maryland R & E Center (Tobacco Farm) 1990
   f. Indiantown Farm Field Day 1989

2. Farm Tours
   a. Calvin Serman Farm 1990
   b. Beltsville Facility CMREC 1989, 1990, 1991
   c. Forage Farm Facility CMREC 1991
   d. Joseph Hottel Egypt Farms 1992
   e. Lemuel Kinnamon and Wayne McFarland Farms Queen Anne's County 1992
   f. No-Tillage Research Tour 1989, 1990, 1991, 1992
   g. Anne Arundel County Producers Breakfast 1992
   h. Monocacy Project Farm Tour 1992

3. Farm tours for international scientists and farmers
   a. Boris Mikhailchenko, Deputy Director, Williams Fodder Research Institute, Moscow, USSR.
   b. Ugandan farmers - sponsored by Agricultural Cooperative Development International 1991

4. Conferences and Workshops
   a. Low Input Farming Workshop - Rodale Institute, Wye Institute and University of Maryland
   b. Maryland County Agent Up-date 1990 and 1991
   c. Maryland Nutrient Management Specialists 1991
   d. Soil Conservation Service - Cover Crop Guidelines 1991
   e. Maryland Grain Producers 1991
   f. Low Input Sustainable Agriculture Conference, Baltimore, Maryland 1991
   g. Commercial Small Fruits and Vegetable Up-date 1991
   h. Carroll County Winter Meetings 1992
   i. Monocacy Water Quality Producer Update 1992

G. Producer Involvement - Farmer/producer in attendance at: Workshops - 75; Conferences -360; Field days - 755; twilight meetings - 65; field tours - 175.

H. List of Project Publications

Completed

Clark, A. J., A. M. Decker, J. J. Meisinger, and J. F. Holderbaum. 1990. Hairy vetch/cereal rye cover crop mixtures for no-tillage corn production. Abstracts, NEBASA Annual meeting, U. of New Hampshire p. 3.

Clark, A. J., A. M. Decker, J. J. Meisinger, and J. F. Holderbaum. 1990. Spring management of hairy vetch/cereal rye mixtures for N production and grain yield. Abstracts, ASA Annual meeting, San Antonio, Texas p. 139.

Davis, S. L., R. R. Weil and A. J. Clark. 1990. Decomposition and N release by legume and cereal cover crops for no-till corn. Abstracts, ASA Annual Meeting, San Antonio, Texas p. 140.

Decker, A. M., J. J. Meisinger, J. F. Holderbaum and A. J. Clark. 1990. Utilizing winter annual cover crops in no-tillage corn systems. Abstracts, ASA annual meeting, San Antonio, Texas p. 140.

Hanson, J. C., D. Johnson, B. V. Lessley, E. Lichtenberg and A. M. Decker. 1990. Economics of cover crops for soil conservation in Maryland. Abstracts, ASA annual meetings, San Antonio, Texas, p. 144.

Meisinger, J. J., P. R. Shipley, and A. M. Decker. 1990. Winter cover crops to retain N within soil/crop systems and reduce nitrate leaching. Abstracts, ASA Annual meetings, San Antonio, Texas, p. 152.

Meisinger, J. J., W. L. Hargrove, R. B. Mikkelsen, J. R. Williams, and V. W. Benson. 1991. Effects of cover crops on groundwater quality, pp. 57-68. In W. L. Hargrove (ed) Cover crops for clean water. Proc. Inter. Conf., April 9-11, 1991, Jackson, TN, Soil and Water Conser. Soc. Am., Ankeny, IA.

Decker, A. M., A. J. Clark, J. J. Meisinger, F. R. Mulford, and V. A. Bandel. 1992. Winter annual cover crops for Maryland corn production systems. University of Maryland Agronomy Mimeo no. 34.

Manuscripts Completed (in review)

Decker, A. M., A. J. Clark, J. J. Meisinger, F. R. Mulford, and M. S. McIntosh. 1993. Legume cover crop contributions to no-tillage corn production systems. Agron. J.

Clark, A. J., A. M. Decker, J. J. Meisinger, F. R. Mulford, and M.S. McIntosh. 1993. Cover crop kill date studies: Hairy vetch effects on corn, nitrogen relations, and soil moisture. Agron. J.

Clark, A. J. and A. M. Decker. 1993. Cover crop kill date studies: Hairy vetch/cereal rye mixture seeding rate evaluations for corn production. Agron. J.

Lichtenberg, E., J. C. Hanson, A. M. Decker, and A. J. Clark. Profitability of legume cover crops in the mid-Atlantic Region. J. Soil and Water Conser. Submitted September 1992.

Hanson, J. C., E. Lichtenberg, A. M. Decker, and A. J. Clark. Profitability of no-tillage corn following a hairy vetch cover crop in the mid-Atlantic Region. J. Prod. Agr. Submitted Sept. 1992.

Manuscripts scheduled (tentative titles and authors)

Soil nitrogen as influenced by cover crop mixtures or pure stands, spring kill date and corn seeding date. A. J. Clark, J. J. Meisinger and A. M. Decker. Soil Science Soc. of Amer. Journal (or Agron. J.)

Early spring elimination of cereal rye from hairy vetch/cereal rye mixtures, and subsequent effects on corn response, soil nitrogen and soil moisture. A. J. Clark, A. M. Decker and F. R. Mulford. Agronomy Journal.

Suitability of the Pre-sidedress nitrogen test (PSNT) for corn in cover crop systems as influenced by cover crop management (and climate?). A. J. Clark, A. M. Decker, M.S. McIntosh and J. J. Meisinger.

Modeling corn response to cover crop management, nitrogen fertilizer and soil moisture. A. J. Clark, A. M. Decker, M.S. McIntosh and J. J. Meisinger.

SUMMARY OF MAJOR PROJECT FINDINGS

1. Further substantiation that fall-seeded annual legumes can supply most, in some cases all, of the N required for maximum no-tillage corn production.

2. Reinforced earlier research findings that FN applied to corn after legume or legume/grass winter covers was more efficiently utilized. This synergistic yield response appeared to be the result of improved soil moisture conditions both before and after the covers were killed and corn was planted.

3. Cover crop kill dates are critical in terms of potential soil moisture stress and maximum N fixation. However, a wide window exists from about April 20 through May 10 for effective cover crop kill and early corn development. An awareness of potential problems for each farm field and a timely management schedule to optimize soil moisture and N fixation must be developed.

