MANAGEMENT AND ASSESSMENT OF WINTER COVER CROP SYSTEMS FOR SUPPLYING NITROGEN TO CORN IN THE MID-ATLANTIC REGION OF THE UNITED STATES

by

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(ABSTRACT)

Research examining cover crop-corn systems focuses on corn planted into chemically desiccated cover crop residue using no-tillage practices. Two field studies including rye (*Secale cereale* L.), hairy vetch (*Vicia villosa* Roth), and rye+hairy vetch cover crops were established to determine the influence of cover crop management on N availability to corn (*Zea mays* L.). The pre-sidedress soil nitrate test (PSNT) and the Nitrate Quick Test were utilized to determine their viability for making N fertilizer recommendations in cover crop-corn systems. Soil N concentrations peaked in the majority of cover crop treatments at the corn four to five leaf stage. Delaying cover crop desiccation from early flowering of rye (early) to early flowering of vetch (late) caused an increase in biomass accumulation in all cover crop treatments, but an increase in N accumulation only in vetch. Vetch provided more plant available N, less soil moisture conservation, and higher corn yields than cover crops including

rye. Early desiccation enhanced plant available N, soil moisture, and corn yield. Mowing cover crop residue enhanced plant available N, soil moisture, and corn yield. The PSNT was a viable method of assessing corn N sufficiency in cover crop systems, but sampling to a depth of 15 cm was adequate. The Nitrate Quick Test was accurate in determining soil nitrate concentrations, but accuracy decreased as soil nitrate decreased.

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Chapter I.
Management and Assessment of Winter Cover Crop Systems for Supplying Nitrogen to Corn in the mid-Atlantic Region of the United States.

1. Introduction

Corn (*Zea mays* L.) is an important crop in the mid-Atlantic region of the United States. In these areas, corn is the number one crop in terms of fertilizer N applied (50). An estimated 638,400 to 1.1 million metric tons of fertilizer N are applied (50, 96, 136, 156) to the approximately 3.8 million hectares of corn planted in the mid-Atlantic states of Maryland, Delaware, Pennsylvania, and Virginia and the neighboring states of West Virginia, Kentucky, Tennessee, North Carolina, South Carolina, and Georgia each year (143, 144).

Recently, groundwater and surface water pollution with nitrate nitrogen (NO_3^--N), partially originating from farmland fertilizer and animal manure N runoff and leaching, has met with much public concern (5, 47, 72, 81, 102, 130). Farm nutrient management strategies or plans have been enacted in response to these concerns (6, 81, 127, 128). The purpose of these nutrient management strategies is to maintain farm production and profitability while preventing groundwater and surface water contamination from farm applied nutrients (6, 81).

Winter cover crops are integral parts of corn production systems in the mid-Atlantic states. Their major benefit is their N supplying capability for

subsequently planted crops, especially corn (66, 118). However, the methods for assessing cover crop N contributions are imprecise, and are dependent on cover crop N content and C/N ratio, residue management, soil type, and climate. The poor predictability of plant available N from cover crops results in imprecise application rates of supplementally required fertilizer N and high potential for N-limited yields or nitrate contamination of water.

A recently calibrated method for assessing soil N contributions to corn in the humid eastern U.S. is soil nitrate testing. The pre-sidedress soil nitrate test (PSNT) has been used successfully to predict corn N sufficiency on fields where organic N sources such as manure and sewage sludge have been applied (31, 35, 82, 84, 87, 115). However, several reports (7, 35, 115) suggest the test is unreliable where alfalfa (*Medicago sativa* L.) is the primary source of N, while another report suggests the PSNT is accurate where other cover crops (i.e. hairy vetch [*Vicia villosa* Roth], crimson clover [*Trifolium incarnatum* L.]) are the primary source of N (87). More research is needed to determine if the PSNT can accurately develop economically and environmentally sound N recommendations for corn where winter cover crops are the primary source of soil N.

Several commercial soil nitrate "quicktest" kits have been marketed to facilitate farmer adoption of the PSNT (35, 70, 116). The ease with which these kits can be used to measure soil [NO_3-N] have furthered the implementation of

the PSNT for making N fertilizer recommendations for corn (31, 35, 116). Research is needed to determine if the quicktest kits are useful tools for measuring soil [NO_3-N] and making fertilizer N recommendations where winter cover crops are the primary source of soil N.

As interest and research in the use of cover crops have increased, questions concerning their management prior to corn planting has also increased. The vast majority of cover crop research has focused on corn that is planted into chemically desiccated cover crop residue using no-tillage practices (10, 19, 21, 28, 56, 59, 68, 86, 90, 147, 159). A lack of synchrony between cover crop N mineralization and corn N uptake has been reported with this system (68). This necessitates additional research to evaluate the influence of cover crop management on the synchrony of cover crop N release with corn N uptake. Furthermore, soil nitrate concentrations need to be measured throughout the growing season in order to determine optimum sampling procedures for assessing N availability to corn in alternative cover crop-corn management systems.

2. Management and Assessment of Winter Cover Crop Systems for Supplying Nitrogen to Corn in the mid-Atlantic Region of the United States

Cover crops are legumes, nonlegumes, or nonlegume-legume mixtures grown to prevent soil erosion and nutrient runoff, add organic matter to the soil, increase soil water retention and availability, increase soil fertility, decrease nutrient leaching (especially NO_3^-), and/or suppress pests (weeds, pathogens, insects) (77, 88, 95). These benefits vary with the type of cover crop grown, establishment methods, residue management, and climatic conditions.

2.1 Historical Use of Cover Crops

Winter cover crops (or green manures) have been used throughout history for their ability to enhance soil productivity. Greeks used green manures as early as 300 B.C. and Romans commonly used green manures for soil improvement (105). Clover and hairy vetch were recommended during United States colonial times to supply N to succeeding crops (8, 88). Rye (*Secale cereale* L.), hairy vetch, and crimson clover were evaluated as N sources for subsequent crops in Alabama in 1898 (27) and were studied extensively early in the 20th century (105).

2.2 Environmental Importance of Cover Crops

Winter cover crops have become increasingly important in the last two decades for environmental and economic reasons. Government programs require certain farmland be vegetatively covered during the winter to prevent erosion (142). The enrichment of surface waters with nitrogen (N) and phosphorus (P), partially originating from farmland runoff, has caused excess growth of aquatic plant and algae life and subsequent fish population decline (102). The use of cover crops as alternative N sources has increased in importance due to rising fuel fertilizer N prices (58).

Excess nitrate (NO_3) in groundwater and surface waters used as human drinking water sources, originating largely from fertilizer or animal manure N, is a potential health hazard (5, 47, 72). Human intake of water containing excessive NO_3 causes methemoglobinemia, a condition characterized by the reduced ability of hemoglobin in the blood to carry oxygen.

Cover crops reduce soil erosion and water runoff by holding the soil in place, decreasing the force of the impact of falling raindrops, and decreasing the velocity and carrying capacity of overland water flow (66, 77, 118). Cover crops also reduce wind erosion in a similar fashion (78, 123). Erosion and water runoff prevention decrease runoff of nutrients (especially N and P) associated with the soil surface and soil surface particles. One study reports reductions in water runoff (61 to 79 percent), soil loss (78 to 88 percent), and N

(66 to 84 percent) and P (65 to 84 percent) transport with cover crops compared with no cover (124).

Winter cover crops, especially nonleguminous species, are excellent scavengers of residual soil N remaining from manure and fertilizer applied to previous crops (22, 45, 118, 123, 131, 161). Uptake by nonleguminous species ranges from 25 to 45 kg N/ha with the exact amount taken up being a function of residual soil N content and mineralization of N in a particular soil system (161).

2.3 Cover Crop Effects on Pest Management

Weeds can be smothered by a cover crop mulch on the soil surface, thereby reducing herbicide needs (41, 69, 77, 118, 167). One explanation is that the reduced transmittance of light to the soil surface under the cover crop residue decreases the emergence of weeds (135). Additionally, rye has been shown to reduce the population of certain broadleaf weeds through its allelopathic effects (77, 118, 135).

Cover crops have been shown to attract beneficial insects that prey on pests of cash crops and to break the cycles of soilborne diseases through crop diversity (77, 103, 117, 118). Although cover crop residues on the soil surface can increase certain pests, especially slugs (*Agriolimax reticulatus* Muller) and armyworm (*Pseudaletia unipuncta* Haworth) (42, 53, 79, 104), reports indicate

that cover crops reduce pests through increasing the biodiversity of soil fauna (24, 77). Furthermore, insect problems can be managed if proper scouting and crop rotation techniques are employed (157).

2.4 Cover Crop Benefits to Soil Productivity

Winter cover crops increase water infiltration into the soil and decrease evaporation losses of soil water if left as a surface mulch (41, 52, 66, 86, 129). This is because the soil surface mulch shades the soil from the sun, insulates the soil from the conductance of heat from the air, and slows water vapor movement from the soil to the air (41). Naderman (94) reported a 25 to 50 percent increase in soil water intake on a fine sandy loam soil following winter cover cropping versus conventionally grown corn.

Cover crops increase soil organic matter content thereby enhancing soil structure by improving soil aggregation, increasing soil macropores, and reducing soil crusting (77). The contribution of organic matter to the soil by cover crops is inherently related to soil erosion control because of increased rainfall capture and retention (78). Furthermore, microbial activity is higher where organic matter is elevated (23, 162).

Soil organic C and N content are increased with the use of cover crops relative to winter fallow (41, 52, 129, 161). The increase is greater under no-tillage than under conventional tillage (41). Ladd et al. (75, 76) reported 72 to

78 percent and 31 to 38 percent legume N in the soil organic N pool after one and eight cropping seasons, respectively, following addition of legume residue.

The major nutrient winter cover crops add to the soil is N, with legumes supplying significant quantities available for succeeding crops (10, 21, 59, 86, 118). Several studies have also reported increases in soil exchangeable K following cover cropping, especially legumes (29, 51, 63). Other researchers reported soils had higher exchangeable Mg and Ca after winter cover crops (63, 80, 164).

2.5 Winter Cover Crops in the mid-Atlantic Region

2.5.1 Soils and Climates of the mid-Atlantic States

The soil and climate of a particular region will greatly influence the success of winter cover crop growth in that area. Certain cover crops are sensitive to severe winters and most are enhanced by a warm spring (118). Inherent soil fertility and water holding capacity will also affect the success of winter cover crops (88). This review will encompass studies conducted in the states of Pennsylvania, Delaware, Maryland, West Virginia, Virginia, Kentucky, Tennessee, North Carolina, South Carolina, and Georgia because of their similar soils and climates and because of the abundance of winter cover crop research available from this region.

Soils in the mid-Atlantic States consist primarily of Ultisols and Inceptisols. Small Alfisol and Entisol inclusions also exist. Ultisols cover most of Georgia, South Carolina, North Carolina, Tennessee, and Virginia while Inceptisols cover most of Pennsylvania, West Virginia, the western part of Virginia, and a portion of Tennessee. Kentucky has approximately equal portions of Ultisols, Inceptisols, and Alfisols (14).

Ultisols of this region are generally highly weathered, well-drained, acidic, and gently to moderately sloping. High contents of iron and aluminum oxides in addition to nonsticky clays provide good workability in the Ultisols of the mid-Atlantic states. Although these soils are not naturally fertile, proper management can insure good crop production in these areas characterized by long growing seasons and adequate moisture (14).

Inceptisols are generally less developed than soils of other orders, except entisols (14). Mid-Atlantic Inceptisols are acidic, low in organic matter, and on moderate to steep slopes. These soils are not naturally fertile, but some can be productive with proper management. Others are less productive because of shallow depth to rock and slow drainage of water.

The inclusions of Entisols and Alfisols in this region are on moderate to level slopes. Entisols can be productive if managed correctly. A controlled water supply is essential to overcome the excessively drained, low water holding nature of these soils. Alfisols are well weathered soils with medium to

high base status and favorable texture for crop production (14). Alfisols rank similarly with Ultisols and Mollisols in their productive ability.

The mid-Atlantic states have a mild climate with an average annual temperature of 15°C (Table 1), average maximum temperature of 20°C (Table 2), and an average minimum temperature of 9°C (Table 3). Precipitation is approximately 114 cm yr^{-1} (Table 4). Fall and winter precipitation average about 9 cm $month^{-1}$ while spring and summer precipitation average about 10 cm $month^{-1}$ (Table 4). Overall, the mid-Atlantic region is a leaching environment, with precipitation being 30 to 50 cm yr^{-1} in excess of evapotranspiration (13).

2.5.2 Adaptability of Cover Crops in the mid-Atlantic Region

Many different cover crops are used in the mid-Atlantic States, most of which exhibit a wide range of adaptability (Tables 5-8). It is important for cover crops to be adapted to the region in which they are to be planted, because poorly adapted cover crop species produce low biomass and N yields (77, 97).

The majority of legume winter cover crops are grown primarily for their N supplying capabilities, while nonlegumes are grown predominately for their rapid fall establishment to provide ground cover and soil N scavenging abilities (19, 24). Nonlegume-legume mixtures have reduced N supplying capabilities, but provide quicker establishment, more winter hardiness, and greater soil N recovering abilities (compared to a legume) (59, 118). Commonly used

Table 1. Average Temperatures for the mid-Atlantic States.*

State	Month												
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Annual
	celsius												
MD	0	2	6	12	17	22	25	25	21	14	8	3	13
KY	1	2	7	13	18	24	25	25	21	15	8	3	14
GA	8	9	13	18	22	26	27	27	24	18	12	8	18
DE	0	1	6	11	17	22	25	24	20	14	8	2	12
WV	1	1	6	12	17	21	23	22	19	13	7	2	12
VA	3	4	8	14	19	23	25	25	20	15	10	4	15
TN	4	6	10	15	20	24	26	25	22	16	10	5	15
SC	7	8	13	17	22	25	27	26	24	18	12	8	17
PA	-2	-1	4	10	16	21	24	22	18	12	6	1	11
NC	6	6	10	15	20	24	26	25	22	16	11	7	16
Average	3	4	8	14	19	23	25	25	21	15	9	4	15

* Ruffner, J.A. and F.E. Bair. 1985. Weather of U.S. cities. 2nd ed. Gale Research Company, Detroit, MI. (119)

Table 2. Average Maximum Temperatures for the mid-Atlantic States.*

State	Month												
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Annual
	celsius												
MD	5	7	12	18	24	29	31	30	26	20	13	7	18
KY	6	7	12	18	24	29	31	30	27	20	12	7	18
GA	13	15	19	24	29	32	32	32	30	25	18	15	24
DE	4	5	11	17	23	28	30	29	26	20	12	6	20
WV	6	7	13	18	24	27	29	29	26	20	12	7	18
VA	8	10	14	20	25	29	31	30	27	21	15	10	20
TN	8	11	16	21	26	30	31	31	28	22	15	10	21
SC	13	14	18	24	27	31	32	31	29	24	18	14	23
PA	2	3	8	15	22	26	29	28	24	17	11	4	16
NC	11	12	16	21	25	29	30	30	27	22	17	12	21
Average	8	9	14	20	25	29	31	30	27	21	14	9	20

* Ruffner, J.A. and F.E. Bair. 1985. Weather of U.S. cities. 2nd ed. Gale Research Company, Detroit, MI. (119)

Table 3. Average Minimum Temperatures for the mid-Atlantic States.*

State	Month												
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Annual
	celsius												
MD	-4	-3	1	6	11	17	20	19	15	8	3	-2	7
KY	-3	-3	2	7	13	18	20	19	15	9	3	-2	8
GA	2	3	7	11	16	20	22	21	18	12	6	3	12
DE	-4	-4	1	6	11	16	13	18	15	8	3	-3	7
WV	-5	-4	0	5	10	15	17	16	12	6	1	-3	6
VA	-2	-1	3	8	13	17	20	19	16	9	4	-1	9
TN	-1	0	4	9	14	18	20	20	16	10	3	0	10
SC	2	3	7	11	16	20	22	22	18	12	7	3	12
PA	-6	-6	-1	4	10	15	18	17	13	7	2	-3	6
NC	0	1	4	9	14	18	21	20	17	11	5	2	10
Average	-2	-1	2	8	13	17	19	19	16	9	4	-1	9

* Ruffner, J.A. and F.E. Bair. 1985. Weather of U.S. cities. 2nd ed. Gale Research Company, Detroit, MI. (119)

Table 4. Average Precipitation for the mid-Atlantic States.*

State	Month												
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Annual
	centimeters												
MD	7.4	7.8	9.4	8.7	8.8	9.9	9.6	11.0	8.6	7.8	7.8	8.8	105.7
KY	10.1	8.3	11.5	9.8	10.0	10.1	10.5	8.7	7.3	6.4	8.5	9.2	111.1
GA	10.6	10.9	13.1	9.9	9.4	10.6	13.3	11.3	9.7	6.3	7.5	10.5	123.2
DE	8.5	7.9	9.5	9.1	9.1	9.7	11.2	11.8	9.2	7.7	8.2	8.9	110.6
WV	8.7	7.6	9.9	9.2	9.8	10.7	12.1	9.8	8.0	7.0	7.2	8.1	109.9
VA	7.9	8.0	9.3	7.9	9.3	9.6	11.9	11.6	8.9	8.4	7.0	8.1	108.0
TN	12.0	11.0	13.4	10.9	10.2	9.8	11.3	9.1	8.1	6.9	9.6	11.6	123.7
SC	9.0	9.5	11.4	8.5	9.8	12.1	14.7	13.3	11.2	8.2	7.3	8.8	123.8
PA	7.2	6.9	8.4	8.6	9.0	9.5	9.7	9.4	8.8	7.1	7.9	7.7	99.9
NC	9.2	9.4	10.5	8.2	10.0	10.8	13.6	12.9	10.9	8.6	7.6	9.4	121.1
Average	9.1	8.7	10.6	9.1	9.5	10.3	11.8	10.9	9.1	7.4	7.9	9.1	113.7

* Ruffner, J.A. and F.E. Bair. 1985. Weather of U.S. cities. 2nd ed. Gale Research Company, Detroit, MI. (119)

Table 5. Legume Biomass, N Content, and C/N Ratio Values.

Cover Crop	Biomass	N Content	C/N ratio*	State	Reference
	---Mg/ha---	---kg N/ha---			
Hairy Vetch	3.8	150	11	NC	(66)
Hairy Vetch	4.3	153	12	GA	(66)
Hairy Vetch	3.7	158	10	NC	(63)
Hairy Vetch	2.8	127	10	GA	(97)
Hairy Vetch	4.1	146	12	GA	(97)
Hairy Vetch	3.3	125	11	KY	(68)
Hairy Vetch	3.4	103	14	KY	(10)
Hairy Vetch	3.4	128	12	GA	(86)
Hairy Vetch	5.1	209	11	KY	(28)
Hairy Vetch	3.1	118	11	KY	(147)
Hairy Vetch	6.2	248	11	MD	(59)
Hairy Vetch	4.3	138	14	VA	(134)
Hairy Vetch	4.0	133	13	MD	(21)
Hairy Vetch	3.3	134	10	NC	(158)
Hairy Vetch	5.3	188	11	NC	(158)
Crimson Clover	5.3	123	19	NC	(66)
Crimson Clover	7.2	170	18	GA	(66)
Crimson Clover	4.8	129	16	NC	(63)
Crimson Clover	3.2	114	12	GA	(97)
Crimson Clover	4.8	108	19	GA	(97)
Crimson Clover	3.5	108	14	GA	(86)
Crimson Clover	2.4	56	19	KY	(28)
Crimson Clover	7.4	229	14	MD	(59)
Crimson Clover	4.7	146	14	MD	(60)
Crimson Clover	4.6	121	17	MD	(21)
Crimson Clover	3.9	113	14	NC	(158)
Crimson Clover	5.5	139	16	NC	(158)
Austrian Winter Pea	5.6	194	13	NC	(66)
Austrian Winter Pea	4.6	161	12	NC	(63)
Austrian Winter Pea	1.6	68	10	GA	(97)
Austrian Winter Pea	1.3	56	10	GA	(86)
Austrian Winter Pea	3.9	147	12	MD	(59)
Austrian Winter Pea	3.9	138	12	MD	(21)
Bigflower Vetch	2.2	67	14	KY	(10)
Bigflower Vetch	1.9	60	14	KY	(28)
Bigflower Vetch	4.6	176	11	MD	(59)
Bigflower Vetch	3.8	101	16	VA	(134)

* Estimates based on plant tissue carbon concentration of 43.5 percent.

Table 5. Legume Biomass, N Content, and C/N Ratio Values -- Continued.

Cover Crop	Biomass	N Content	C/N ratio*	State	Reference
	---Mg/ha---	---kg N/ha---			
Subterranean Clover**	6.0	160	16	NC	(66)
Subterranean Clover	4.0	114	15	GA	(66)
Common Vetch**	4.3	134	14	GA	(66)
Common Vetch	4.6	174	12	MD	(59)
Berseem Clover**	1.5	45	15	GA	(97)
Berseem Clover	2.6	67	17	GA	(86)
Arrowleaf Clover**	2.8	146	8	MD	(59)

* Estimates based on plant tissue carbon concentration of 43.5 percent.

** Subterranean Clover (*Trifolium subterraneum* L.)
Common Vetch (*Vicia sativa* L.)
Berseem Clover (*Trifolium alexandrinum* L.)
Arrowleaf Clover (*Trifolium vesiculosum* Savi)

Table 6. Nonlegume Biomass, N Content, and C/N Ratio Values.

Cover Crop	Biomass	N Content	C/N ratio*	State	Reference
	--Mg/ha--	--kg N/ha--			
Rye	6.3	100	27	NC	(63)
Rye	1.5	14	47	KY	(68)
Rye	2.0	14	62	KY	(10)
Rye	4.6	46	44	DE	(90)
Rye	3.4	36	41	KY	(28)
Rye	3.7	44	37	KY	(147)
Rye	6.5	47	60	VA	(134)
Rye	5.9	79	32	NC	(158)
Rye	8.2	90	38	NC	(158)
Wheat	1.3	39	16	GA	(97)
Wheat	1.4	26	23	GA	(97)
Wheat	1.8	32	24	GA	(86)
Wheat	5.0	74	29	MD	(59)
Wheat	3.5	39	39	MD	(21)
Oats	3.5	46	33	DE	(90)
Barley	4.5	70	28	MD	(59)

* Estimates based on plant tissue carbon concentration of 43.5 percent

Table 7. Nonlegume-Legume Blend Biomass, N Content, and C/N Ratio Values.

Cover Crop	Biomass	N Content	C/N ratio**	State	Reference
	--Mg/ha--	--kg N/ha--			
Rye+Hairy Vetch	7.9	159	22	DE	(90)
Rye+Hairy Vetch	8.6	155	24	VA	(134)
Rye+Crimson Clover	8.2	147	24	DE	(90)
Oats+Crimson Clover	6.4	160	17	DE	(90)
Oats+Hairy Vetch	6.0	151	17	DE	(90)
Wheat+Hairy Vetch	7.1	232	13	MD	(59)
Wheat+Bigflower Vetch	6.8	179	17	MD	(59)
Wheat+Common Vetch	6.2	223	12	MD	(59)
Wheat+Austrian Winter Pea	6.6	194	15	MD	(59)

* Estimates based on plant tissue carbon concentration of 43.5 percent.

Table 8. Average Values for Cover Crop Biomass, N Content, and C/N Ratio.

Cover Crop	Biomass	N Content	C/N ratio	Observations
	--Mg/ha--	--kg N/ha--		
Hairy Vetch	4.0	151	12	15
Crimson Clover	4.8	129	16	12
Austrian Winter Pea	3.5	127	12	6
Bigflower Vetch	3.1	101	14	4
Rye	4.7	52	43	9
Wheat	2.6	42	26	5
Rye+Hairy Vetch	8.3	157	23	2

nonleguminous cover crops are the small grains and include rye, wheat (*Triticum aestivum* L.), oats (*Avena sativa* L.), and barley (*Hordeum vulgare* L.). These cover crops are adapted to a wide range of soils and climates and prove useful in the mid-Atlantic region (161). Rye, however, is the most widely used nonlegume winter cover crop because, relative to the other small grains, it produces a larger amount of winter ground cover, is more winter hardy, and scavenges more residual N (Table 8) (64, 88, 118).

Legume cover crops commonly used in this region are hairy vetch, crimson clover, bigflower vetch (*Vicia grandiflora* var. *Kitaibeliana* W. Koch), and austrian winter pea [*Pisum sativum* sap. (L.) Poir] (Tables 5 & 7-8) (66, 129). Various others are used to a much lesser extent and prove to be less beneficial than the previously mentioned legume crops (Tables 5 & 9).

Hairy vetch and crimson clover appear to be the two best adapted and most widely used legume cover crops in the mid-Atlantic (Table 8) (41, 63, 86, 97, 141, 159). They establish easily, are winter hardy, break dormancy early in the spring, grow rapidly, assimilate high amounts of N, and result in good yield responses by summer crops that follow them (41, 59, 141). Crimson clover has better early season fall growth and matures earlier in the spring than hairy vetch, but produces and releases less N, is less cold tolerant, and produces less biomass than hairy vetch in the northern mid-Atlantic states (Table 8) (41, 59, 66, 68, 118, 129).

2.6 Important Characteristics of Winter Cover Crops that Influence N Accumulation and Availability to Corn

Approximately 80 to 90 percent of the N in cover crops is contained in topgrowth (i.e. aboveground biomass) (118, 129). Mitchell and Teel (90) reported less than one third of the total dry matter was below ground and the N concentration in the roots was less than half that in the topgrowth of seven winter cover crops studied. The percentage of total N accumulated in the roots ranged from 8 to 23 percent with an overall average of 12 percent. Reeves et al. (111) reported that N accumulation in roots of crimson clover and rye ranged from 12.1 to 21.4 percent and 8.6 to 15.3 percent, respectively. This is extremely important because studies have indicated that the quantity of cover crop N produced is dependent mainly on biomass production and N concentration of the tissue (97). Cover crops with lower N concentrations can produce as much N as crops with higher N concentrations if the former produces more total biomass than the latter, and vice versa (77, 97, 129).

Cover crop N release is dependent on cover crop N content and thus, cover crop C/N ratio (37). Winter cover crop C/N ratios range from approximately 10 to 60 (Tables 5-6). Legumes generally have C/N ratios of less than 20 and nonlegumes generally have C/N ratios of greater than 30 (Tables 5-6) (68, 86, 158, 159). Most research agrees that vegetative material and/or organic matter with a C/N ratio less than 20 results in net N mineralization,

greater than 30 results in net N immobilization, and between 20 and 30 results in neither net N immobilization or mineralization (37, 139, 155).

Legumes produce more biomass and N when compared to nonlegumes (Tables 5-6 & 8) (41, 68, 91, 118, 158). Additionally, legumes accumulated higher levels of P, K, Ca, and Mg than rye (45). Legumes also provide more N for a subsequent corn crop while nonlegumes recycle more soil N during the fall and winter (10, 45, 59, 68, 86, 88, 118). Early season soil inorganic N, corn N uptake, and corn yield are higher following legumes than following nonlegumes (28, 40, 68, 145, 148, 159).

Hairy vetch is reported to produce the most biomass and N of all winter cover crops (41, 68, 118) (Tables 5-6 & 8) (91, 158). Nitrogen contributions of hairy vetch to corn is the highest of all legumes (91, 158).

Most investigators agree that winter legumes reduce N leaching very little compared to nonlegumes (45, 88). The reductions for nonlegumes are approximately 60-70 percent and the reductions for legumes are approximately 10-23 percent (88, 125). Nonlegumes compete in a timely manner with N leaching because of their rapid fall establishment, and since they have small ranges in N concentration, the nonlegume that produces the most dry matter immobilizes the greatest amount of N (88). Additionally, nonlegume N uptake has been shown to be a function of the N application to the previous crop (22,

67, 121, 145). Research indicates N recovery by nonlegumes to be in the following order: rye > wheat > barley = oats (88, 132).

Legumes inability to reduce N leaching significantly is attributed to their small amount of fall growth which allows N to leach during the winter before the legumes resume active spring growth (65, 88). Studies have shown, though, that legumes will not begin to fix N_2 until soil NO_3^--N is low (54, 154). It is estimated that 40 to 70 percent of legume N uptake is met by fixation, while the remaining is met by uptake of indigenous soil N (33). Thus, legumes have the potential to reduce NO_3^--N leaching to the extent that they use soil N rather than N_2 fixation to meet their N needs (88).

Legumes decompose and release N faster than nonlegumes due to lower C/N ratios (45, 158). Soil N levels are also higher in corn systems including legumes rather than nonlegumes, despite higher corn N uptake in legume systems (28, 68, 145, 148, 159). Corn N uptake following legumes is reported to be as much as 60 kg N ha^{-1} higher than following nonlegumes (148). Furthermore, corn yields are reported to be 60 percent higher following legumes than following nonlegumes without supplemental N fertilization (40).

Winter cover crops reduce soil moisture in the spring, which could possibly retard germination and early season growth of corn (118, 129). Conversely, this may be a benefit on poorly drained soils because soil water is transpired in the spring to allow earlier planting of the subsequent crop (52, 66).

Investigators have concluded that soil water depletion by a rye or hairy vetch cover crop is significantly greater than that of fallow, even to a depth of 60 cm, at the time of corn planting (18, 19, 92, 145). Two weeks to one month after corn planting, though, the soil water content is reported to be significantly greater under the cover crop mulch as compared with no cover (19, 145). Two months after corn planting soil water content differences between the two systems disappear (19).

Moschler et al. (91) reported rye to be the best cover crop (including legumes and fallow) to sod plant corn into due to rye's large amount of persistent water conserving mulch (N fertilizer was applied in all cases). Wheat seemed to be the second best. Munawar et al. (92) reported similar results and stated that killing rye several weeks before corn planting enhanced early season soil moisture when compared to killing rye immediately prior to corn planting.

Nitrogen from cover crops can be immobilized as soil organic nitrogen and be unavailable to the first summer crop that follows, but available to crops after that (40, 41, 43). Corn N uptake increases of as much as 30 kg N ha^{-1} have been attributed to cover crops from previous years (85, 145). This is probably attributable to the increase in soil organic N, but could be partially due to improved soil physical condition and water relations resulting from the increased organic matter (40, 41, 43).

Winter cover crops can increase denitrification by supplying denitrifiers with available carbon (C) through root exudation and mineralization of decaying tissue (26). The C exudates stimulate microbial respiration and thereby deplete soil oxygen, further enhancing denitrification. Drury et al. (26) reported that hairy vetch and red clover produced 100 and 90 ppm N as N_2O, respectively, while 3.5 ppm N as N_2O was emitted from a bare soil surface. These researchers suggested delaying N fertilizer applications to crops following plowing or chemical killing of winter cover crops in order to decrease the potential for denitrification.

2.6.1 Legumes

2.6.1a N Mineralization and Corn N Recovery

Ebelhar et al. (28) and Utomo (145) measured inorganic soil nitrogen following winter cover cropping and winter fallow. No differences in soil N were found at corn planting, but three to five weeks later hairy vetch plots were significantly higher in inorganic N than fallow plots. Ebelhar et al. (28) found hairy vetch plots had 22 to 30 more mg N/ha than fallow plots in the 0 to 7.5 cm soil depth, but by the end of July this difference ceased. They also reported that corn yields were about 2.5 Mg/ha higher following hairy vetch than following winter fallow where no N fertilizer was applied.

Corn recovery of cover crop N is substantially lower than that of inorganic fertilizer N, and is often influenced by climate, N content of the added residue, soil fertility status, and previous cropping history (24, 129). Studies have reported that approximately 29 to 38 percent of cover crop N is recovered by corn (68, 90, 159). Reports suggest that legume N is 31 to 85 percent as efficient as fertilizer N, depending on climatic and management factors (38, 133). Smith et al. (129) found ^{15}N recoveries in grain crops of 7 to 30 % from labeled legume and nonlegume residues as compared to an average of 25 to 40 percent recovery from inorganic N fertilizer.

Soil inorganic N and N recovery by corn are less from winter cover crop residue than N fertilizer due to both greater cover crop N immobilization and the dependence of cover crop N mineralization on decomposition rate (153). Huntington et al. (68) suggested that poor synchronization between N release and corn need and uptake was the cause. The authors suggested that cover crops should be managed to increase N decomposition rate to enhance corn N recovery. Varco (148) found that legume N was twice as likely as fertilizer N to be immobilized in the organic N fraction of the soil, which may explain why McCraken et al. (85) reported higher corn yield and corn N uptake following a 10 year history of hairy vetch winter cover cropping compared to a 10 year history of N fertilization.

2.6.1b Corn Responses to Legume Cover Crops

Three unique yield responses of corn crops following legume cover crops compared to corn in fallow cropping systems with a range of fertilizer N rates have been observed (32, 71, 129). The first type of response characterizes legumes as N contributors only, i.e. corn may or may not respond to fertilizer N in either system, but at high rates of N the fallow-corn system and legume-corn system are equal in yield (129).

In the second type of response, corn following a legume maintains a higher yield than corn in a fallow system, despite N rate (129). This indicates that legumes provide yield enhancing benefits in addition to N. These benefits may be increased soil water efficiency, better pest control, or something termed the "rotation effect" (129).

Utomo et al. (147) observed higher corn yields following a hairy vetch cover crop compared to corn following fallow, but concluded that reducing N fertilizer requirements for corn following legumes was not practical because of the higher corn yield potential in these systems. Similar corn yield patterns were observed by Moschler et al. (91), Ebelhar et al. (28), and Mitchell and Teel (90). In determining the significance of N-related versus non-N related benefits of legumes, most reports state that an N contribution is almost always seen and additional benefits are not (129).

In the third type of response, increasing fertilizer N rates reverse the yield rankings of the two systems, i.e. yields following legumes are higher at low N rates but lower at high N rates when compared to corn yields following fallow (129). This suggests legumes supply N to subsequent crops when N is limiting but have a negative effect on corn yield when N is sufficient. One explanation is that the legume produces some phytotoxic substance(s) or allelochemical(s) that retard corn yield (19, 129). Corak et al. (19) and Worsham (166) have reported responses of this type.

2.6.1c Effects of Management Techniques on Legume Yield, Decomposition, and N Release and on Corn Yield

Wagger (158, 159) studied the effects of cover crop desiccation timing relative to corn planting [early desiccation/early plant (EE), early desiccation/late plant (EL), and late desiccation/late plant (LL)] on cover crop biomass and N content and on corn growth and yield. The delay in cover crop desiccation resulted in a 41 percent and 61 percent increase in dry matter produced by crimson clover and hairy vetch, respectively. Corresponding increases in total cover crop N content for the delayed desiccation were 23 percent for crimson clover and 41 percent for hairy vetch, although differences in C/N ratios were not significant between desiccation times. The delay in desiccation had more of

an effect on vetch because it matures 3 to 4 weeks later than crimson clover in North Carolina.

Vetch released N faster than clover, likely due to lower vetch C/N ratios. The early desiccation fostered a faster rate of cover crop residue decomposition for both covers, but by 16 weeks after corn planting the N remaining between kill times for each residue had approached nearly the same level. Estimates of N released from clover by week 8 suggest the available N for corn to be greater for early desiccation time. Ranells and Wagger (108), in a separate study, reported killing crimson clover at late bloom stage maximized the covers topgrowth N content and subsequent N release. In contrast to clover, the increased N content of vetch due to late desiccation compensated for a somewhat slower decomposition rate.

Corn following hairy vetch responded to N fertilizer only with the EL treatment, indicating poor synchronization between corn N need and vetch N release with this treatment. Corn following crimson clover responded to fertilizer N under the EE and LL management schemes and yield levels were comparable to those with hairy vetch. However, Wagger reported higher corn N recovery and no response to fertilizer N for clover under the EL management scheme, indicating the possibility of enhanced synchrony between clover N mineralization and corn N demand with that treatment. It seemed that increasing the time interval between clover kill and corn planting enhanced the

synchrony of the release of the more slowly available clover N (compared to vetch) with corn N need and uptake.

2.6.2 Nonlegumes

2.6.2a N Mineralization and Corn N Recovery

Nonlegumes are reported to contribute small amounts of N to corn, with many corn systems including nonlegumes being characterized by N immobilization (10, 21, 59, 86, 141, 165). This is due to their low N content and high C/N ratio, which often results in immobilization of residue N, indigenous soil N, and fertilizer N (Tables 6 & 8) (24, 59, 158). Also, as one study describes, the majority of N mineralized from rye becomes available only after a period corresponding to corn silking (68). This suggests poor synchronization between N release via cover crop mineralization and corn N need and uptake in a nonlegume-corn system. The major benefits a nonlegume can offer are winter ground cover, soil N recycling, and soil water conservation (19, 24, 48, 88, 91, 118).

2.6.2b The Effects of Management Techniques on Nonlegume Yield, Decomposition, and N Release and on Corn Yield

The same study by Wagger (158, 159) that was discussed in section 2.6.1c included rye as one of the cover crop treatments. Delaying cover crop

kill resulted in an increase in biomass and N production, but both desiccation times resulted in net N immobilization. Corn following rye responded to N fertilizer under all treatments, but the EL treatment responded to the highest rate of N, indicating delaying corn planting after rye desiccation may result in greater N immobilization. Wagger stated subjecting a high C/N ratio material to a longer contact period with soil microbes increased the potential for N immobilization.

2.6.3 Effect of Tillage on Cover Crop Decomposition and N Release and Corn Yields

Although cover crop decomposition and mineralization are faster under conventional tillage systems, cover crop N release, corn N uptake, and corn yield are reported to be similar under both conventional till and no-till systems (11, 15, 28, 34, 45, 62, 85, 91, 100, 107, 147, 150, 155, 163). Moisture, not cover crop N mineralization, appears to be the major yield limiting factor resulting from tillage differences. Corn yields are higher in no-till systems during years of limited rainfall (due to the water conserving mulch) while corn yields are similar under both systems in years of adequate rainfall (152, 153, 159).

Researchers in Kentucky, Georgia, and North Carolina report faster decomposition and N release from cover crops in conventional tillage

compared to no-tillage (45, 148, 152, 153, 158, 163). These scientists stated residue degradation was limited by moisture, not N concentration of the tissue. Differences in N release patterns for both systems are frequently attributed to climate, with N release patterns being faster overall with greater differences between systems in years of adequate rainfall and slower overall with lesser differences between systems in years of inadequate rainfall. However, reports suggest that N release in either system is sufficiently fast to benefit a subsequent crop and that significant differences are limited to a short period of time immediately after initial cover crop kill (158, 163).

Availability of N to corn has been reported to be higher under conventional tillage than no-tillage due to greater mineralization in conventionally tilled soils (41, 145, 147, 152). However, reports exist displaying a decrease in soil inorganic N recovery with residue incorporation into the soil than when left on the soil surface (150, 153). Again, the explanation is that cover crop N mineralization is more dependent on precipitation than on tillage (150, 152, 153).

Investigators agree that few differences exist in N recovery by corn under either tillage system (32, 140, 148, 152). Varco et al. (151, 152) found little difference in recovery of legume crop N between no-till and conventional till corn, which averaged 57 and 52 percent, respectively. The average recovery, however, of isotopically labeled vetch residue did vary with tillage and averaged

32 percent for conventional tillage and 20 percent with no-till. The greater effect of no-till on isotopic recovery than recovery by difference suggests greater exchange between soil N and vetch N pools and greater (or longer) storage of vetch N in soil N pools (24).

2.6.4 Nonlegume-Legume Blends

Nonlegume-legume blends have been used to acquire the advantages of both species of cover crops. The nonlegume provides early season fall establishment and soil N uptake before the extensive leaching season begins, while the legume provides rapid spring growth and N contributions to a following corn crop. Despite the benefits of blends, very little research has been done to determine their usefulness and viability as a winter cover crop.

Hairy vetch-rye blends have been shown to supply 75 to 112 kg N ha^{-1} to corn while hairy vetch-wheat mixtures have contributed 50 kg N ha^{-1} (90, 118). In contrast, nonlegume-legume blends have also been shown to contribute very little N to a following corn crop (59). Moschler et al. (91) found that corn yields were not statistically different between blends and nonlegumes alone. Research does indicate, however, that N fertilizer recommendations for corn following a cover crop blend can be reduced (17, 90, 118).

Mitchell and Teel (90) reported little increase in dry matter yield between rye and rye-hairy vetch or rye-crimson clover mix, but a drastic increase in total

N produced by the cover was observed when a legume was included. It was reported that rye suppressed the legume growth, though. Additionally, dry matter yield and total N produced was drastically increased when either of the legumes was added to an oat cover crop, but the oat contributed less than 10 percent of the dry matter. A study in Virginia (91) reported the inclusion of hairy vetch or crimson clover in with a small grain also only slightly increased biomass yields of the winter cover.

Mitchell and Teel (90) reported that approximately 33 percent of legume N was released from a blend and taken up by corn in a single season. Corn yields were higher for the blends than for fallow or the nonlegume alone. They also reported that corn N fertilizer recovery was suppressed by the covers, indicating fertilizer N immobilization by the rye part of the blend.

2.7 Tillage Effects on N Availability, Corn N Recovery, and Corn Yield in Cover Crop Systems

Tillage practice influences major processes in soil that influence N availability to crops. Tillage decreases NO_3^- leaching, denitrification, ammonia volatilization, and N immobilization and increases N mineralization (2, 3, 4, 25, 30, 44, 73, 106, 113, 114, 137, 138, 160). Tillage also decreases soil moisture, soil organic matter, incidence of disease and insect infestations, soil surface microbial activity, and soil surface acidity and increases soil temperatures and

soil temperature fluctuations, factors that indirectly affect N availability and crop uptake (9, 12, 23, 90, 101, 104, 129, 146, 162).

2.8 Measuring and Predicting N Contributions from Winter Cover Crops to Corn

2.8.1 Techniques for Measuring Cover Crop N Contributions to Corn

Various methods for measuring cover crop N contributions to subsequent crops have been used by researchers in the past. For all these methods, cover crop N contributions are comprised of both biologically fixed N and soil N uptake by the cover crop (57). Using the vast amount of research measuring these N contributions from cover crops, estimates have been devised for crediting cover crops with N contribution values, or fertilizer replacement values, based on the cover crop species (Tables 9-11).

Measuring the N content of the cover crop biomass is the simplest of the N contribution measurement methods. This is calculated by multiplying the amount of cover crop biomass added to the soil by the N concentration of that biomass to arrive at a quantity of N (in kg ha^{-1}) produced by the cover (57). A major limitation of this method is that only a portion of the cover crop N will be available to the next crop. The remainder can be accounted for in soil organic matter, the inorganic N pool, or in losses from the system. Nitrogen

Table 9. Legume Cover Crop N Contributions to Corn.