4. Cereal rye can immobilize large amounts of soil N. Mineralization of this N for corn production is relatively low the first year even when the rye is killed early.

5. Corn grain yields following late-killed rye are often improved because of more efficient summer soil water use in spite of the fact that larger amounts of soil N are immobilized.

6. Mineralization of N from killed hairy vetch is more rapid than from killed rye and the mineralization rate of vetch/rye mixtures is intermediate. Senescence and mineralization of lower vetch leaves while the cover mixture is still growing appears to speed up mineralization of the rye component of that mixture. More definitive research is needed to confirm this observation.

7. The botanical composition of a fall-seeded vetch/rye mixture adjusts to residual soil N levels. This provides the producer with an excellent nitrogen management tool. More research is needed in this area to more clearly identify these relationships.

8. Logic suggests that in time an equilibrium will be established between N immobilization and mineralization and that the resulting soil N pool may be different for each cover. Research is needed in this area before it will be possible to fine-tune FN requirements.

9. The PSNT does not accurately reflect the N contributions of cover crops to the succeeding corn crop. Adjustments must be made for cover crop N contributions but more research will be required to clarify these relationships.

10. Large-scale farm demonstrations provided data to show that small-plot research findings can be applied to farm production fields.

11. Nitrogen partitioning within the canopies of cereal rye and hairy vetch differed widely and changed with time. Because of the vetch canopy structure and chemical characteristics of vetch leaves, data suggest that a substantial amount of N was released prior to the cover being killed with a herbicide.

12. Canopy structure and chemical characteristics of rye and vetch also affected dry matter disappearance and N release after the covers were killed with a herbicide. For example vetch "melted" down so that most of the plant material came in contact with the soil while much of the rye remained upright and free of soil contact for much of the season. Cell wall N was much higher for rye (12-18%) than for vetch (3-8%).

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Holderbaum, J. F., A. M. Decker, J. J. Meisinger, F. R. Mulford, and L. R. Vough. 1990. Harvest management of a crimson cover crop for no-tillage corn production. Agron. J. 82:918-923.

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POTENTIAL CONTRIBUTIONS AND PRACTICAL APPLICATIONS:

A. If findings of this study are widely adapted, it would be possible for producers to reduce fertilizer nitrogen costs with little or no reduction in grain production levels. There would also be a substantial reduction in erosion and leaching losses from farm land.

B. Further testing will be required but it appears that cereal rye/legume mixtures can approximate pure legume stands in terms of subsequent corn grain yields. Soil moisture conservation efficiency will be improved and recycling of unused FN will approach that of pure rye stands.

AREAS NEEDING ADDITIONAL STUDY:

Studies are needed to more clearly identify the effects of long-term cover crop use in terms of soil organic matter levels, soil nitrogen availability etc. This is especially needed for legume/grass mixtures. How much does the legume in the mixture accelerate the decomposition of the grass component?

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AGRONOMY MIMEO

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Winter Annual Cover Crops for Maryland Corn Production Systems

A. M. Decker, A. J. Clark, J. J. Meisinger, F. R. Mulford, and V. A. Bandel.

OVERVIEW

A. Description and Benefits:

Cover crops are living ground covers grown between periods of regular crop production. Some of the benefits of using cover crops are to:

1. Reduce soil erosion.
2. Add organic matter.
3. Improve soil physical condition.
4. Increase crop yields.
5. Improve water use efficiency in no-tillage systems.
6. Fix atmospheric nitrogen (N) to reduce production costs.
7. Improve fertilizer nitrogen (FN) responses on corn.
8. Recycle unused soil N to reduce leaching losses.

B. Maximum benefits will be realized by selecting the cover crop species that meets the specific climate, soil and cropping needs of individual farm fields.

1. Cover crop selection is the critical first step.
   a. Legumes - fix N and increase water use efficiency.
   b. Grasses - do not add N to the soil; they are excellent recyclers of unused soil N; but the following corn crop requires extra FN.
   c. Legume/grass mixtures - include desirable attributes of each component.

2. Fall establishment of cover crops is second critical step.
   a. Seed as early as possible. Seed after silage harvest or use a shorter season corn hybrid for grain.
   b. Consider aerial seeding before crop harvest, especially after soybeans.
   c. Drilling results in better stands than broadcasting due to better seed placement and seed/soil contact. Seedings can be conventional or no-till.

3. Proper management of established cover crop stands maximizes benefits.
   a. Graze or clip when excessive fall growth occurs. This increases N-fixation and reduces legume stand losses due to diseases.
   b. Spring cover growth can be grazed, harvested for silage, plowed under, or left on the surface as a mulch and N source for no-till corn seedings.
   c. Spring kill date will vary with cover crop species and spring rainfall pattern, but most legumes should be killed by late April to early May. Grasses should usually be killed by early April.
   d. Wait 5 to 15 days before no-tilling into killed covers. This allows soil surface to dry and warm up for faster corn germination and growth.
   e. Corn can sometimes be no-tilled before legume covers are killed; however, this practice is risky on heavy soils during a wet spring.

Educating People To Help Themselves

COVER CROP BENEFITS AND CONSTRAINTS

A. Soil erosion control

Farm land is most susceptible to soil, water, and nutrient losses during the winter between fall harvest and spring replanting. Cover crops provide soil protection during this period by intercepting raindrops, increasing infiltration, and reducing runoff. Early seeded covers that establish rapidly and remain green during the winter offer maximum protection. Cover crops killed and left on the surface also protect the soil against erosion, especially during early corn establishment; this advantage is lost when the covers are plowed under. Annual grasses provide more effective early erosion control than legumes although grass/legume mixtures are also good since the grass component establishes quickly and the legume fills in between the grass plants.