Cover Crop	N Contribution	State	Reference
	---kg N/ha---		
Hairy Vetch	78[3]	KY	(149)
Hairy Vetch	200[3]	NC	(166)
Hairy Vetch	66[3]	KY	(56)
Hairy Vetch	45[1]	KY	(68)
Hairy Vetch	75[3]	KY	(10)
Hairy Vetch	85[4]	KY	(10)
Hairy Vetch	75[3]	TN	(141)
Hairy Vetch	125[4]	TN	(141)
Hairy Vetch	103[4]	GA	(86)
Hairy Vetch	95[3]	GA	(86)
Hairy Vetch	142[1]	GA	(86)
Hairy Vetch	152[2]	GA	(86)
Hairy Vetch	95[3]	KY	(28)
Hairy Vetch	70[1]	MD	(59)
Hairy Vetch	96[2]	MD	(59)
Hairy Vetch	55[1]	MD	(21)
Hairy Vetch	65[2]	MD	(21)
Hairy Vetch	45[1]	NC	(158)
Hairy Vetch	170[3]	KY	(147)
Hairy Vetch	30[1]	KY	(19)
Crimson Clover	100[3]	NC	(166)
Crimson Clover	90[4]	GA	(86)
Crimson Clover	77[3]	GA	(86)
Crimson Clover	116[1]	GA	(86)
Crimson Clover	112[2]	GA	(86)
Crimson Clover	22[3]	KY	(28)
Crimson Clover	59[1]	MD	(59)
Crimson Clover	64[2]	MD	(59)
Crimson Clover	45[1]	MD	(61)
Crimson Clover	43[1]	MD	(60)
Crimson Clover	52[1]	MD	(21)
Crimson Clover	62[2]	MD	(21)
Crimson Clover	40[1]	NC	(158)
Bigflower Vetch	64[3]	KY	(56)
Bigflower Vetch	65[3]	KY	(10)
Bigflower Vetch	75[4]	KY	(10)
Bigflower Vetch	15[3]	KY	(28)
Bigflower Vetch	58[1]	MD	(59)
Bigflower Vetch	87[2]	MD	(59)

Table 9. Legume Cover Crop N Contributions to Corn -- Continued.

Cover Crop	N Contribution	State	Reference
	---kg N/ha---		
Austrian Winter Pea	79(4)	GA	(86)
Austrian Winter Pea	91(3)	GA	(86)
Austrian Winter Pea	73(1)	GA	(86)
Austrian Winter Pea	96(2)	GA	(86)
Austrian Winter Pea	56(1)	MD	(21)
Austrian Winter Pea	64(2)	MD	(21)
Austrian Winter Pea	57(1)	MD	(59)
Austrian Winter Pea	86(2)	MD	(59)
Berseem Clover	53(4)	GA	(86)
Berseem Clover	27(3)	GA	(86)
Berseem Clover	36(1)	GA	(86)
Berseem Clover	50(2)	GA	(86)
Common Vetch	86(1)	MD	(59)
Common Vetch	91(2)	MD	(59)
Arrowleaf Clover	54(1)	MD	(59)
Arrowleaf Clover	59(2)	MD	(59)
Subterranean Clover	4(1)	MD	(59)
Subterranean Clover	4(2)	MD	(59)

(1) N contribution determined by subtracting corn N recovery in a fallow plot from corn N recovery in legume a plot, i.e. corn N recovery difference method.

(2) N contribution determined by subtracting corn N recovery in a nonlegume plot from corn N recovery in a legume plot, i.e. corn N recovery difference method.

(3) N contribution determined by ascertaining the N fertilizer required by corn in a fallow plot to reach the same yield as corn in a legume plot without fertilizer N, i.e. N fertilizer replacement method.

(4) N contribution determined by ascertaining the N fertilizer required by corn in a nonlegume plot to reach the same yield as corn in a legume plot without fertilizer N, i.e. N fertilizer replacement method.

Table 10. Nonlegume-Legume Blend Cover Crop N Contributions to Corn.

Cover Crop	N Contribution	State	Reference
	---kg N/ha---		
Rye+Crimson Clover	112[2]	DE	(90)
Rye+Hairy Vetch	112[2]	DE	(90)
Oats+Hairy Vetch	112[2]	DE	(90)
Oats+Crimson Clover	112[2]	DE	(90)
Wheat+Hairy Vetch	56[2]	TN	(17)
Wheat+Hairy Vetch	8[1]	MD	(59)
Wheat+Bigflower Vetch	-5[1]	MD	(59)
Wheat+Austrian Winter Pea	18[1]	MD	(59)
Wheat+Common Vetch	78[1]	MD	(59)

(1) N contribution determined by subtracting corn N recovery in a fallow plot from corn N recovery in legume a plot, i.e. corn N recovery difference method.

(2) N contribution determined by ascertaining the N fertilizer required by corn in a fallow plot to reach the same yield as corn in a legume plot without fertilizer N, i.e. N fertilizer replacement method.

Table 11. Legume N Contributions to Corn Averaged by Cover Crop Species.

Cover Crop	N Contribution	Observations
	---kg N/ha---	
Hairy Vetch	94	22
Crimson Clover	67	14
Bigflower Vetch	59	7
Austrian Winter Pea	75	8

contribution values using this technique are limited and therefore estimates using this method will not be reported in this review.

Another method utilizes ^{15}N to enrich the cover crop plant material (152, 153). The succeeding crop is then analyzed to determine the quantity of ^{15}N it recovered (152, 153). Although this can be an accurate method for determining cover crop N contributions to corn there is high cost and/or difficulty involved in the purchasing of ^{15}N and the analysis of plant and soil samples for ^{15}N enrichment (57). Few nitrogen contribution values have been reported using this technique, therefore, estimates using this method will not be reported in this review.

A third method utilized is the N-fertilizer equivalence or N-fertilizer replacement value of a cover crop. Fertilizer-N equivalence (or replacement) is defined as the amount of N fertilizer needed in a fallow or nonlegume cover crop treatment to achieve a crop yield equal to that obtained on the winter cover crop treatment without N fertilizer (41, 51, 57, 86, 129). Some researchers (51, 55, 120, 129) have suggested weaknesses in this approach due to the fact it does not take into account cover crop effects on soil temperature, soil water relations, soil physical condition, alteration of the N supplying capacity of the soil, and other factors that may lead to higher yields under a cover cropping system. A major advantage of the fertilizer-N equivalence method is that the value of the cover crop can be estimated, for

management purposes, in terms of two easily determined parameters, i.e. crop yield and N fertilizer applied (41, 129).

The final technique for measuring N contributions by cover crops is the corn N recovery (uptake) difference method. Corn N recovery difference is calculated by subtracting corn N uptake on a fallow or nonlegume cover crop system from the corn N uptake on a legume or nonlegume-legume cover crop system (with no fertilizer nitrogen applied in either system). Similarly, this technique does not take into account cover crop effects on soil temperature, soil water relations, and soil physical condition which may alter cover crop and soil N availability (51, 86, 120, 129).

The N contribution values for different cover crops vary considerably, due to differences in biomass and N content of the cover, location, and climate (Tables 9-11). Moreover, the different measurement techniques predict variable N contributions, even for the same cover crop, location, and/or year (Tables 9 & 12). A method is required that will consistently predict site-specific supplemental fertilizer N needs for corn following cover crops.

2.8.2 Soil N Testing for Predicting Corn N Needs in Cover Crop Systems

A soil test method has recently been developed for predicting N contributions to corn and may application where cover crops contribute significant amounts of N. This technique is called the pre-sidedress soil nitrate

test (PSNT) (82, 84). This is different than the traditional cover crop N contribution measurement methods in that values are based on a soil test, not on crop yield or N recovery. The PSNT is accomplished by taking a soil sample to a depth of 30 cm immediately prior to corn fertilizer N sidedress time (corn height of 30 to 45 cm) (82, 84, 89). The soil sample is analyzed for NO_3^--N upon which a fertilizer N recommendation is based (82, 89).

A critical value of 20-25 mg NO_3^--N kg soil^{-1} at sidedress time has been reported by most for separating N responsive and N nonresponsive sites (16, 31, 35, 36, 46, 83, 87). Development of a sliding scale for N fertilizer recommendations has met with little success using the PSNT, although some have recommended reducing N fertilizer applications at certain levels of soil NO_3^--N (31, 35, 36, 46, 87). Evanylo and Alley (31) recommended that N applications not be reduced when soil [NO_3^--N] was less than 11 mg NO_3^- kg soil^{-1}, were not needed when soil [NO_3^--N] was greater than 20 mg NO_3^- kg soil^{-1}, and could be reduced by 25 to 50 percent when soil [NO_3^--N] was between 11 and 20 mg NO_3^- kg soil^{-1}.

Fox et al. (35) and Meisinger et al. (87) reported that the majority of sites where N needs were not accurately predicted were sites with soil NO_3^--N levels lower than the critical values, i.e. fertilizer N was not needed as the PSNT predicted. These researchers indicated deeper sampling may be required on coarse textured soils in order to improve the accuracy of the PSNT. Meisinger

et al. (87) reported total soil mineral N [NO_3^--N+NH_4^+-N] was no more accurate a predictor of corn N need than NO_3-N. However, their work did not predominately include cover crop N sources, which might nitrify slower than manure or biosolids for which the the test was originally developed.

Most research thus far has reported good success with the PSNT where some readily mineralizable N source has been applied, such as animal manure or sewage sludge (31, 35, 87, 115). Very little research has been done using the PSNT where winter cover crops are the primary source of soil N, although one study in Maryland reported the PSNT accurately predicted N sufficiency for corn following crimson clover and hairy vetch (87). Furthermore, some reports claim that the test is unreliable on soils where alfalfa (*Medicago sativa* L.) has been grown (7, 35, 115). These researchers stated that not enough N had mineralized from the legume residue by the time of soil sampling, but that legume N mineralized fast enough to meet corn needs. One contrasting report studying the usefulness of the PSNT on past alfalfa fields exists (16).

This should not discourage the potential for PSNT use on soils with winter cover crops. The majority of cover crop plant material is aboveground, whereas the majority of alfalfa plant material is belowground. This will create a concentration of N at the soil surface where cover crops have been grown, while N will be more evenly distributed throughout the soil profile where alfalfa

has been grown. Moreover, alfalfa management for hay or grazing may influence its N content and N release patterns.

Several problems have been encountered with the use of the PSNT (82, 83). First, there is the potential for NO_3^--N leaching out of the sample zone, but the NO_3^--N is still located within the root zone, causing an unrequired N fertilizer recommendation based on the test. Second, soil NO_3^--N can leach out of the root zone after sampling, causing the N fertilizer recommendation to be too low for optimum corn yields. Third, if the early season climate is cool and wet, favoring low rates of N mineralization, and then after the PSNT sample is taken the climate warms up, favoring rapid N mineralization, fertilizer N recommendations may be too high.

Soil NO_3^--N quicktest kits have been commercially produced to facilitate farmer adoption of the PSNT (35, 70, 116). Three quicktest kits have been developed and are as follows: Nitrate Quick Test marketed by Hawk Creek Laboratory, Glen Rock, Pennsylvania, and developed in conjunction with Pennsylvania State University; N-Trak marketed by Hach Company, Loveland, Colorado, and developed in conjunction with Iowa State University; and Cardy Nitrate Meter developed and marketed by Spectrum Technologies (112). These tests can provide results within 1 to 24 hours.

The Nitrate Quick Test has been recommended by researchers in Virginia based on its accuracy and ease of operation, compared to the other

quicktests (31). Evanylo and Alley (31) reported r^2 values of 0.81, 0.69, and 0.50 for the Nitrate Quick Test, N-Trak, and Cardy Nitrate Meter, respectively, when compared to intensive laboratory soil NO_3^--N analysis. Roth et al. (115) reported the Nitrate Quick Test was 82 percent as accurate as extensive laboratory analysis, but the test could not account for N availability from cover crop residues. Other research on the same test derived results of 0.98 r^2 when comparing intensive laboratory determined [NO_3-N] with Nitrate Quick Test determined [NO_3-N] (70, 116).

2.9 Costs versus Benefits of Using Winter Cover Crops

Controversy exists over the economic feasibility of cover crop-corn systems because of the cover crop seeding costs, opportunity costs, and risk of winter kill (41, 98, 126, 129). Most researchers agree that, under present prices, it is doubtful that the practice of using cover crops can be economically viable if the only purpose is to offset N fertilizer purchases for summer cash crops (1, 41, 98). However, legume cover crops can be profitable if yields of summer crops are increased substantially above that attributable to the N contribution (20, 39, 41, 43, 99, 126).

Several studies have reported that cover crops can be economically viable. A recent study in Maryland evaluated the profitability of no-till corn following a hairy vetch cover crop (49). These scientists reported that corn

following hairy vetch plus 134 kg N ha^{-1} was higher yielding and more profitable than any combination of N fertilizer following fallow or winter wheat. They also reported that even a risk averse farmer would choose this combination, based on three years of data. However, because a corn price of \$0.96 kg^{-1} was used in their calculations, the results may not be valid for some years when corn prices are below this level. Another study in Virginia reported that winter wheat yields were correlated with the amount of residual mineral N remaining in the soil, indicating the economic importance of nonlegume N recycling (122).

Many opportunity costs associated with cover crops have limited their use in farming systems. Delayed planting of the summer cash crop to allow for increased N accretion by the cover may reduce soil moisture and temperature and subsequently delay maturation of the summer crop (1, 118). Additionally, the task of planting the cover in the fall may increase costs due to a faster harvest (more machines and labor) and earlier harvest (which may reduce yields) of the cash crop (1). Insects and diseases that are associated with cover crop residues are also a potential cost (1). Additionally, the risk of corn yield variance increases following crimson clover or hairy vetch when compared to fallow (99).

Winter cover crops provide many benefits which include soil erosion control, environmental protection, increased soil productivity, water conservation, pest reduction, nutrient recycling, and decreased fossil fuel use

(1, 129). It is very difficult to assign a dollar value to these various benefits. Winter cover crops could increase in profitability if dollar values could be assigned to these various benefits.

The risks and costs associated with cover crop production may be minimized by employing alternative management practices. Drilling, rather than broadcasting, seed will provide greater seed-soil contact, which can improve germination and establishment of the cover (118). Crimson clover has shown the ability to reseed itself, thereby eliminating fall seeding costs (18, 74, 92, 93, 109, 110, 146). Insuring proper *Rhizobium* inoculation for legume seed will enhance establishment, fall growth, and N fixation (118). Finally, a spring harvest or grazing of a winter cover crop has been suggested by researchers as a possible way of reducing costs (60, 61).

2.10 Conclusions

Winter cover crops are important components in whole farm systems. Corn following cover crops benefit in a wide variety of ways. Although much cover crop research has already been done, there is still a lack of knowledge in this area. The current methods used to credit cover crop N contributions to corn are imprecise. A better procedure is required to determine corn N sufficiency in cover crop-corn systems and, ideally, this method should predict corn N needs for a specific cover crop, site, and year. Although the PSNT is

being used successfully to predict corn N needs in the humid east of the U.S., there are conflicting reports on whether the test is viable where winter cover crops are the primary source of soil N. Additionally, the quicktest kits developed to facilitate farmer adoption of the PSNT have been examined very little in cover crop-corn systems.

The majority of cover crop research in the past has focused on corn planted into chemically desiccated cover crop residue using no-tillage practices. Reports indicate poor synchronization of cover crop N release with corn N uptake in these systems. Alternative management techniques may enhance N release from cover crop residue, thereby making N available to corn at times of greater need. Additionally, optimum sampling times for alternative cover crop management systems are required.

2.11 Objectives

1) To quantify plant available N contributions to corn from three cover crop combinations via soil testing and plant analysis.

2) To determine the synchrony of N mineralized from cover crops (as measured soil nitrate and ammonium) with corn development.

3) To validate or refine the calibration of the pre-sidedress soil nitrate test for corn where cover crops are the primary source of soil N.

4) To determine the accuracy of a commercially available quicktest kit for measuring soil nitrate where cover crops are the primary source of soil N.

5) To determine the effect of several cover crop combinations on total cover crop biomass and N content.

6) To determine the effect of desiccation timing on cover crop biomass, N content, and N mineralization (as measured soil nitrate and ammonium), and on corn N concentration and grain yield.

7) To determine the effect of cover crop mowing and disking on cover crop N mineralization (as measured soil nitrate and ammonium) and on corn N concentration and grain yield.

8) To determine the optimum soil sampling time for predicting corn N needs in alternative cover crop management systems.

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Chapter II.
The Pre-sidedress Soil Nitrate Test in Winter Cover Crop-Corn Systems.

ABSTRACT

Current pre-sidedress soil nitrate test (PSNT) and Nitrate Quick Test research describes conflicting results concerning the viability of the tests on soils where winter cover crops are the primary source of soil N. A study was initiated to determine the reliability of the PSNT and Nitrate Quick Test as tools for making fertilizer N recommendations for corn where cover crops are the primary source of soil N. Cover crops treatments including rye (*Secale cereale* L.), hairy vetch (*Vicia villosa* Roth), rye+hairy vetch, and fallow were established as main plots to provide a range of soil N availability to a subsequent corn crop. The split plot treatment was sidedress fertilizer N rate, consisting of six rates ranging from 0-250 kg N/ha in 50 kg increments. Soil and corn tissue were sampled throughout the growing season in the 0 kg N/ha check plots to assess periodic soil N availability. Soil N concentrations peaked at corn four to five or eight to ten leaf stage and were concentrated in the top 15 cm of the soil. Soil and corn N concentrations and corn yields indicated higher N availability on vetch and fallow plots with or without supplemental N. The Nitrate Quick Test was accurate in determining soil NO_3-N concentrations, producing an overall correlation coefficient of 0.93 when compared with soil NO_3-N determined by intensive laboratory extraction and analysis procedures.

Current recommended soil sampling procedures produced critical soil [NO_3-N] values within the reported range for PSNT utilization, however sampling to a depth of 15 cm was adequate for the use of established critical values. Additionally, measuring total soil mineral N and/or sampling two weeks later than the recommended time may provide flexibility in soil sampling when the PSNT is to be used to make fertilizer N recommendations for corn.

1. Introduction

Winter cover crops are integral parts of corn production systems in the mid-Atlantic states. Their major benefit is their N supplying capability for subsequently planted crops, especially corn (7, 15). However, methods for assessing cover crop N contributions to corn are imprecise, and are dependent on cover crop N content and C/N ratio, residue management, soil type, and climate (15). The poor predictability of cover crop N availability to corn results in inaccurate applications of supplementally required fertilizer N. Therefore, the specificity of cover crop N contribution values may be better evaluated through the use of a test that is site-specific.

A recently calibrated method for assessing soil N contributions to corn in the humid eastern U.S. is soil nitrate testing. The pre-sidedress soil nitrate test (PSNT) has been used successfully to predict corn N sufficiency on fields where organic N sources such as manure or sewage sludge have been applied (4, 5, 11, 12, 13, 16). However, reports suggest the test is unreliable where alfalfa (*Medicago sativa* L.) is the primary source of soil N (1, 5, 16). In contrast, Meisinger et al. (13) declared the test was accurate where hairy vetch (*Vicia villosa* Roth) or crimson clover (*Trifolium incarnatum* L.) was the major source of soil N. Therefore, current PSNT research is inconclusive concerning the viability of the test where cover crops are the primary source of soil N.

Additionally, soil nitrate "quicktest" kits have been commercially produced to facilitate farmer adoption of the PSNT (5, 8, 18). These tests can provide results within 1 to 24 hours (14). The Nitrate Quick Test, marketed by Hawk Creek Laboratory, Glen Rock, Pennsylvania, and developed in conjunction with Pennsylvania State University (14), has been recommended by Evanylo and Alley (4) based on its accuracy and ease of operation compared to other quicktests. Investigations have reported r^2 values ranging from 0.81-0.98 for the Nitrate Quick Test, when compared to intensive laboratory soil NO_3-N analysis (4, 8, 16, 18). However, most quicktest research has focused on soils amended with animal manure or sewage sludge (1, 4, 5, 11, 12, 13, 16). Therefore, current Nitrate Quick Test research is inconclusive concerning the viability of the test where cover crops are the primary source of soil N.

The objectives of this study were (i) to quantify plant available N contributions to corn from three cover crop combinations via soil testing and plant analysis; (ii) to determine the synchrony of N mineralized for cover crops (as measured soil nitrate and ammonium) with corn development; (iii) to validate or refine the calibration of the pre-sidedress soil nitrate test for corn where cover crops are the primary source of soil N; and, (iv) to determine the accuracy of a commercially available quicktest kit for measuring soil nitrate where cover crops are the primary source of soil N.

2. Material and Methods

2.1 Field Plot Specifications

Field studies were conducted at the Kentland Research Farm (KRF) in Blacksburg, Virginia, and at the Northern Piedmont Agricultural Experiment Station (NPAES) in Orange, Virginia, from fall 1991 to fall 1993. The soil series at the NPAES was a Starr silty clay loam (fine-loamy, mixed, thermic, Fluventic Dystrochrepts). The study was conducted on two soil series at the KRF - a McGary silt loam (fine, mixed, mesic, Typic Argiaquolls) from fall 1991 to fall 1992 and a Shottower cobbly loam (clayey, kaolinitic, mesic, Typic Paleudults) from fall 1992 to fall 1993. See Tables 1-6 for field plot histories and climate information.

This study employed a split plot design. Four cover crop treatments, fallow, hairy vetch, rye (*Secale cereale* L. var. Wheeler), and a rye-hairy vetch mix, were established in fall 1991 and fall 1992 as main plots. The split plot treatments consisted of six N fertilizer rates ranging from 0 to 250 kg ha^{-1} in 50 kg increments. Main plots were replicated four times at all locations except at the NPAES in 1992-93 where three replications were used.

Land preparations before cover crop planting consisted of herbicide application, moldboard plowing, rotary tilling, harrowing and/or disking (Table 7). Limestone, phosphorus, and potassium were applied according to soil test recommendations (3) (Table 8).

Table 1. Northern Piedmont Agricultural Experiment Station Field Plot History - Study Year 1991-1992.

Time Period	Crop(s) Grown*	Amendment(s) Applied
Spring/Summer 1989	Grain Sorghum	560 kg ha^{-1} 10-10-10
	Fallow	--
Fall/Winter 1989	Small Grain	672 kg ha^{-1} 5-10-10
	Fallow	--
Spring/Summer 1990	Soybeans	1120 kg ha^{-1} 0-5-10
	Fallow	--
Fall/Winter 1990	Small Grain	--
	Fallow	--
Spring/Summer 1991	Fallow	--

* Replications were located on different areas of the station. Therefore all replications had not been treated similarly in the past.

Table 2. Kentland Research Farm Field Plot History - Study Year 1991-1992.

Time Period	Crop Grown	Amendment(s) Applied
Spring/Summer 1989	Alfalfa	--
Fall/Winter 1989	Small Grain	73 kg N, 140 kg P_2O_5, and 140 kg K_2O ha^{-1}
Spring/Summer 1990	Fallow	--
Fall/Winter 1990	Fallow	--
Spring/Summer 1991	Fallow	--

Table 3. Northern Piedmont Agricultural Experiment Station Field Plot History - Study Year 1992-1993.

Time Period	Crop Grown	Amendment(s) Applied
Spring/Summer 1990	Sod	--
Fall/Winter 1990	Sod	--
Spring/Summer 1991	Sod	--
Fall/Winter 1991	Sod	--
Spring/Summer 1992	Pearl Millet	672 kg ha^{-1} 10-10-10, 2.8 metric tons lime ha^{-1}

Table 4. Kentland Research Farm Field Plot History - Study Year 1992-1993.

Time Period	Crop Grown	Amendment(s) Applied
Spring/Summer 1990	Sod	--
Fall/Winter 1990	Sod	--
Spring/Summer 1991	Sod	--
Fall/Winter 1991	Sod	--
Spring/Summer 1991	Sod	--

Table 5. Kentland Research Farm (KRF) and Northern Piedmont Agricultural Experiment Station (NPAES) Climatological Data: 1991-1992.

Location	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG
	Month											
	Temperature (°C)											
KRF	19	13	7	4	2	4	6	11	14	18	23	20
NPAES	20	14	8	5	3	4	6	13	16	20	25	22
	Precipitation (cm)											
KRF	1.2	0.7	7.6	14.0	7.5	8.8	8.3	13.8	10.8	15.8	23.8	10.9
NPAES	7.1	4.7	3.9	12.7	4.1	6.2	8.1	6.7	13.6	12.3	6.9	7.0

Table 6. Kentland Research Farm (KRF) and Northern Piedmont Agricultural Experiment Station (NPAES) Climatological Data: 1992-1993.

Location	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG
	Month											
	Temperature (°C)											
KRF	18	11	7	1	3	0	3	10	17	20	25	22
NPAES	19	12	8	3	3	2	5	12	19	22	26	24
	Precipitation (cm)											
KRF	4.4	5.5	9.6	6.0	8.4	8.2	17.6	8.6	11.1	9.1	8.4	8.3
NPAES	10.2	3.3	14.4	13.3	9.4	6.6	21.3	11.2	8.8	5.6	5.5	8.8

Table 7. Land Preparations Before Cover Crop Planting.

Time Period	Land Preparation
Northern Piedmont Agricultural Experiment Station	
Fall 1991	None needed. Land fallow and weed free.
Kentland Research Farm	
Fall 1991	Moldboard plowed and disked.
Northern Piedmont Agricultural Experiment Station	
Fall 1992	Moldboard plowed, disked, rotary tilled, and harrowed.
Kentland Research Farm	
Fall 1992	Moldboard plowed and disked, 5.84 l ha^{-1} Paraquat herbicide applied.

Table 8. Amendment Applications Made According to a Soil Test Recommendation.

Date	Amendment(s) Applied
Northern Piedmont Agricultural Experiment Station	
27 AUG 1991	34 kg P_2O_5 & 56 kg K_2O ha^{-1}
22 MAY 1992	67 kg P_2O_5 & 34 kg K_2O ha^{-1}
17 JUN 1993	134 kg K_2O ha^{-1}
Kentland Research Farm	
18 SEP 1992	134 kg P_2O_5 & K_2O ha^{-1}
10 MAY 1993	67 kg P_2O_5 & K_2O ha^{-1}

Rye and "common" hairy vetch were seeded at 101 kg ha^{-1} (303 seeds m^{-2}) and 28 kg ha^{-1} (117 seeds m^{-2}), respectively (22) (Tables 9-12). The rye-hairy vetch mix rate was 67 kg ha^{-1} (201 seeds m^{-2}) rye and 19 kg ha^{-1} (80 seeds m^{-2}) hairy vetch (21) (Tables 9-12). All cover crops were planted with a grain drill at a row spacing of 17.8 cm. Soon after cover crop emergence an electric fence was erected around the vegetative covers to prevent deer damage.

The vegetative covers were killed each spring with an application of 1.75 l ha^{-1} Gramoxone [1,1'-dimethyl-4,4'-bipyridinium ion] plus 1.17 l ha^{-1} nonionic surfactant [Alkyly aryl polyethoxy ethanol phosphates and organic phosphatic acids] (23) (Tables 9-12). A cultipacker was rolled over the cover crops after gramoxone application to simplify no-till corn (*Zea mays* L. var. Pioneer 3154) planting into the heavy cover crop residues (Tables 9-12). This corn variety was chosen because of its high yield potential at both locations and its resistance to gray leaf spot (*Cercospora zeae-maydis* and *C. sorghi* var. *maydis*), a commonly observed disease at the KRF location. The corn was planted at a population of 65,600 plants ha^{-1} with a row spacing of 74.1 cm. The corn was thinned to a population of 54340 plants ha^{-1} several weeks after emergence.

The dimensions of the KRF main plots were 8.3 m by 27.4 m and the split plots were 4.6 m by 8.3 m in 1991-92. In 1992-93, the main plots were 9.1

Table 9. Field Work Log Northern Piedmont Agricultural Experiment Station Study Year - 1991-1992.

Date	Activity
4 OCT 1991	Seeded cover crops.
16 MAR 1992	Counted plant populations.
27 APR 1992	Sampled soil and cover crops.
28 APR 1992	Sprayed cover crops with Paraquat.
5 MAY 1992	Rolled over covers with tractor, planted corn, and applied weed control.
21 MAY 1992	Sampled soil.
12 JUN 1992	Sampled soil and measured soil temperature.
18 JUN 1992	Sampled soil and whole corn plants, measured soil temperature, and applied sidedress N.
6 JUL 1992	Sampled soil and corn leaves, and measured soil temperature.
29 JUL 1992	Sampled ear leaves in fallow and vetch cover crop treatments.
12 AUG 1992	Sampled ear leaves in rye and rye-vetch cover crop treatments.
2 OCT 1992	Harvested grain and silage.

Table 10. Field Work Log Kentland Research Farm Study Year - 1991-1992.

Date	Activity
4 OCT 1991	Seeded cover crops.
17 MAR 1992	Counted plant populations.
22 MAY 1992	Sampled soil and cover crops. Sprayed cover crops with Paraquat.
28 MAY 1992	Rolled over cover crops with cultipacker.
2 JUN 1992	Finished rolling over cover crops with cultipacker and planted corn.
3 JUN 1992	Applied weed control.
18 JUN 1992	Sampled soil.
8 JUL 1992	Sampled soil and measured soil temperature.
15 JUL 1992	Sampled soil and whole corn plants, measured soil temperature, and applied sidedress N.
24 JUL 1992	Sampled soil and corn leaves, and measured soil temperature.
14 AUG 1992	Sampled ear leaves in majority of cover crop treatments. Others sampled in following two weeks as silks became apparent.
6 OCT 1992	Harvested grain.

Table 11. Field Work Log Northern Piedmont Agricultural Experiment Station Study Year - 1992-1993.

Date	Activity
14 SEP 1992	Seeded cover crops.
8 APR 1993	Counted plant populations.
30 APR 1993	Sampled soil and cover crops. Sprayed cover crops with Paraquat.
3 MAY 1993	Rolled over covers with cultipacker, planted corn, and applied weed control.
4 MAY 1993	Applied rest of weed control.
12 MAY 1993	Sampled soil.
26 MAY 1993	Sampled soil and measured soil temperature.
8 JUN 1993	Sampled soil and whole corn plants, measured soil temperature, and applied sidedress N.
21 JUN 1993	Sampled soil and corn leaves, and measured soil temperature.
19 JUL 1993	Sampled ear leaves in fallow, vetch, and rye-vetch cover crop treatments.
28 JUL 1993	Sampled ear leaves in rye cover crop treatments.
20 SEP 1993	Harvested grain and silage.

Table 12. Field Work Log Kentland Research Farm Study Year - 1992-1993.

Date	Activity
15 SEP 1992	Seeded cover crops.
14 APR 1993	Counted plant populations.
17 MAY 1993	Sampled soil and cover crops.
19 MAY 1993	Sprayed cover crops with Paraquat.
21 MAY 1993	Rolled over covers with cultipacker, and planted corn.
24 MAY 1993	Applied weed control.
1 JUN 1993	Sampled soil.
15 JUN 1993	Sampled soil and measured soil temperature.
25 JUN 1993	Sampled soil and whole corn plants, measured soil temperature, and applied sidedress N.
9 JUL 1993	Sampled soil and corn leaves, and measured soil temperature.
5 AUG 1993	Sampled ear leaves.
1 OCT 1993	Harvested grain.

m by 27.4 m and the split plots were 4.6 m by 9.1 m. Split plot width permitted six rows of corn to be planted. The main plots at the NPAES measured 9.1 m by 18.3 m and the split plots measured 3.1 m by 9.1 m in 1991-92. The main plots measured 8.2 m by 27.4 m and the split plots measured 4.6 m by 8.5 m in 1992-93. Split plots contained five corn rows in 1991-92 and six corn rows in 1992-93.

Corn seed was treated with 51.4 g Kernal Guard [Lindane, Captan, and Diazinon; Gamma isomer of 1,2,3,4,5,6-hexachloro-cyclohexane; cis-*N*-Trichloromethylthio-4-cyclohexane-1,2-dicarboximide; O,O-diethyl O-(2-isopropyl-4-methyl-6-pyrimidinyl) phosphorothioate] per 22.7 kg seed by mixing in the planter box to prevent seedcorn maggot (*Delia platura* Meigen) infestations (23). Scouting for cutworms (*Agrotis ipsilon* Hufnagel and *A. gladiaria* Morrison), armyworm (*Pseudaletia unipuncta* Haworth), stalk borers (*Papaipema nebris* Guen.), and slugs (*Agriolimax reticulatus* Muller) was done according to IPM recommendations (23). A cutworm infestation at the NPAES in 1992 required an application of 4.7 l ha^{-1} Lorsban [O,O-diethyl O-(3,5,6-trichloro-2-pyridinyl) phosphorothioate].

Weeds were controlled with various combinations of herbicides applied after corn planting and based on Virginia Cooperative Extension recommendations (23) (Tables 9-13).

The split plot N rate treatments were applied as 30 % urea ammonium nitrate solution with a CO_2 pressurized backpack sprayer when the corn was at the 4 to 5 leaf stage (approximately 4 weeks after emergence) (Tables 9-12). The fertilizer was streamed 15 cm to the side of the rows.

2.2 Field Plot Sampling

Soil was sampled after cover crop planting to determine residual soil N content. Fifteen two cm diameter soil cores were collected at depths of 0 to 15 cm, 15 to 30 cm, and 30 to 60 cm from the study area. Soil samples were immediately frozen with dry ice and remained frozen until laboratory N extraction and analysis was performed.

Cover crop plant populations were measured taken after winter dormancy to determine plants per meter^2 (Tables 9-12). Plants (plus tillers in the plots containing rye) were counted in 30 cm sections of row at predetermined plot locations. Rye and vetch were counted separately in the rye-vetch mix plots. Four counts per main plot were taken, averaged, and used to calculate plants meter^{-2}.

Cover crop tissue was sampled before desiccation to determine N content and biomass accumulation (Tables 9-12). An open-ended sheet metal cylinder 47.5 cm in diameter was used as a sampling tool. The covers were sampled by cutting the plants inside the cylinder at ground level. Rye and

Table 13. Herbicide Combinations Used to Control Weeds.

Date	Herbicides Applied		Composition
----------Northern Piedmont Agricultural Experiment Station (NPAES)----------			
5 MAY 1992	5.6 l ha^{-1} Bicep	Atrazine:	2-chloro-4-ethylamino-6-isopropylamino-*s*-triazine
		Metolachlor:	2-chloro-*N*-(2-ethyl-6-methylphenyl)-*N*-(2-methoxy-1-methylethyl)acetamide
	3.1 l ha^{-1} Princep	Simazine:	2-chloro-4,6-bis(ethylamino)-*s*-triazine
	1.75 l ha^{-1} Gramoxone	Paraquat:	1,1'-dimethyl-4,4'-bipyridinium ion
	1.17 l ha^{-1} Surfactant	Surfactant:	Alkyly aryl polyethoxy ethanol phosphates and organic phosphatic acids
3 MAY 1993	2.3 l ha^{-1} Princep		See above
	Bicep, Gramoxone, and surfactant applied same as above.		
----------Kentland Research Farm----------			
3 JUN 1992	Same as NPAES in 1992		See above
24 MAY 1993	9.3 l ha^{-1} Roundup	Glyphosate:	Isopropyl amine salt of N-(phosphonomethyl) glycine
	7 l ha^{-1} Lasso	Alachlor:	2-chloro-2'-6'-diethyl-N-(methoxymethyl)-acetamide
	1.68 kg ha^{-1} Atrazine		See above
	1.12 kg ha^{-1} Princep		See above
	2.34 l ha^{-1} Surfactant		See above

vetch in the rye-vetch mix plots were hand separated immediately. Two random samples were taken per main plot.

Soil was also sampled before cover crop desiccation to determine initial soil N content (Tables 9-12). Ten two cm diameter soil cores were collected at depths of 0 to 15 cm and 15 to 30 cm from each main plot. Inorganic soil N was tracked throughout the season to determine periodic soil N concentration (Tables 9-12). Soil samples were taken at corn emergence, 2 weeks after emergence, the 4 to 5 leaf stage (approximately 4 weeks after emergence), and the 8 to 10 leaf stage (approximately 6 weeks after emergence). Ten two cm diameter soil cores were sampled at depths of 0 to 15 cm and 15 to 30 cm in each main plot through the 4 to 5 leaf stage. Five two cm diameter soil cores were taken at depths of 0 to 15 cm and 15 to 30 cm in each 0 kg N ha^{-1} check plot at the 8 to 10 leaf stage (after split plot N rate treatments were applied). All soil samples were immediately frozen with dry ice and remained frozen until laboratory N extraction and analysis was performed.

Soil temperatures were measured during the season to aid in interpreting differences in soil N mineralization, corn N uptake, and corn growth patterns (Tables 9-12). Measurements were made in the top 3 cm of soil at 2 weeks after corn emergence, at the 4 to 5 leaf stage, and at the 8 to 10 leaf stage. Data collection was accomplished using a two channel sensor and inserting a

connecting thermocouple into the soil. Five measurements were made per main plot on each occasion.

Corn tissue was sampled during the season to determine N uptake and estimate relative soil N availability (Tables 9-12). Whole plant samples were collected at the 4 to 5 leaf stage by cutting 6 plants at ground level in each main plot. Leaf samples were taken at the 8 to 10 leaf stage and was accomplished by sampling the uppermost mature leaf from 6 different plants in each 0 kg N ha^{-1} check plot. Leaf samples were also collected at corn silking by cutting the leaf opposite and below the corn ear from 6 different plants in each 0 kg ha^{-1} check plot.

Corn yields at the NPAES in 1992 were estimated by sampling whole corn plants from 5 m of the center row in each split plot (Tables 9-12). Yields at the NPAES in 1993 were estimated similarly except 3 m of the center 2 rows of each split plot were sampled (Tables 9-12). In both years whole plants and grain were separated. Yields at the KRF were estimated by sampling ears from 3 m of the center 2 rows in each split plot (Tables 9-12). All samples were weighed and subsampled in the field for moisture determination.

2.3 Laboratory Analysis

Soil moisture was determined by weighing the field moist samples, drying the samples in a forced air oven at 105 °C until constant weight was

achieved, and reweighing. Sample weighing and moisture calculations were done according to Gardner (6).

Soil nitrate (NO_3^-) and exchangeable ammonium (NH_4^+) was extracted from thawed, moist soil samples with 2M KCl in a ratio of approximately 10 parts extractant to 1 part soil (9). Extracts were centrifuged, instead of filtered to remove particulates, in order to avoid extract contamination from filter paper (20).

Nitrate concentrations in soil extracts were determined colorimetrically with a QuikChem Automated Ion Analyzer according to QuikChem Method No. 12-107-04-1-B (10), a Griess-Ilosvay procedure. Ammonium concentrations in the soil extracts were also determined colorimetrically with the same instrument using QuikChem Method No. 12-107-06-2-A (10), an indophenol method, modified by substituting salicylic acid for phenol. Soil sample extractions were duplicated and repeated when differences exceeded 1.0 mg N kg^{-1} soil or 10 percent deviation from the mean, whichever was less.

Soil nitrate concentrations were also determined using the Nitrate Quick Test (developed by Hawk Creek Laboratory, Glen Rock, Pennsylvania, in conjunction with Pennsylvania State University). Thawed soil samples were analyzed for NO_3-N according to test kit instructions prepared by Roth et al. (17).

Cover crop and corn tissue samples were dried in a forced air oven at 65 °C until constant weight was achieved. Cover crop and 4 to 5 leaf stage corn samples were weighed to determine biomass accumulation and N content. Dried samples were ground in a Wiley Mill until they passed through a 10 holes cm^{-2} mesh. Cover crop samples and 4 to 5 leaf stage corn samples were ground further by rolling 24 hours on a conveyor in glass jars containing 10 to 12 stainless steel rods to ensure adequate mixing.

Total Kjeldahl Nitrogen (TKN) was determined by digesting ground plant tissue and analyzing the digests for ammonium using a QuikChem Automated Ion Analyzer. The procedure QuikChem Method No. 13-107-06-2-B (10) was modified to obtain a higher digestion temperature. This was done by digesting 0.10 g tissue with 0.75 g of a catalyst mixture (K_2SO_4 and HgO in a 25 to 1 ratio (Pope Kjeldahl Mixtures, #1 pumice, Dallas, Texas)) and with 1.25 ml H_2SO_4. The color reagent was also diluted to expand the effective range of the method to cover the anticipated range of sample N contents. Data quality was maintained with frequent analysis of a U.S. Department of Commerce, National Institute of Standards and Technology plant tissue sample (SRM 1547) of a known N content. All samples were digested and analyzed in duplicate and repeated when differences exceeded 0.10 percent N or 10 percent deviation from the mean, whichever was less.

Corn grain and stover were weighed separately in the field and then dried in a forced air oven at 65 °C until constant weight was achieved. Moisture was calculated and yields were corrected and expressed for grain (15.5% moisture) and silage (65% moisture).

2.4 Data Analysis

Data was analyzed using the General Linear Model procedure of the Statistical Analysis System (SAS) (19). Additionally, mean separations were executed on cover crop (biomass, N content, and C/N ratio), soil N ([NO_3-N], [NH_4-N], and total soil mineral [N]), and corn N (corn [N] and corn N uptake) data using the Analysis of Variance (ANOVA) procedure of SAS (19).

A quadratic and plateau model was employed to ascertain corn N response parameters for each cover crop combination. The Regression (REG) procedure of SAS was used to determine quadratic regression equations that matched corn N response, and the Nonlinear (NLIN) method of SAS was then used to determine maximum corn yield (plateau) and N rate required for maximum corn yield (19).

Soil N concentrations (i.e. [NO_3-N], [NH_4-N], and total soil mineral [N]) were plotted versus time to observe the rate of N mineralization. Soil moisture and temperature were also graphed versus time to aid in interpreting soil [N], corn [N], and corn N uptake at differing sample times. Additionally, soil [NO_3-

N] and total soil mineral [N] were plotted versus relative corn grain yield at various sample times and soil depths to determine the best fit to pre-existing PSNT calibrations.