B. Organic Matter

Cover crops add organic matter to the soil by adding fixed carbon from the air through above and below ground residues. Organic matter benefits will vary with cover type and tillage system. Plowing winter covers under will speed up the rate of microbial activity and cover crop decomposition. When soils are tilled, both soil moisture and organic matter can be lost. The detrimental effects of continuous plow tillage on soil organic matter and tilth are illustrated in Table 1. Soil physical conditions and corn grain yields were best when corn was planted after 20 years of continuous pasture and poorest following continuous uncropped, tilled fallow. Continuous soybeans were almost as detrimental as fallow, in part due to the small amount of crop residue returned. Continuous wheat or a 5-year rotation with 3 years of pasture was almost as good as continuous pasture due to high residue additions and reduced winter erosion. The benefits of crop rotations are obvious from these data. A continuous corn system with a winter cover crop is in reality a one-year rotation that has many of the benefits of longer more complicated systems. A 5-yr California study with subterranean clover as a no-till cover crop increased soil organic matter over the no cover check by 1.3% at the 0-2" soil depth and by 0.2% at the 2-6" depth (9). A classic cover crop experiment in Connecticut also reported an increased soil organic matter level of 0.3% following grass covers (10). When killed cover crop residues are left on the soil surface with no-tillage, conditions are favorable for microbial decomposition of the plant residue but the rates are slower than with plow-tillage. Surface crop residues can increase soil organic matter, provide for better aeration and improved water regimes which favor microbial decomposition of these residues. This will improve nutrient storage, water infiltration, and ultimately, crop production.

Table 1. Crop rotation on a Beltsville silt loam soil improved soil conditions and increased crop yields (Strickling, 1975, 11).

20-yr Crop Rotation Systems	Corn Yields Year 21 100 lbs N/A	Soil Organic Matter	Soil Aggregate Stability
	bu/A	%	%
Continuous fallow	32	0.85	6.0
Continuous pasture (P)	153	2.24	45.7
Continuous wheat (W)	144	2.15	41.9
Continuous corn (C)	51	1.66	11.9
Continuous soybeans (S)	66	1.39	8.7
C-W-C	90	1.75	34.3
C-S-W-C	96	1.81	25.0
C-W-P-P-P-C	152	2.19	40.6

C. Water use efficiency:

Winter cover crops can have a marked influence on soil moisture before and after they are killed and left on the soil surface for no-till corn planting.

1. Before Cover Crop Kill

An actively growing cover crop can remove significant amounts of soil moisture. If allowed to grow too long in the spring, soil moisture needed for rapid germination and early corn growth can be depleted. Water use by covers is especially troublesome when March and April rainfall is abnormally low. However, even in below normal rainfall years, soil moisture stress can usually be avoided if the cover is killed by the last week of April. This allows 1 to 3 weeks, if needed, for rain to replenish soil surface moisture before planting corn.

Cover crops differ widely with regard to soil moisture conservation and use. Recent research demonstrated that hairy vetch, which produces a tight uniform cover, results in higher soil moisture before the crop is killed than will a more open rye canopy, or a light weed cover (Fig. 1, top graph). Vetch provides conditions for reduced water runoff, increased infiltration and reduced evaporation from the soil surface. In wet springs, especially on heavier soils, surface soil moisture under the vetch may actually be too high for proper seed placement and good seed/soil contact when planting no-till corn. In such cases, a 5-15 day delay between herbicide application and corn planting may be needed for the soil surface to dry. This delay will also allow soil temperatures to increase for more rapid corn germination. When excess spring moisture is an annual problem, rye may be a better choice to speed up soil drying and allow earlier corn planting.

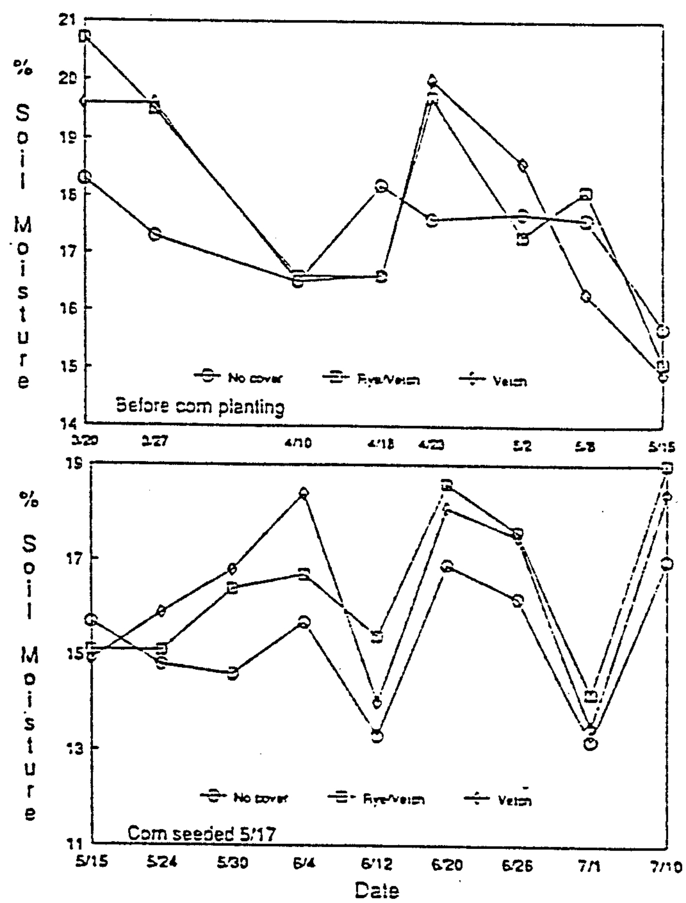

Figure 1. Effects of winter covers in no-till corn system on soil moisture before (top) and after (bottom) corn planting. Poplar Hill, 1991.

2. <u>After Cover Crop Kill</u>

Herbicide-killed cover residues left on the soil surface reduce water runoff, increase infiltration, and reduce surface evaporation. This improves soil moisture conservation, especially before the corn canopy closes when soil surface evaporation is high. Late-killed covers result in better soil moisture conservation than early-killed covers because of heavier, more complete ground cover. Cover residues shade the soil to reduce water evaporation and early weed invasion. Killed legume covers, like vetch, conserve more soil moisture than the more open canopy provided by small grain. Maryland research has shown that vetch/rye mixtures have maintained the best soil moisture relationships into the corn growing season including the very dry year of 1991 (Fig. 1, lower graph). Research data also indicate that soil moisture conservation following corn planting was a more important factor than soil water depletion prior to cover crop kill. However, the net effect of pre-plant water use by the cover vs. post-plant water conservation will obviously depend on the degree of water stress in a particular growing season and the timing of that stress period. This more favorable soil moisture following vetch and vetch/rye mixtures helps explain the enhanced response of corn to nitrogen fertilizer (see synergism, D-2).

D. Soil Nitrogen Relationships:

Cover crops can affect soil N relations by serving as N sources for the next crop, by improving crop response to FN and by conserving residual N that might otherwise be lost to leaching. Corn is one of the most important agronomic crops in Maryland and requires more N than most other crops. Nitrogen is an expensive fertilizer nutrient to manufacture. Price is dependent on the highly variable cost of petroleum used in the manufacturing process. Therefore, efficient N management is extremely important for profitable corn production systems.

1. Nitrogen availability to succeeding crops:

Cover crop N must be released by soil microbes before it can be available for crop use. Legumes killed while still vegetative contain 3 to 4% N and are rapidly decomposed to release N from roots and above-ground growth. For this reason, starter N may not be needed when seeding corn following legume cover crops but can be included with starter P. By mid- to late-summer, most of the legume residue will have broken down and released N for use by a corn crop. Nitrogen release time is related to cover crop species and growth stage at killing. For example, when hairy vetch is killed around May 1, it is still vegetative with 3 to 4% N so microbial decomposition will be rapid. Crimson clover at that date with only 2 to 2.5% N will likely be in full bloom with a lower leaf percent and more fibrous stems resulting in a slower decomposition rate.

Small grain covers, which have a higher fiber and lower N content (1 to 1.5%), decompose more slowly than legumes. Most annual legumes contain adequate N for rapid decomposition of root and top growth by soil microbes while grasses must rely on soil N for this to proceed. The tie up of soil N during plant residue decomposition is called immobilization. This immobilization of soil N by grasses can cause N-deficient corn, especially early in the growing season. Starter FN will usually be required when seeding corn following small grain or other grass cover crops, (unless the field has a history of manure applications). As small grains mature, the N concentration decreases, making it more difficult for soil microbes to decompose the residue. Small grain covers will immobilize less soil N if killed early. However, if early-killed rye provides inadequate moisture conserving mulch, corn grain yields can be lower than after late-killed rye with a better mulch.

The amount of N fixed by fall-seeded legumes and available for subsequent crop use depends on legume species, time of fall establishment, growth stage when killed the following spring, and method of kill. While values vary, approximately 70% of legume-fixed N is found in the top growth. About 60% of total fixed N becomes available the first year. Realistic N credits for hairy vetch, Austrian winter peas, and crimson clover are tabulated in Table 2.

Table 2. Estimated nitrogen credits for three winter legume cover crops.

Cover Crop	Lower Coastal Plain		Central Piedmont	
	Average	Range	Average	Range
	- lbs available N/acre -			
Hairy vetch	100	70-130	80	40-100
Winter peas	90	50-120	60	20-90
Crimson clover*	80	40-120	50	10-85

* Crimson may winter kill in the Piedmont if seeded late and winter is severe.

2. Synergism of Legumes and FN

Synergism might be simply defined as "1 + 1 = 3". We have observed greater FN benefits to corn following legumes, especially vetch, than when following small grain or no seeded cover. Grain yields were higher regardless of how much FN was applied to non-legume covers. This synergism may be due to better soil moisture, improved soil structure, or other "rotation effects" that are not yet well understood. For whatever reason, grain yields following a legume cover are usually greater than following small grain or no cover crop (Fig. 2).

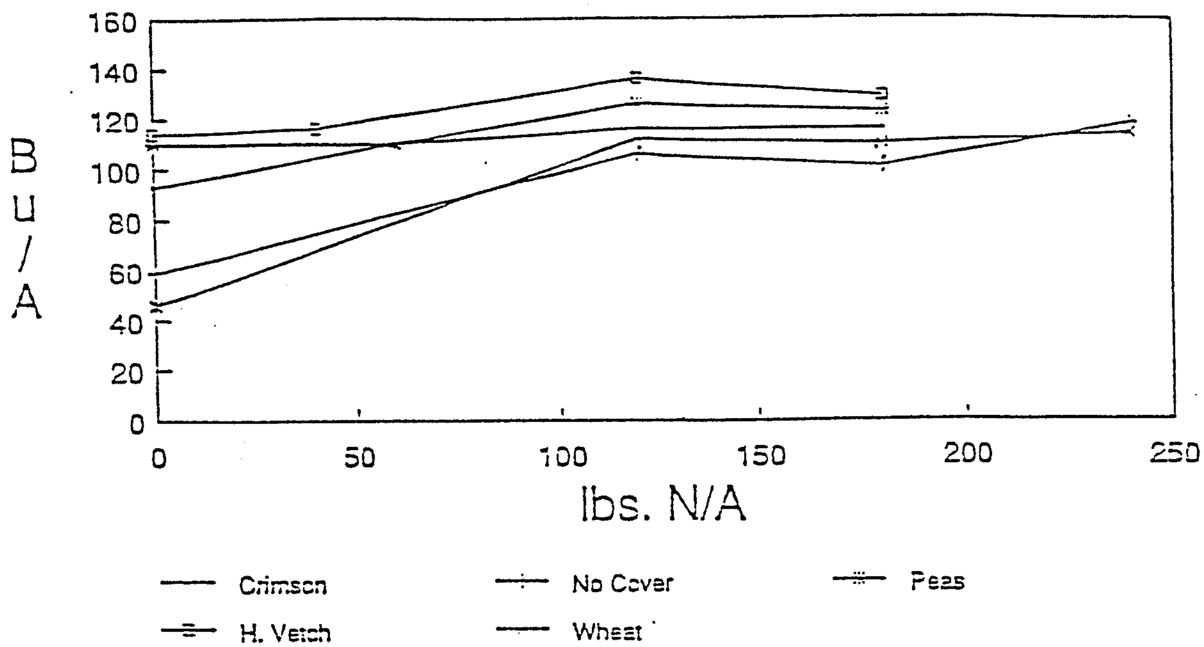

Figure 2. Corn grain yields following five winter covers and four fertilizer nitrogen rates on corn. Poplar Hill, 1983-1988.

Do Not Over-fertilize Corn Following Legume Cover Crops. Legume N credits must be accounted for in your fertilizer program. Depending on soil type, between 40 and 100 lbs of FN will give maximum corn yields following winter legumes. More FN may be needed if legume cover crops are killed before April 20 because legume N production will be low. Due to N immobilization, corn following a small grain cover will require (20-50 lbs/A) more FN than if no cover crop is planted.