The Correlation (CORR) procedure of SAS was used to compare soil NO_3-N concentrations determined by intensive laboratory extraction and analysis with soil NO_3-N determined by the Nitrate Quick Test (19). Additionally, soil NO_3-N concentrations determined by the Nitrate Quick Test were plotted versus relative corn yield at various soil sample times and soil sample depths to determine the closest fit to existing PSNT calibrations.

3. Results and Discussion

3.1 Cover Crop Data

Cover crop treatments including rye accumulated very high amounts of biomass and N at both locations during 1992 (Tables 14-15), resulting in greater or comparable biomass and N yields as vetch. This indicates that rye has the potential to accumulate greater or similar biomass and N content totals to vetch where soil N is plentiful (Table 16). C/N ratios were also relatively low, demonstrating high rye N uptake despite high biomass yields.

Rye in the rye alone treatments and rye in the rye+vetch treatments were not significantly different in biomass or nitrogen yields even though rye in the rye+vetch mix was seeded at a lower rate than rye alone. This demonstrates rye's ability to compensate for stand differences. The vetch contributed little biomass or nitrogen to the mixed stand. Visual observations indicated vetch was probably smothered by the vigorous growth of the rye portion of the crop mix on the high N soil.

Biomass of the vetch only treatments were lower than the other cover crop treatments at both locations. However, vetch only nitrogen contents were comparable at the Northern Piedmont Agricultural Experiment Station (NPAES) but lower at the Kentland Research Farm (KRF) than rye or rye+vetch. This low biomass and nitrogen production by vetch at the KRF was probably due to poor germination. Vetch plant populations at the KRF in spring 1992 were

Table 14. Effects of Cover Crop Treatments on Rye and Hairy Vetch Biomass, N Accumulation, and C/N Ratios. Kentland Research Farm - 1992.

Cover Crop	Biomass			Nitrogen			C:N Ratio		
	Rye	Vetch	Total	Rye	Vetch	Total	Rye	Vetch	Total
	Mg/ha			kg/ha					
Rye	9.23	--	9.23	109	--	109	38	--	38
Vetch	--	1.64	1.64	--	67	67	--	11	11
Rye+Vetch	10.49	0.18	10.67	142	6	148	33	12	32
LSD	NS	0.80**	3.00*	NS	40**	67*	NS	NS	16*

* Differences among means within columns are significant at the 0.01 probability level.

** Differences among means within columns are significant at the 0.05 probability level.

Table 15. Effects of Cover Crop Treatments on Rye and Hairy Vetch Biomass, N Accumulation, and C/N Ratios. Northern Piedmont Agricultural Experiment Station - 1992.

Cover Crop	Biomass			Nitrogen			C:N Ratio		
	Rye	Vetch	Total	Rye	Vetch	Total	Rye	Vetch	Total
	Mg/ha			kg/ha					
Rye	7.35	--	7.35	120	--	120	29	--	29
Vetch	--	3.66	3.66	--	143	143	--	11	11
Rye+Vetch	7.47	0.10	7.57	138	3	141	25	21	24
LSD	NS	1.65*	2.81*	NS	62*	NS	NS	NS	13*

* Differences among means within columns are significant at the 0.01 probability level.

Table 16. Kentland Research Farm (KRF) and Northern Piedmont Agricultural Experiment Station (NPAES) Fall Soil N Data.

Location	[NO3-N]	[NH4-N]	[NO3-N]+ [NH4-N]
	----------mg/kg----------		
	----------1991----------		
	--Soil Sample Depth 0-15 cm--		
KRF	40.77	4.03	44.80
NPAES	42.73	4.95	47.68
	-Soil Sample Depth 15-30 cm-		
KRF	40.86	4.11	44.97
NPAES	22.97	5.45	28.42
	-Soil Sample Depth 30-60 cm-		
KRF	5.94	7.96	13.90
NPAES	15.37	3.78	19.15
	----------1992----------		
	--Soil Sample Depth 0-15 cm--		
KRF	9.10	7.96	17.06
NPAES	1.14	14.03	15.17
	-Soil Sample Depth 15-30 cm-		
KRF	4.11	4.78	8.89
NPAES	2.26	9.76	11.98
	-Soil Sample Depth 30-60 cm-		
KRF	3.08	3.59	6.67
NPAES	0.00	4.78	4.78

lower than at any other site and/or year, evidence of poor vetch germination (Table 17). Precipitation at the KRF in September and October of 1991 was extremely low (Table 5), therefore inhibiting vetch germination and fall growth.

Cover crop production was quite different during 1993 than 1992 (Tables 18-19). Rye biomass and nitrogen yields were much lower than 1992 because of the low residual soil N (Table 16). Rye containing cover crops still produced higher biomass than vetch at the KRF, but all cover crops were similar in biomass accumulation at the NPAES. Nitrogen assimilation by rye was the lowest of all cover crop treatments at both locations in 1993 and C/N ratios were relatively high.

Rye in the rye alone treatments and rye in the rye+vetch treatments were not significantly different in biomass or nitrogen content even though rye in the rye+vetch mix was seeded at a lower rate than rye alone. Again, this demonstrates rye's ability to compensate for stand differences. The vetch portion of the mix accumulated higher biomass and nitrogen than during the previous year and contributed to the overall biomass and nitrogen of the mixed stand. The vetch was able to better compete with the rye part of the mixture since rye growth was lower and slower due to low soil N availability (Table 17).

Rye in the rye+vetch mix produced the same amount of biomass as rye alone during 1993. The rye+vetch plots were intermediate between rye alone

Table 17. Kentland Research Farm (KRF) and Northern Piedmont Agricultural Experiment Station (NPAES) Spring Cover Crop Plant Populations.

	plants*/m²					
	KRF			NPAES		
Cover Crop	Rye	Vetch	Total	Rye	Vetch	Total
	1992					
Rye	1986	---	1986	1756	---	1756
Vetch	---	33	33	---	77	77
Rye+Vetch	1357	42	1399	1516	55	1571
	1993					
Rye	644	---	644	728	---	728
Vetch	---	104	104	---	78	78
Rye+Vetch	473	58	531	607	67	674

* Plants=tillers for rye.

Table 18. Effects of Cover Crop Treatments on Rye and Hairy Vetch Biomass, N Accumulation, and C/N Ratios. Kentland Research Farm - 1993.

Cover Crop	Biomass			Nitrogen			C:N Ratio		
	Rye	Vetch	Total	Rye	Vetch	Total	Rye	Vetch	Total
	Mg/ha			kg/ha					
Rye	4.77	--	4.77	36	--	36	59	--	59
Vetch	--	1.83	1.83	--	62	62	--	13	13
Rye+Vetch	4.06	0.63	4.69	33	19	52	53	16	40
LSD	NS	0.46*	2.05*	NS	27*	22**	NS	2**	10*

* Differences among means within columns are significant at the 0.01 probability level.

** Differences among means within columns are significant at the 0.05 probability level.

Table 19. Effects of Cover Crop Treatments on Rye and Hairy Vetch Biomass, N Accumulation, and C/N Ratios. Northern Piedmont Agricultural Experiment Station - 1993.

Cover Crop	Biomass			Nitrogen			C:N Ratio		
	Rye	Vetch	Total	Rye	Vetch	Total	Rye	Vetch	Total
	Mg/ha			kg/ha					
Rye	3.83	--	3.83	44	--	44	38	--	38
Vetch	--	4.12	4.12	--	188	188	--	10	10
Rye+Vetch	3.83	1.12	4.95	47	48	95	35	10	23
LSD	NS	2.77**	NS	NS	NS	84**	NS	NS	10*

* Differences among means within columns are significant at the 0.01 probability level.
** Differences among means within columns are significant at the 0.05 probability level.

and vetch alone in N accumulation. This was also reflected in the C/N ratio of the mixture, placing it between the C/N ratios of rye alone and vetch alone.

Vetch biomass yields were significantly lower than either of the other cover crop treatments at the KRF. However, vetch biomass production was comparable to rye and rye+vetch at the NPAES. This low biomass production by vetch at the KRF was probably due to the competition by weeds. Weeds were very vigorous in the early spring, probably because this land had been plowed the previous fall after years in pasture, thereby triggering germination of many dormant weed seeds. Nitrogen production by vetch was higher than either rye or rye+vetch in 1993. Nitrogen yields were significantly higher than either of the other cover crops at NPAES but only significantly higher than rye at the KRF, probably due to the lower vetch biomass yields.

3.2 Soil Nitrogen Concentration Data

Soil N concentrations were significantly higher at a soil depth of 0-15 cm than a soil depth of 15-30 cm at both locations and both years. Soil N at the 15-30 cm soil depth was used in combination with soil N at the 0-15 cm soil depth to calculate a soil N concentration at the 0-30 cm soil depth. Soil N is reported for the 0-15 cm and 0-30 cm soil depths.

3.2.1 Kentland Research Farm - 1992

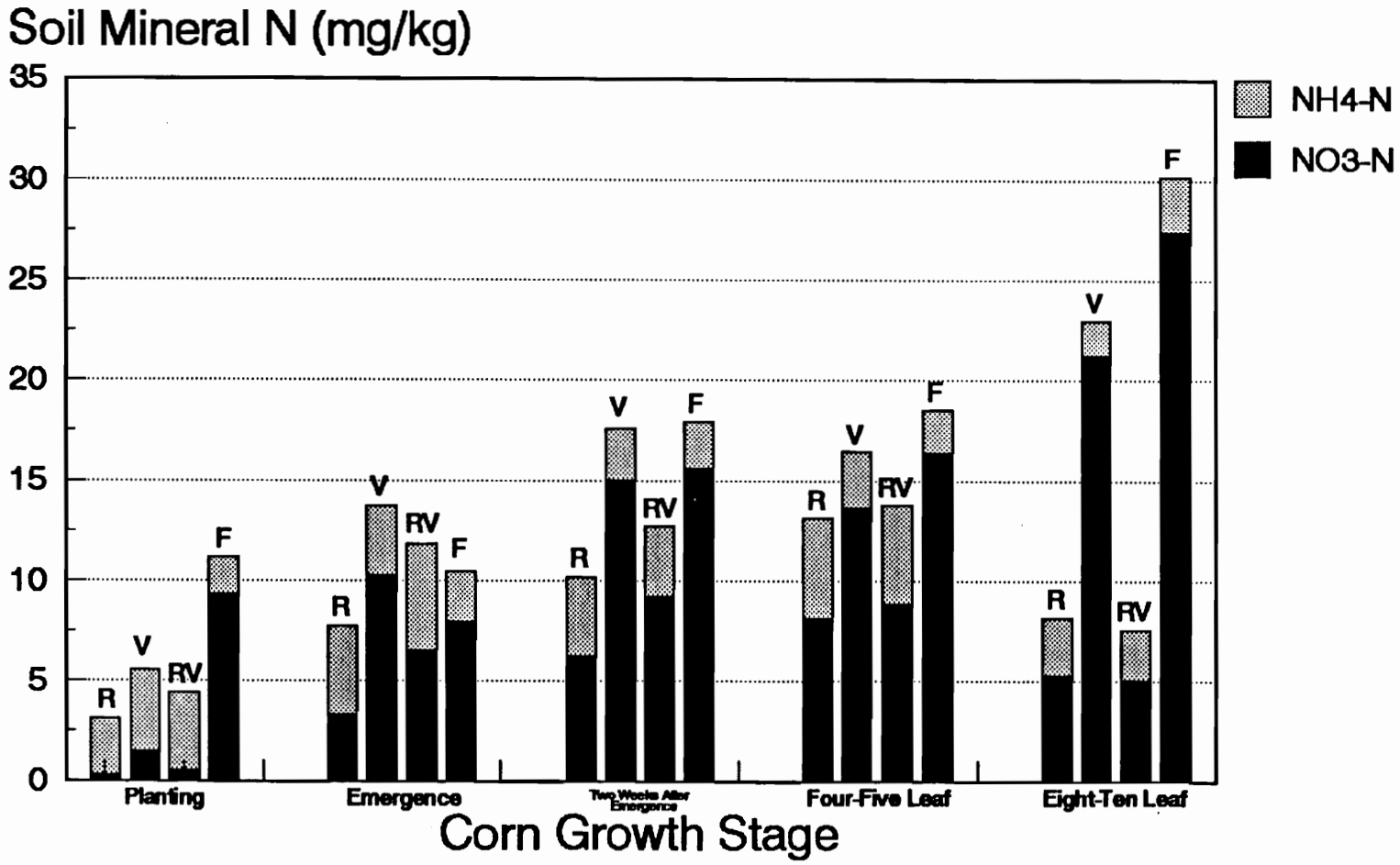
Soil N concentrations at the KRF in 1992 at corn planting were relatively low, except in fallow plots (Figures 1-2). Soil nitrate ([NO_3-N]) and total soil mineral N ([NO_3-N + NH_4-N]) were higher in the fallow treatment when compared to the other cover crop treatments, probably due to high residual soil N (Table 16) and no N scavenging cover. Ammonium was the predominate form of soil N for all treatments except fallow, where NO_3-N predominated. Soil N concentrations and soil N concentration differences between covers were similar at the 0-30 cm soil depth.

Cover crops mineralized rapidly by corn emergence, indicated by soil N concentrations at both soil depths. Soil [NO_3-N] was higher in the vetch and fallow treatments compared to cover crops including rye, most likely due to the more rapid nitrification of residual soil N on these plots with small amounts of low carbon ground cover. Vetch N content was so low (Table 14) that it probably influenced the soil N concentration less than the high amount of residual N already contained in this soil. Soil N concentrations were slightly lower at the 0-30 cm depth (except for fallow treatments), a reflection of higher N in the top 15 cm of the soil where plant residues were concentrated.

All treatments continued to increase in N concentration by two weeks after corn emergence. Fallow and vetch plots possessed almost identical [NO_3-N], [NH_4-N], and total soil mineral N concentrations, likely due to similar soil

Figure 1. Kentland Research Farm Soil N-1992

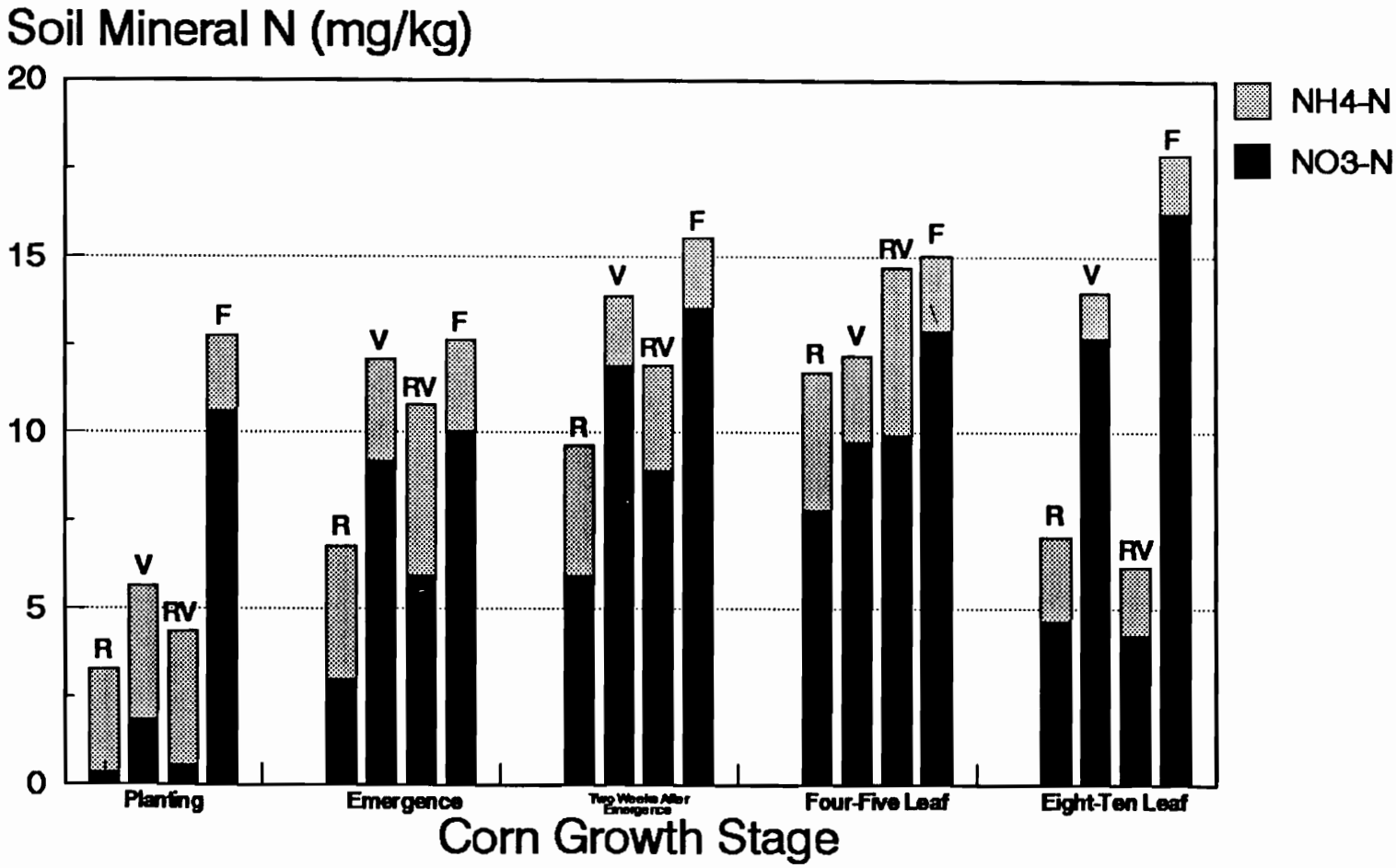
Soil Sample Depth 0 - 15 cm



R=Rye V=Vetch RV=Rye+Vetch F=Fallow

Figure 2. Kentland Research Farm Soil N-1992

Soil Sample Depth 0 - 30 cm



R=Rye V=Vetch RV=Rye+Vetch F=Fallow

moisture contents, soil temperatures, and nitrification patterns on this high N soil (Figures 3-4). Rye plots were lower in [NO_3-N] and higher in [NH_4-N] (only at 0-15 cm soil depth) compared to fallow and vetch treatments, indicating slower nitrification in these areas including high carbon rye. Furthermore, soil [NO_3-N] in the vetch and fallow plots were higher than in rye treatments, most likely due to more rapid nitrification in these plots with less ground cover and higher soil temperature. Rye-vetch cover crop plots were not different from any other cover crop treatments, indicating this cover crop may mineralize N in patterns intermediate to rye and vetch or fallow. The trends were similar at the 0-30 cm soil depth but the N concentrations were slightly lower, reflecting higher soil N concentrations in the top 15 cm of the soil where plant residues were concentrated and soil temperatures were higher. Additionally, soil N concentrations were greater in the 0-15 cm than the 0-30 cm soil depth at subsequent sample times, locations, and years, unless otherwise noted.

Visual observations indicated that corn plants on vetch and fallow plots were significantly larger than corn plants on rye containing cover crop treatments. The rye containing cover crops were allowed to grow very large (Table 14) before corn planting. This caused corn growth to be stunted throughout the growing season in rye containing treatments due to cool soil temperatures and high soil moisture produced by the abundant rye mulch.

Figure 3. Kentland Research Farm

Soil Moisture - 1992

0 - 30 cm Soil Depth

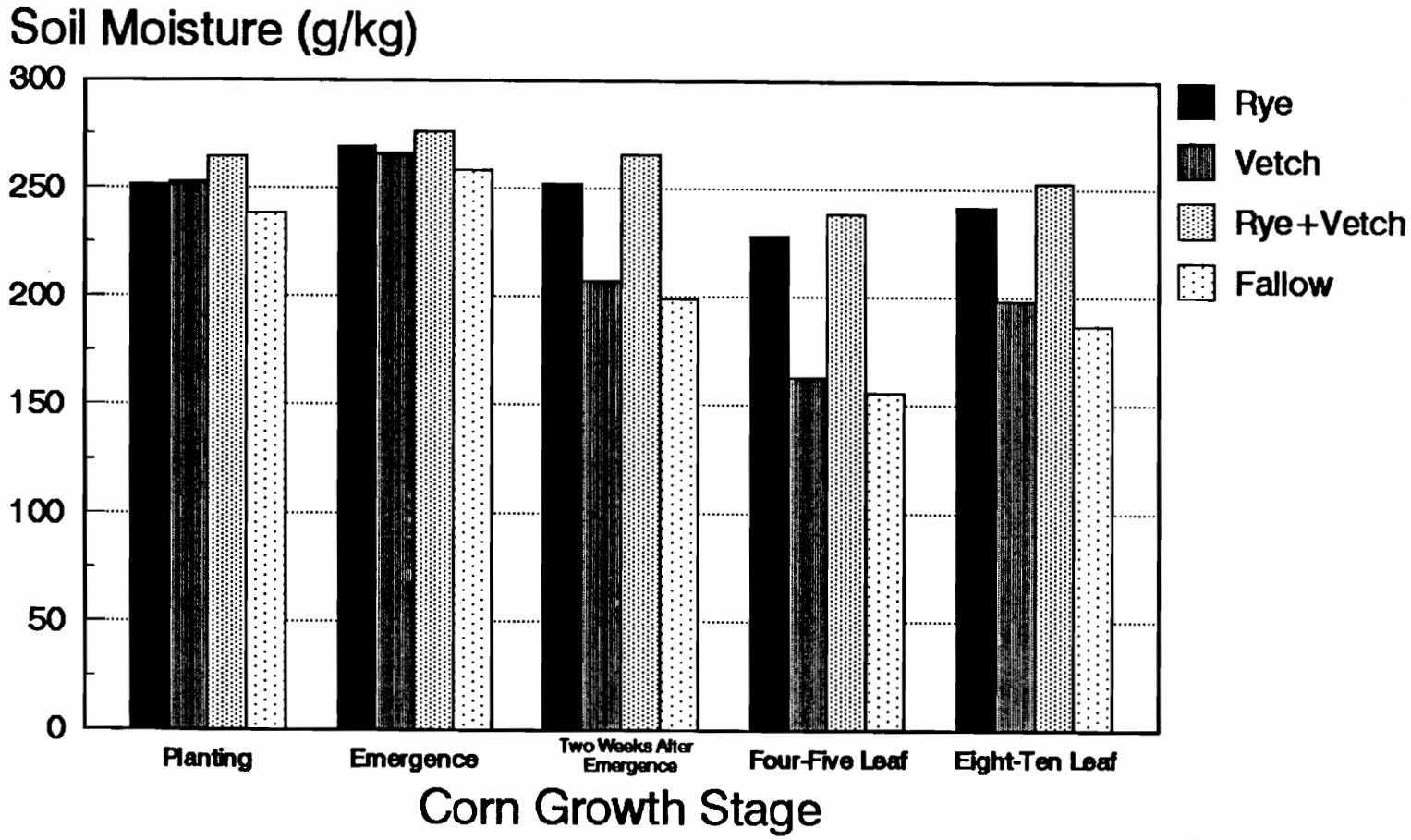
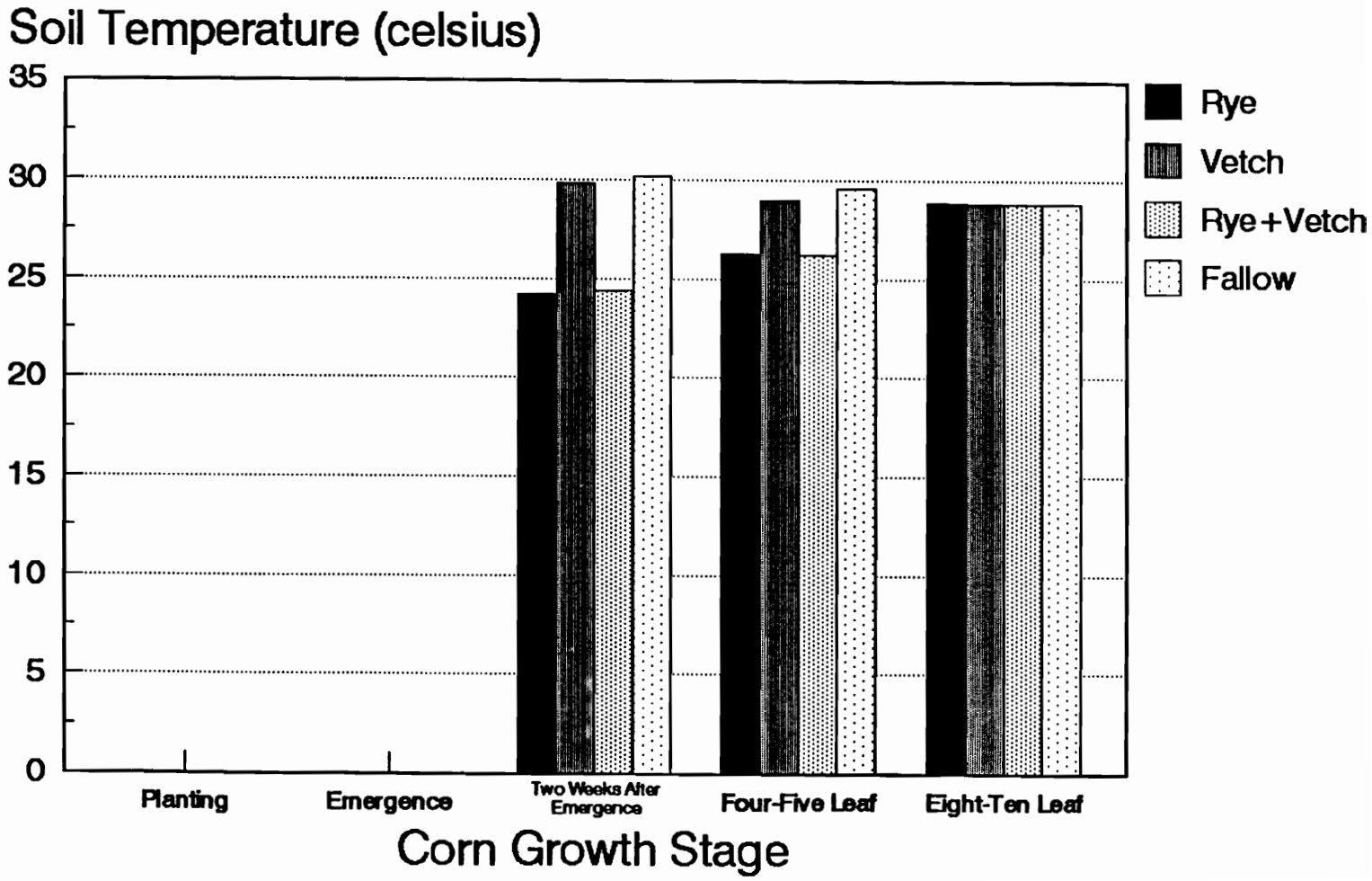


Figure 4. Kentland Research Farm

Soil Temperature - 1992



Therefore, early season corn N uptake was likely greater on vetch and fallow plots than on rye containing treatments.

Nitrogen concentrations at the corn four to five leaf stage in fallow and vetch plots had remained very similar from two weeks after emergence, likely due to low soil moisture that hindered mineralization and nitrification (Figure 3) and/or rapid corn N uptake that kept soil N concentrations uniform between sample times. In contrast, rye and rye+vetch plots had slight increases in soil N concentrations, possibly because soil moisture remained favorable for mineralization and nitrification (Figure 3), allowing these treatments to continue to make N available. Additionally, corn plants on plots including rye likely had low corn N uptake which caused for the soil N concentration increases. Soil [NO_3-N] in the treatments including rye were similar or slightly higher in the 0-30 cm soil depth compared to the 0-15 cm soil depth, indicating leaching in these plots where soil moisture was plentiful.

Soil N concentrations had increased in the vetch and fallow plots at the corn eight to ten leaf stage, producing higher N concentrations than at any other sample time. This was likely due to increased soil moisture and/or increased capillary water rise which reduced the potential for leaching. Rye and rye+vetch plots decreased in their N concentrations, probably because of slowed mineralization in these plots containing a high C/N ratio material. Apparently, the rye and rye+vetch plots exhausted the rapidly available soil N

supply due to corn N uptake, mineralization, and leaching to this point, because soil temperatures could not be the cause for slowed mineralization. Additionally, it is possible these plots could not mineralize N fast enough to meet the drastically increasing corn N needs due to N immobilization during the breakdown of the carbonaceous plant material.

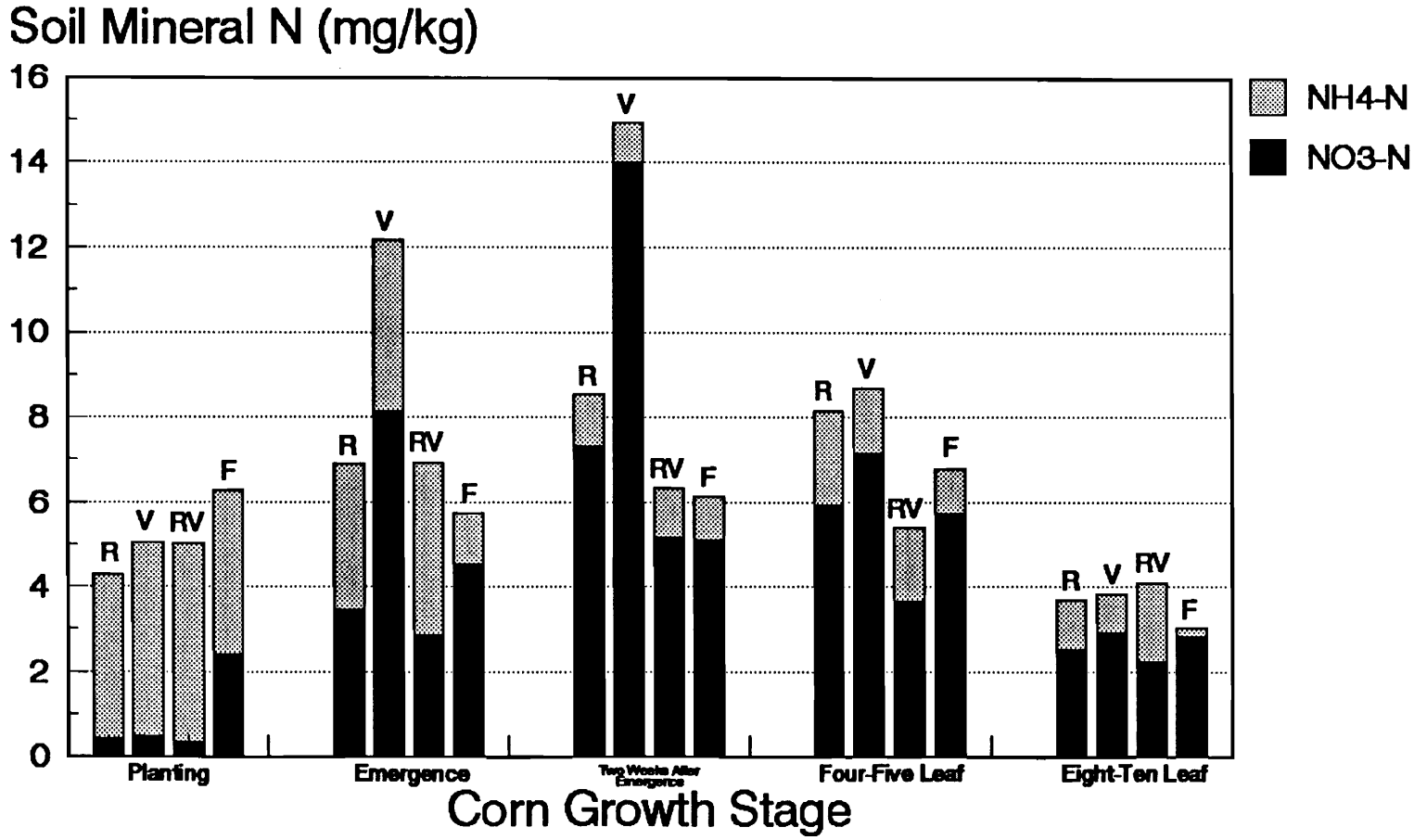
3.2.2 Northern Piedmont Agricultural Experiment Station - 1992

Soil N concentrations at the NPAES in 1992 at corn planting were very similar in all treatments (Figures 5-6). Soil [NO_3-N] was higher in the fallow treatment compared to other treatments, due to high soil N carried over winter from the previous fall (Table 16) and no N scavenging cover. Ammonium was the predominate form of soil N for all treatments except fallow at the 0-30 cm soil depth. Nitrate concentration in fallow plots was higher in the 0-30 than 0-15 cm soil depth. Similar trends were observed at corn emergence and two weeks after corn emergence. Possibly NO_3-N moved to greater depths in these plots with no water requiring cover and therefore resulted in higher [NO_3-N] as depth increased.

Soil N concentrations increased in all cover crop treatments, except fallow, between planting and corn emergence. Nitrate-N concentrations were higher in vetch and fallow plots than in treatments including rye, due to N mineralization from vetch residue and/or from residual soil N (Table 16). Soil

Figure 5. Northern Piedmont Agricultural Experiment Station Soil N-1992

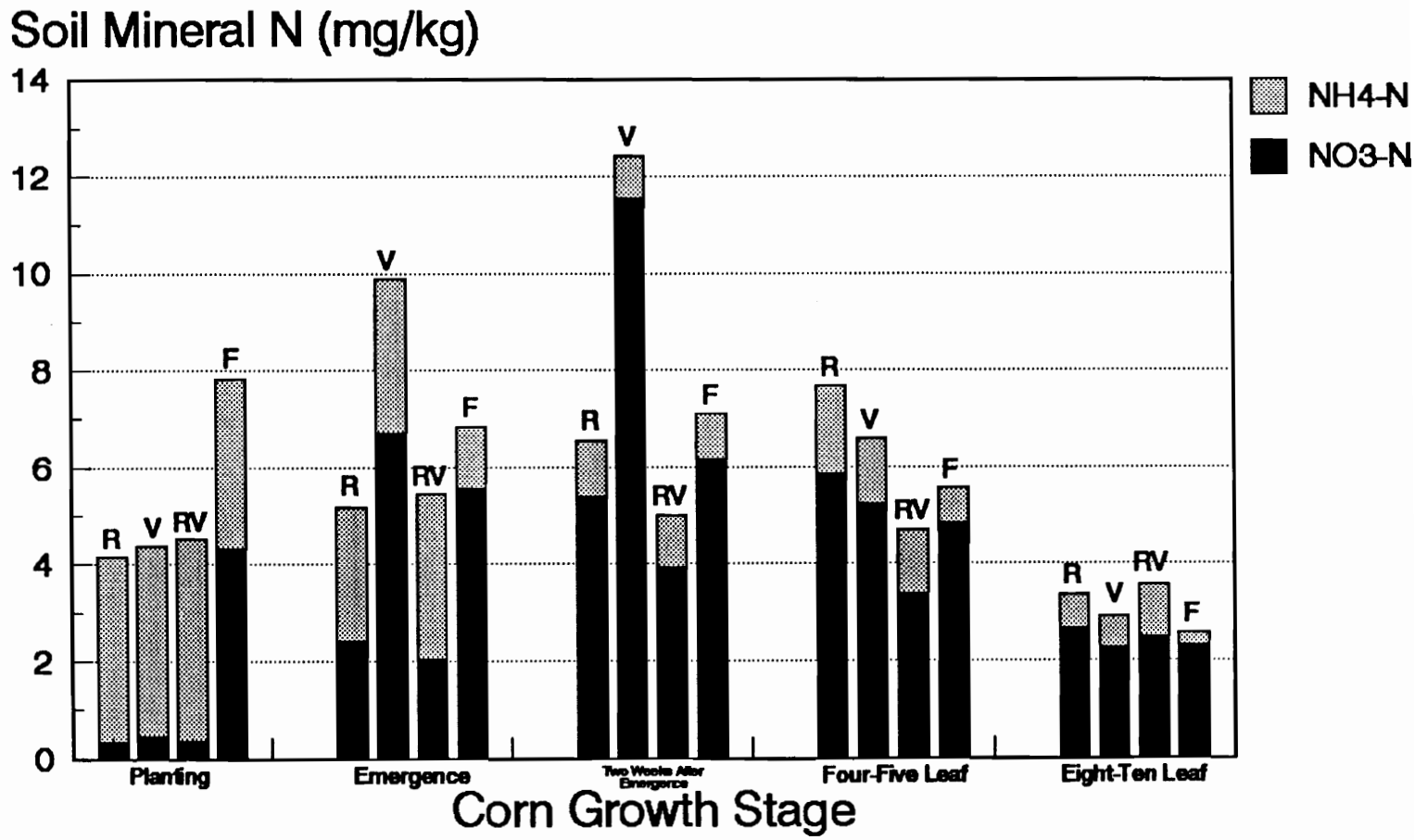
Soil Sample Depth 0 - 15 cm



R=Rye V=Vetch RV=Rye+Vetch F=Fallow

Figure 6. Northern Piedmont Agricultural Experiment Station Soil N-1992

Soil Sample Depth 0 - 30 cm



R=Rye V=Vetch RV=Rye+Vetch F=Fallow

[NO_3-N] increased in the rye and rye+vetch plots from corn planting, likely due to N mineralization on the high N soil where very little plant N uptake was now occurring.

All treatments peaked in NO_3-N and total mineral N concentration at two weeks after corn emergence. Vetch plots were higher than other cover crop treatments in [NO_3-N] and total mineral N concentration, likely due to mineralization of vetch N and soil N. Fallow N concentrations may have been limited by soil moisture, leaching, and/or rapid corn N uptake (Figures 7-8).

Visual observations indicated that corn plants on vetch and fallow plots were significantly larger than corn plants on rye containing cover crop treatments. The rye containing cover crops were allowed to grow very large (Table 15) before corn planting. This caused corn growth to be stunted throughout the growing season in rye containing treatments due to cool soil temperatures and high soil moisture produced by the abundant rye mulch. Therefore, early season corn N uptake was likely greater on vetch and fallow plots than on rye containing treatments.

Vetch plots decreased in [NO_3-N] and total mineral N concentration at the corn four to five leaf stage due to N leaching and/or higher corn N uptake at this sample time. Fallow, rye, and rye+vetch N concentrations were similar from two weeks after emergence. Fallow treatment N concentrations were probably limited again by soil moisture, leaching, and/or rapid corn N uptake.

Figure 7. Northern Piedmont Agricultural Experiment Station Soil Moisture - 1992
0 - 30 cm Soil Depth

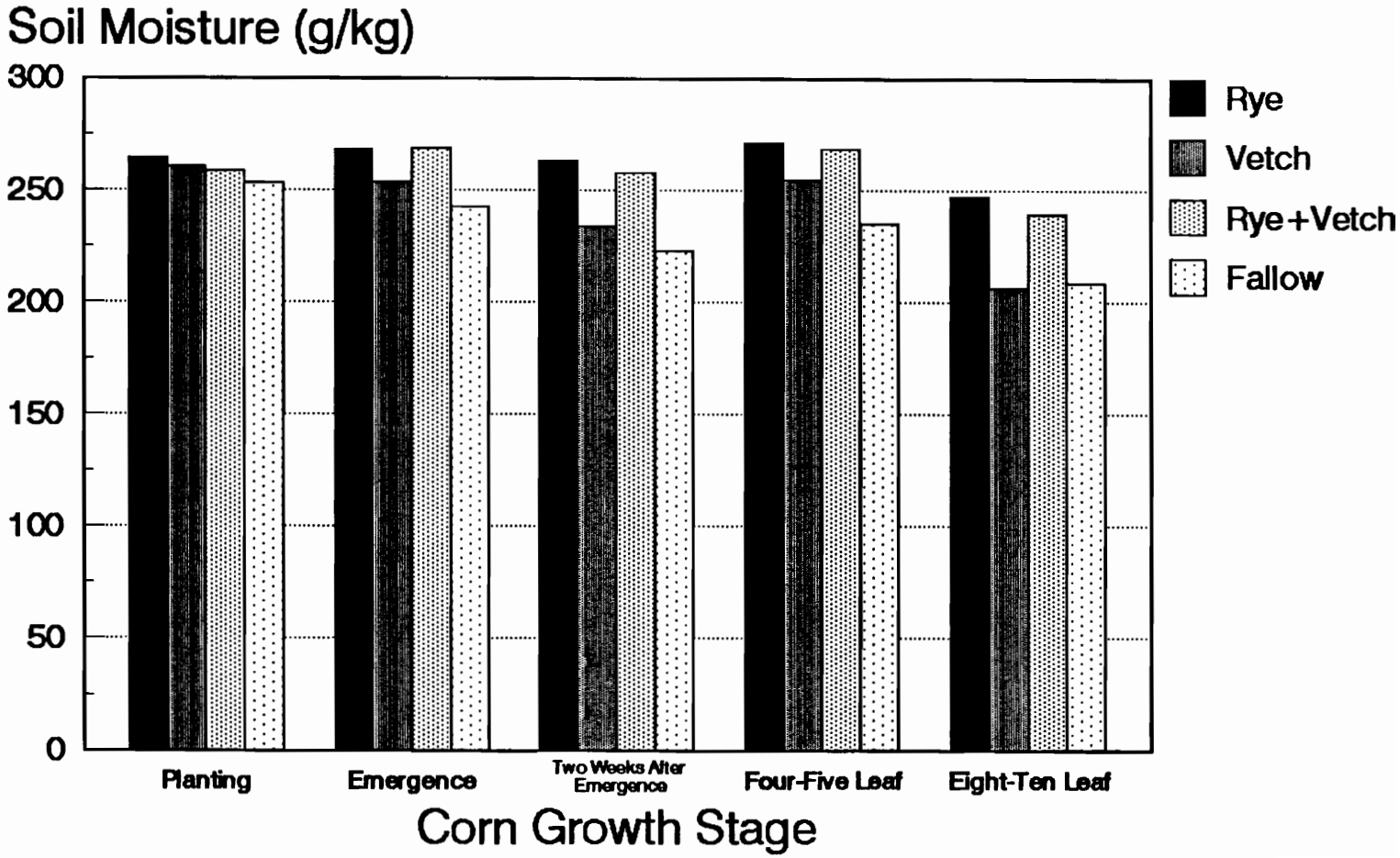
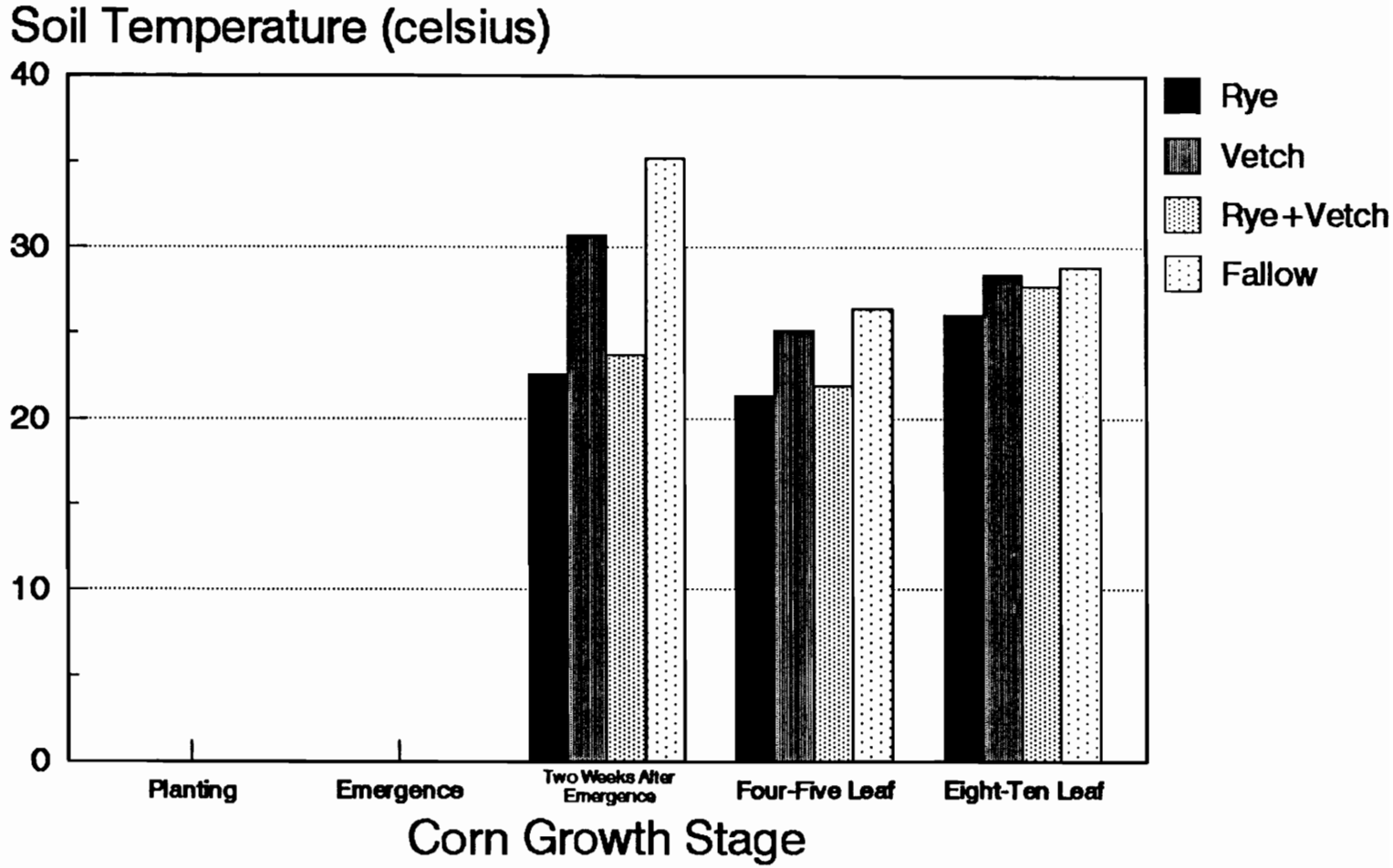


Figure 8. Northern Piedmont Agricultural Experiment Station Soil Temperatures - 1992



By the corn eight to ten leaf stage soil N concentrations had decreased in all cover crop treatments, probably because of rapid N uptake by corn that depleted available soil N in the top 30 cm of soil.