3. Conserving Residual Fertilizer N With Cover Crops

Nitrate losses from agriculture into water sources are a concern to society, to agricultural producers, and to farm technical advisors. The agricultural community has an obligation to itself and to society to minimize potential nitrate pollution by developing more efficient N management practices. One such practice is the use of winter cover crops to conserve nitrate, through crop N uptake, during the high-risk, nitrate leaching season of September through May.

Research on a Maryland Coastal Plain soil applied corn FN tagged with 15-N (an isotopic form of N found in minute quantities in nature) in order to follow the fate of FN. Each fall after corn harvest, tagged FN in the soil was measured to a depth of 30 inches. Cereal rye, annual ryegrass, hairy vetch, and crimson clover covers were then planted. Starting in mid-March the following spring FN recovery by the various covers was determined, Fig. 3. Grass covers were more efficient than legumes in recycling unused FN with recoveries of 40 to 60% by mid-April. Legume covers were less efficient, averaging less than 10% FN recovery. Spring nitrate-N concentrations in shallow groundwater below these covers were: 12 ppm for cereal rye, 18 ppm for vetch and 17 ppm for weeds. The greater recovery by rye was reflected in lower nitrate-N concentrations in shallow groundwater. Other research on Maryland's Eastern Shore has also concluded that grass cover crops can reduce the soil nitrate-N concentrations in shallow groundwater (2). A recent extensive literature review concluded that grass covers can reduce both the mass of N leached and the nitrate-N concentrations of the leachate by 20 to 80%, compared to no cover crop (8). The use of cover crops, particularly grasses or grass/legume mixtures, are good management practices to conserve N within the soil/crop system and to reduce nitrate-N contamination of our water resources.

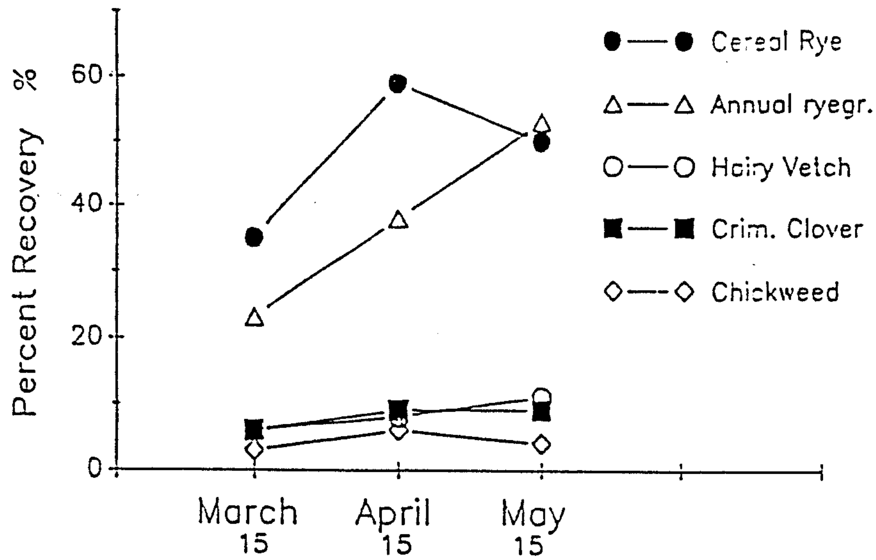

Figure 3. Recovery by five winter covers of fertilizer nitrogen left after corn. (Meisinger, et al. 1991, 8)

COVER CROP SELECTION AND MANAGEMENT

The selection and management of cover crops depends on specific farm conditions. These would include the farm crop rotation system, work schedules, equipment availability, possible use of covers for livestock feed, and a primary purpose for cover crop use, i.e. providing N for the next crop, erosion control, or preventing nitrate leaching. Rotation can dictate cover crop planting methods and seeding dates. For example, legumes or grasses can be easily established after corn, while faster germinating, more winter hardy grasses are more suitable after soybeans. If covers are to be used for livestock feed, grass/legume mixtures produce greater tonnage of a more nutritionally balanced forage.

It is not practical to consider all combinations of crop rotations, potential cover crop uses, and cover crop species in this publication. The remaining discussion will focus on covers used in continuous no-till corn systems.

The use of winter cover crops can improve any rotation that leaves fields unprotected during the winter. When the spring-planted crop is corn or other FN demanding crop, legume covers will be the best choice, especially on soils with low residual N. However, if residual FN levels are high after fall harvests, because of drought, excessive N fertilization etc., a non-legume cover, such as cereal rye, would be better. When the amount of unused soil N is in doubt, a vetch/rye mixture would provide more environmental protection while supplying N to reduce cover crop costs to the farmer. When soil N is high, rye in the mixture will take up the excess N and will dominate the mixture. When the residual N level is low, less N will be taken up by rye and vetch will dominate. This relationship is illustrated in Table 3.

Timely fall establishment of winter covers can more easily be accomplished if some corn can be harvested early as silage rather than as grain. This is especially useful in the shorter Piedmont growing season. Spring growth of covers can be available for grazing before most permanent pastures are ready or they can be harvested for silage before planting corn. A 3-year study at Poplar Hill compared corn production following crimson clover in which the spring growth was used as pasture, silage, or left in place as a mulch and N source for corn. Corn grain yields were reduced 20 to 30% when the crimson was removed as silage. Grain yield were highest when the cover was grazed because frequent defoliation stimulated N fixation and more N was recycled within the system. Total forage production (crimson + corn) was 20% higher than when no cover was seeded. These data demonstrate that the grazing season can be extended, total forage yields increased, and net return increased by using a winter cover crop (5). Grass-legume mixtures are better suited to livestock systems since they are more productive than pure legume stands, and are also more suitable for grazing and silage preservation.

Table 3. Spring dry matter yields and nitrogen contents of rye and rye/vetch mixture components in the second year of a cover crop/no-till corn study. Covers were planted in the fall of 1989, killed the following spring and corn was planted no-till. After the 1990 corn harvest covers were replanted for the second time into the same plots.