3.2.3 Kentland Research Farm - 1993

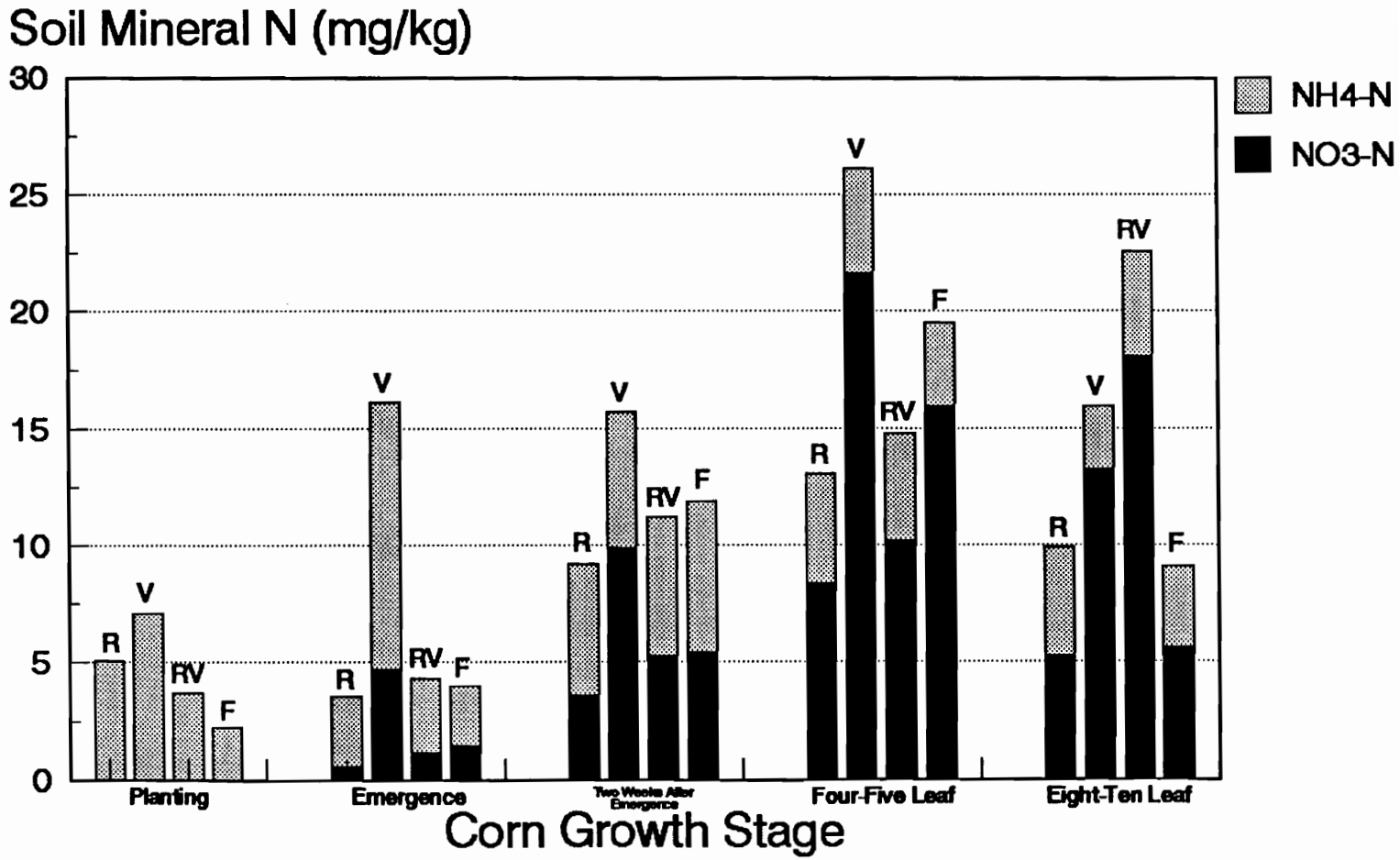
Soil NO_3-N was undetectable at corn planting at the KRF in 1993, all measurable N was in the NH_4-N form (Figures 9-10). Low moisture content and/or low soil N (Figure 11, Table 16) may have slowed nitrification, thereby limiting soil [NO_3-N]. Furthermore, it is possible any available NO_3-N may have been assimilated by the cover crops. Since fallow plots were covered with weeds, N assimilation by weeds on these plots is also probable.

Mineralization and nitrification had begun by corn emergence, as indicated by the appearance of NO_3-N in all cover crop treatments. Soil [NO_3-N], soil [NH_4-N], and total soil mineral N concentrations were higher in vetch plots than in other cover crop plots. Mineralization rates were apparently higher in the vetch treatments than the others. All treatments were still dominated by the NH_4-N form of mineral N.

Nitrification continued at two weeks after emergence, although NH_4-N was still the predominate form of mineral N in all treatments but vetch, indicating greater nitrification with vetch (Figures 9-10). Total soil mineral N concentrations had also increased in all treatments but vetch, however vetch

Figure 9. Kentland Research Farm Soil N-1993

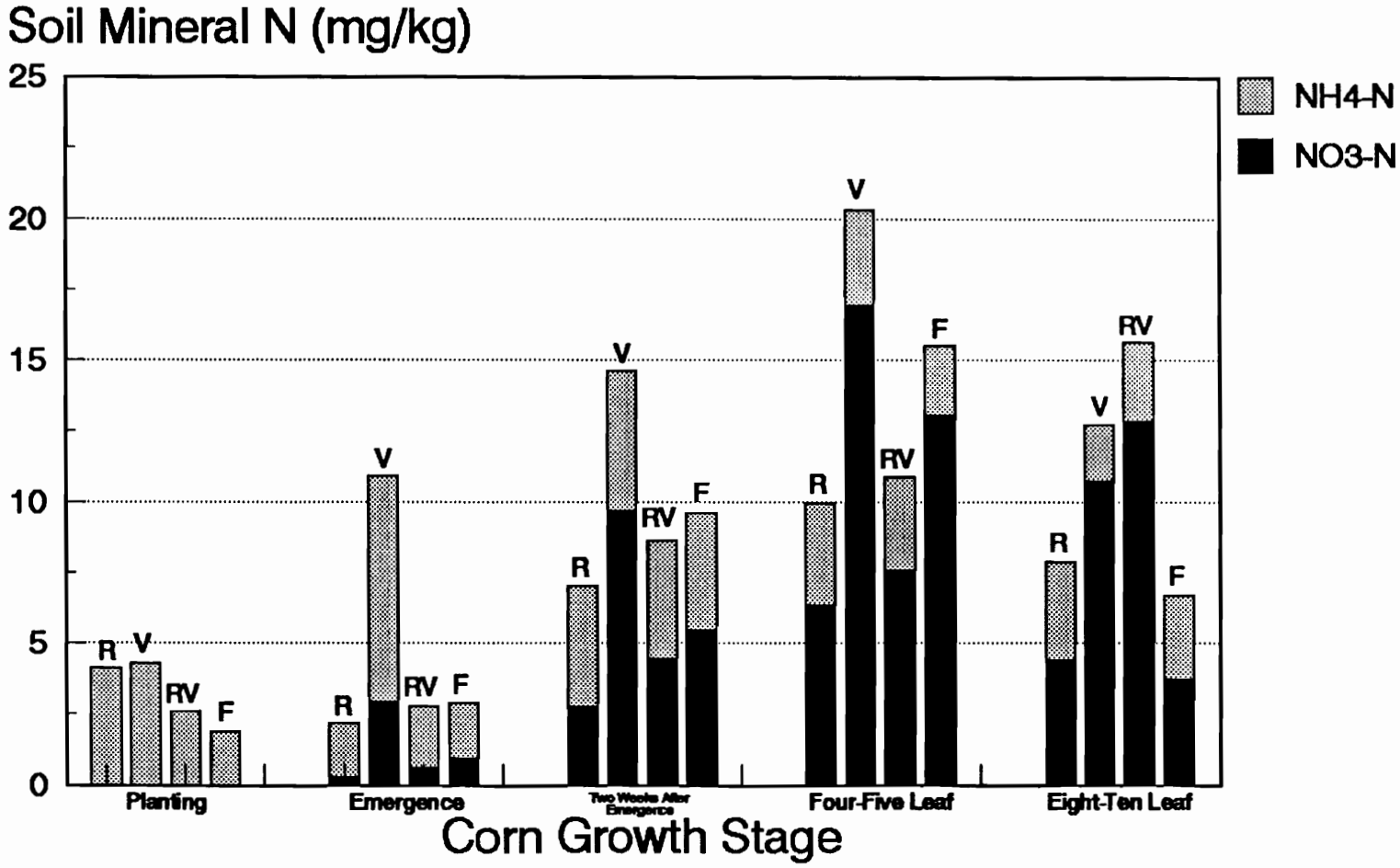
Soil Sample Depth 0 - 15 cm



R=Rye V=Vetch RV=Rye+Vetch F=Fallow

Figure 10. Kentland Research Farm Soil N-1993

Soil Sample Depth 0 - 30 cm

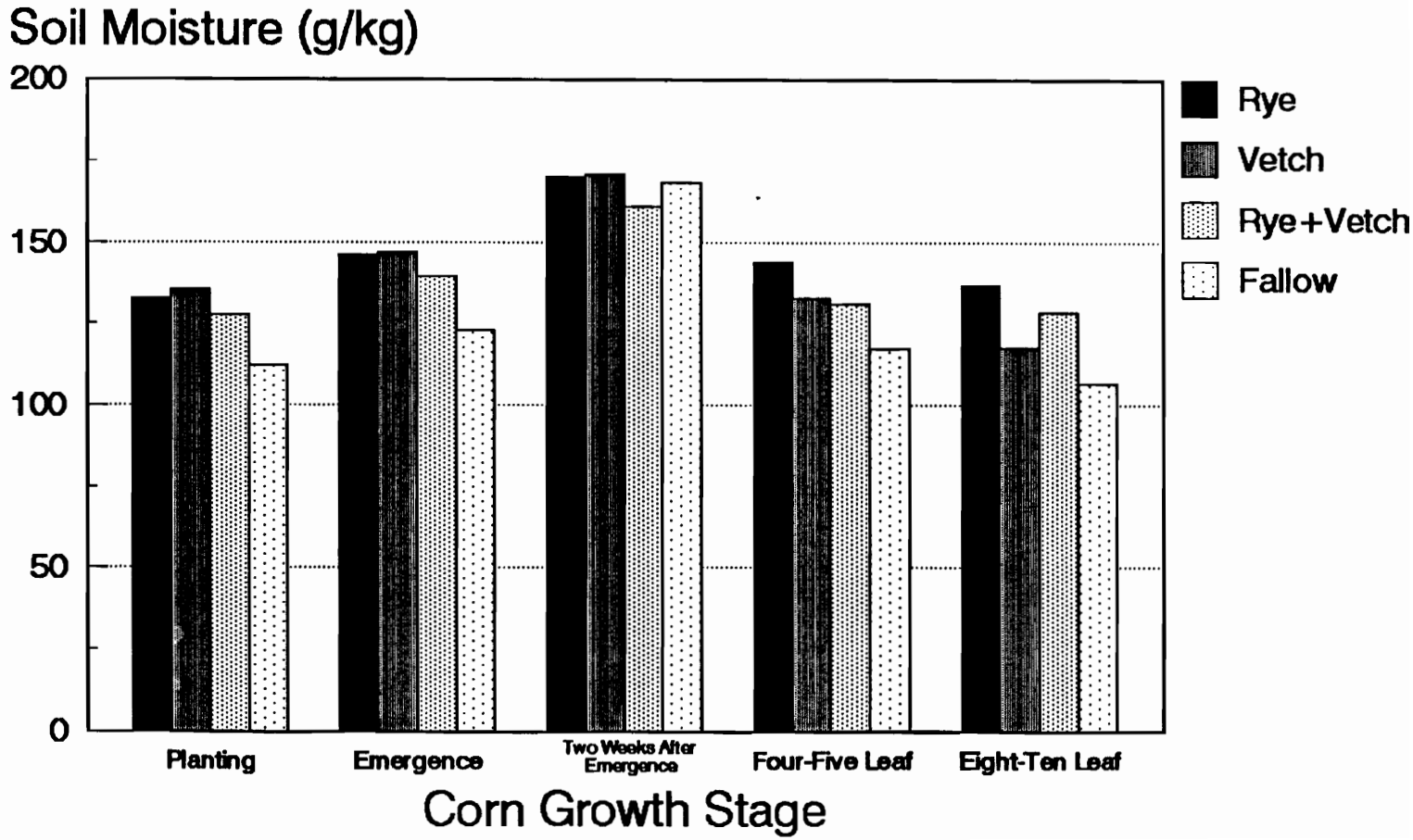


R=Rye V=Vetch RV=Rye+Vetch F=Fallow

Figure 11. Kentland Research Farm

Soil Moisture - 1993

0 - 30 cm Soil Depth



contained the highest soil mineral N concentration and [NO_3-N]. Fallow, rye and rye+vetch plots had lower [NO_3-N] than vetch, indicating less nitrification and/or more leaching on these plots.

Soil N concentrations peaked in all treatments but rye+vetch at the corn four to five leaf stage and all treatments were now dominated by the NO_3-N form of N. Rye and rye+vetch plots were restricted in their N mineralization capacities, probably by the high C/N ratio of their biomass and, possibly, by lower soil temperatures (Figure 12).

By the eight to ten leaf stage of corn soil mineral N concentrations in all treatments but rye+vetch had decreased. All treatments were still dominated by the NO_3-N form of N which indicated nitrification was still occurring. The decrease in N concentrations could be a result of more rapid corn N uptake and subsequent soil N depletion. The rye+vetch treatment peak at this time could possibly indicate cover crops including a mixture of rye and vetch need a slightly longer time for N mineralization than a legume alone.

3.2.4 Northern Piedmont Agricultural Experiment Station - 1993

Soil NO_3-N was undetectable at corn planting at the NPAES in 1993, all measurable N was in the NH_4-N form (Figures 13-14). The only exception was that the fallow plots had a small amount of NO_3-N, likely due to the absence of

Figure 12. Kentland Research Farm

Soil Temperature - 1993

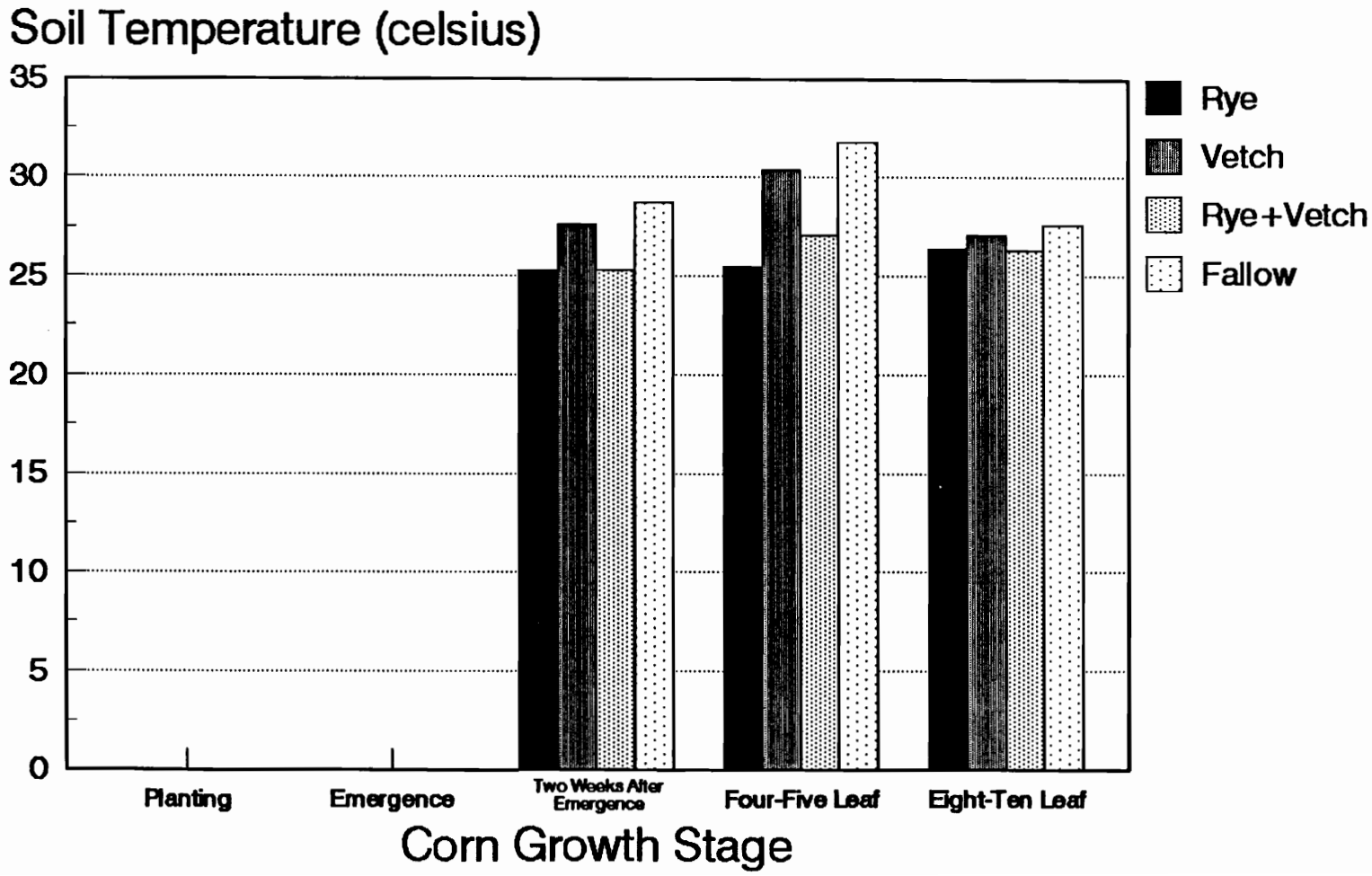
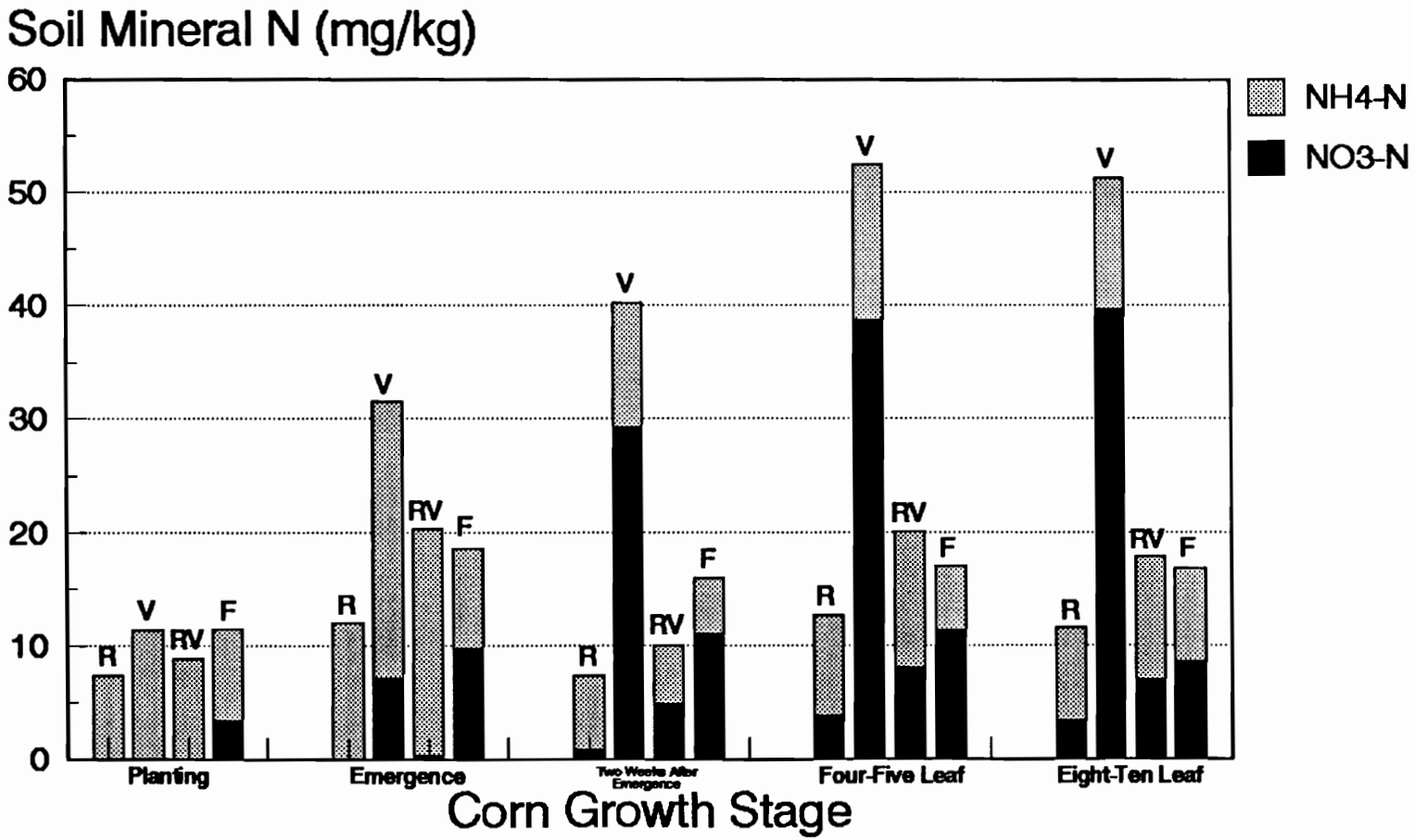


Figure 13. Northern Piedmont Agricultural Experiment Station Soil N-1993

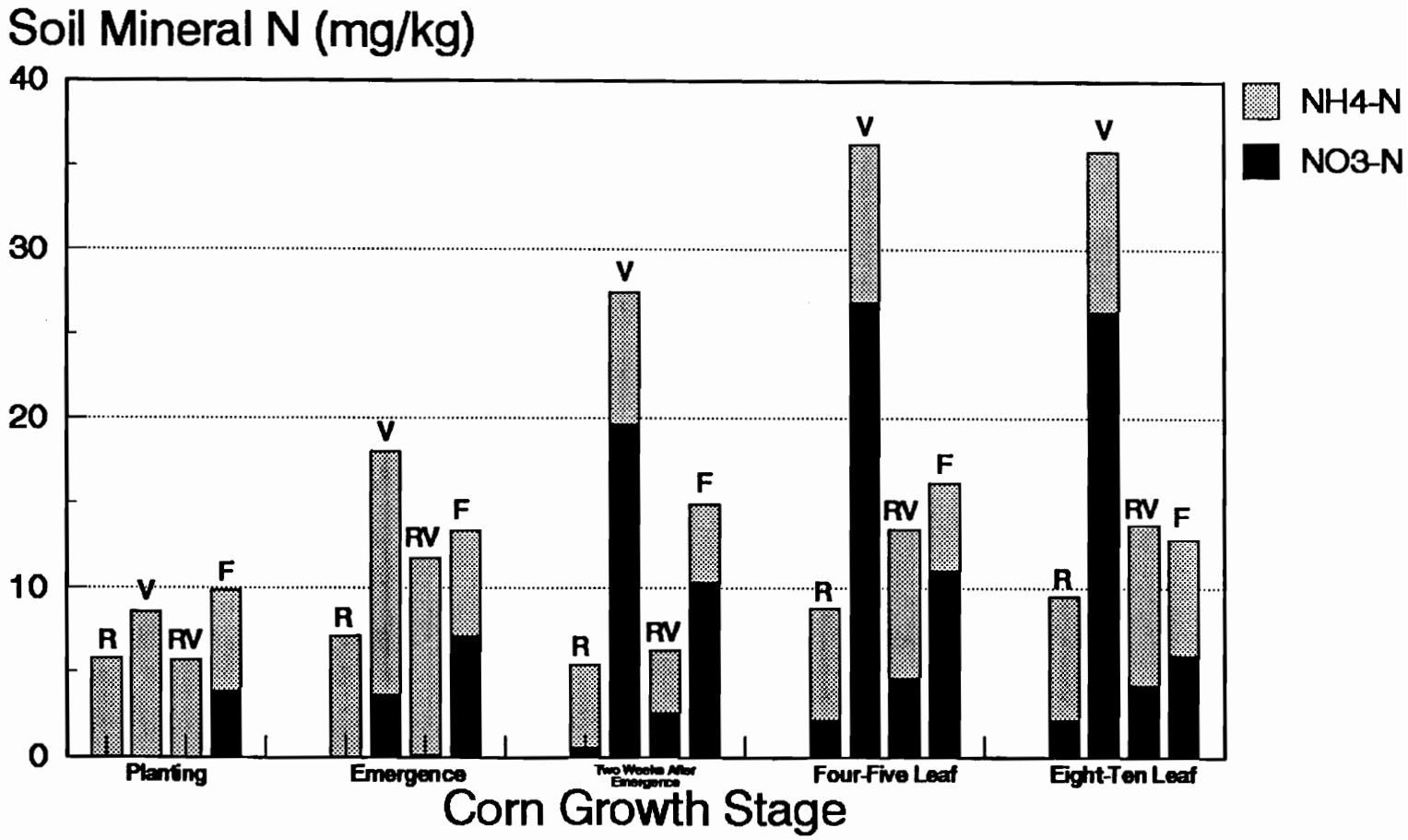
Soil Sample Depth 0 - 15 cm



R=Rye V=Vetch RV=Rye+Vetch F=Fallow

Figure 14. Northern Piedmont Agricultural Experiment Station Soil N-1993

Soil Sample Depth 0 - 30 cm



R=Rye V=Vetch RV=Rye+Vetch F=Fallow

an N scavenging cover. Additionally, fallow plots were higher in total N concentration than treatments including rye at the 0-30 cm soil depth.

Total soil mineral N increased in all treatments by corn emergence, but were still dominated by the NH_4-N form of soil N. This indicated that mineralization was occurring but very little nitrification was occurring. Vetch and fallow contained higher NO_3-N concentrations than treatments including rye, indicating higher nitrification on these plots. Additionally, vetch plots had higher total mineral N concentrations than the other cover crop plots, indicating higher N mineralization in vetch treatments than the other cover crop treatments.

Soil [NO_3-N] had increased by two weeks after emergence in all plots, with the NO_3-N form of N dominating all cover crop treatments but rye (Figures 13-14). Soil mineral N concentrations decreased from corn emergence in all treatments but vetch, probably due to corn N uptake and/or N leaching. Vetch plots had higher [NO_3-N] and total mineral N concentrations than all cover crop treatments, with fallow plots higher in [NO_3-N] and total N concentrations than plots containing rye. Nitrification in treatments including rye was probably restricted by rye N immobilization.

Soil N concentrations peaked in all plots at the four to five leaf stage of corn, with vetch having the highest [NO_3-N] and total mineral N concentrations of all cover crops. Ammonium-N dominated the rye and rye+vetch plots, possibly due to corn N uptake that depleted soil NO_3-N. Soil N in fallow plots

was similar to that at two weeks after emergence, likely due to similar mineralization patterns, corn N uptake, and soil temperatures (Figure 15).

Soil N concentrations at the corn eight to ten leaf stage were very similar to those at the corn four to five stage. This was most likely because corn N uptake was restricted by a lack of soil moisture. Soil moisture decreased rapidly due to a lack of precipitation prior to this sample time and inhibited corn growth and yield (Table 6, Figure 16).

3.2.5 Nitrate Quick Test Accuracy

The Nitrate Quick Test produced NO_3-N concentrations very similar to those obtained by intensive laboratory analysis, with an overall R^2 value of 0.93 (Figure 17). However, in 1992 the test was significantly less accurate than in 1993, producing R^2 values of 0.82 and 0.99, respectively (Figures 18-19). The overall NO_3-N concentrations were higher throughout the season in 1993 than in 1992. Therefore, as noted in the literature (1, 5, 8, 16, 17, 18), the test was less accurate at lower soil NO_3-N concentrations.

This fact was supported upon segregation of NO_3-N concentrations into low and high ranges and recalculating coefficients of determination. A [NO_3-N] of 10 mg/kg was employed as the critical point. The laboratory analyzed [NO_3-N] was used as the breaking point because it was assumed that this was the most accurate representation of actual soil [NO_3-N]. Concentrations less than

Figure 15. Northern Piedmont Agricultural Experiment Station Soil Temperatures - 1993

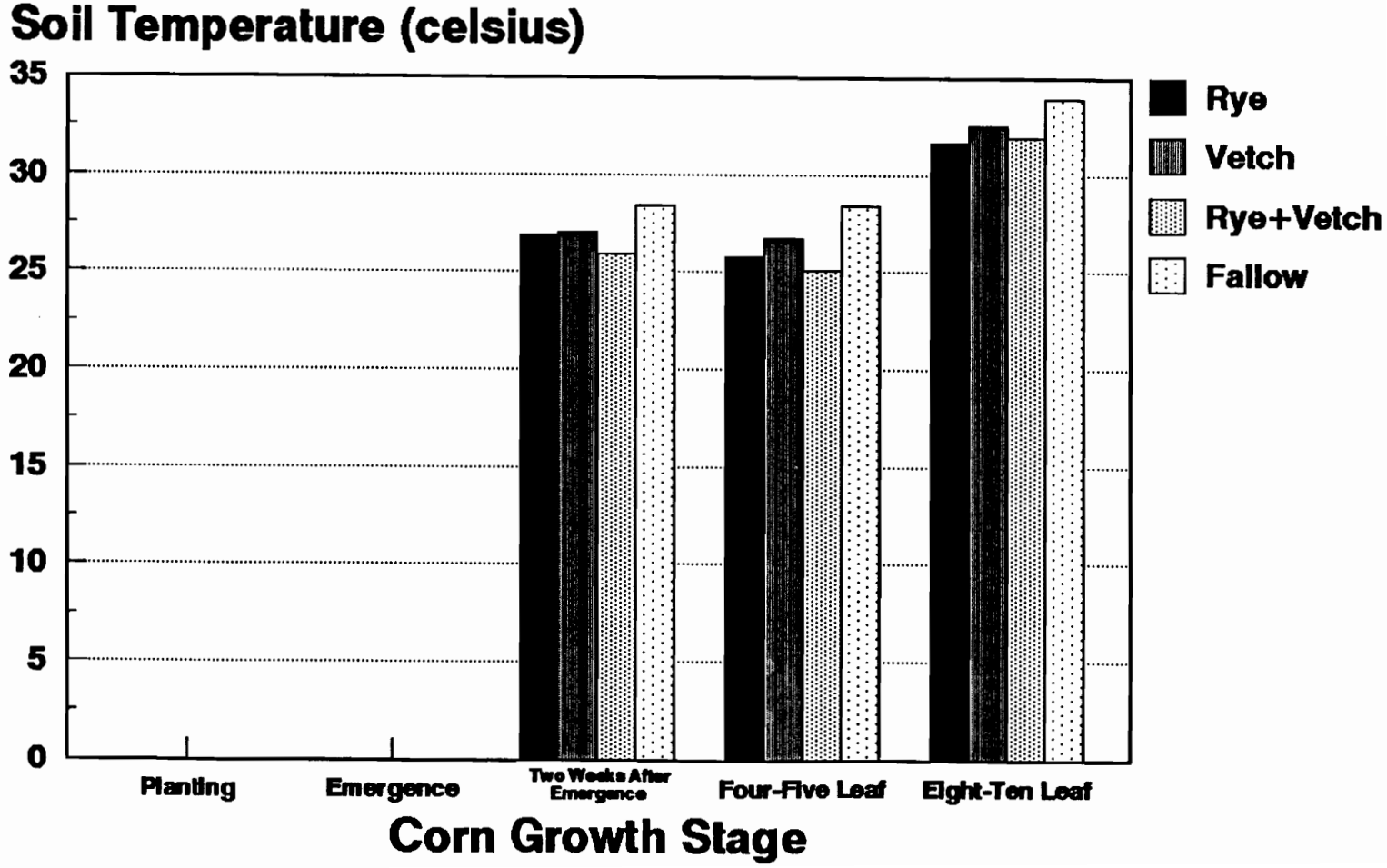


Figure 16. Northern Piedmont Agricultural Experiment Station Soil Moisture - 1993 0 - 30 cm Soil Depth

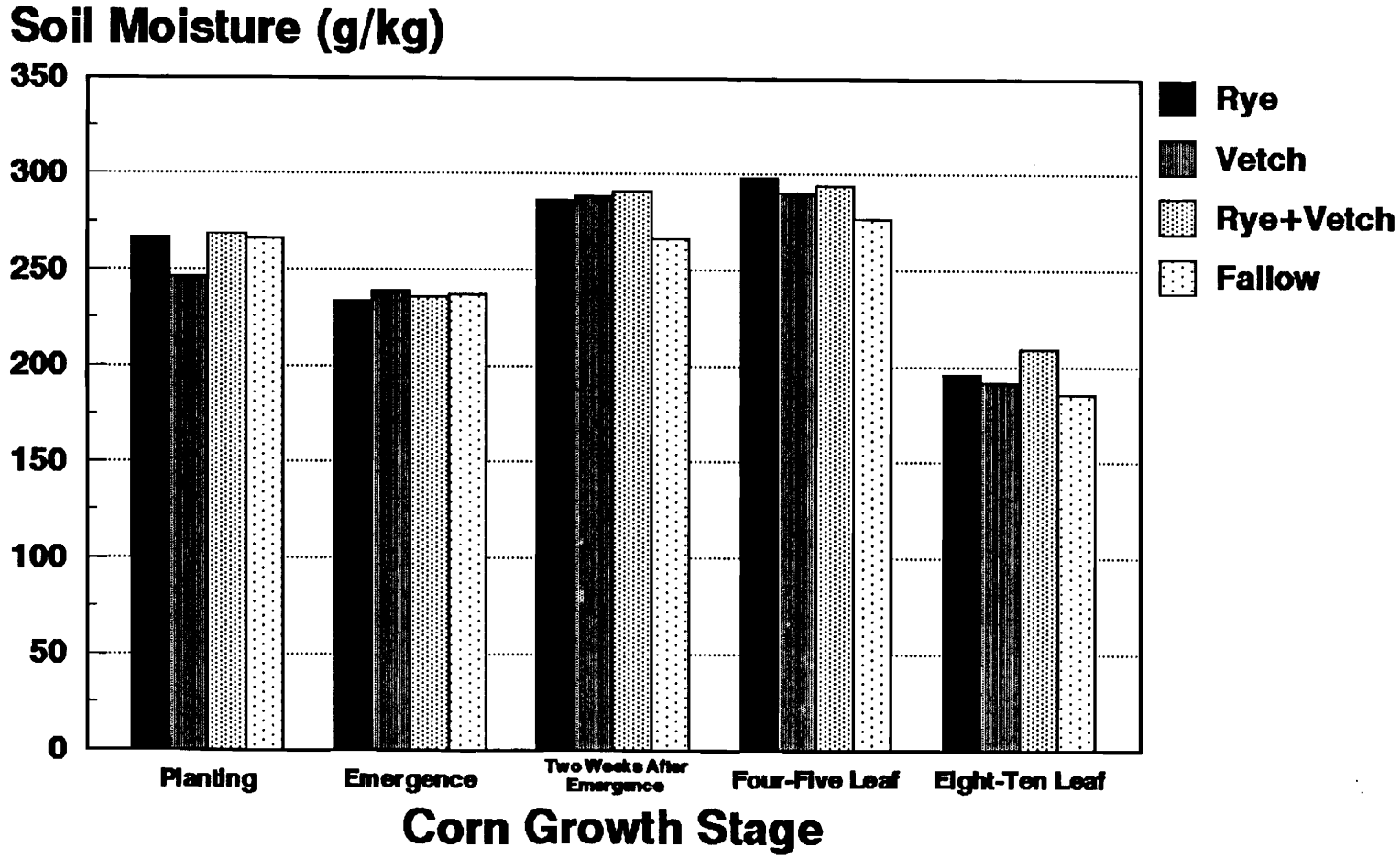


Figure 17. Nitrate Quick Test Analyzed [NO3-N] vs. Intensive Laboratory Analyzed [NO3-N]

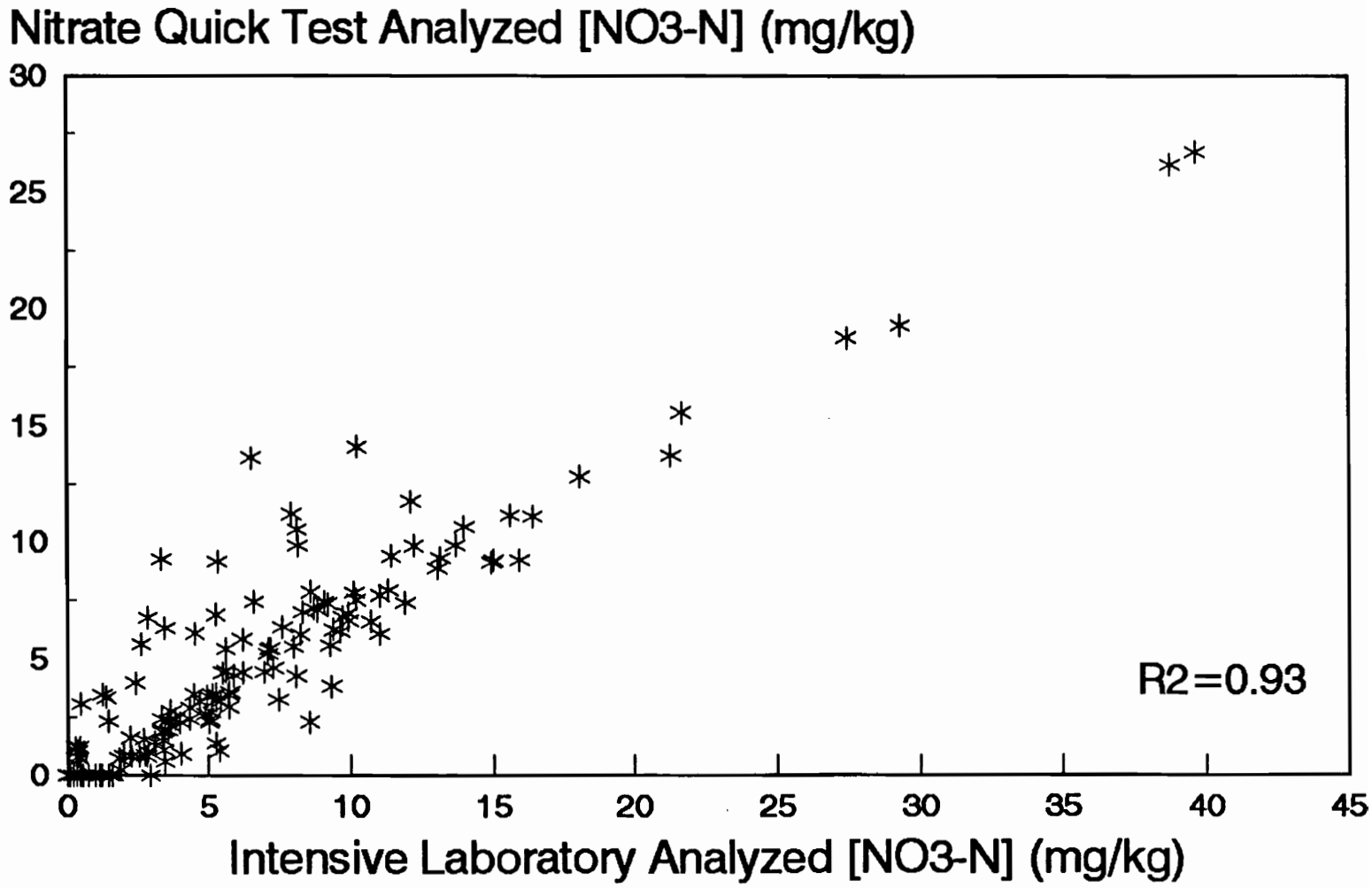


Figure 18. Nitrate Quick Test Analyzed [NO3-N] vs. Intensive Laboratory Analyzed [NO3-N] - 1992

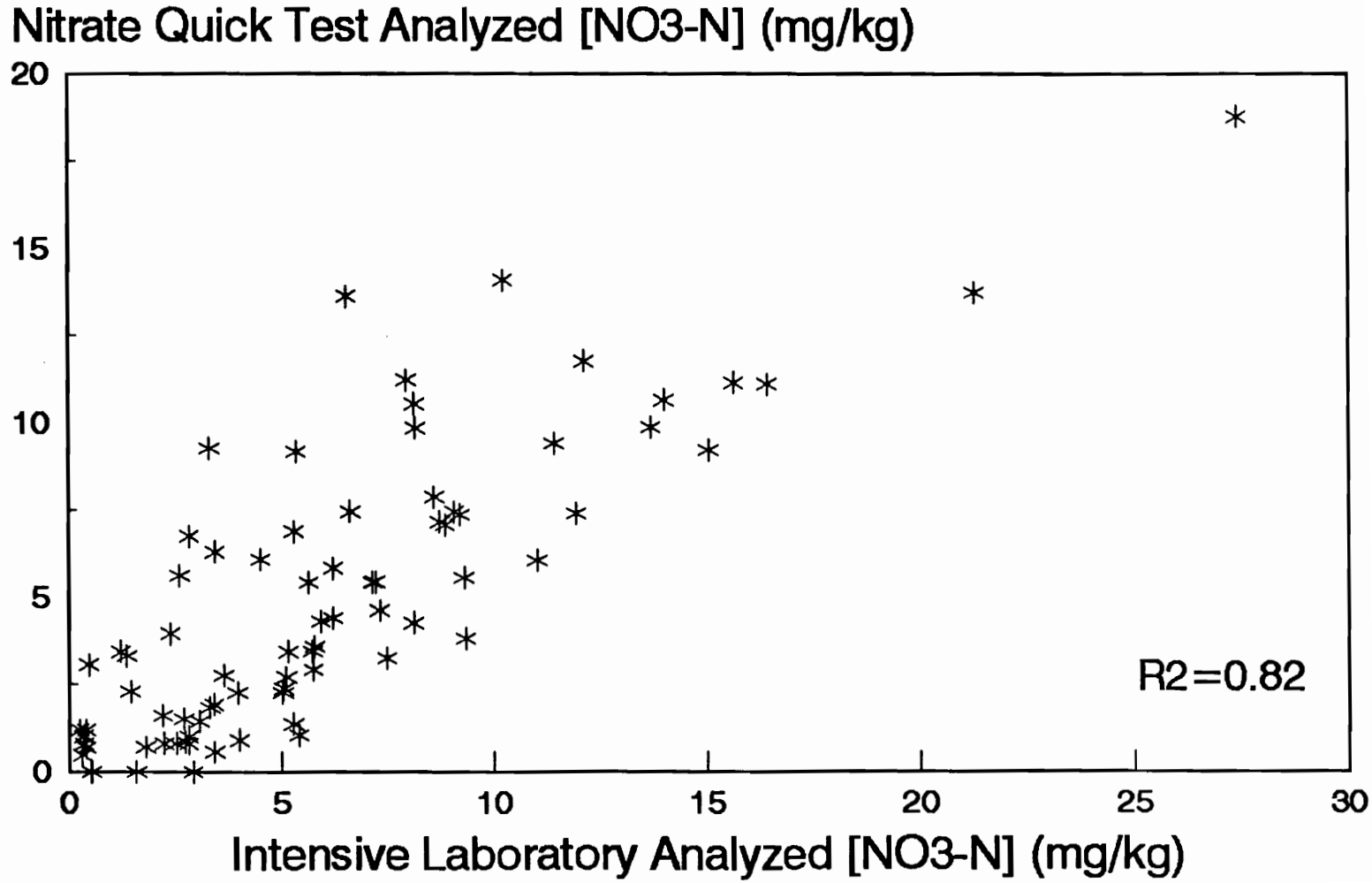
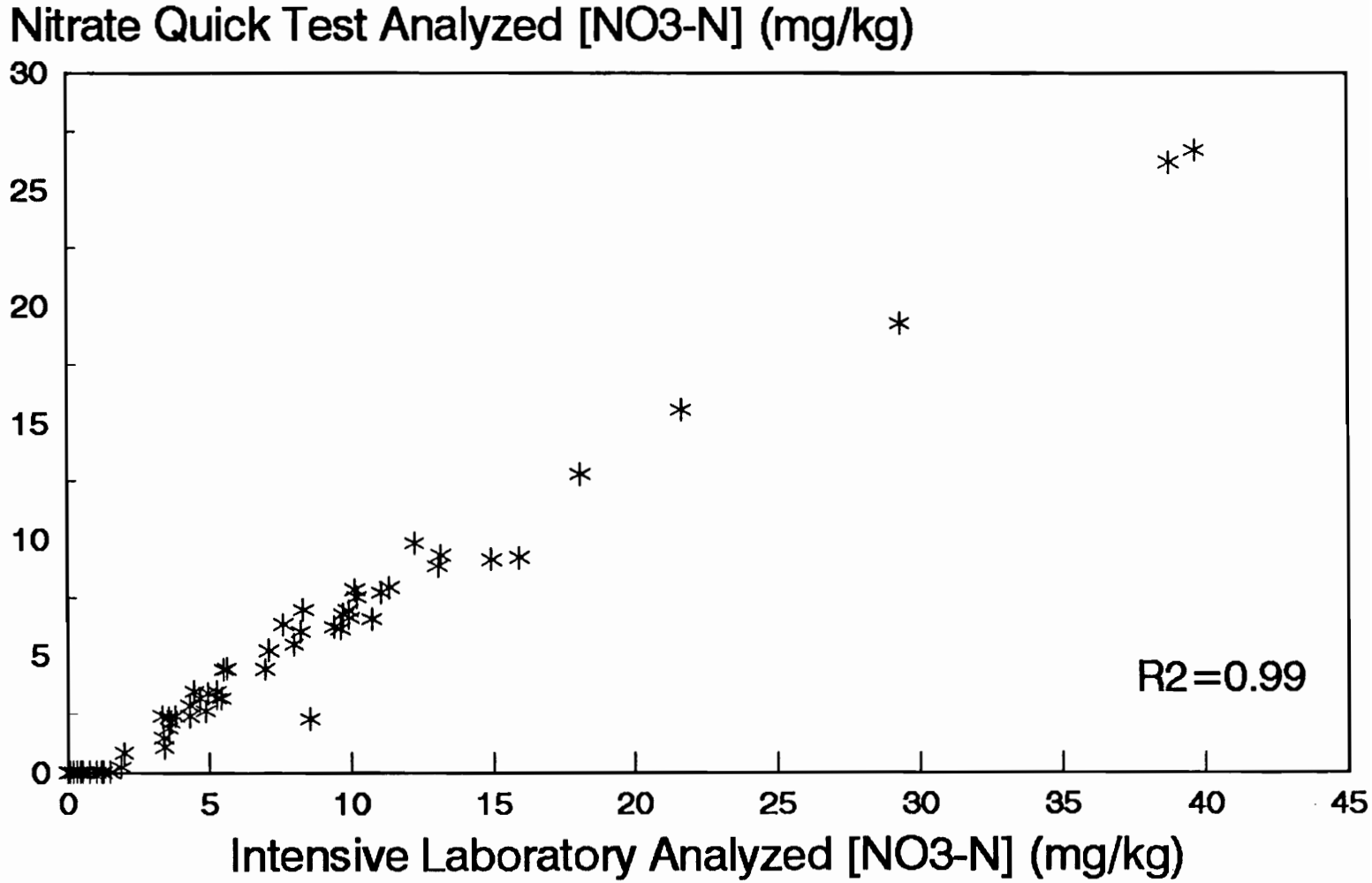


Figure 19. Nitrate Quick Test Analyzed [NO3-N] vs. Intensive Laboratory Analyzed [NO3-N] - 1993



10 mg/kg resulted in an R^2 of 0.79, while concentrations greater than 10 mg/kg resulted in an R^2 of 0.95 (Figures 20-21).

Coefficients of determination were always lower for the relationship between quick test and laboratory analysis of NO_3-N at lower soil NO_3-N concentrations, regardless of whether the low concentrations were due to cover crop, sampling time, or sampling depth. Relationships between quick test and laboratory analysis of NO_3-N for a variety of factors (i.e. cover crop, sampling time, sampling depth) are presented in Appendix A. However, because modification in fertilizer N recommendations would only be made at higher soil NO_3-N concentrations, the inaccuracy of the Nitrate Quick Test at low soil [NO_3-N] should not affect N recommendation.

3.3 Corn N Concentration Data

3.3.1 Kentland Research Farm - 1992

It might appear on initial examination that the rye and rye+vetch cover crops supplied greater amounts of available N than vetch and fallow to the corn at the four to five leaf stage of corn (Table 20). However, as stated in section 3.2.1, corn plants in the rye and rye+vetch plots were significantly smaller in size than the corn plants in the vetch and fallow plots, and therefore corn N uptake was probably lower in the rye containing treatments. Therefore,

Figure 20. Nitrate Quick Test Analyzed [NO3-N] vs. Intensive Laboratory Analyzed [NO3-N]

Laboratory Analyzed [NO3-N] Less Than 10

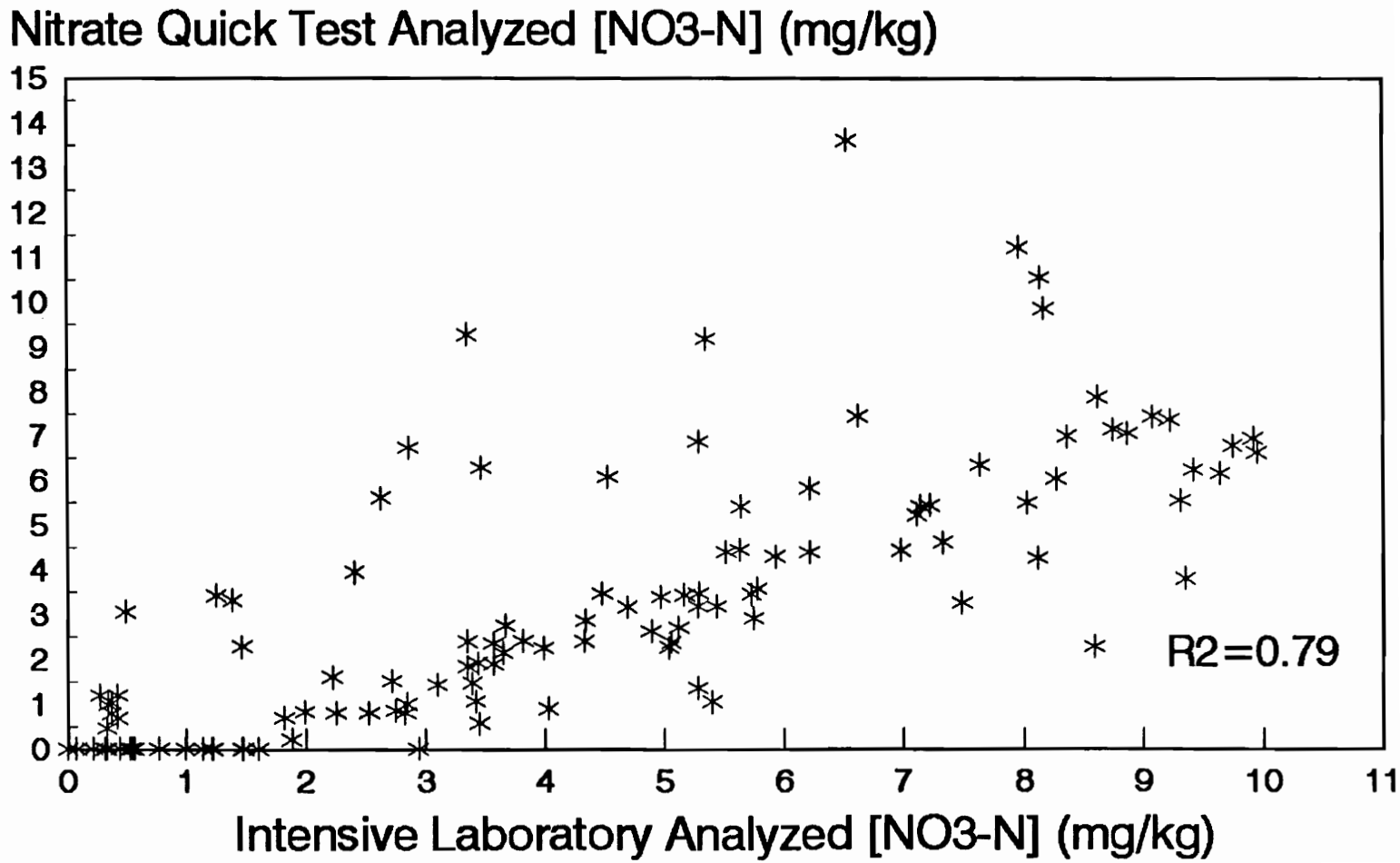


Figure 21. Nitrate Quick Test Analyzed [NO3-N] vs. Intensive Laboratory Analyzed [NO3-N]

Laboratory Analyzed [NO3-N] Greater Than 10

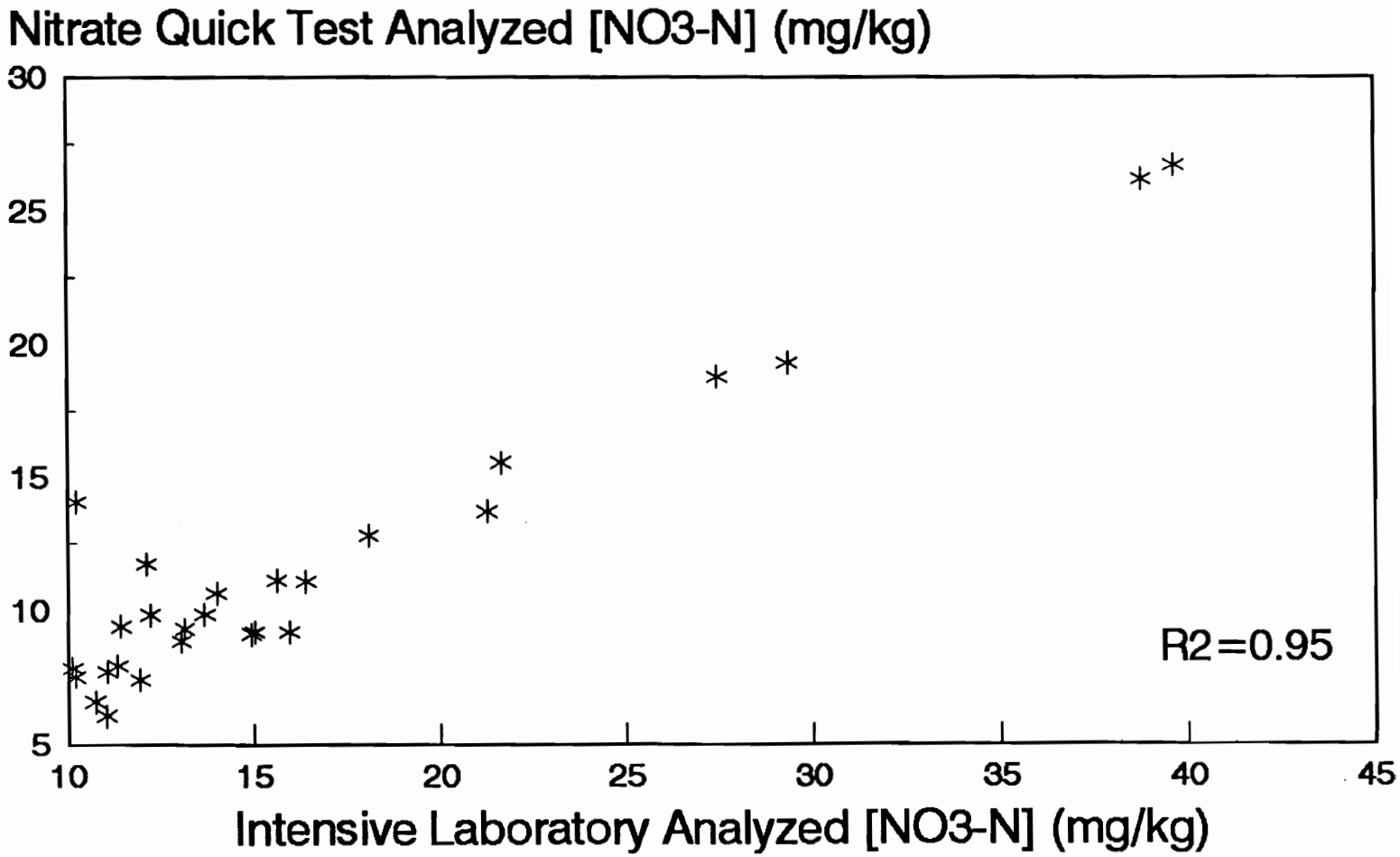


Table 20. Kentland Research Farm Corn N Concentrations - 1992.

Cover	Corn Growth Stage: Four-Five Leaf	Eight-Ten Leaf	Silking
	g/kg		
Rye	29.4	28.1	17.9
Vetch	24.6	26.0	30.8
Rye+Vetch	31.9	29.5	17.2
Fallow	24.7	27.0	27.4
LSD	5.2**	NS	6.2*

* Differences among means within columns are significant at the 0.01 probability level.

** Differences among means within columns are significant at the 0.05 probability level.

Table 21. Northern Piedmont Agricultural Experiment Station Corn N Concentrations - 1992.

Cover	Corn Growth Stage: Four-Five Leaf	Eight-Ten Leaf	Silking
	g/kg		
Rye	32.6	24.0	11.1
Vetch	27.4	23.7	20.3
Rye+Vetch	29.5	24.0	11.5
Fallow	29.2	25.9	25.6
LSD	NS	NS	3.9*

* Differences among means within columns are significant at the 0.01 probability level.

differences in corn N concentration are most likely due to differences in corn plant size than soil N availability.

Size differences between corn plants were less at the corn eight to ten leaf stage than corn four to five leaf stage, yet corn plants in the fallow and vetch plots were still significantly larger than those in the rye and rye+vetch plots. No significant differences between corn N concentration were detected at this sample time. Therefore, at this sample time also, differences in corn N concentration are most likely due to differences in corn plant size than soil N availability.

The corn silking stage provided corn N concentrations that were influenced very little by differences in corn plant size. Vetch and fallow had significantly higher N concentrations than rye and rye+vetch, indicating higher N availability of the fallow and vetch treatments. This is supported by the soil N data in Figures 1-2. Corn plants on vetch plots did not have higher N concentrations than corn plants on fallow plots, indicating similar soil N availability between treatments.

3.3.2 Northern Piedmont Agricultural Experiment Station - 1992

It might appear on initial examination that the rye and rye+vetch cover crops supplied greater amounts of available N than vetch and fallow to the corn at the four to five leaf stage of corn (Table 21). However, as stated in section

3.3.2, corn plants in the rye and rye+vetch plots were significantly smaller in size than the corn plants in the vetch and fallow plots, and therefore corn N uptake was probably lower in the rye containing treatments. Therefore, differences in corn N concentration are most likely due to differences in corn plant size than actual soil N availability.

Size differences between corn plants were less at the corn eight to ten leaf stage than corn four to five leaf stage, yet corn plants in the fallow and vetch plots were still significantly larger than those in the rye and rye+vetch plots. No significant differences between corn N concentration were detected at this sample time. Therefore, at this sample time also, differences in corn N concentration are most likely due to differences in corn plant size than soil N availability.

The corn silking stage provided corn N concentrations that were influenced very little by differences in corn plant size. Vetch and fallow gave significantly higher corn N concentrations than rye and rye+vetch, indicating higher N availability in the fallow and vetch treatments. This is supported by the soil N data in Figures 5-6. Additionally, corn plants on fallow plots had higher N concentrations than corn plants on vetch plots, indicating higher soil N availability on these plots.

3.3.3 Kentland Research Farm - 1993

Corn N concentration was higher in the vetch treatments than the plots containing rye at the corn four to five leaf stage (Table 22). This indicates higher soil N availability in vetch plots, as the soil N figures did (Figures 9-10). Corn N uptake values mimicked N concentration values, again indicating higher N availability on vetch and fallow plots compared to plots including rye (Table 23).

Two weeks later at the corn eight to ten leaf stage no significant differences between corn N concentration were detected. All treatments but rye+vetch decreased in N concentration from the corn four to five leaf stage, indicating soil N depletion by the corn. This was especially evident in the fallow plots where corn N concentration decreased significantly, mimicking soil N concentration at this time.

Vetch and rye+vetch had significantly higher N concentrations than rye and fallow at corn silking, indicating higher N availability of the rye+vetch and vetch treatments, and again supported by the soil N data (Figures 9-10). This result supports the hypothesis that rye+vetch cover crop N may be released and become available soon enough and in sufficient quantities to meet corn needs, yet the N may not be detectable at the times when sampling usually occurs.

Table 22. Kentland Research Farm Corn N Concentrations - 1993.

Cover	Corn Growth Stage: Four-Five Leaf	Eight-Ten Leaf	Silking
	g/kg		
Rye	39.3	37.6	18.3
Vetch	45.6	41.6	24.0
Rye+Vetch	39.9	40.0	24.0
Fallow	42.7	37.0	19.7
LSD	4.6*	NS	4.3**

* Differences among means within columns are significant at the 0.01 probability level.

** Differences among means within columns are significant at the 0.05 probability level.

Table 23. Northern Piedmont Agricultural Experiment Station Corn N Concentrations - 1993.

Cover	Corn Growth Stage: Four-Five Leaf	Eight-Ten Leaf	Silking
	g/kg		
Rye	41.2	27.8	14.6
Vetch	53.0	36.5	23.8
Rye+Vetch	44.2	27.8	19.7
Fallow	48.6	27.0	16.7
LSD	7.4*	2.3*	4.8*

* Differences among means within columns are significant at the 0.01 probability level.

Table 24. Kentland Research Farm (KRF) and Northern Piedmont Agricultural Experiment Station (NPAES) Corn N Uptake at Sidedress - 1993.

Cover	----------kg N/ha----------	
	---------KRF---------	-------NPAES-------
Rye	1.71	0.75
Vetch	4.01	4.61
Rye+Vetch	2.42	1.74
Fallow	3.43	6.58
$LSD_{0.01}$	1.21	2.25
$LSD_{0.05}$	0.84	1.49

3.3.4 Northern Piedmont Agricultural Experiment Station - 1993

Corn plants in vetch plots were higher in N concentration than corn in plots containing rye at the four to five leaf stage of corn (Table 23), indicating higher N availability in vetch treatments. This is supported by the soil N data in Figures 13-14. Additionally, corn in fallow treatments had higher N concentrations than corn in rye plots, probably because of N immobilization by carbonaceous rye. Corn plant size was also a factor this year and location, with fallow and vetch plots having larger corn plants than rye and rye+vetch plots. Therefore, this may have again masked soil N availability differences because corn plant size may have caused the differences in corn N concentration. Corn N uptake values supported this difference showing lower N uptake amounts on rye and rye+vetch plots at the corn four-five leaf stage due to very small corn plants (Table 24). Additionally, fallow had higher N uptake but lower N concentration than vetch plots, indicating larger plants on the fallow plots.

Two weeks later, at the corn eight to ten leaf stage, the corn plants were visually very similar in size. Corn plants in the vetch plots had significantly higher N concentrations than the other treatments, indicating higher N availability on these plots. Therefore, differences in corn N concentration were most likely due to differences in soil N availability.

Corn N concentrations were higher in the vetch plots than in the rye and fallow plots at corn silking, indicating higher N availability in the vetch treatments. Rye+vetch plots also had higher N concentrations than rye treatments, exhibiting the higher N availability from rye+vetch than rye alone. Again, this result supports the hypothesis that a rye+vetch cover crop N may be released and become available soon enough and in sufficient quantities to meet corn needs, yet the N may not be detectable at the times when sampling usually occurs.

3.4 Corn Yield Data

Corn grain yield at the KRF in 1992 only responded to N rate in rye treatments (Table 25, Figure 22). This is most likely due to a combination of factors including: a rain delayed corn planting date, a cool wet spring and early summer, excessive rye growth (Table 14), and also the high residual soil N at this location (Tables 5 and 16, Figure 4). All these factors worked to limit corn yield potential and corn N response. It is probable that much of the residual N was immobilized in the rye plots, therefore, additional N was required to achieve maximum yield. Fallow and vetch plots still had the higher yields than treatments including rye, most likely due to poor early season corn growth in plots containing rye which reduced yield potential.

Table 25. Kentland Research Farm (KRF) and Northern Piedmont Agricultural Experiment Station (NPAES) Grain Yield Parameter Relationships - 1992.

Cover	Yield Plateau*	N Rate**	Yield at N rate=0	Relative Yield***
	-Mg/ha-	-kg N/ha-	-Mg/ha-	---%---
			KRF	
Rye	5.37	181	3.25	61
Vetch	6.49	0	6.49	100
Rye+Vetch	4.81	0	4.81	100
Fallow	6.29	0	6.29	100
			NPAES	
Rye	9.00	216	2.84	32
Vetch	11.68	171	8.42	72
Rye+Vetch	8.88	192	2.89	33
Fallow	11.19	75	8.98	80

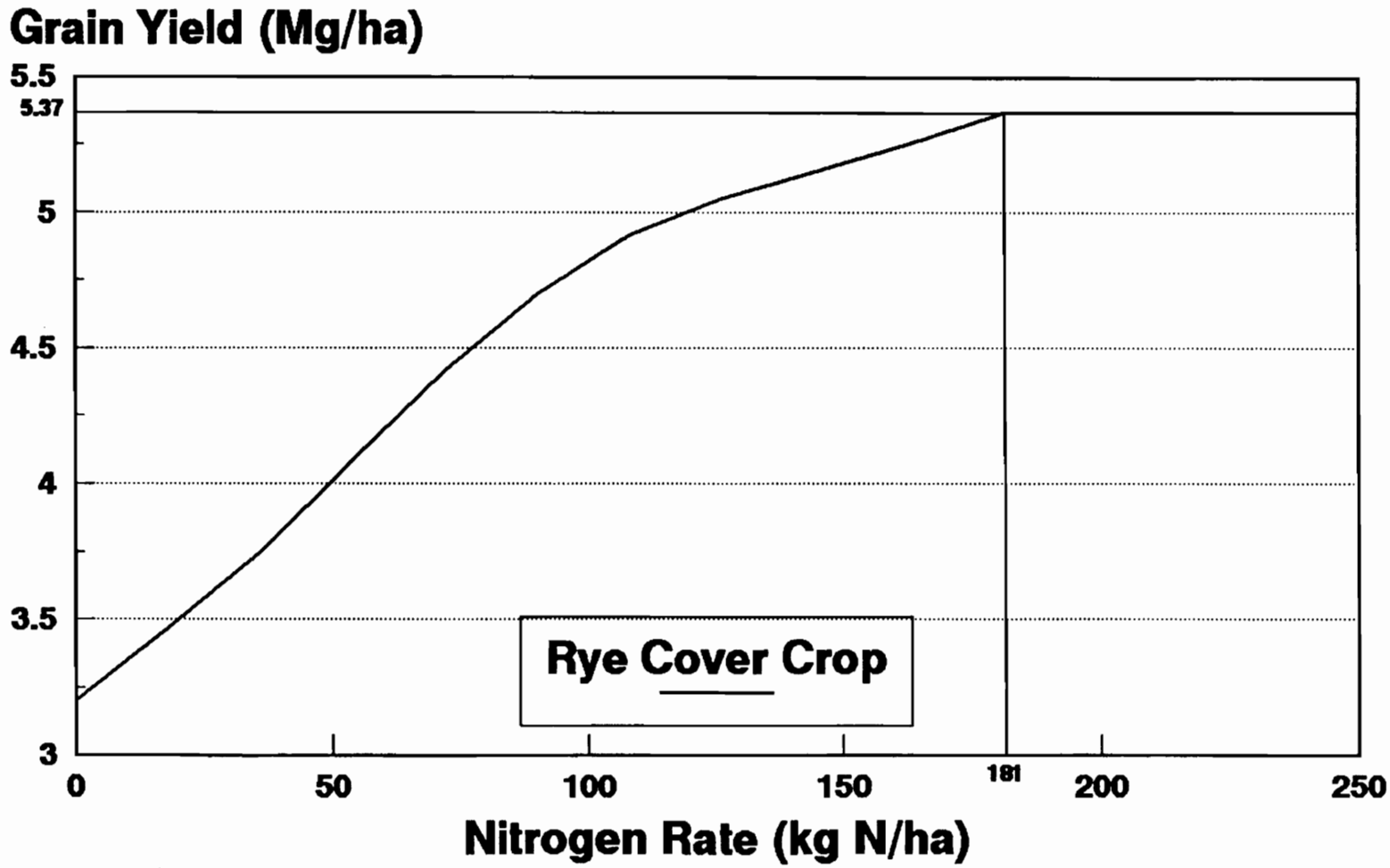
* Plateau yield as determined by quadratic and plateau model.

** N rate at inflection point of the quadratic and plateau response curve.

*** (Yield at N rate=0/Yield plateau)*100.

Figure 22. Kentland Research Farm - 1992

Quadratic and Plateau Response Curve



Grain yield for all cover crop treatments in 1992 at the NPAES responded to N rate (Table 25, Figures 23-26). Corn in rye and rye+vetch treatments yielded less and required the higher levels of fertilizer N to reach maximum yield than fallow and vetch. The major factor controlling the yield difference was probably the excessive rye growth which reduced corn growth through N immobilization and soil temperature reduction (Tables 5 and 16 and Figures 7-8). Vetch plots required higher N rates to reach maximum corn yield than fallow plots. However, N rates for fallow and vetch at 90 % of maximum yield are closer than at 100 % maximum yield, due to less of a yield gain in the vetch plot than in the fallow treatment between 90 and 100 % maximum yield.

Grain yield in 1993 at the KRF was influenced by N application at all levels of cover (Table 26, Figures 27-30). Rye and rye+vetch treatments required the highest levels of N to reach maximum yield, most likely due to N immobilization by the rye. Vetch and fallow plots required similar rates of N, most likely because of the relatively low N production by vetch.

Corn grain yield in fallow and vetch treatments at the NPAES in 1993 did not respond to N rate (Table 26, Figures 31-32). Yield was limited by rainfall, not N, in fallow and vetch treatments (Table 6 and Figures 13-14). Rye and rye+vetch treatments yielded more than vetch and fallow plots due to greater water availability in plots containing the moisture conserving rye mulch. Additionally, rye and rye+vetch treatments required high levels of N, most likely

Figure 23. Northern Piedmont Agricultural Experiment Station - 1992 Quadratic and Plateau Response Curve

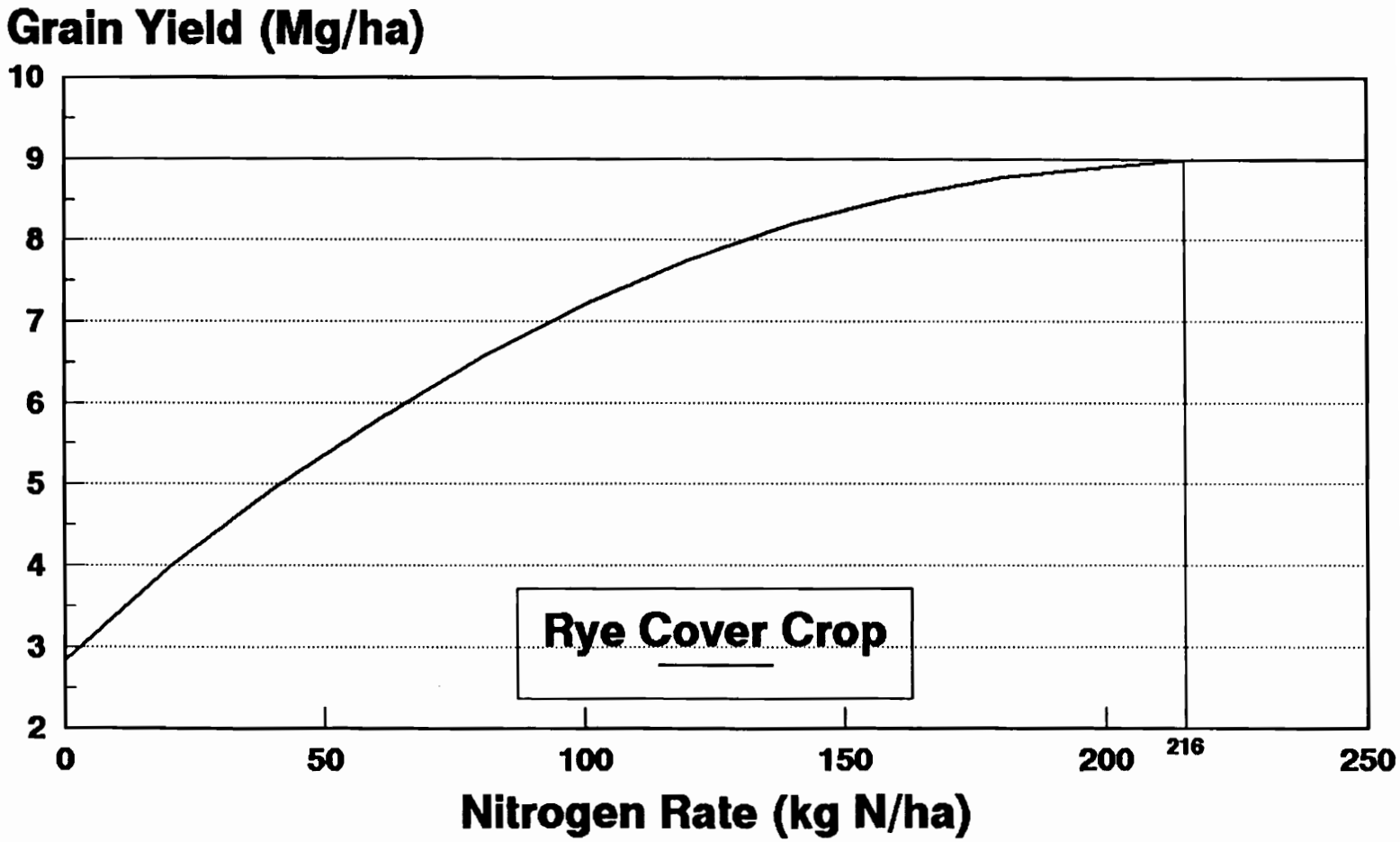


Figure 24. Northern Piedmont Agricultural Experiment Station - 1992 Quadratic and Plateau Response Curve

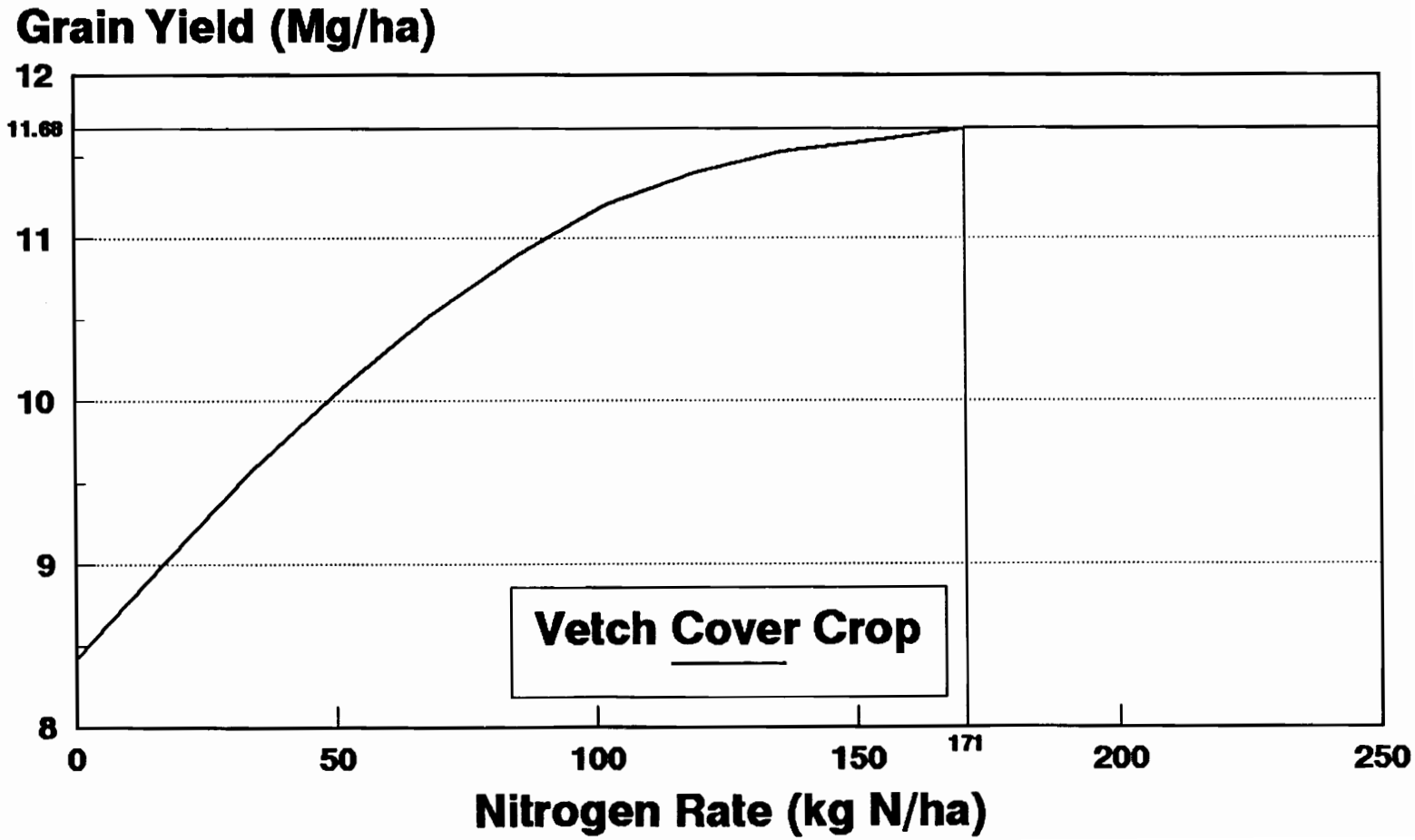


Figure 25. Northern Piedmont Agricultural Experiment Station - 1992 Quadratic and Plateau Response Curve

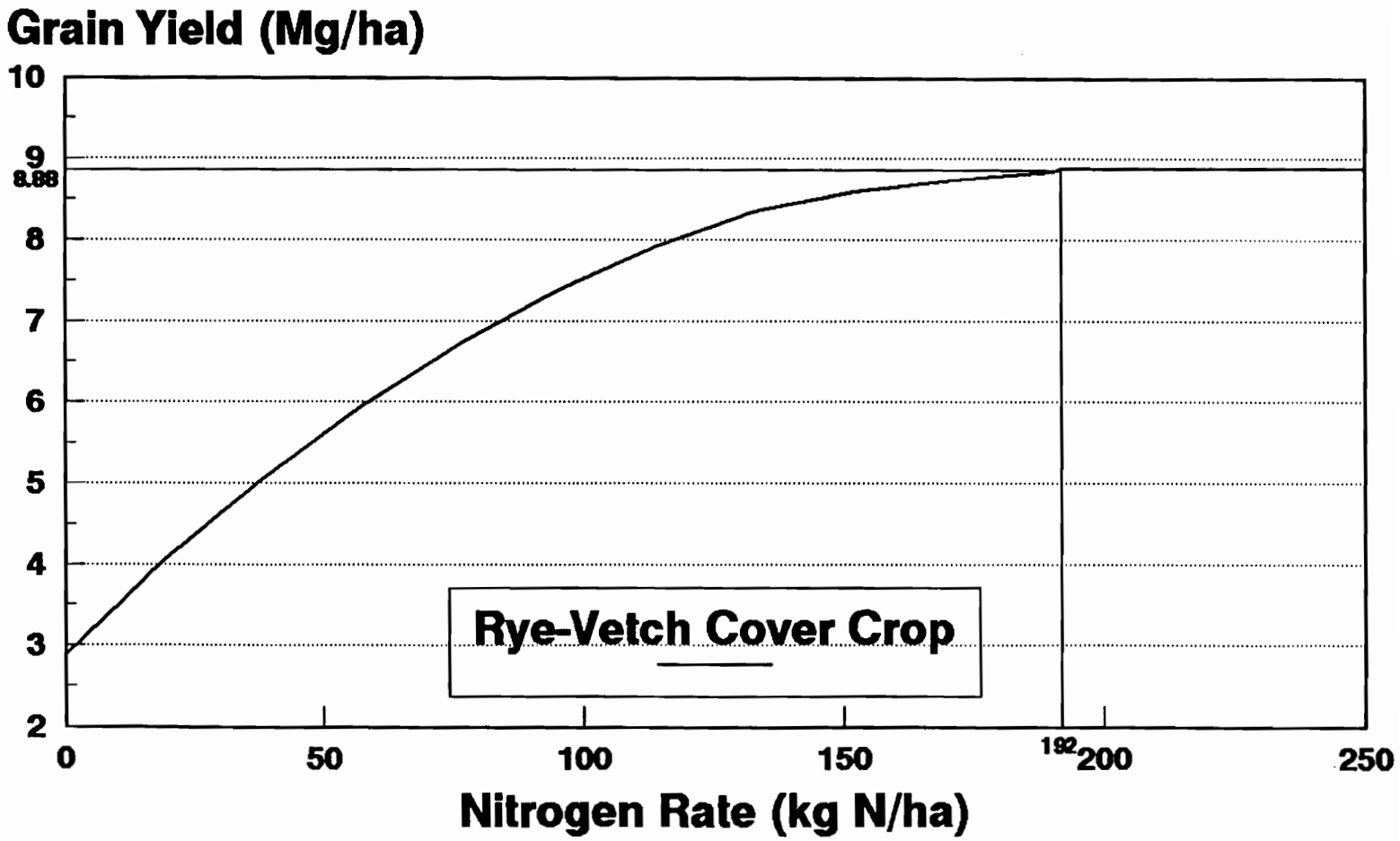


Figure 26. Northern Piedmont Agricultural Experiment Station - 1992 Quadratic and Plateau Response Curve

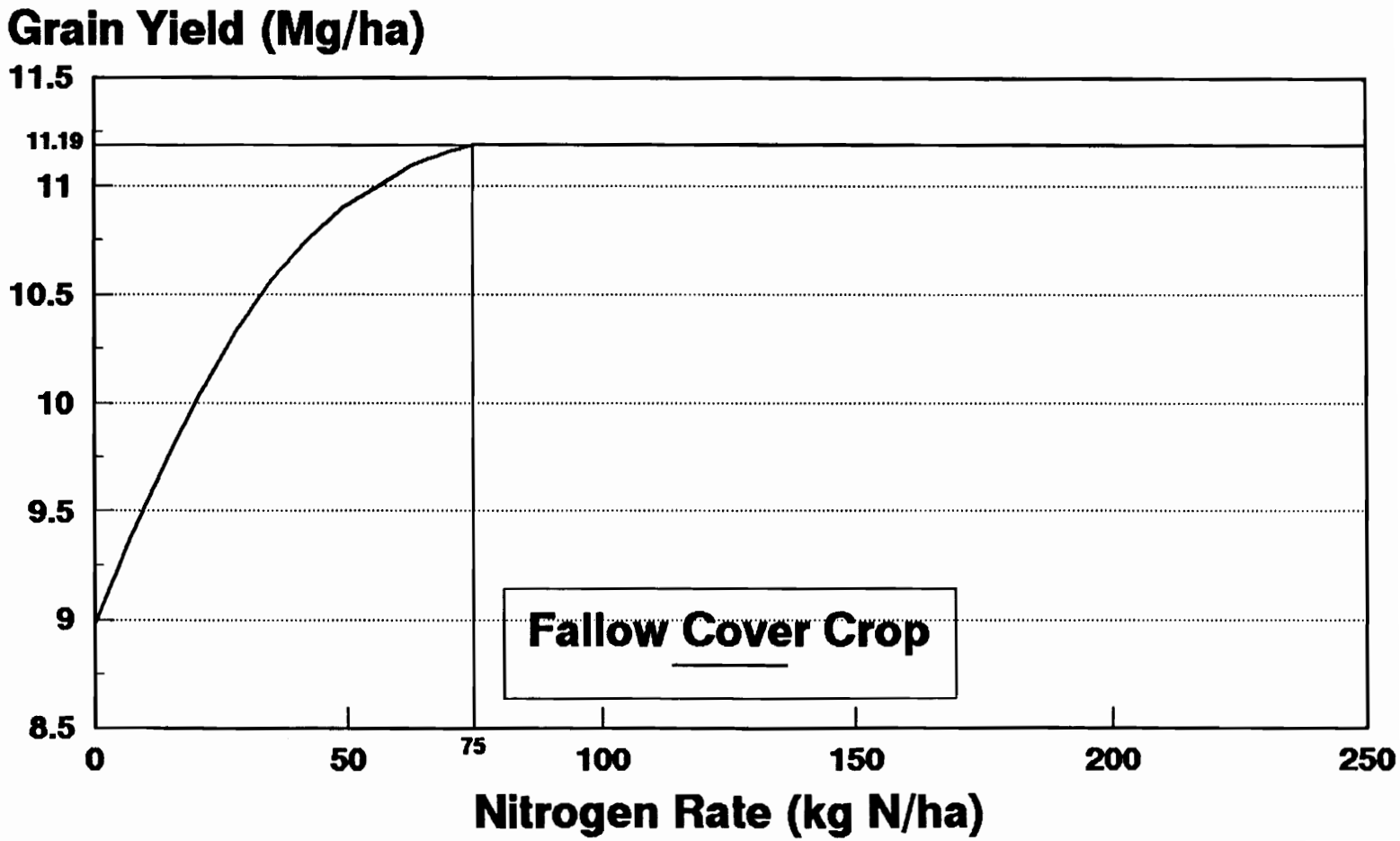


Table 26. Kentland Research Farm (KRF) and Northern Piedmont Agricultural Experiment Station (NPAES) Grain Yield Parameter Relationships - 1993.