Nitrogen applied to corn	Topgrowth D.M. in 1991			Topgrowth N in 1991		
	Vetch/rye mix		Pure rye	Vetch/rye mix		Pure rye
	Vetch	Rye		Vetch	Rye	
		- lbs/A -			- lbs/A -	
0	3749	2254	2815	170	25	24
80	3419	4123	2694	129	38	23
160	3452	4805	3397	135	41	29
240	1693	7718	3507	65	73	26

A. Cover crop selection

Selecting the right cover crop is the most important first step. Questions such as this must be asked: Is the cover crop adapted to my soil and climatic conditions? Do I have the equipment and time needed to fit covers into my cropping system? If the answer is no to any of these types of questions consider other cover crops, other establishment methods, or other cropping systems that are more compatible with your farming operation.

During the early 1980's a large number of winter covers were evaluated at both Coastal Plain and Piedmont locations (4). The species discussed below were identified as best suited for Maryland corn production systems. Other species may be suitable but have not been adequately tested. Note that all of the early Maryland evaluations were made with no-tillage corn following the covers. However, New Jersey research with hairy vetch and cereal rye covers reported similar corn responses when covers were plowed down or killed with herbicides for no-till seeding (3).

1. Hairy vetch (*Vicia villosa*)

Vetch is the most winter hardy and widely adapted of all legumes evaluated. Corn grain yields have consistently been higher following vetch than any cover tested. Vetch makes most of its growth during April and will fix 2 to 3 lbs N per acre per day. It remains vegetative during this period, percent N is high and, when killed, decomposition and N release is more rapid than for most covers. When killed during the last week of April, 40 to 80 lbs of sidedressed FN will give maximum grain yields (Fig. 4). In some years on some soils no FN will be needed. Killed vetch is one of the easiest covers to plant into since it drys down rapidly to form a tight uniform mat. This mat provides excellent moisture conservation resulting in a synergistic response to applied FN. This tight, uniform thatch can reduce early weed invasion, but pigweed in corn following vetch has been an occasional problem. Increased spray gallonage and/or pressure may be needed to insure that residual herbicides reach the soil surface at burndown, or a post emergence herbicide may be needed.

On light soils in some years when the soil surface under the vetch canopy is dry and warm, corn can be planted into the live vetch with the knockdown herbicide applied after corn planting. No-till coulters will easily cut through the standing vetch and will give good seed/soil contact, thus eliminating the need to wait 5 to 15 days for covers to dry before corn planting. This will only work, however, if the soil is dry and warm enough for corn planting. This will not work on heavy soils in a wet spring.

Vetch has large seeds and is one of the easiest covers to establish by conventional seeding methods or by aerial seeding into standing corn when the canopy starts to dry and open up or into soybean just before leaf drop. Aerial seeding into soybeans has a higher success rate than aerial seeding into corn. Vetch has a high hard seed content and can reseed itself if allowed to set seed before it is killed. This would be useful in a continuous corn system, but could present a weed problem in rotations which include small grain. For this reason, vetch is not the best choice for all farm situations. However, vetch ahead of corn would be killed long before seed set so any volunteer plants could only come from hard seeds left from the original vetch planting. These volunteer seedlings can easily be eliminated from small grains with a single spring application of 2,4-D or Harmony. Seeding rate: 15 to 25 lbs/acre.

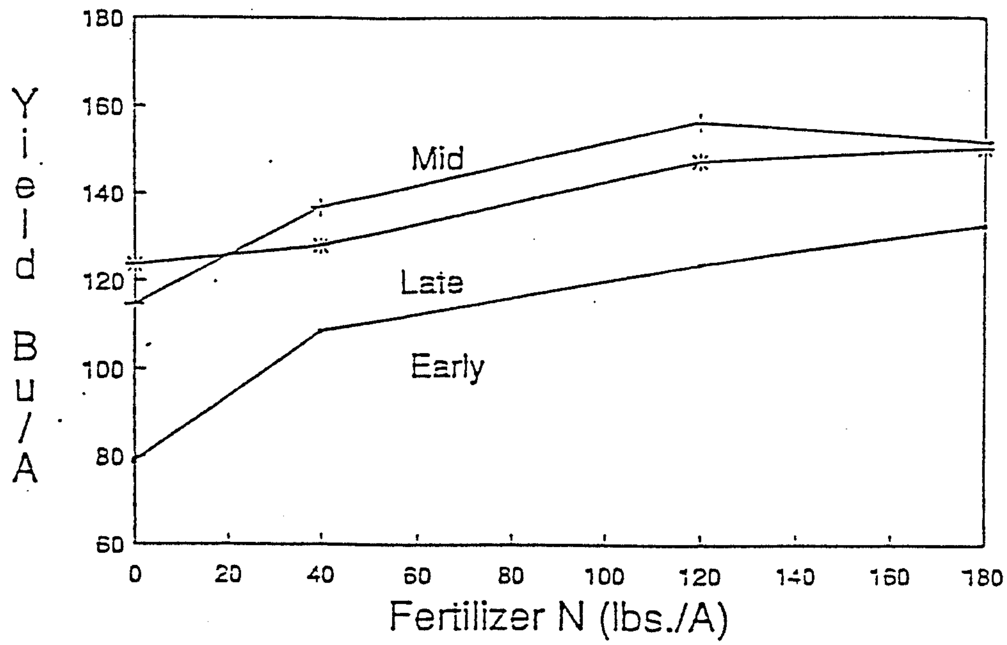

Figure 4. Corn grain yields following hairy vetch killed early (early April), mid (late April) or late (early May) with four FN rates on corn. Poplar Hill Coastal Plain location, 1986-89.

2. Austrian Winter Peas (Pisum arvensis)

Peas are similar to hairy vetch in terms of N production, N availability and soil mulching but high grain yields following peas are less consistent because of susceptibility to winter crown rot diseases resulting in winter stand losses. This is especially true when peas are grown for more than one year on the same field. Peas are more difficult to establish than vetch, and seed cost is higher. Unlike vetch, drilling the seed is essential for satisfactory stand establishment. Peas do not create a weed problem in subsequent crops. Seeding rate: 60 to 100 lbs/acre.

3. Crimson Clover (Trifolium incarnatum)

Crimson is less winter hardy than either vetch or peas, and may not be adapted to many areas of the Piedmont. Crimson has a high hard seed content and when allowed to set seed in the spring will produce adequate seed under the corn for fall establishment. Unlike vetch, however, it does not present a weed problem in small grain because the seed is small enough to be screened out at the combine. It matures more rapidly than vetch or peas, and should be killed about one week earlier (early bloom before flower color starts to fade). It is less susceptible to crown rot diseases than peas but more susceptible than vetch. Seeding rate: 15 to 20 lbs/acre.