Cover	Yield Plateau*	N Rate**	Yield at N rate=0	Relative Yield***
	-Mg/ha-	-kg N/ha-	-Mg/ha-	---%---
			KRF	
Rye	8.83	129	4.57	61
Vetch	9.36	104	7.50	80
Rye+Vetch	9.06	183	6.19	68
Fallow	9.16	106	7.24	79
			NPAES	
Rye	6.43	209	3.54	55
Vetch	4.71	0	4.71	100
Rye+Vetch	6.06	281	4.41	73
Fallow	4.93	0	4.93	100

* Plateau yield as determined by quadratic and plateau model.

** N rate at inflection point of the quadratic and plateau response curve.

*** (Yield at N rate=0/Yield plateau)*100.

Figure 27. Kentland Research Farm - 1993

Quadratic and Plateau Response Curve

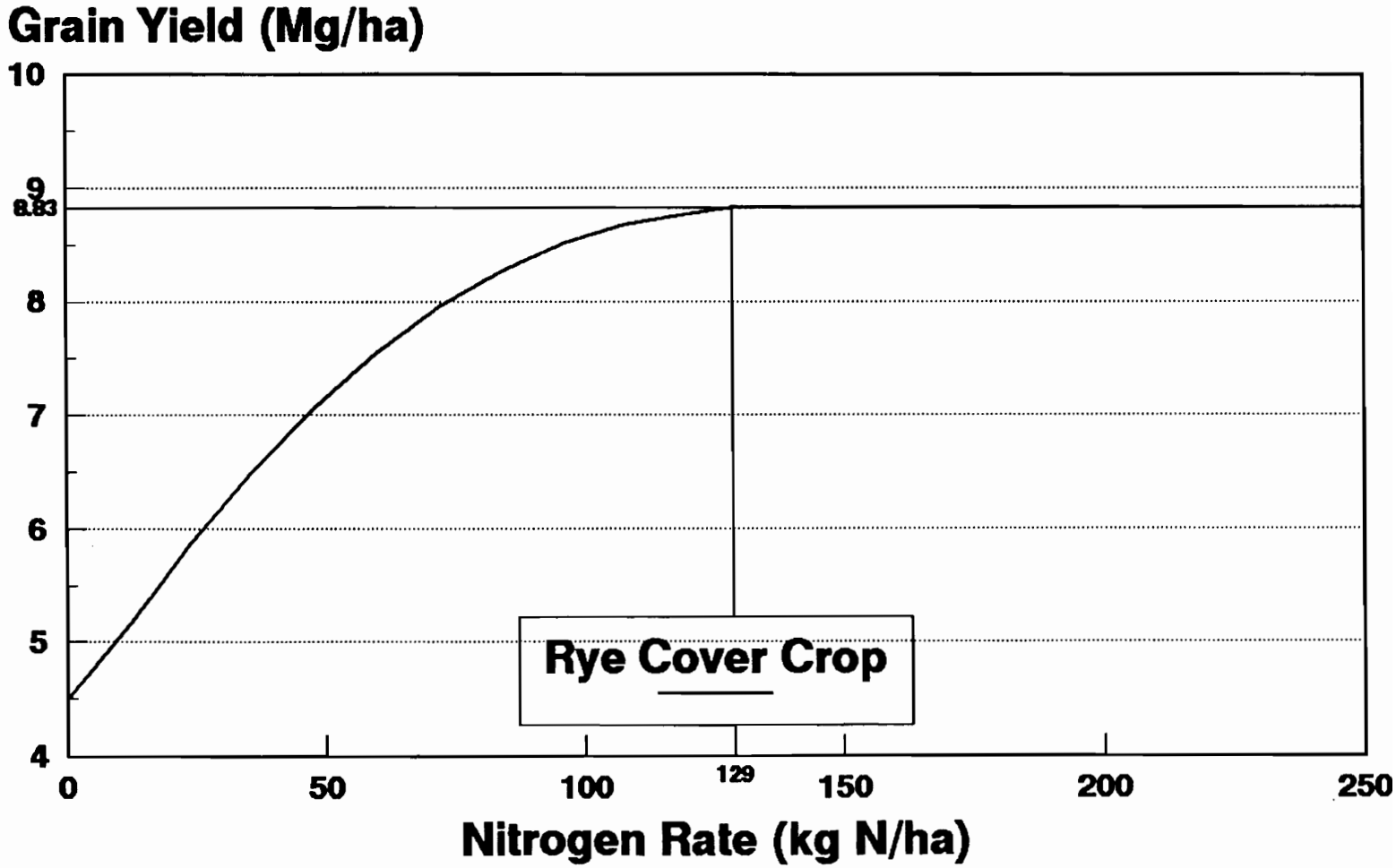


Figure 28. Kentland Research Farm - 1993

Quadratic and Plateau Response Curve

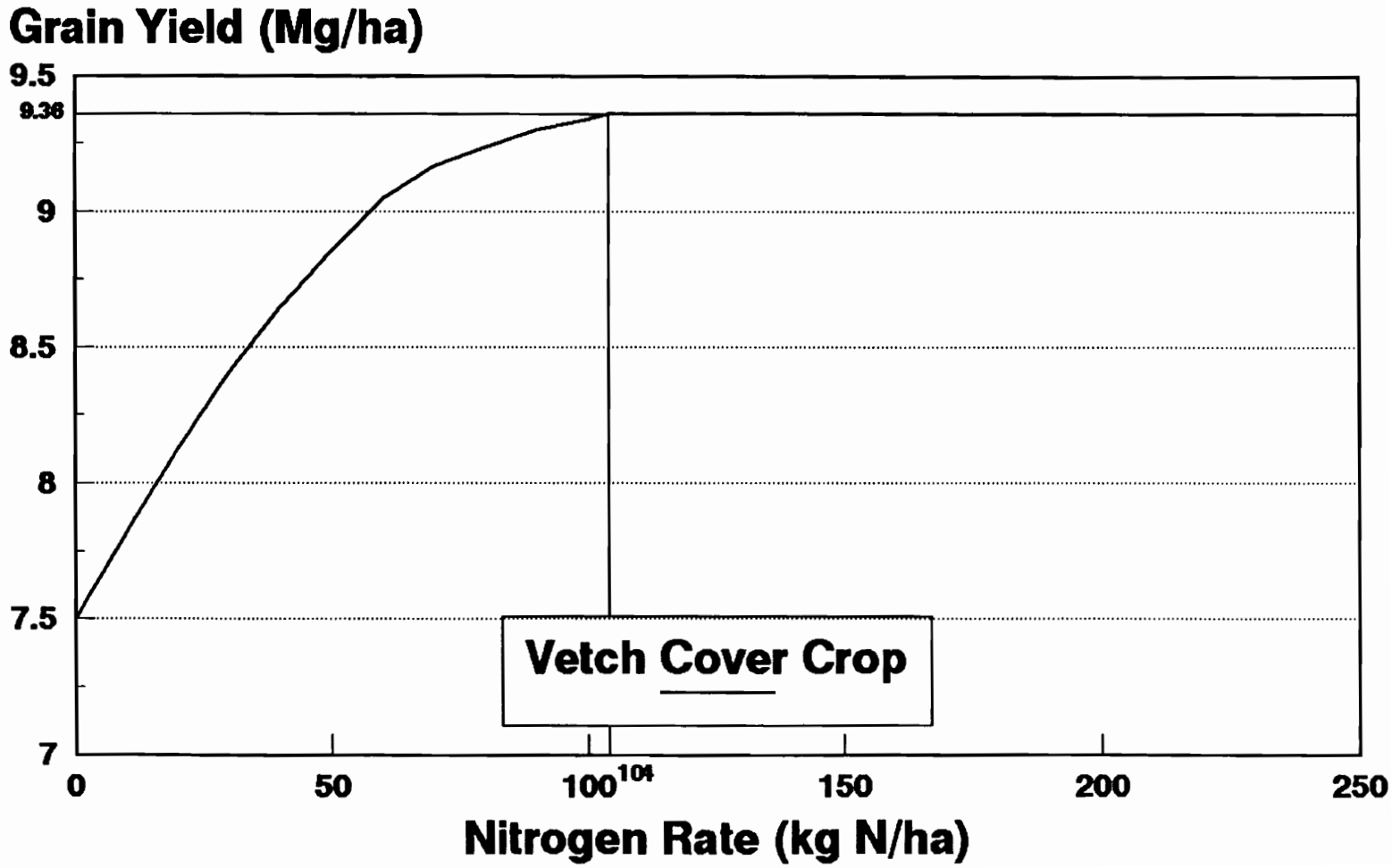


Figure 29. Kentland Research Farm - 1993

Quadratic and Plateau Response Curve

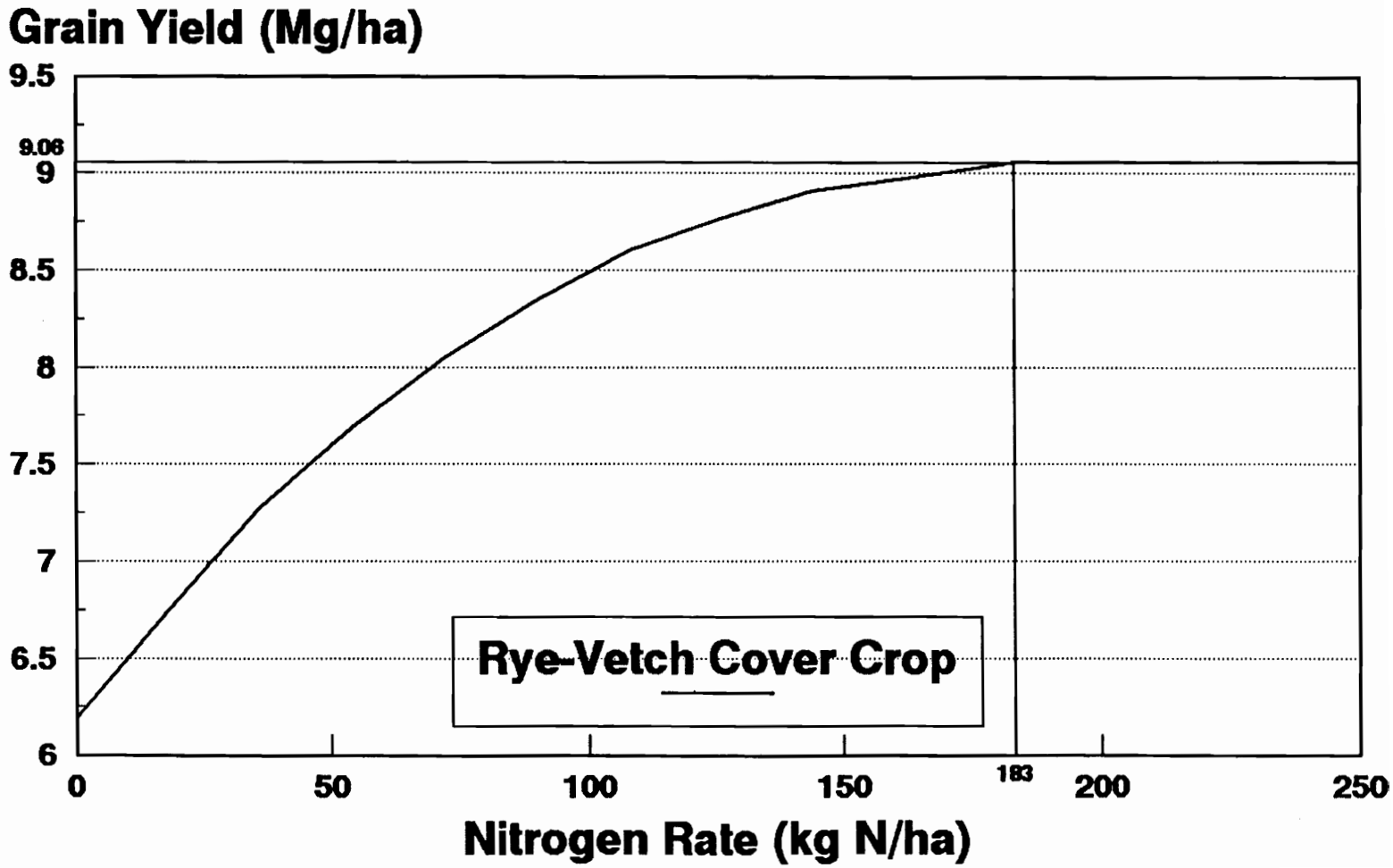


Figure 30. Kentland Research Farm - 1993

Quadratic and Plateau Response Curve

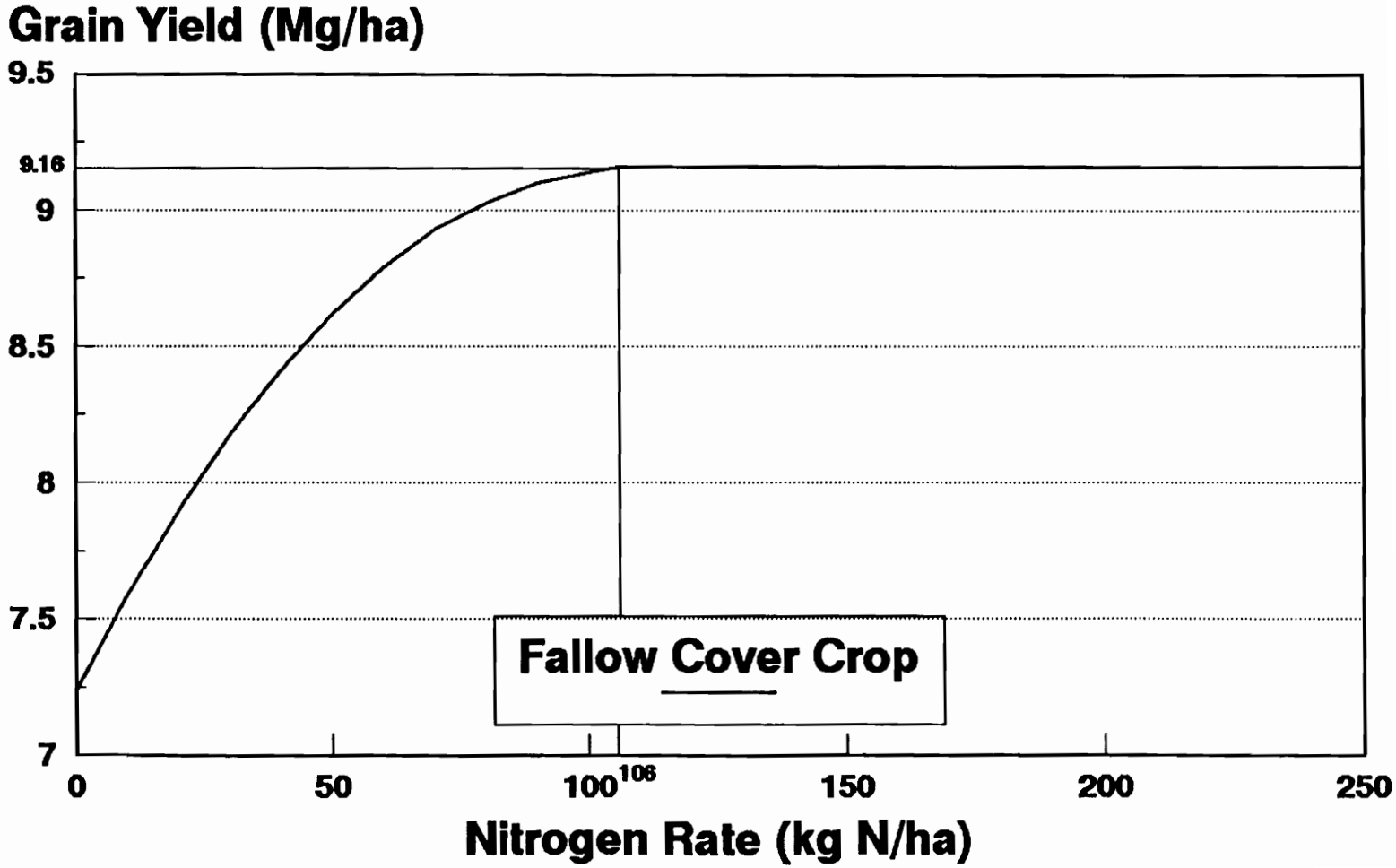


Figure 31. Northern Piedmont Agricultural Experiment Station - 1993 Quadratic and Plateau Response Curve

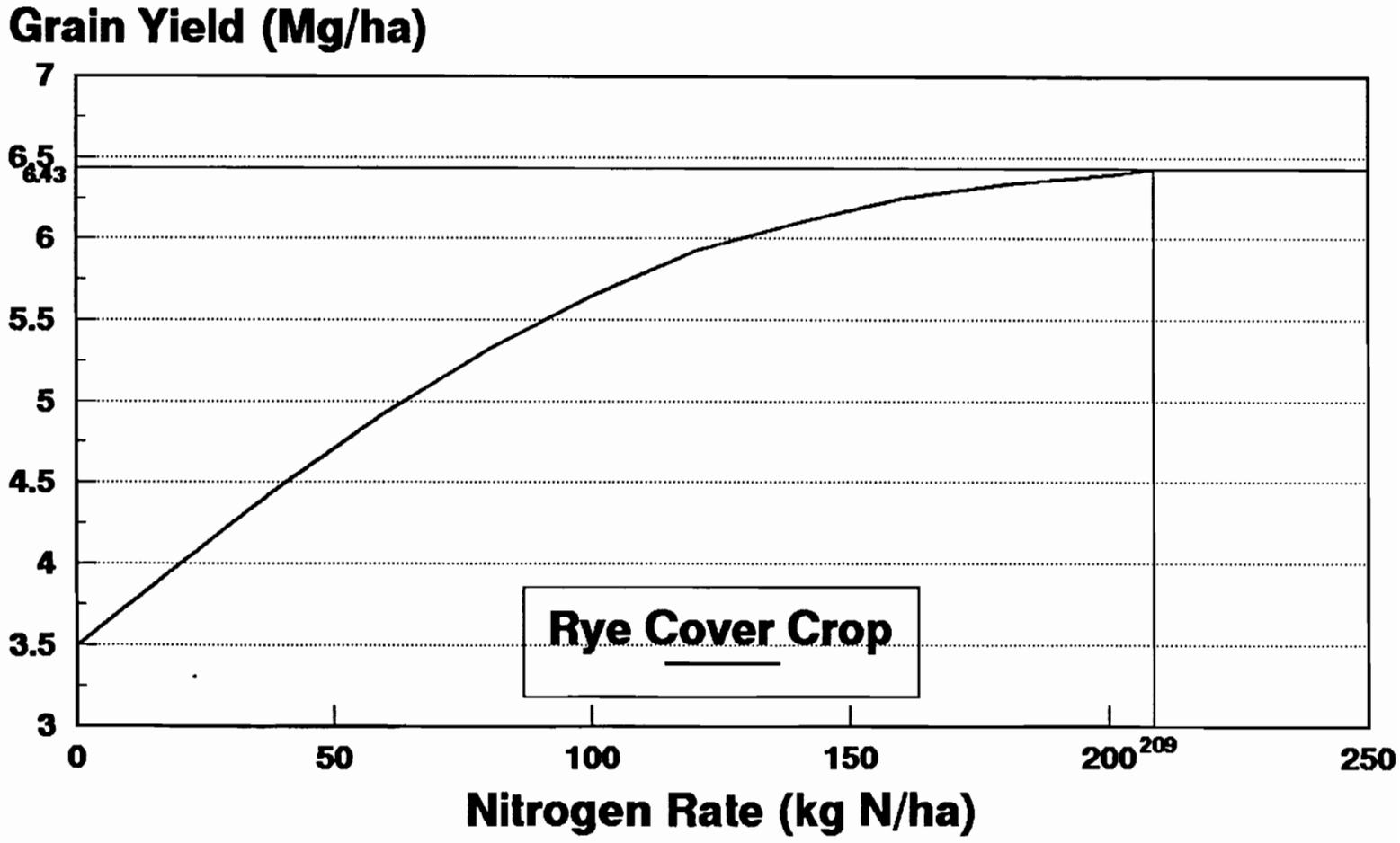
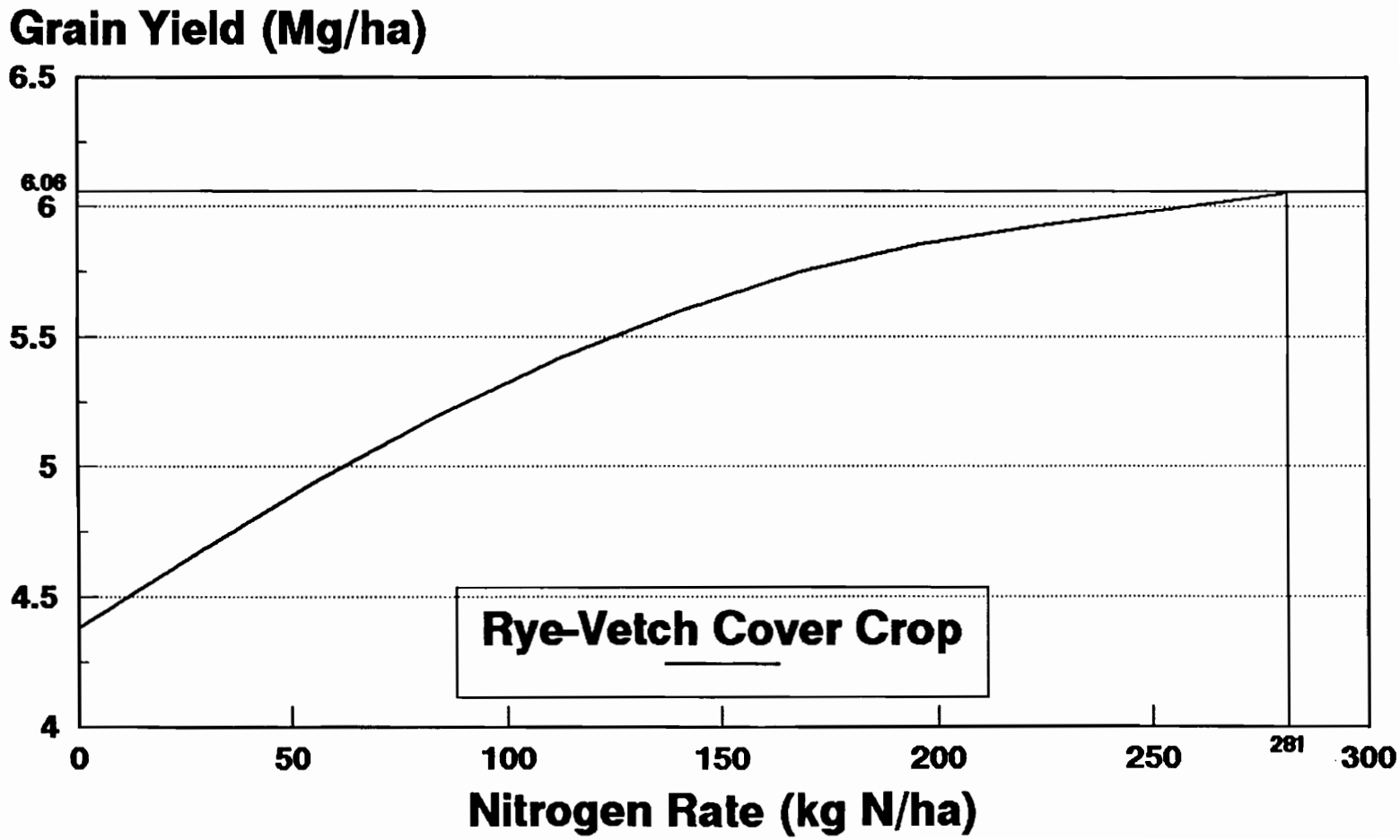


Figure 32. Northern Piedmont Agricultural Experiment Station - 1993 Quadratic and Plateau Response Curve



due to N immobilization by the carbonaceous rye and a low fertilizer N use efficiency where moisture was limited. Rye+vetch plots yielded higher than rye plots at N rate=0, but required more N to reach maximum yield. Additionally, fallow and vetch plots had similar yields, most likely because vetch residue decomposition was so advanced when moisture stress developed that little mulch was remaining on vetch plots for soil water conservation.

Corn silage yields in all cover crop treatments responded to N rate in 1992 at the NPAES (Table 27, Figures 33-36). Yields in treatments containing rye were lower than fallow and vetch both at maximum yield and yield at N rate=0, again due to a cool wet spring, late planting, and excessive rye growth that stunted corn growth and reduced yield potential.

Silage yield at the NPAES in 1993 responded greatly to N rate only in rye and rye+vetch treatments (similar to grain yields, Table 26) (Table 27, Figures 37-39). Yield was limited by rainfall, not N, in fallow and vetch treatments (Table 6 and Figures 13-14). Rye and rye+vetch treatments yielded more than vetch and fallow plots due to greater water availability in plots containing the moisture conserving rye mulch. Additionally, rye and rye+vetch treatments required high levels of N, most likely due to N immobilization by the carbonaceous rye and a low fertilizer N use efficiency where moisture was limited. Rye+vetch plots yielded higher than rye plots without supplemental N, but required more N to reach maximum yield. This may have been caused by increased N availability

Table 27. Northern Piedmont Agricultural Experiment Station Silage Yield Parameter Relationships.

Cover	Yield Plateau*	N Rate**	Yield at N rate=0	Relative Yield***
	-Mg/ha-	-kg N/ha-	-Mg/ha-	---%---
		1992		
Rye	42.07	182	20.12	48
Vetch	52.73	190	40.17	76
Rye+Vetch	40.52	131	17.63	44
Fallow	50.57	90	43.66	86
		1993		
Rye	28.30	219	17.79	63
Vetch	24.57	0	24.57	100
Rye+Vetch	29.39	371	22.26	76
Fallow	26.69	45	23.08	86

* Plateau yield as determined by quadratic and plateau model.

** N rate at inflection point of the quadratic and plateau response curve.

*** (Yield at N rate=0/Yield plateau)*100.

Figure 33. Northern Piedmont Agricultural Experiment Station - 1992 Quadratic and Plateau Response Curve

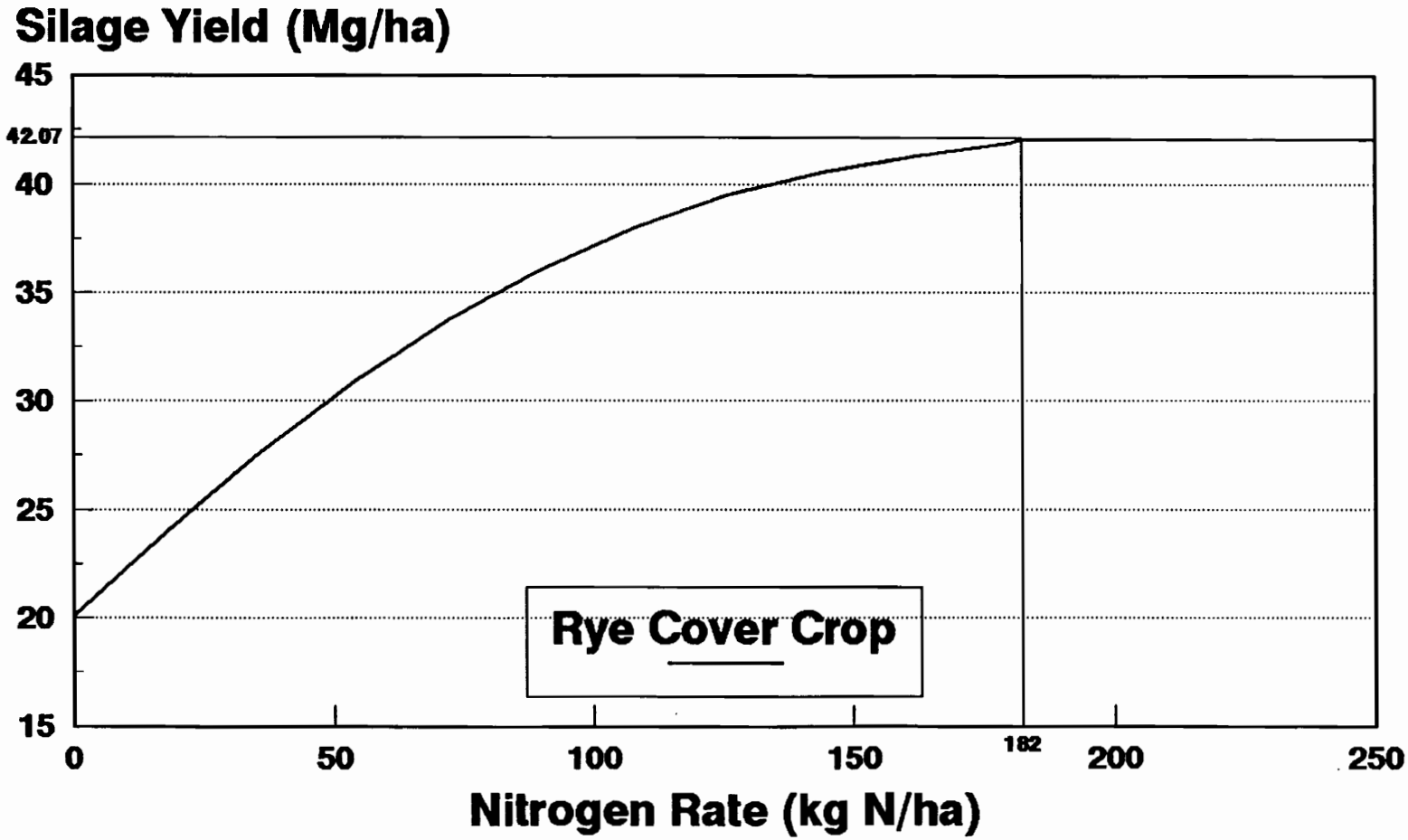


Figure 34. Northern Piedmont Agricultural Experiment Station - 1992
Quadratic and Plateau Response Curve

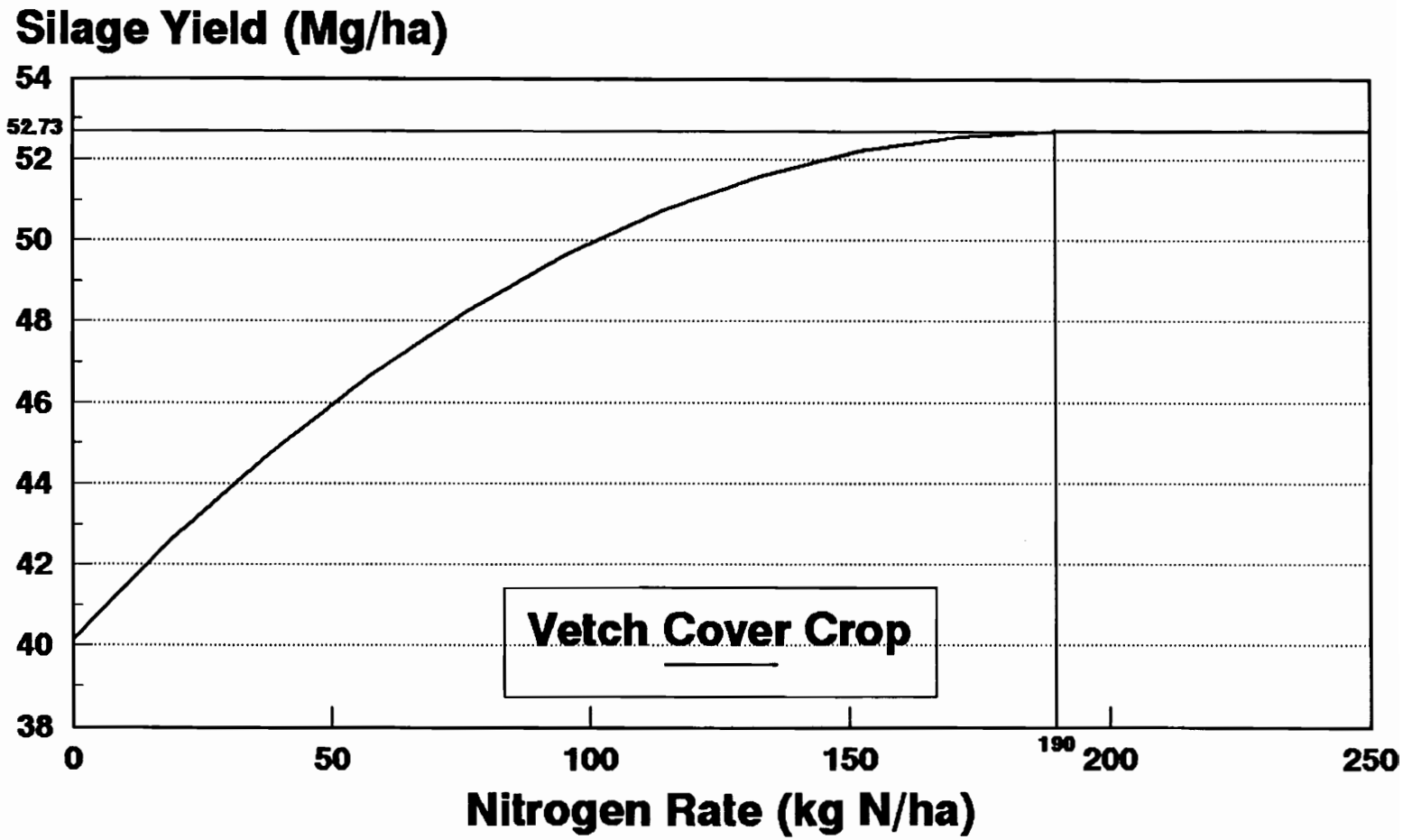


Figure 35. Northern Piedmont Agricultural Experiment Station - 1992 Quadratic and Plateau Response Curve

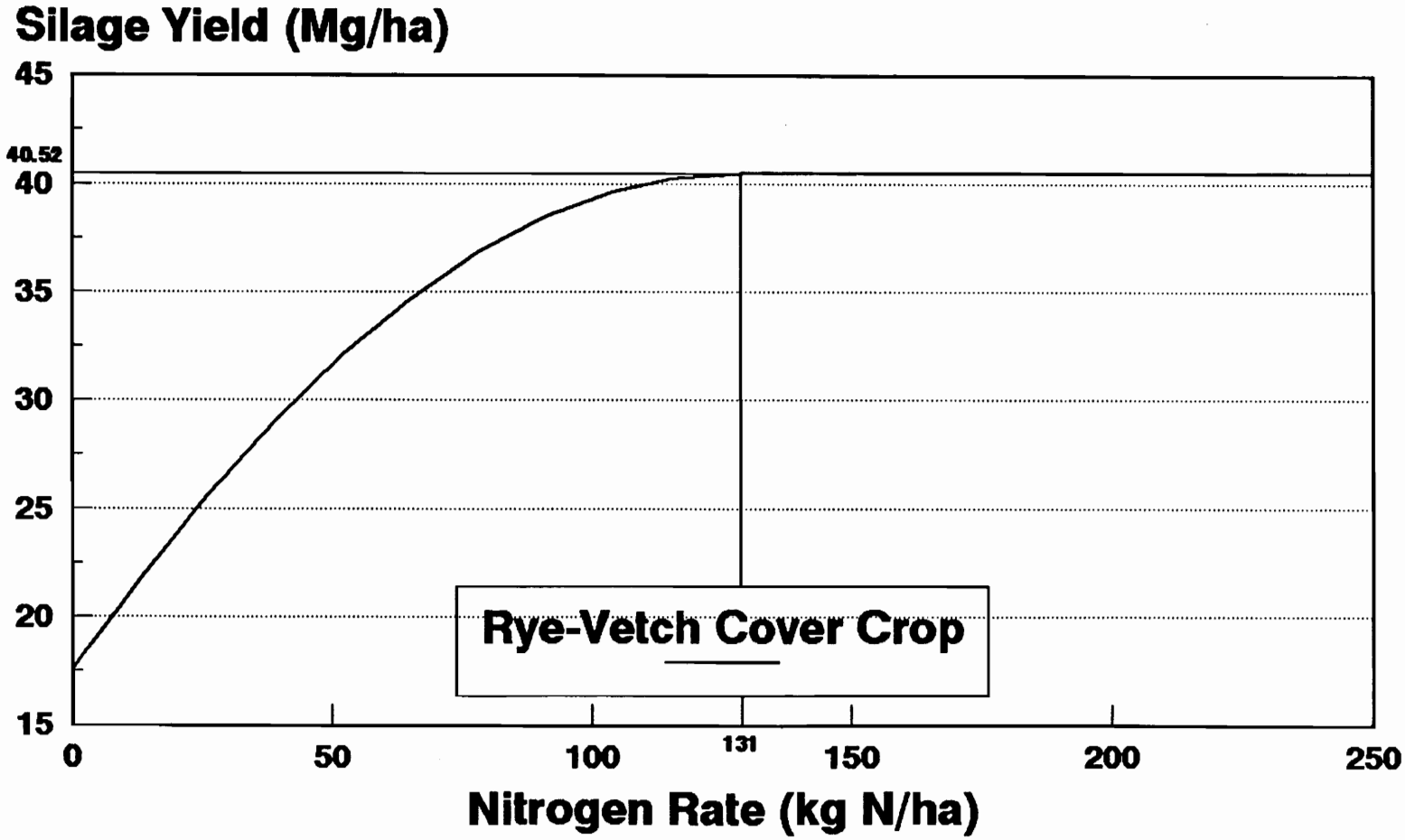


Figure 36. Northern Piedmont Agricultural Experiment Station - 1992 Quadratic and Plateau Response Curve

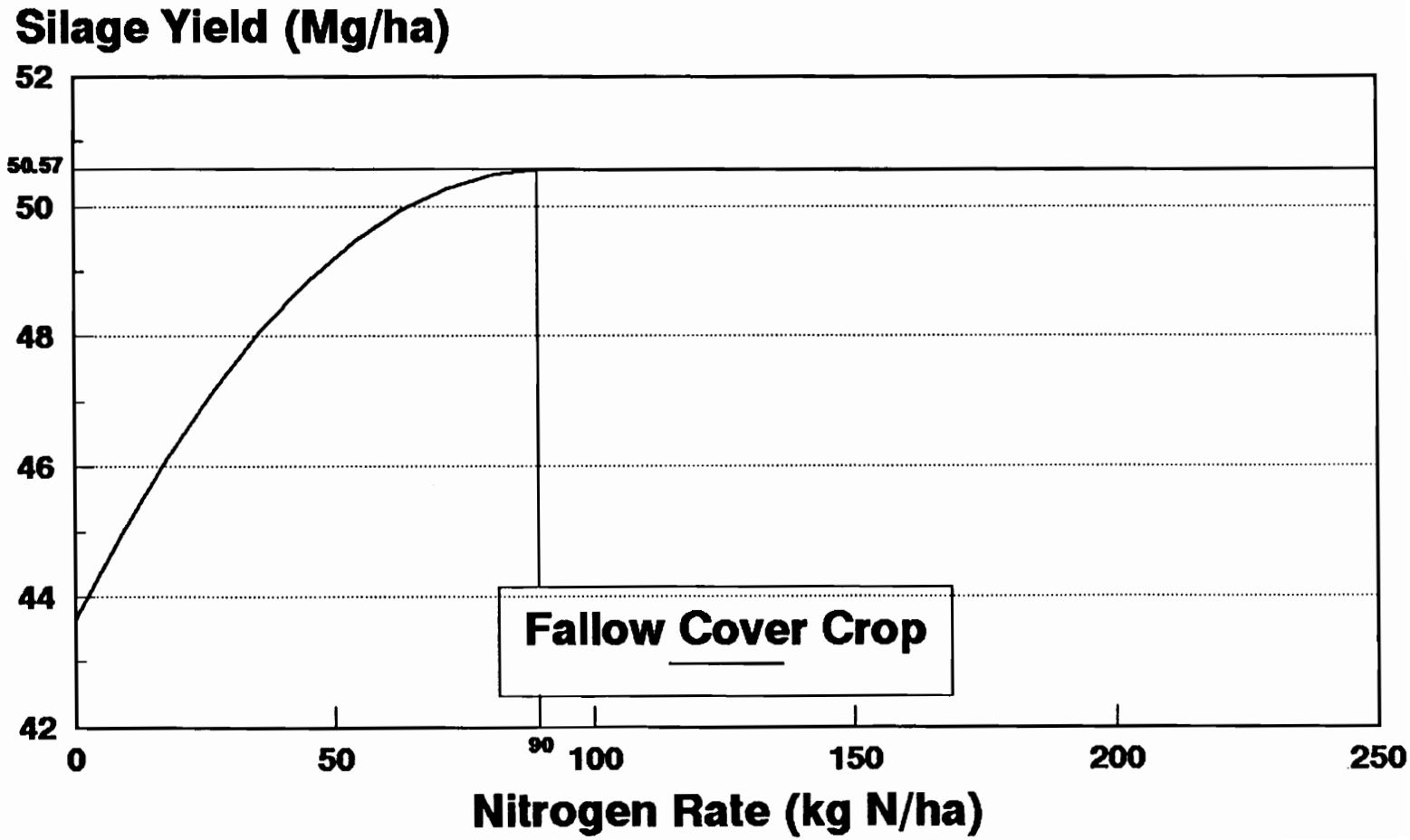


Figure 37. Northern Piedmont Agricultural Experiment Station - 1993 Quadratic and Plateau Response Curve

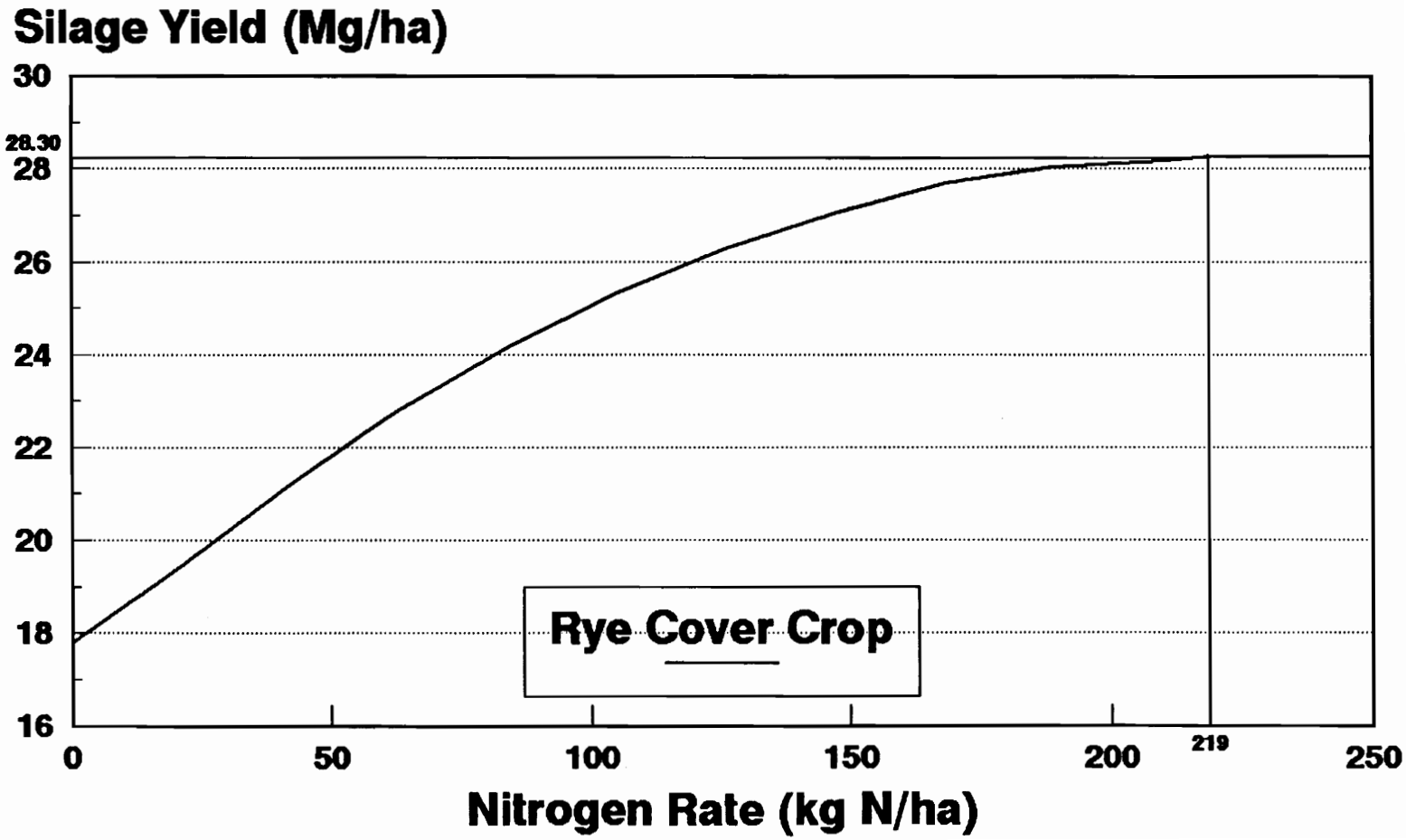


Figure 38. Northern Piedmont Agricultural Experiment Station - 1993 Quadratic and Plateau Response Curve

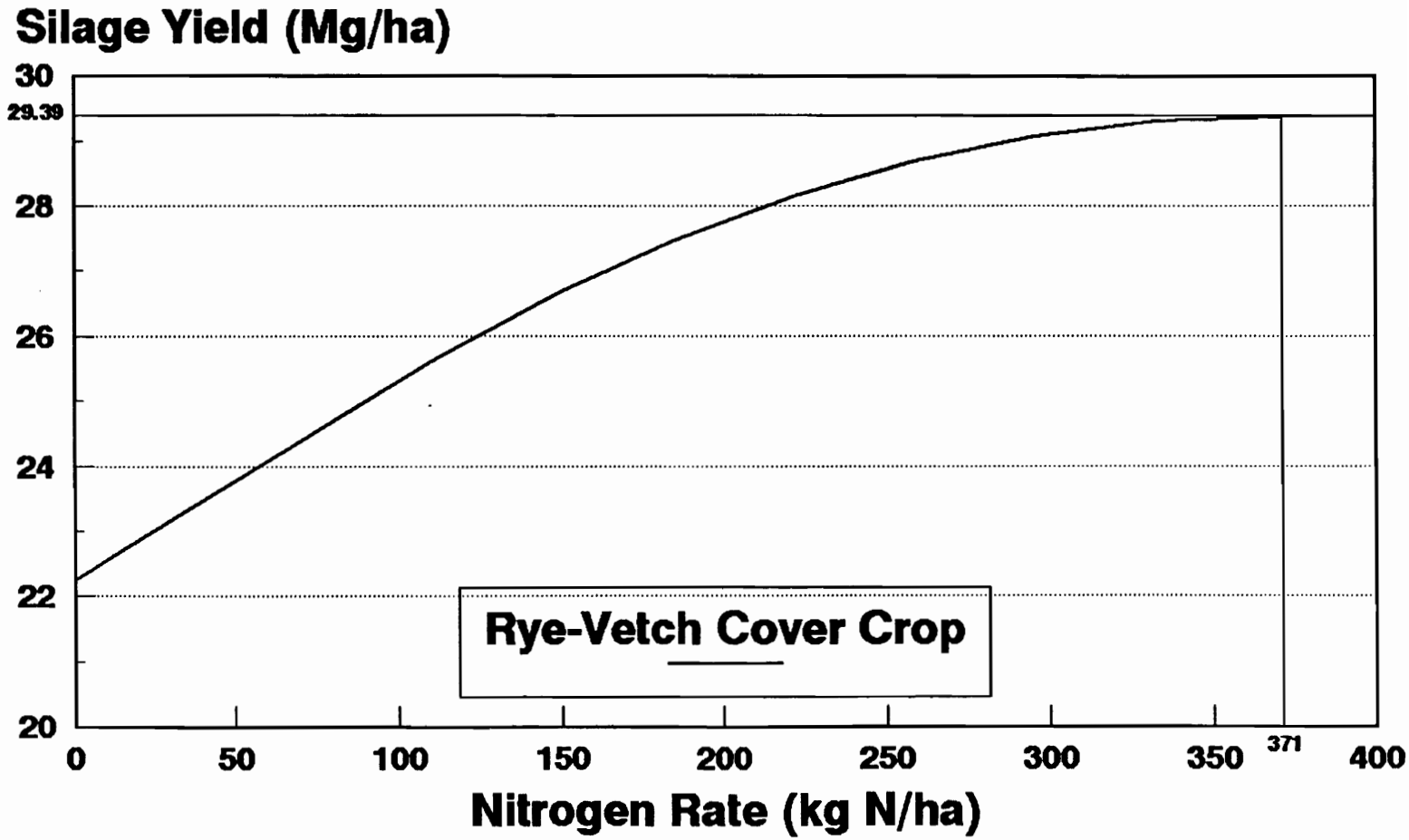
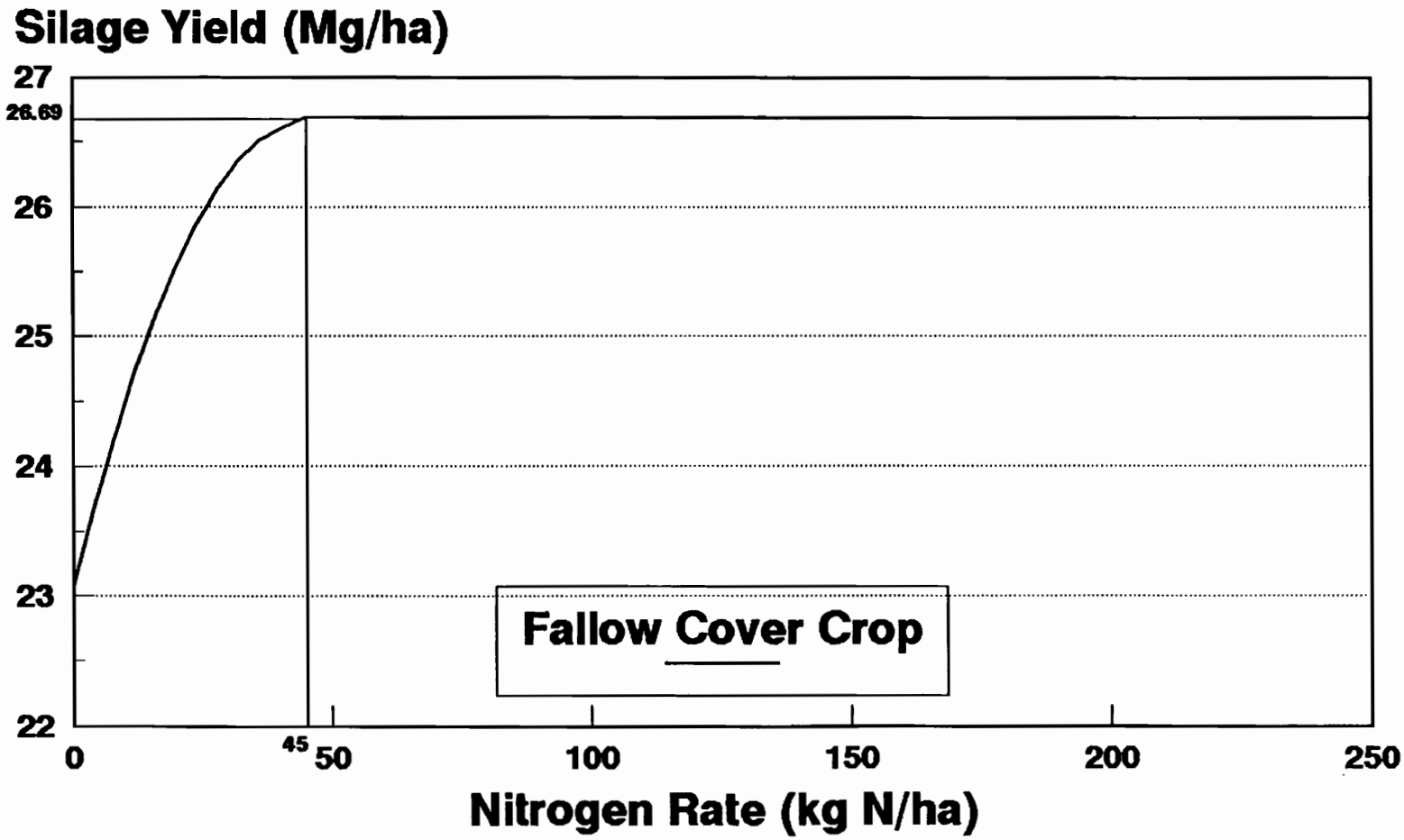


Figure 39. Northern Piedmont Agricultural Experiment Station - 1993 Quadratic and Plateau Response Curve



on rye+vetch plots where no fertilizer N was applied, also indicated by corn N concentrations at silking (Table 24).

3.5 Predictability of Corn N Needs Grown After Winter Cover Crops

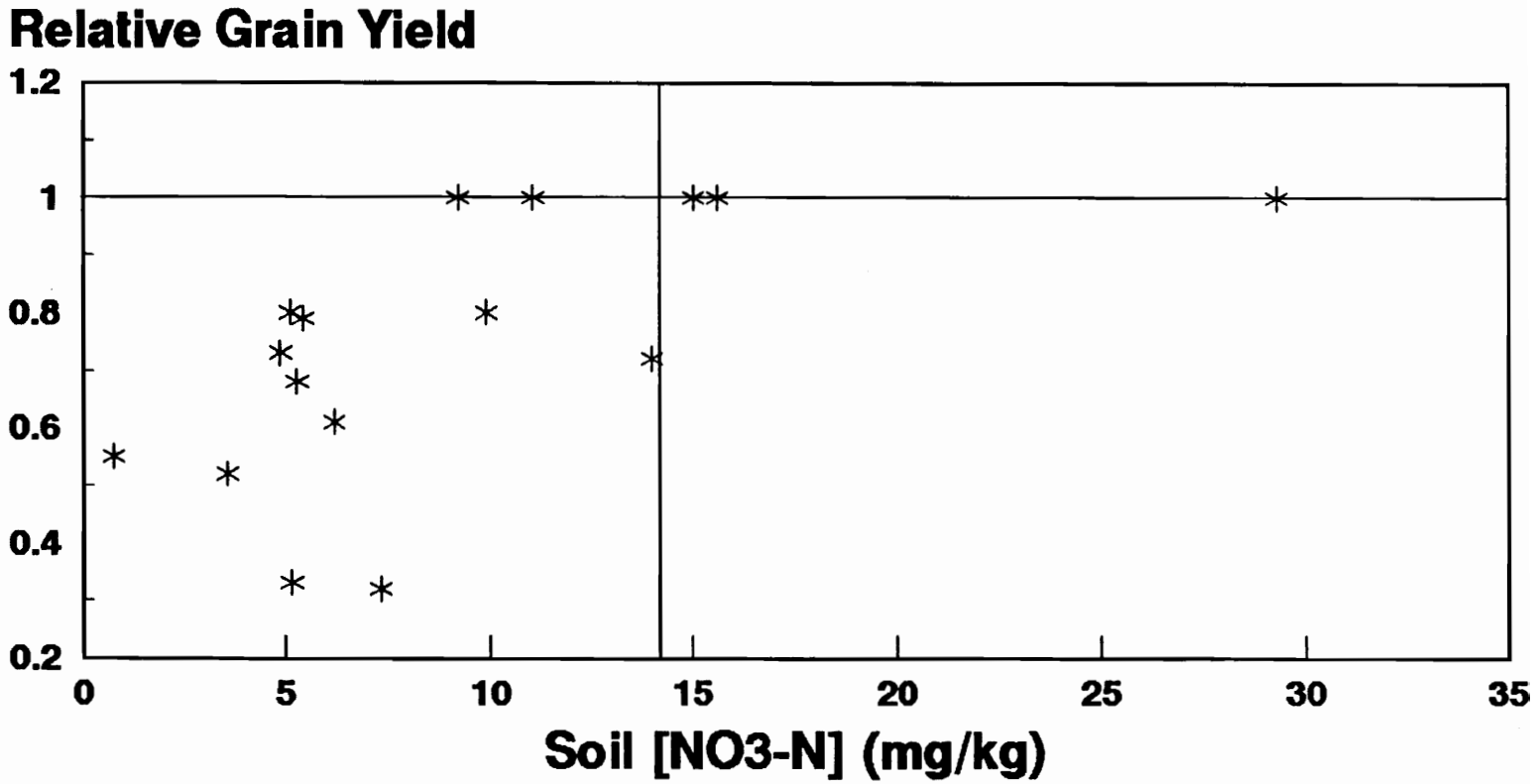
The predictability of supplemental fertilizer N needs for corn following winter cover crops was analyzed using the Cate-Nelson technique (2) to separate N responsive and N nonresponsive sites. Relative corn grain yield from all cover crop treatments in this study was plotted versus soil NO_3-N and mineral N concentration at a variety of soil sample times and depths. The Cate-Nelson technique employing two perpendicular lines was utilized to maximize the number of points in the upper right and lower left quadrants of the scatter plots. Differences in the predictability of supplemental fertilizer N need were found with sampling time, sampling depth, and forms of soil N measured.

Relative grain yield versus soil [NO_3-N] at two weeks after corn emergence showed critical values between 10 and 15 mg/kg (Figures 40-43). Additionally, the 0-30 cm soil depth resulted in a lower critical value than the 0-15 cm soil depth, indicating (as soil N figures did, Figures 1-2, 5-6, 9-10, and 13-14) lower soil N concentrations at this depth. Combining [NO_3-N] and [NH_4-N] resulted only in slightly higher critical values at this sample time, again with a lower value at the 0-30 cm soil depth (Figures 42-43).

Figure 40. Relative Yield vs. Soil NO3-N*

Two Weeks After Corn Emergence

Soil Sample Depth 0 - 15 cm

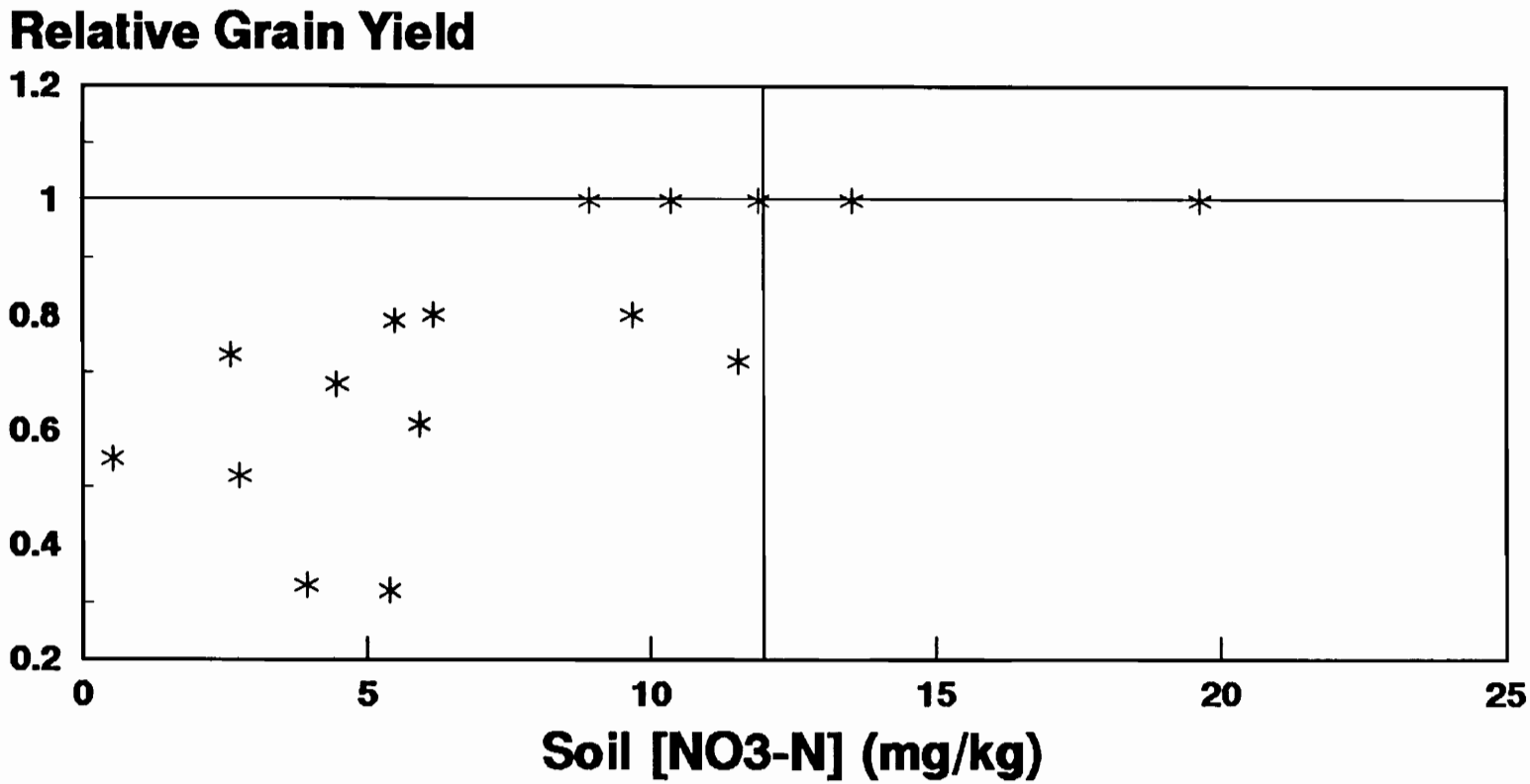


* Data from Kentland Research Farm and Northern Piedmont Agricultural Experiment Station 1992-1993.

Figure 41. Relative Yield vs. Soil NO3-N*

Two Weeks After Corn Emergence

Soil Sample Depth 0 - 30 cm

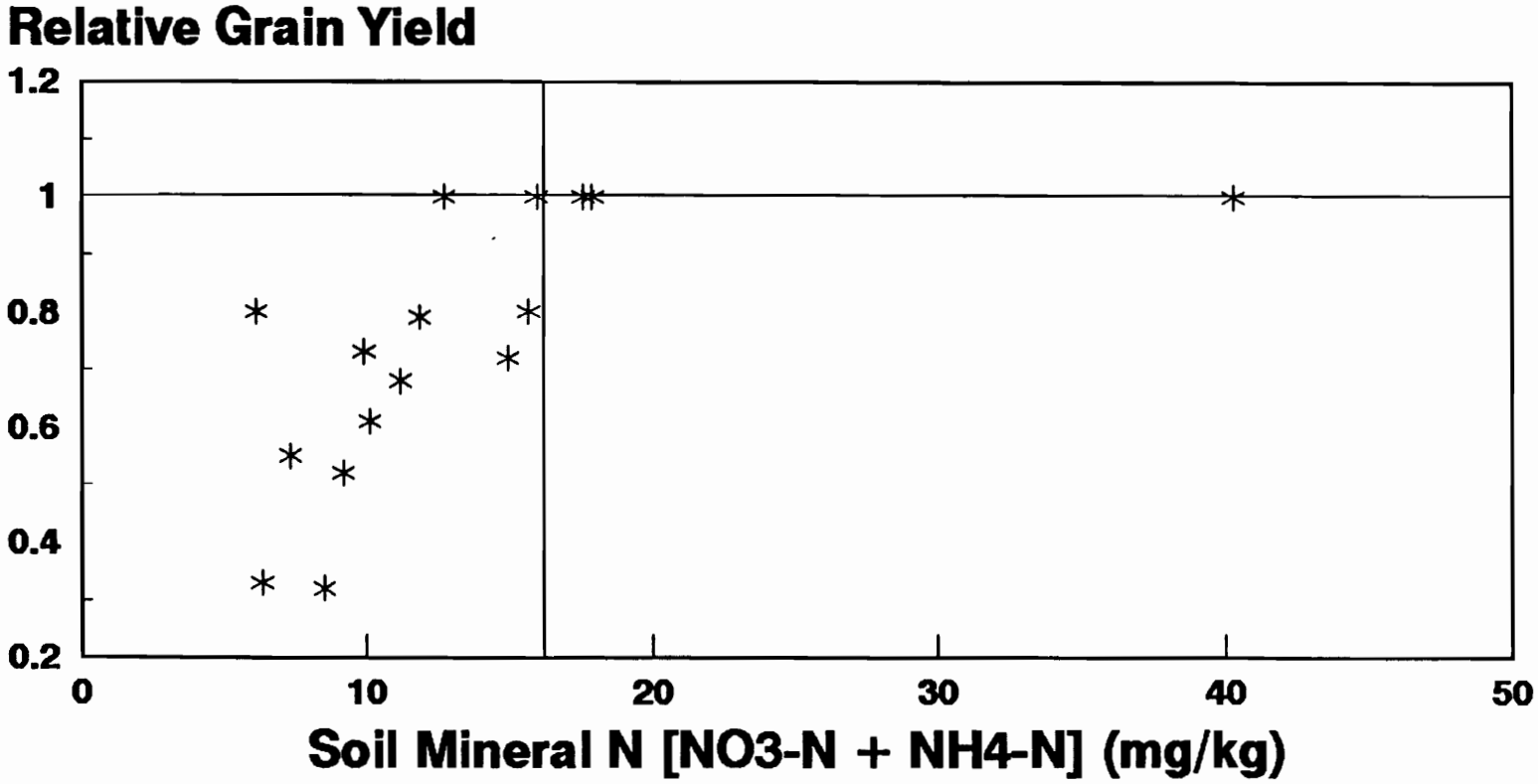


* Data from Kentland Research Farm and Northern Piedmont Agricultural Experiment Station 1992-1993.

Figure 42. Relative Yield vs. Soil Mineral N*

Two Weeks After Corn Emergence

Soil Sample Depth 0 - 15 cm

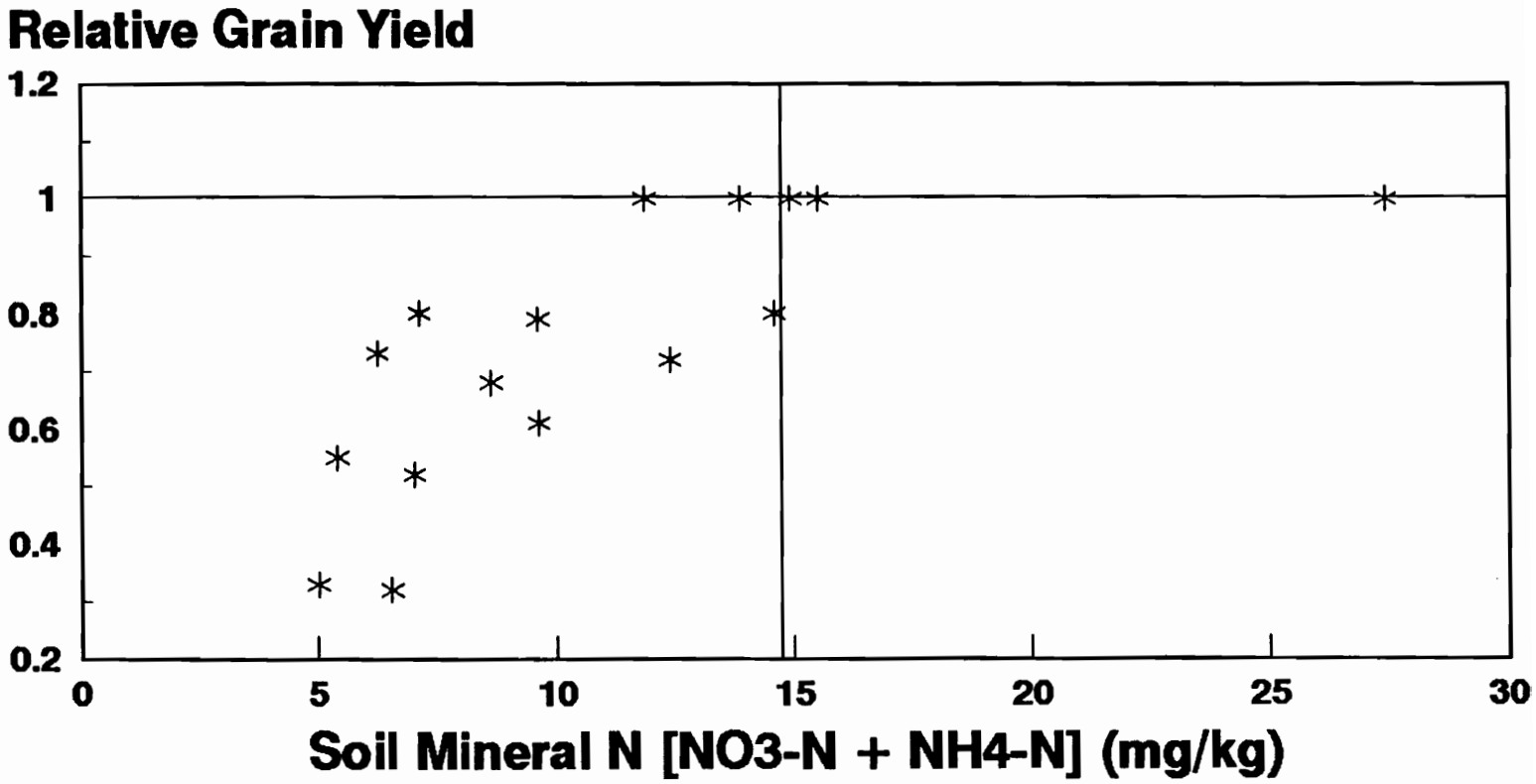


* Data from Kentland Research Farm and Northern Piedmont Agricultural Experiment Station 1992-1993.

Figure 43. Relative Yield vs. Soil Mineral N*

Two Weeks After Corn Emergence

Soil Sample Depth 0 - 30 cm



* Data from Kentland Research Farm and Northern Piedmont Agricultural Experiment Station 1992-1993.

Relative grain yield versus soil [NO_3-N] at the corn four to five leaf stage showed critical values between 17 and 22 mg/kg (Figures 44-47). Combining [NO_3-N] and [NH_4-N] resulted only in slightly higher critical values at this sample time (Figures 46-47). Additionally, only one point was located in the upper right quadrant for all combinations at this sample time. Sites that provide a wide range of soil N concentrations and relative corn grain yields are required to use the Cate-Nelson technique to develop precise critical values. Therefore, additional data are needed that includes more soil N concentrations near (above and below) the current PSNT critical values and relative corn yields near 1. These additional data may be used to refine the critical values where cover crops are the primary source of N.

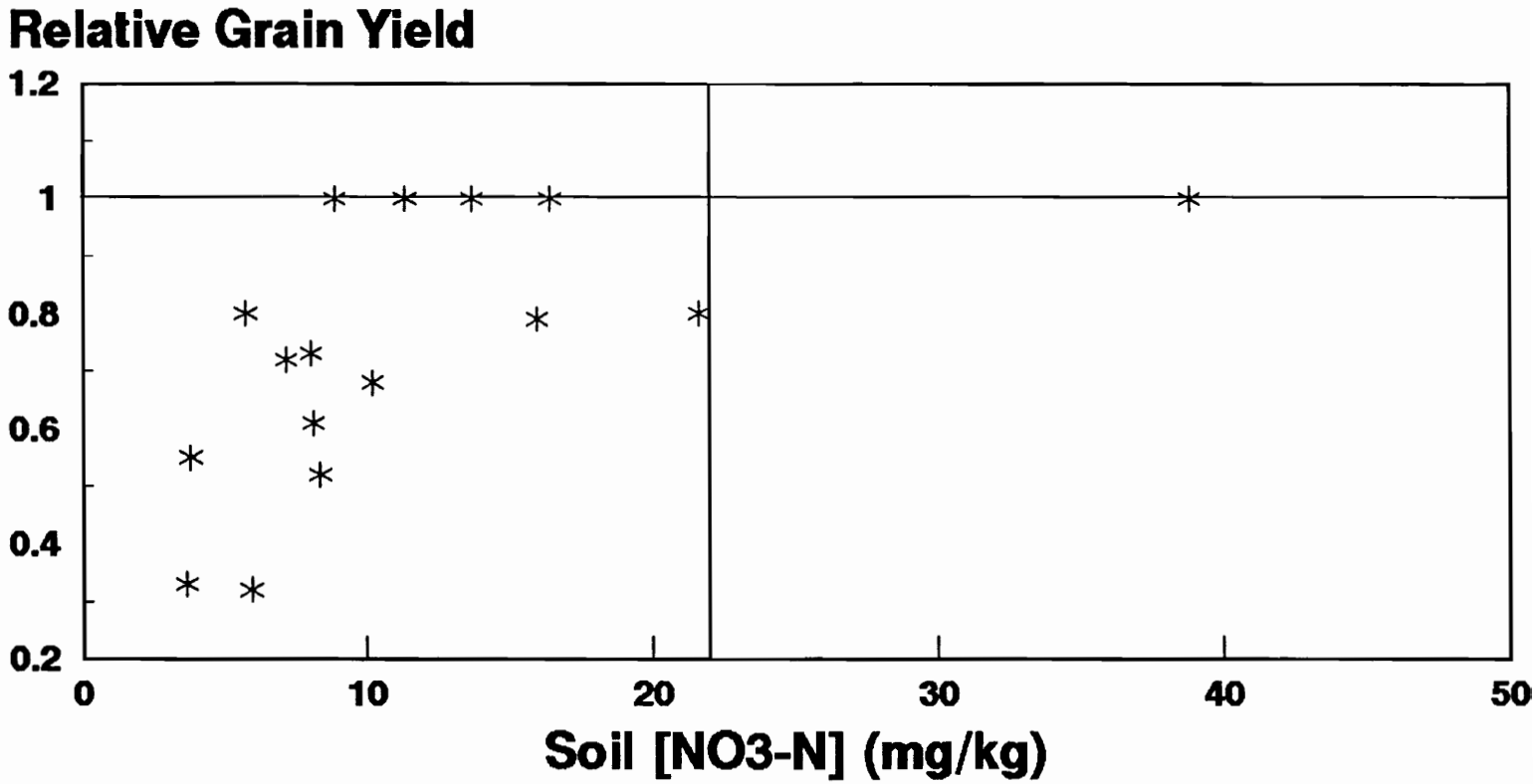
Relative grain yield versus soil [NO_3-N] at the corn eight to ten leaf stage provided critical values between 12 and 19 mg/kg (Figures 48-49). Again, combining [NO_3-N] and [NH_4-N] resulted only in slightly higher critical values at this sample time (Figures 50-51).

Soil [NO_3-N] or total soil N concentrations for separating corn N responsive from N nonresponsive currently published range from 18-25 mg/kg (1, 4, 5, 11, 12, 13, 16). Soil [NO_3-N] and total soil N concentrations at two weeks after corn emergence were lower than these reported values (Figures 40-43). Although the data for this study is limited to four site years, it is likely

Figure 44. Relative Yield vs. Soil NO3-N*

At Corn Four-Five Leaf Stage

Soil Sample Depth 0 - 15 cm

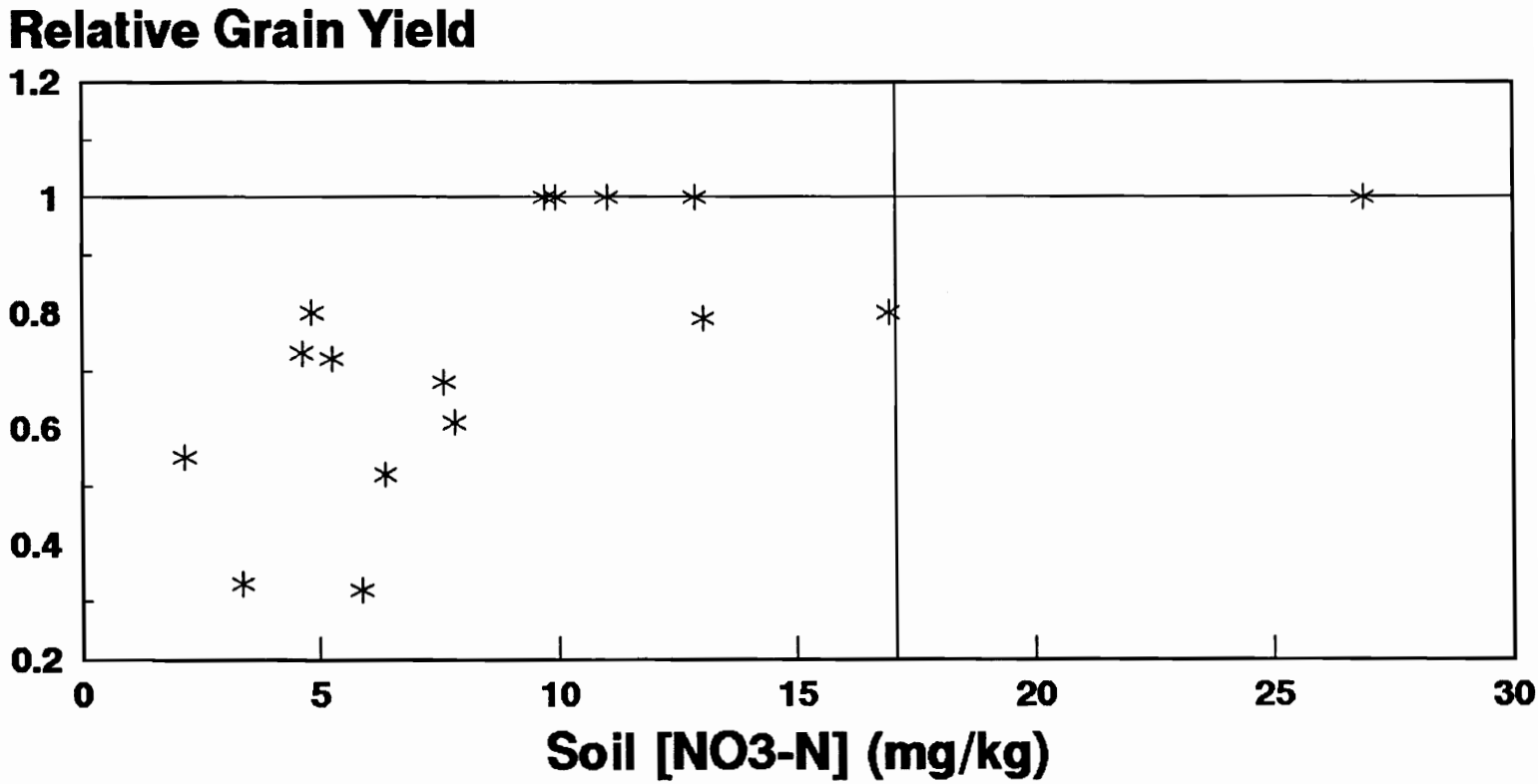


* Data from Kentland Research Farm and Northern Piedmont Agricultural Experiment Station 1992-1993.