4. Cereal Rye (Secale cereale)

Rye establishes readily, provides excellent early ground cover, is disease resistant and winter hardy, makes more winter growth and takes up more residual N than other small grains or any of the above mentioned legumes. Because of its winter hardiness, rye can be seeded later than most winter cover crops, but for maximum protection against erosion and maximum uptake of leachable nitrates it should be planted as soon as possible after summer crops are harvested. However, if planted before the Hessian Fly-free date, increased fly populations may reduce wheat yields on nearby fields the following spring.

While rye is one of the most effective winter covers for recycling unused soil N, very little of that N will be available to the following summer crop if the rye is killed too late. In order to minimize this N immobilization, rye should be killed while vegetative or at least no later than late joint (Feeks stage 8) to early boot (stage 9). This will be late March to early April in the lower Coastal Plain and about one week later for the central Piedmont. Rye grows and matures very rapidly in the spring and one rain at the wrong time can make it extremely difficult to kill at the ideal growth stage. When killed late, increased FN rates will be needed to obtain corn yield goals. Recent Maryland research suggests that early killing of rye (late March) does not eliminate N immobilization and does not always provide adequate mulch for effective soil moisture conservation. If rye is killed in late March and the next 4 to 6 weeks have above normal rainfall, significant nitrate leaching can also occur.

Cultivated crops compete with weeds for light, moisture and plant nutrients. This is often more than simple competition for space. Chemicals with allelopathic potential are present in virtually all plant tissues. The production and toxicity of these chemicals varies widely among species. Rye produces enough allelopathic chemicals to reduce weed populations. In some cases these have even been implicated in corn stand reductions. In addition to alleopathy, volunteer rye can be a serious weed problem for certified small grain producers. Seeding rate: 90 to 120 lbs/A (1.5 to 2 bu.).

5. Legume/Grass Mixtures

Legume/grass mixtures provide scavenging of residual N by the grass and N production by legumes, resulting in corn grain yields which are higher than those following a pure grass, but usually lower than yields following pure legumes (Fig. 5). This may be a necessary trade-off to reduce nitrate contamination of groundwater without a large sacrifice in yield goals.

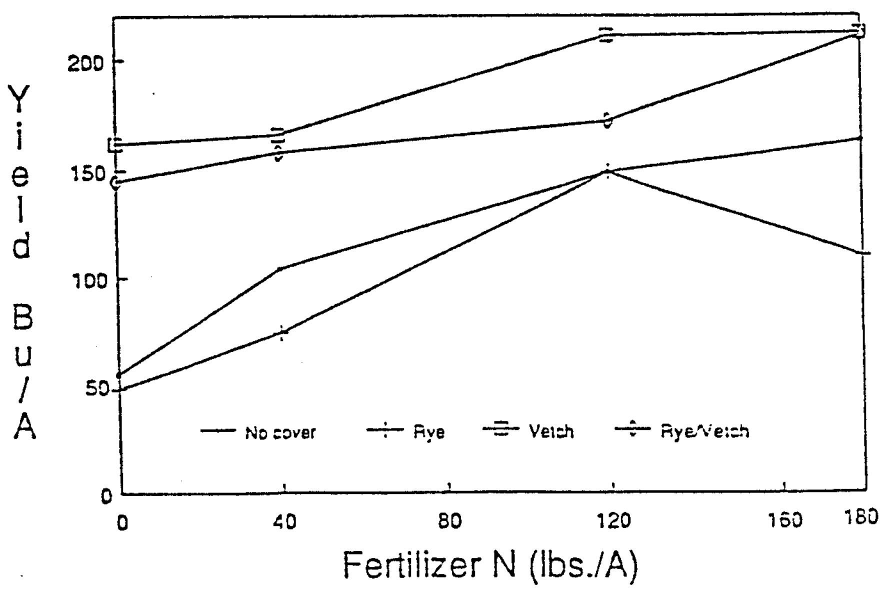

Figure 5. Corn grain yields following no cover, rye, vetch or rye/vetch mixture killed 5/9 with corn planted 5/16 and four corn FN rates. Forage Farm (Piedmont) 1990.

Mixtures can actually serve as a "safety valve" in terms of managing residual soil N levels. Research shows that the botanical composition of mixtures will adjust to residual soil N levels (Table 3, page 6). When residual soil N levels were high rye dominated the mixture and when the N levels were low vetch dominated. When excessive FN (240 lbs/A) was applied to corn, rye growth in the mixture was higher following vetch/rye than following rye alone. Nitrogen accumulation in the topgrowth paralleled that of dry matter yields. In the same study, vetch following unfertilized corn produced 5002 lbs of dry matter and 190 lbs of N, only 5 lbs less than the vetch/rye mixture. Total N production by mixtures is often greater than for pure legume stands, but because of the rye component, more FN may be required for top corn yields. Vetch/rye mixtures can be allowed to grow longer in the spring than pure rye, especially if vetch is at least 50% of the mixture. Kill dates of vetch-dominant mixtures should approach kill dates for pure vetch stands. Rye-dominant mixtures should be managed more like pure rye. Because dry matter yields of mixtures are higher, increased spray volume and/or pressure may be needed for adequate herbicide coverage. The heavier mulch produced by mixtures contributes to better soil moisture conservation but requires a longer period between cover kill and corn planting. This is necessary to allow time for the soil to dry and warm up and for covers to dry so that planter coulters can cut cleanly through the heavy mulch to achieve good seed/soil contact. Seeding rate: 42 lbs rye with 18 lbs vetch, 15 lbs crimson, or 60 lbs of peas per acre.

6. Other cover crops to consider

Early studies (4) established that fall-seeded annual legumes produced more winter/spring growth and provided more N to succeeding crops than adapted fall-seeded perennial forage legumes.

a. Subterranean clover (*Trifolium subterranean*) shows some promise for Maryland but produces less N and is less winter hardy than other legumes listed above. It should be considered only for the Coastal Plain. It is a low-growing legume that produces a very tight thatch which is extremely effective in reducing early weed invasion. Seed is produced below the soil surface, making it an ideal reseeder. Satisfactory stands were maintained by natural reseeding for four years in continuous no-till corn at Poplar Hill. It has a low hard seed content that allows it to germinate completely during the summer in some years. When this occurs too early in the summer, stands can be lost because it is sensitive to heavy shading produced by the corn. Seeding rate: 15 to 20 lbs/acre.

b. Oats (*Avena sativa*) rapidly provides soil coverage to guard against erosion and fall leaching losses. Winter oat varieties winter kill in many areas of the state so provide less protection against winter leaching. Fall-seeded spring oats produce excellent fall growth if seeded early and since they do not survive freezing temperatures, knockdown herbicides are not needed prior to no-till corn planting. Seeding rate: 32 to 64 lbs/A (1 to 2 bu).

c. Wheat (*Triticum aestivum*) and barley (*Hordeum vulgare*) can be used in place of rye. They are less effective recyclers of soil N than rye but, like rye, additional FN will be needed to maintain corn yields. They are later maturing than rye so may be more desirable when seeded with a legume for spring silage harvest. Seeding rate: 60 to 120 lbs/A (1 to 2 bu).

d. Annual ryegrass (*Lolium multiflorium*) makes excellent fall and late spring growth but is less effective than rye in recycling unused soil N. It is potentially a more serious weed problem than either vetch or rye if allowed to go to seed. Seeding rate: 20 lbs/A.

e. (*Brassica napus*) may be as effective as rye for erosion control and recycling of unused FN if established by mid to late September. Research is needed to establish relative value as winter covers. If early rye planting creates a serious Hessian Fly problem species such as rape or canola may offer a viable substitute. When canola is grown for oil seed production, unless combine adjustments are carefully made, substantial amounts of seed can pass through the combine and create a weed problem. However, any volunteer canola plants are easily killed with recommended corn or soybean herbicide programs. Seeding rates 4-5 lbs/A drilled, 5-8 lbs broadcast.

B. Fall Cover Crop Establishment

Seeding cover crops in fields that would otherwise go through the winter without a living plant cover will benefit any cropping system. However, maximum benefits can only be achieved when fall establishment results in early complete ground cover. When this is accomplished, erosion and leaching losses will be less, weed problems will be fewer, soil moisture use efficiency will improve, and legume N fixation will be maximized.

1. Seeding date

All covers, especially legumes, should be seeded as early as possible. Optimum dates are Sept. 10 in the Piedmont and Sept. 20 in the Coastal Plain. Seed covers no later than Oct. 1 or Oct. 15 for respective regions. Early seedings result in more complete winter ground cover and better spring growth. Wye researchers reported fall cover crop yield increases of over 80% when rye was seeded 9/13 rather than 10/13 (1). Rye can be seeded later than legumes although very late seedings will sacrifice ground cover and N recycling. Consider using a shorter-season corn hybrid in continuous corn to allow for early cover crop seeding. Other options include aerial seedings into standing corn or soybeans, or seeding a cover crop where double-crop soybeans were not planted following small grain harvest. Cover crops fit easily into livestock systems where corn silage is harvested early enough for timely seeding. Cover crops must be seeded early; do not delay corn crop seeding until all corn and soybean fields are harvested.

2. Seeding methods

Cover crops can be seeded by no-till or conventional methods. Vetch, peas and rye can be seeded with a grain drill, while the clovers may require a small-seeded legume box on the drill. Plant large-seeded legumes at a depth of 1 to 1.5 inches, and small-seeded legumes, such as crimson or the Brassicas, at 1/4 to 3/4 inches. Vetch, crimson and rye may be aerially seeded into standing corn as the canopy opens up, or into soybeans, just before leaf drop. As the soybean leaves drop they cover the seed to create ideal conditions for germination and early seedling development. Broadcast seedings into standing corn are more dependent on timely rainfall than when seeding into soybeans. Broadcast seedings can be made onto lightly disked soil but the most consistent stands are obtained by drilling. This insures proper seeding depth and good seed/soil contact. This is true even if seeding must be delayed until after corn harvest if the late seeding date is not exceeded. Broadcast seeding rates should be increased by about 20% over the drilling rates listed for individual species.

C. Spring Cover Crop Management and Corn Planting

Covers can be killed by plowing under, herbicide applications, or by mowing, and corn can be planted conventionally or no-till. New Jersey research found no difference in corn silage yields when hairy vetch or cereal rye were plowed under with corn planted into conventional seedbed, compared to killing these covers with herbicides followed by no-till corn planting (3).

Maryland cover crop and corn yield data used in this publication were obtained from no-till corn plantings into herbicide-killed cover crops. This program included Gramoxone plus residual herbicides for later germinating broadleaf and grassy weeds. Herbicide costs may be reduced with pure legume covers by using a 2,4-D/Banvel knockdown followed by post-emergence herbicides such as 2,4-D or Bladex for broadleaf and grassy weeds when IPM indicates a potential problem. Experience shows that 5 to 15 days should be allowed between chemical burndown and no-till corn seeding. When slower acting herbicides, such as 2,4-D or glyphosate, are used more time may be needed for covers to dry and soil to warm and dry for proper seed placement and fast corn germination. Seeding into heavy residue covers while the killed stems are still tough can present problems. It is essential that coulters cut cleanly through plant residues rather than just pushing them into the soil. When this occurs poor seed-soil contact results and poor stands are likely. Planter adjustment is critical to insure that corn seed is placed below the mulch at the proper soil depth.

If the cover is plowed down, microbial breakdown of the plant material will be more rapid. But, in the case of cereal grains such as rye, additional FN will still be required. Plowing eliminates the advantage of a mulch that conserves soil moisture and may, thus, eliminate one of the real advantages of a cover crop. No-tilling corn into living vetch and mowing to kill the vetch after corn has emerged can reduce the need for knockdown herbicides. This can be successful in some years but can also result in severe competition with corn for soil moisture and plant nutrients. For this technique to work, mowing must be delayed until around June 1 in order for mowing to kill the vetch. However, if mowing is delayed that long the growing point of corn can be damaged. Crimson clover, on the other hand, can be killed by mowing in early May since it will be in the reproductive growth phase at that time. However, any cover crop allowed to grow into May can cause soil moisture deficits in some years.

Cover crops can be grazed prior to planting corn. Research and experience suggest that more N is fixed when legumes are grazed. In addition most of the consumed N is returned to the field by the grazing animal. The grazed or harvested cover will also leave an easier surface for no-till establishment of corn.

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