Figure 45. Relative Yield vs. Soil NO3-N*

At Corn Four-Five Leaf Stage

Soil Sample Depth 0 - 30 cm

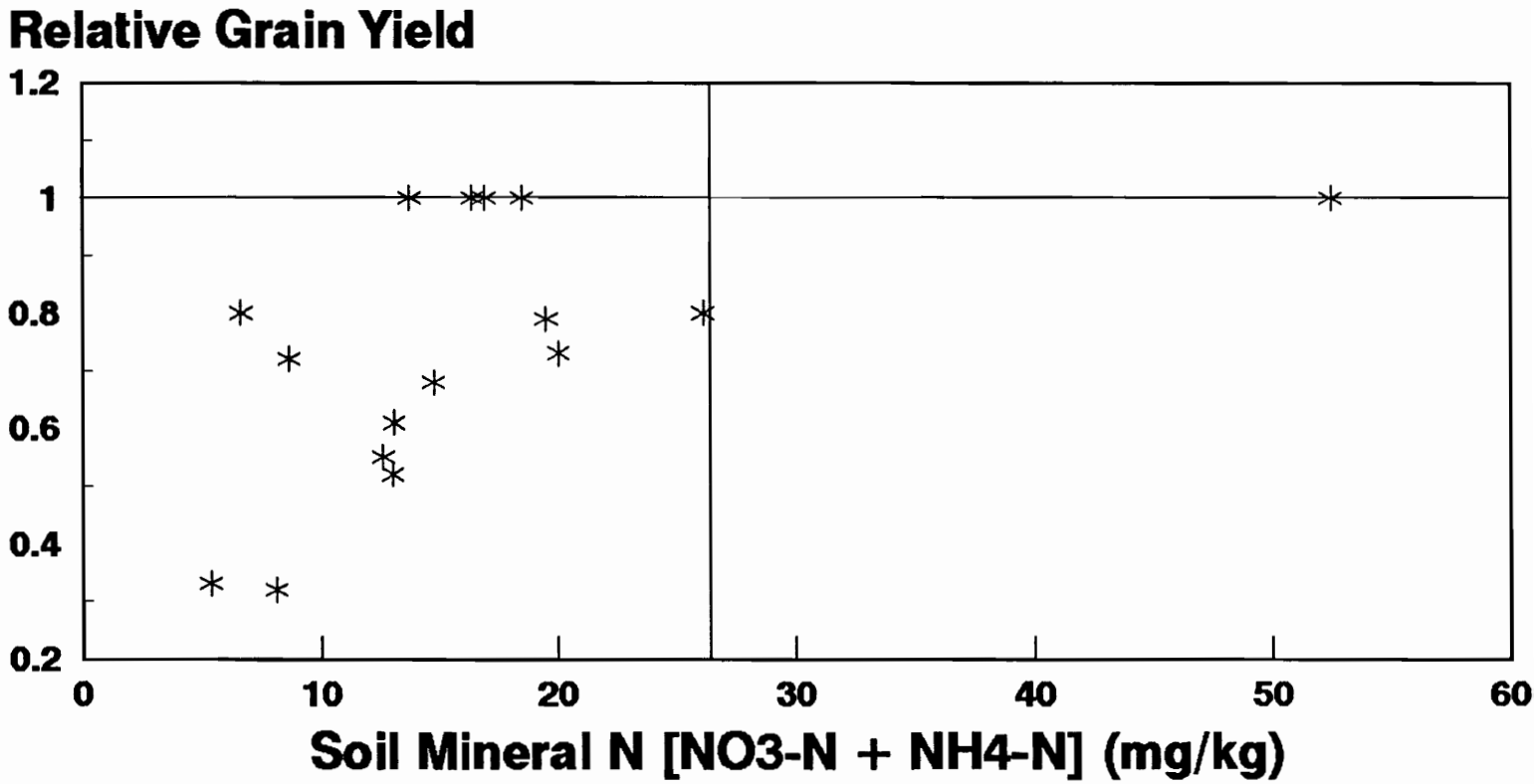


* Data from Kentland Research Farm and Northern Piedmont Agricultural Experiment Station 1992-1993.

Figure 46. Relative Yield vs. Soil Mineral N*

At Corn Four-Five Leaf Stage

Soil Sample Depth 0 - 15 cm

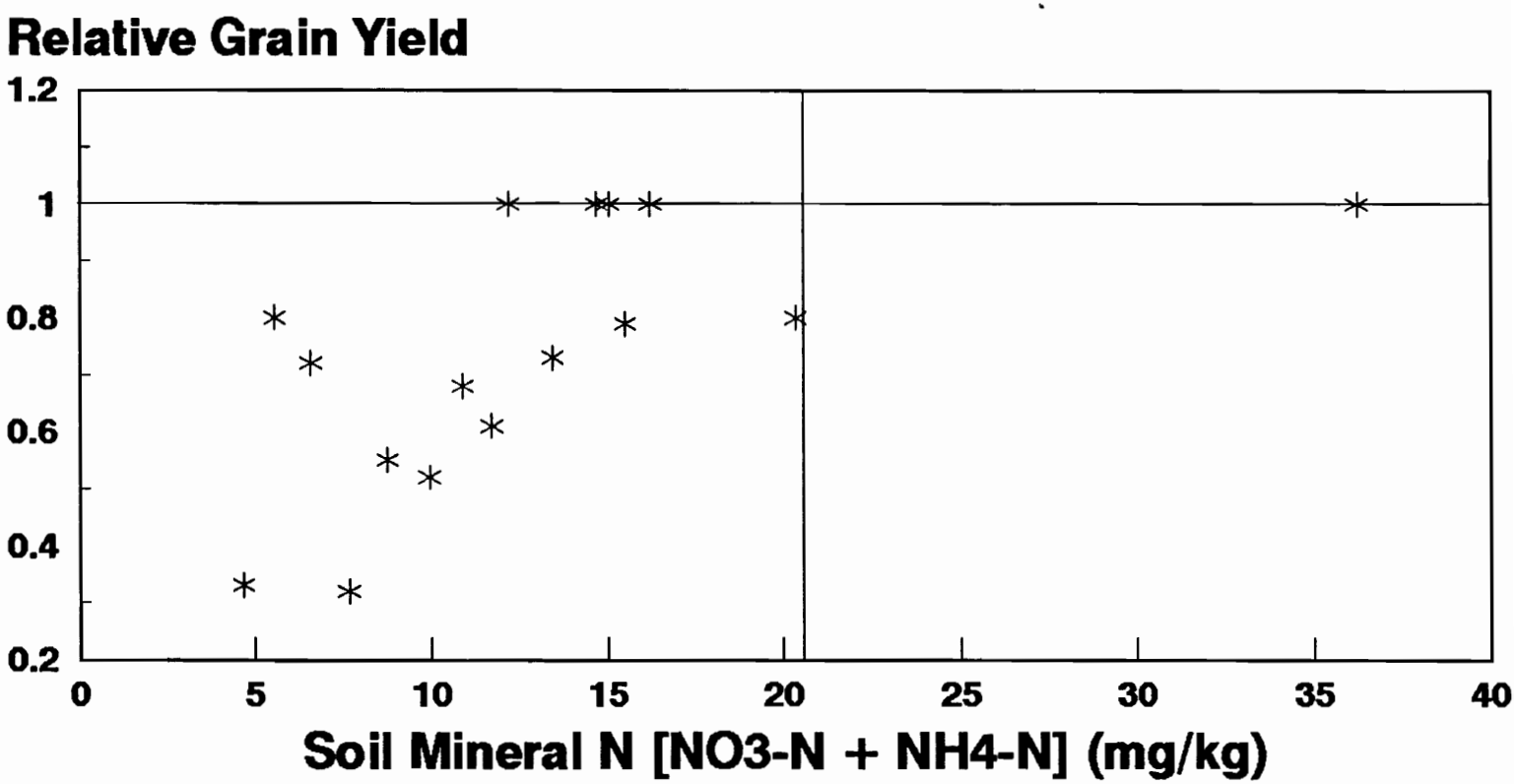


* Data from Kentland Research Farm and Northern Piedmont Agricultural Experiment Station 1992-1993.

Figure 47. Relative Yield vs. Soil Mineral N*

At Corn Four-Five Leaf Stage

Soil Sample Depth 0 - 30 cm

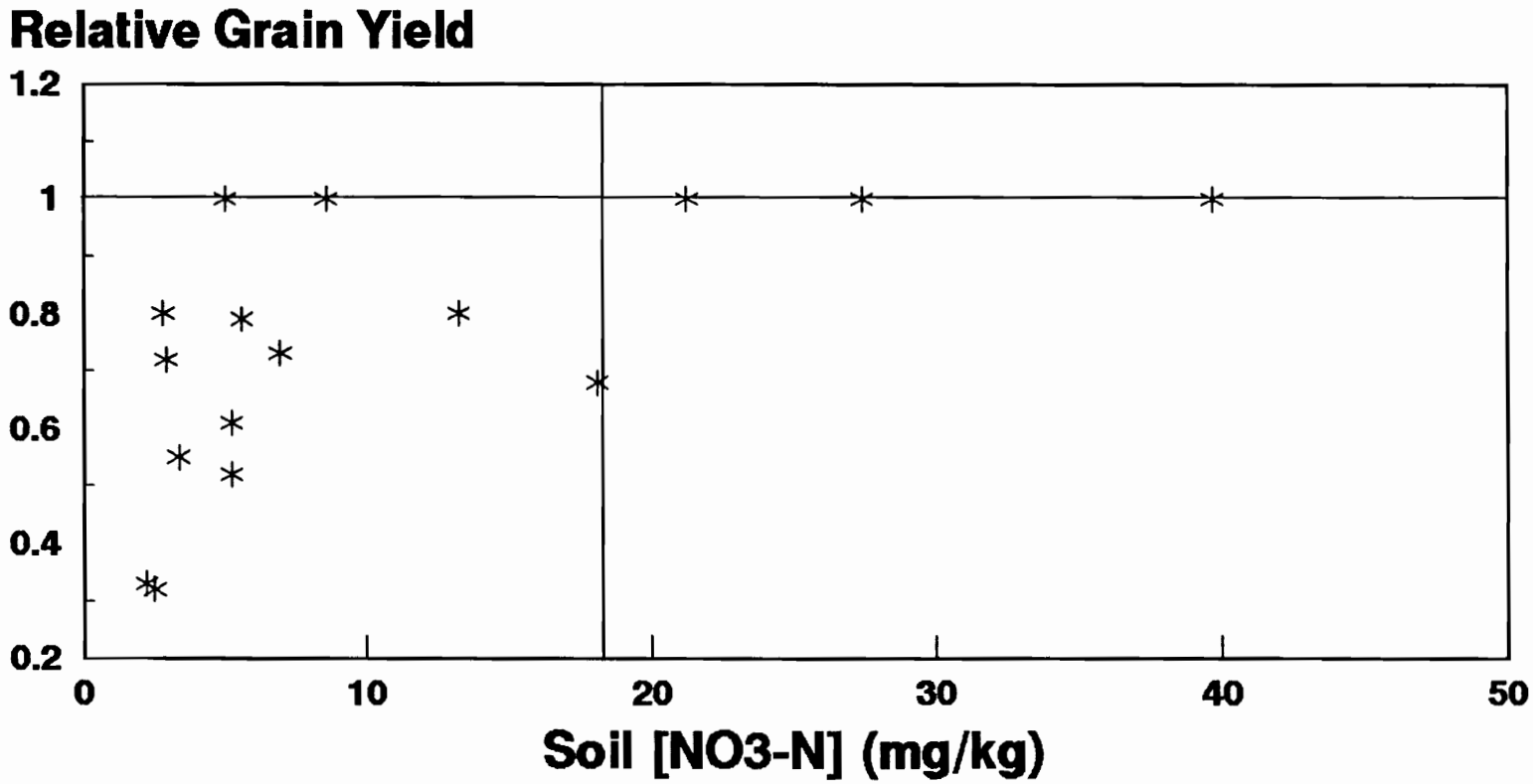


* Data from Kentland Research Farm and Northern Piedmont Agricultural Experiment Station 1992-1993.

Figure 48. Relative Yield vs. Soil NO3-N*

At Corn Eight-Ten Leaf Stage

Soil Sample Depth 0 - 15 cm

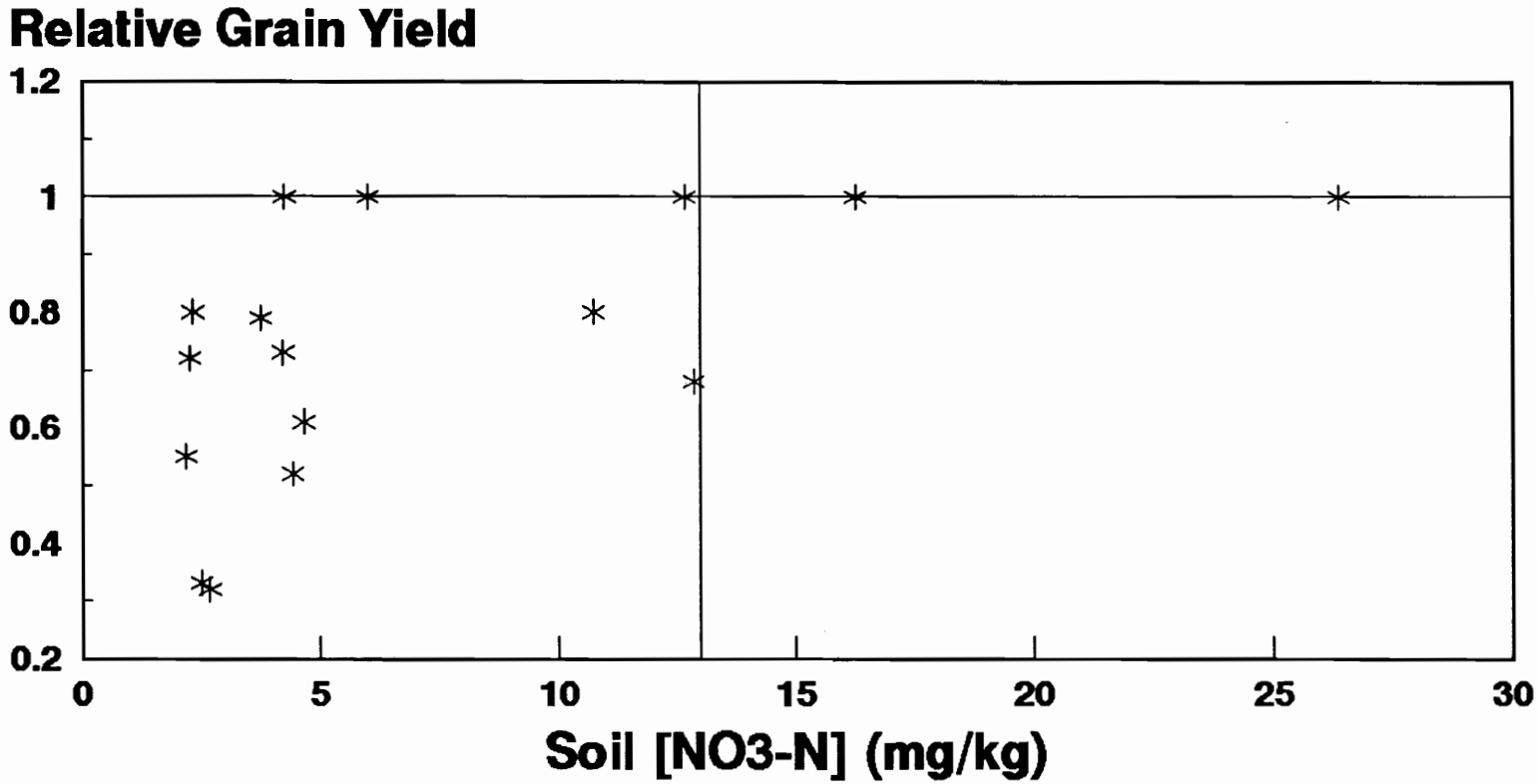


* Data from Kentland Research Farm and Northern Piedmont Agricultural Experiment Station 1992-1993.

Figure 49. Relative Yield vs. Soil NO3-N*

At Corn Eight-Ten Leaf Stage

Soil Sample Depth 0 - 30 cm

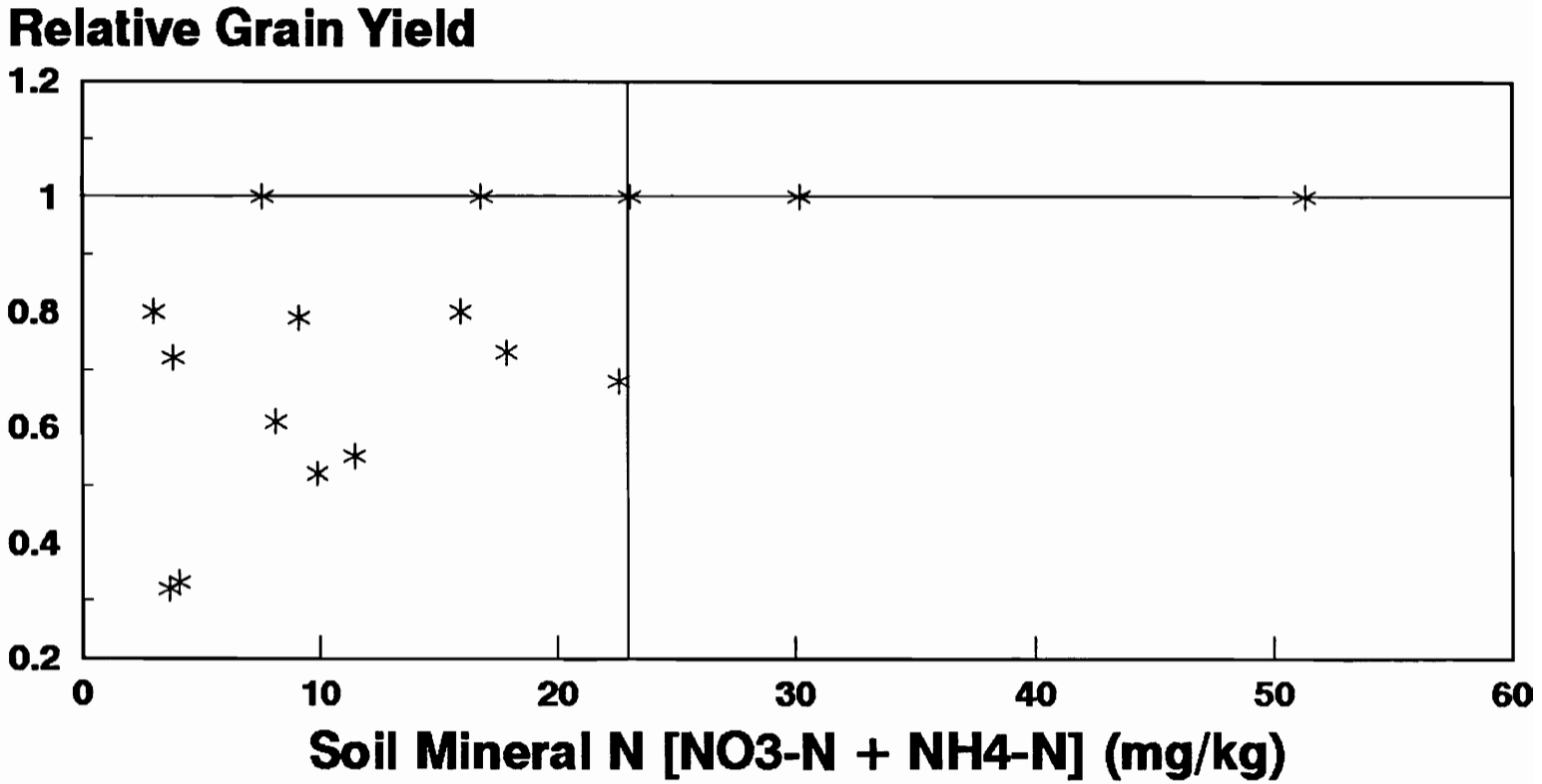


* Data from Kentland Research Farm and Northern Piedmont Agricultural Experiment Station 1992-1993.

Figure 50. Relative Yield vs. Soil Mineral N*

At Corn Eight-Ten Leaf Stage

Soil Sample Depth 0 - 15 cm

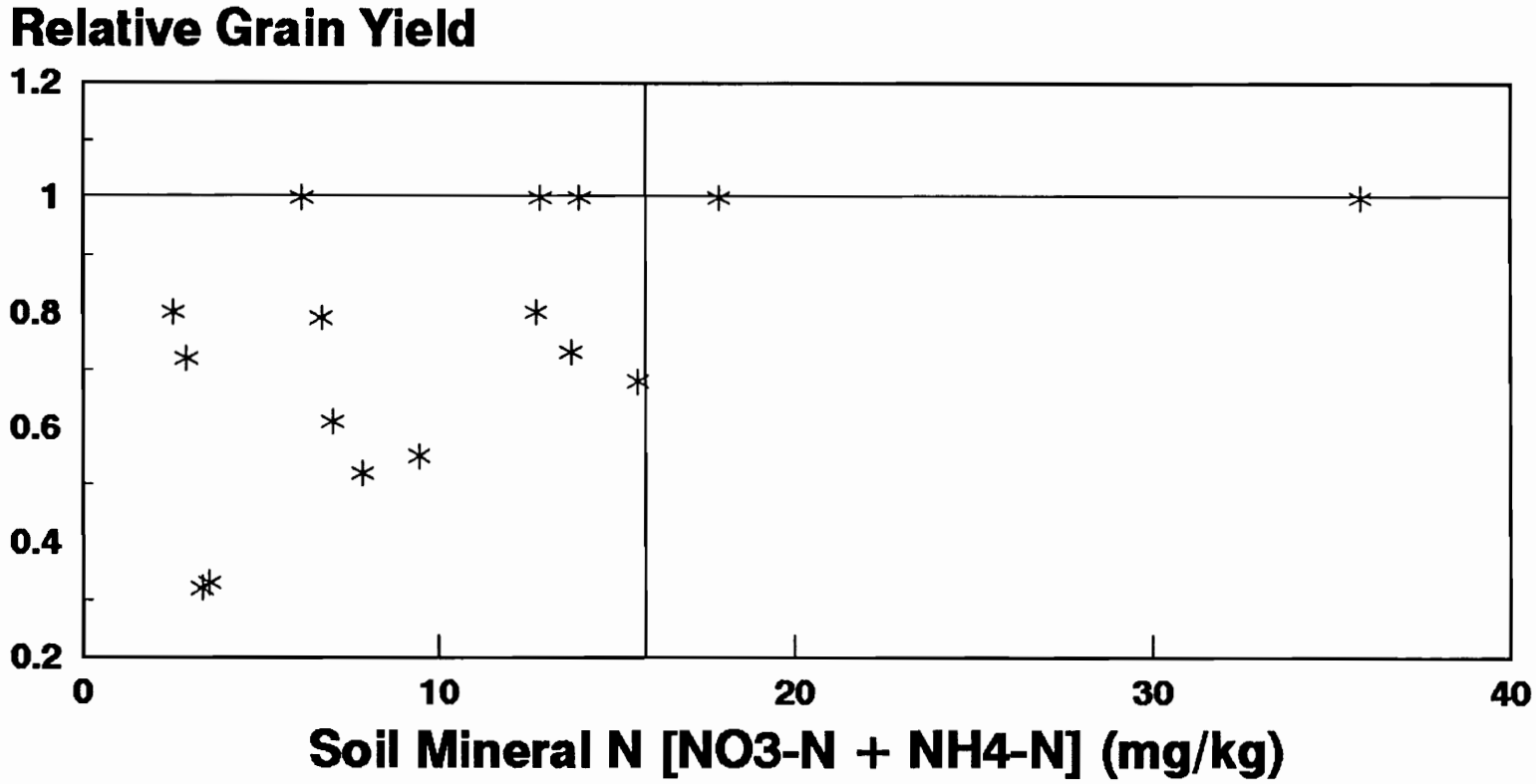


* Data from Kentland Research Farm and Northern Piedmont Agricultural Experiment Station 1992-1993.

Figure 51. Relative Yield vs. Soil Mineral N*

At Corn Eight-Ten Leaf Stage

Soil Sample Depth 0 - 30 cm



* Data from Kentland Research Farm and Northern Piedmont Agricultural Experiment Station 1992-1993.

this sample time is too early for peak N mineralization from cover crop systems in most years.

Critical values derived for the optimum time of sampling for the PSNT, i.e. the four to five leaf stage of corn (1, 4, 5, 11, 12, 13, 16) produced a good fit to the ranges of values currently reported (Figures 44-47). Relative grain yield versus [NO_3-N] at the 0-15 cm soil depth and relative grain yield versus total soil N concentration at the 0-30 cm soil depth produced a critical value of 21 mg/kg, the value now being used in Virginia to separate N responsive from N nonresponsive sites (4).

Relative yield versus soil [NO_3-N] at the 0-30 cm soil depth provided a critical value lower than the reported range (Figure 45). The current range of 18-25 mg/kg was largely derived for soils amended with animal wastes and sewage sludge (1, 4, 5, 11, 12, 16), sources of N that are normally incorporated throughout the plow layer. Cover crop N-sources are often employed in no-tillage systems and N movement between spring cover crop kill and the four to five leaf stage of corn may not be as deep as where manure and biosolids are the major source of N. Therefore, sampling to only a depth of 15 cm may provide just as accurate a test of soil NO_3-N availability as sampling to 30 cm in the manured and sludged soils.

When soil mineral N was utilized to determine critical values at the four to five leaf stage, the 0-30 cm soil depth showed a critical value of 21 mg/kg

(Figure 47). This indicates that sampling to 30 cm may be needed on sites with cover crop residues concentrated at the soil surface and when measuring both forms of available soil N.

Critical values derived from the 0-15 cm soil depth were still within range at the corn eight to ten leaf stage (Figures 48 and 50), although the values were slightly lower than the previous sample time. This indicates that significant amounts of cover crop N are still being mineralized and can be detected in the top 15 cm of the soil (where cover crop residues are concentrated) to use for predicting corn N needs. Therefore, sampling soil to a depth of 15 cm two weeks later than the recommended sampling time may provide sampling flexibility in years when soil cannot be sampled at the recommended time.

3.6 Predictability of Corn N Needs With the Nitrate Quick Test

Soil NO_3-N determination employing extensive soil extraction and analysis procedures may require two weeks for completion. Therefore, timely sidedress fertilizer N recommendations and applications may be difficult when dependent on lengthy soil NO_3-N analyses. Soil NO_3-N analysis with the Nitrate Quick Test is faster than other NO_3-N analysis techniques, therefore using this test has encouraged more timely fertilizer N recommendations and provided greater flexibility in soil sampling.

Identical comparisons as those in section 3.5 (except soil mineral N) were executed using soil [NO_3-N] determined with the Nitrate Quick Test. Plotting soil [NO_3-N] versus relative yield at two weeks after corn emergence produced critical values ranging from 9-11 mg/kg, much lower than the 18-25 mg/kg range reported in the literature (1, 4, 5, 11, 12, 13, 16) (Figures 52-53). Soil N concentrations had not peaked at this sample, therefore the test accuracy was limited by low soil NO_3-N concentrations. Additionally, as with the following two soil sample times, the critical value was higher at the 0-15 cm soil depth, indicating higher concentrations of soil NO_3-N at this depth where cover crop residues were concentrated.

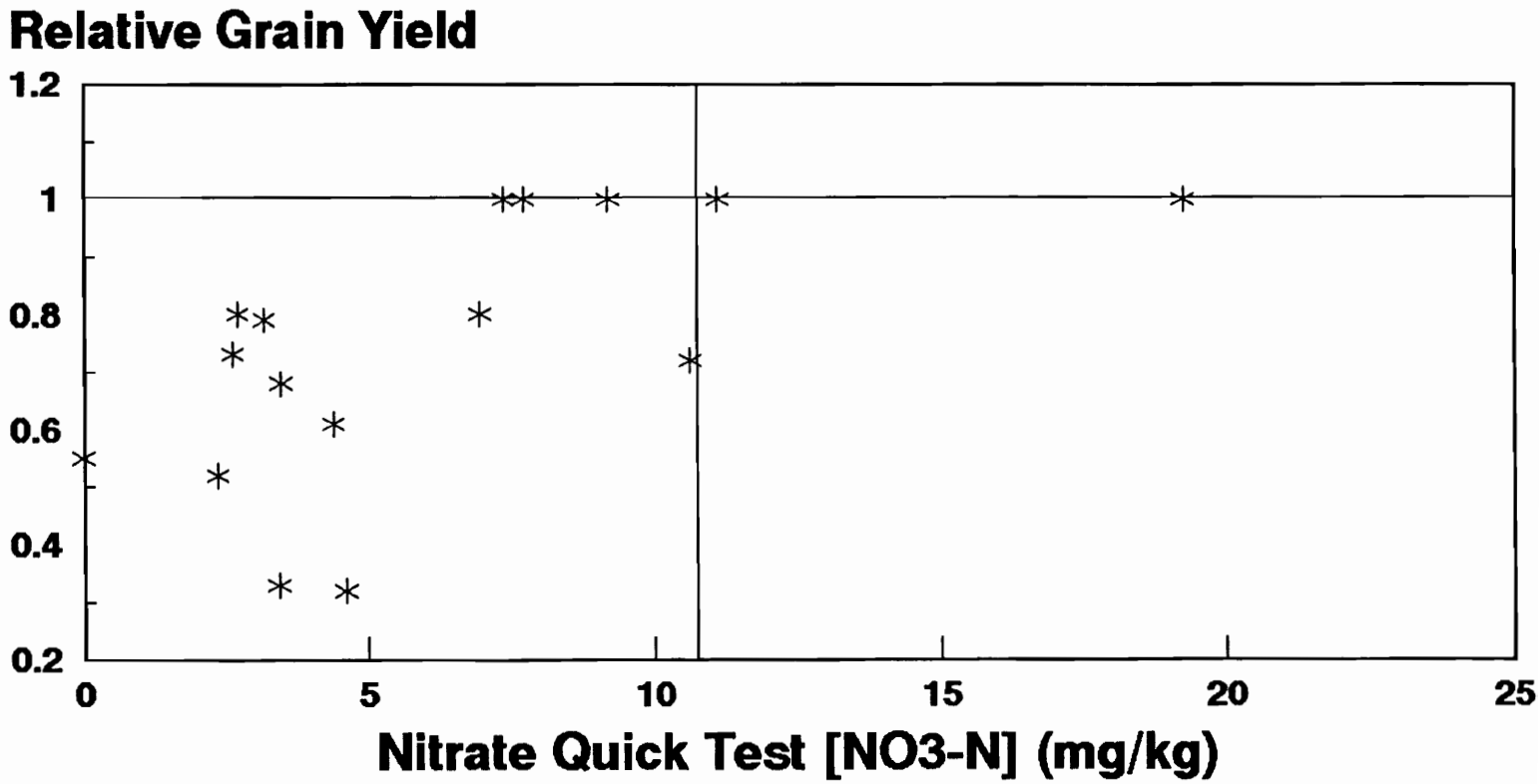
Critical values ranging from 12-16 mg/kg were derived at the four to five leaf stage of corn (Figures 54-55). The critical value at the 0-15 cm soil depth was close to the published values. It is likely soil [NO_3-N] detection with the test was more accurate at this sample time since the majority of maximum NO_3-N concentrations occurred at the corn four to five leaf stage.

Critical values ranging from 9-13 mg/kg were produced at the eight to ten leaf stage of corn (Figures 56-57), much lower than the values currently published. It is likely the poor relationship between the derived and published critical values was due to lower soil NO_3-N concentrations at this sample time.

Figure 52. Relative Yield vs. Soil NO3-N*

At Two Weeks After Corn Emergence

Soil Sample Depth 0 - 15 cm

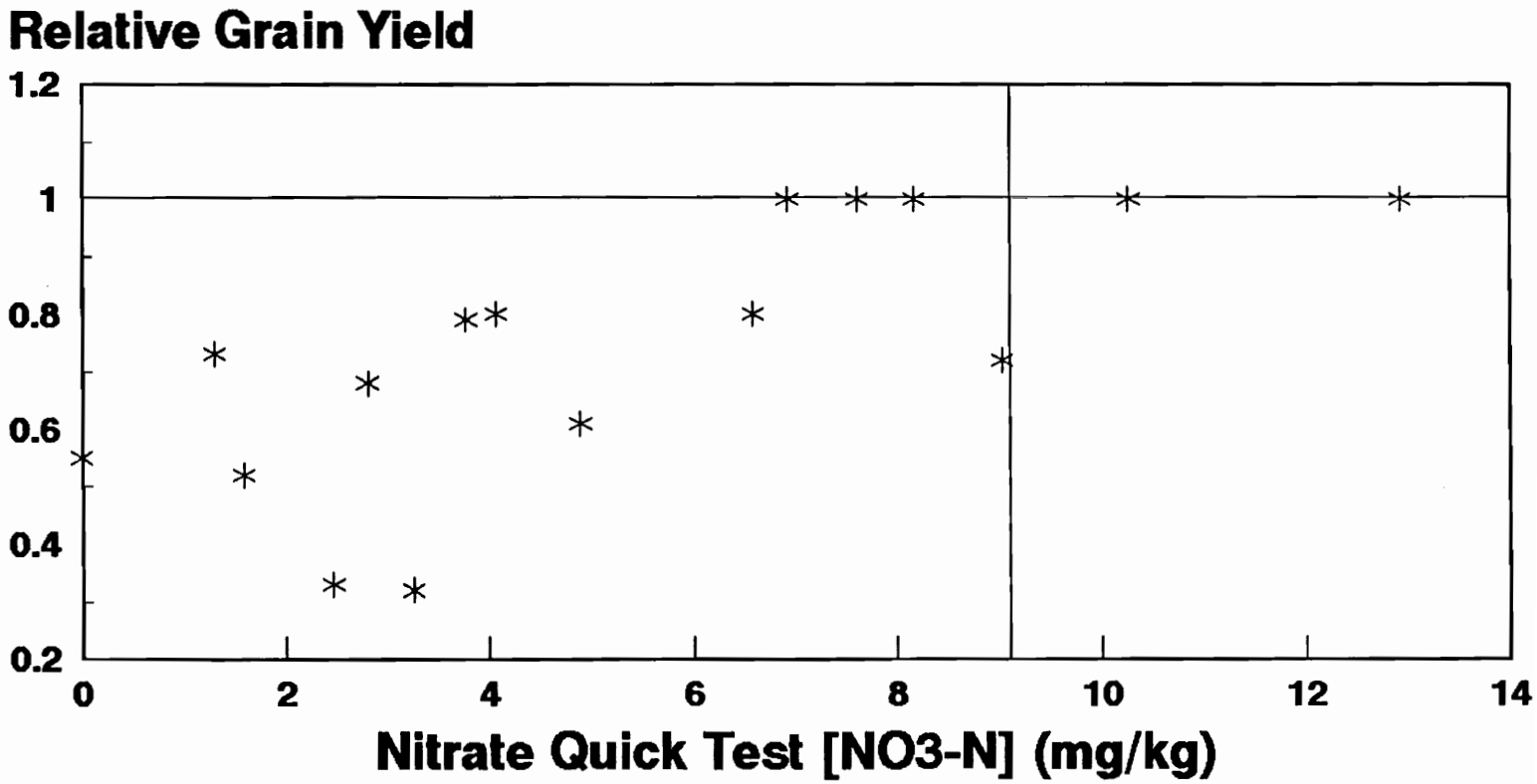


* Data from Kentland Research Farm and Northern Piedmont Agricultural Experiment Station 1992-1993.

Figure 53. Relative Yield vs. Soil NO3-N*

At Two Weeks After Corn Emergence

Soil Sample Depth 0 - 30 cm

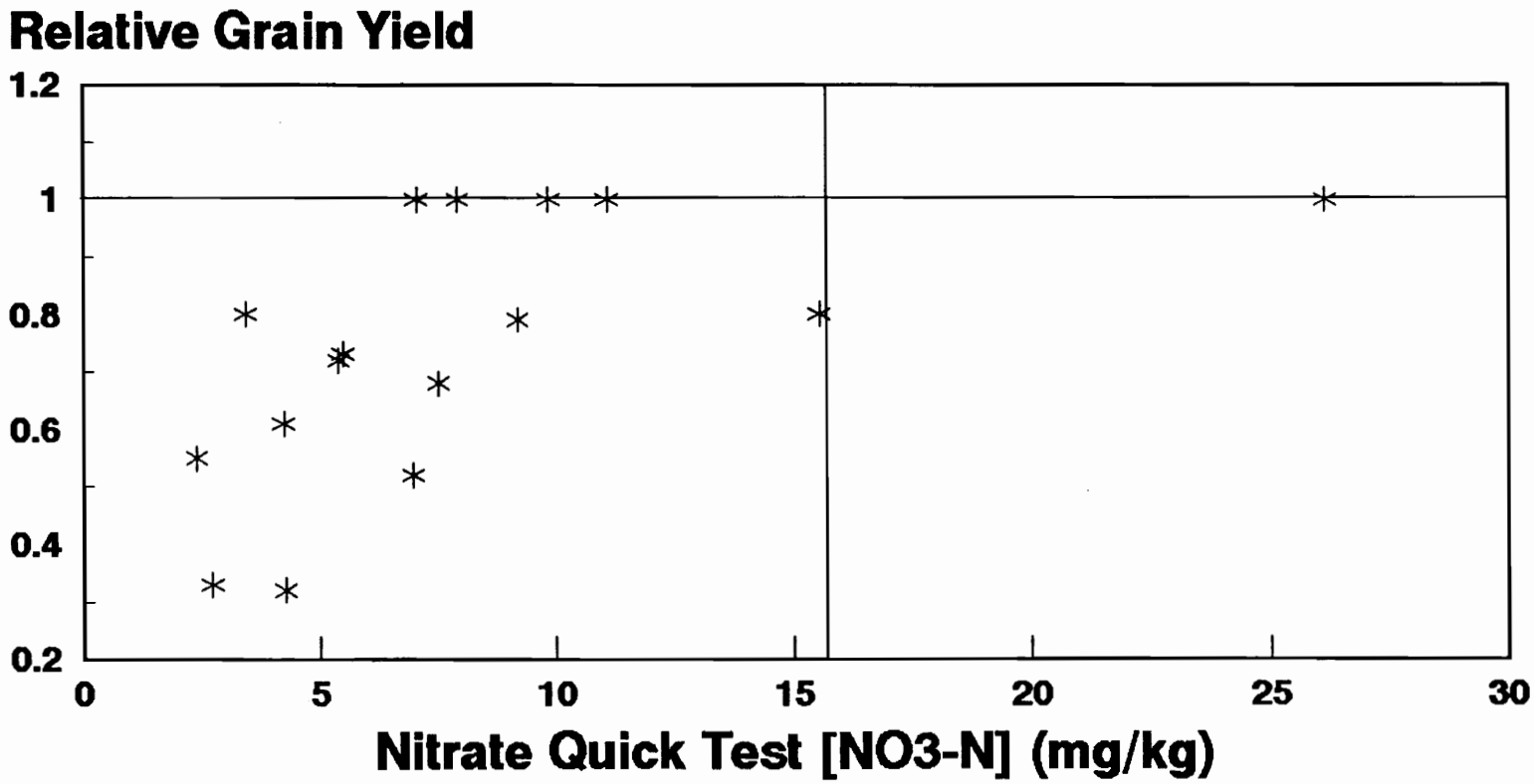


* Data from Kentland Research Farm and Northern Piedmont Agricultural Experiment Station 1992-1993.

Figure 54. Relative Yield vs. Soil NO3-N*

At Corn Four-Five Leaf Stage

Soil Sample Depth 0 - 15 cm

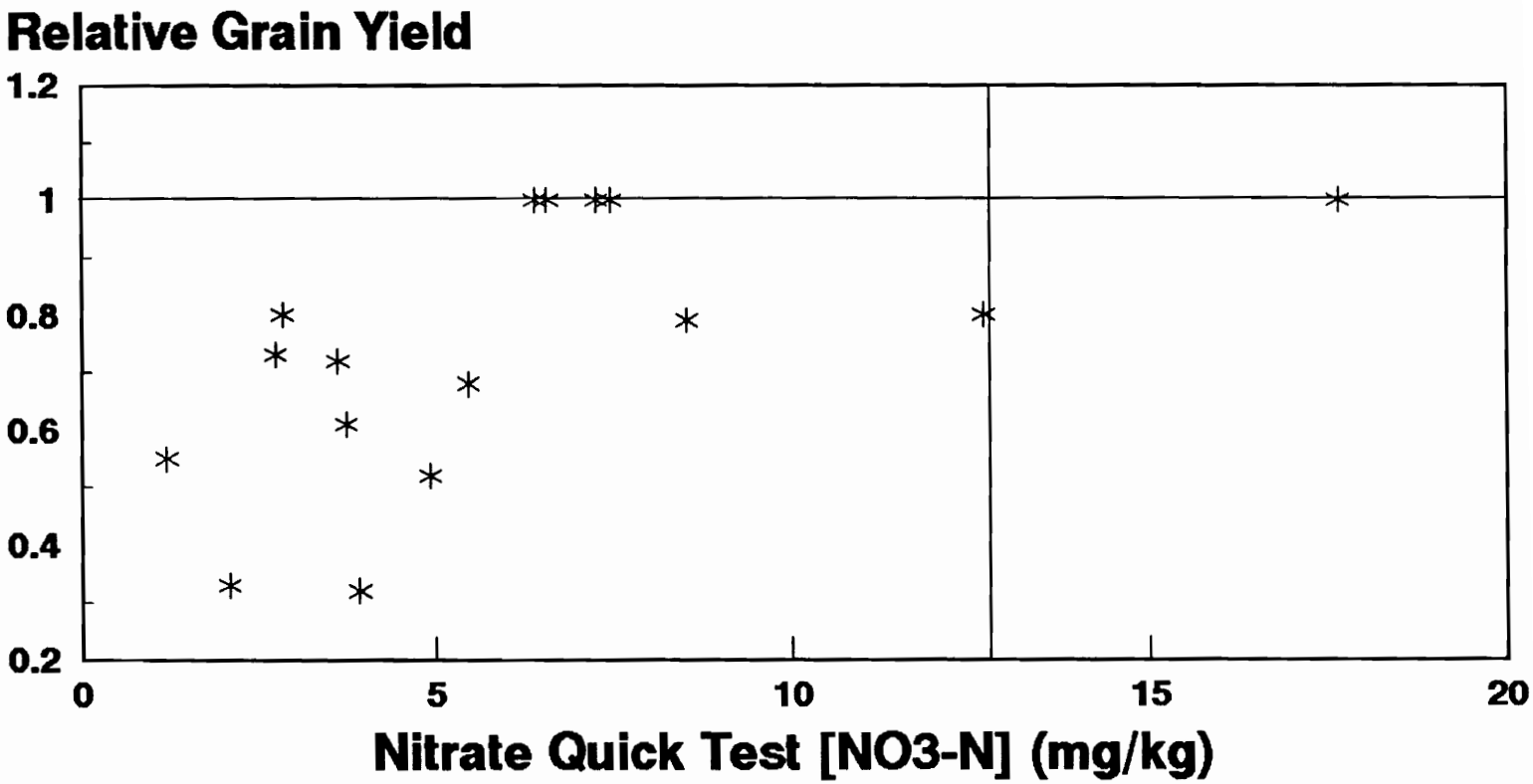


* Data from Kentland Research Farm and Northern Piedmont Agricultural Experiment Station 1992-1993.

Figure 55. Relative Yield vs. Soil NO3-N*

At Corn Four-Five Leaf Stage

Soil Sample Depth 0 - 30 cm

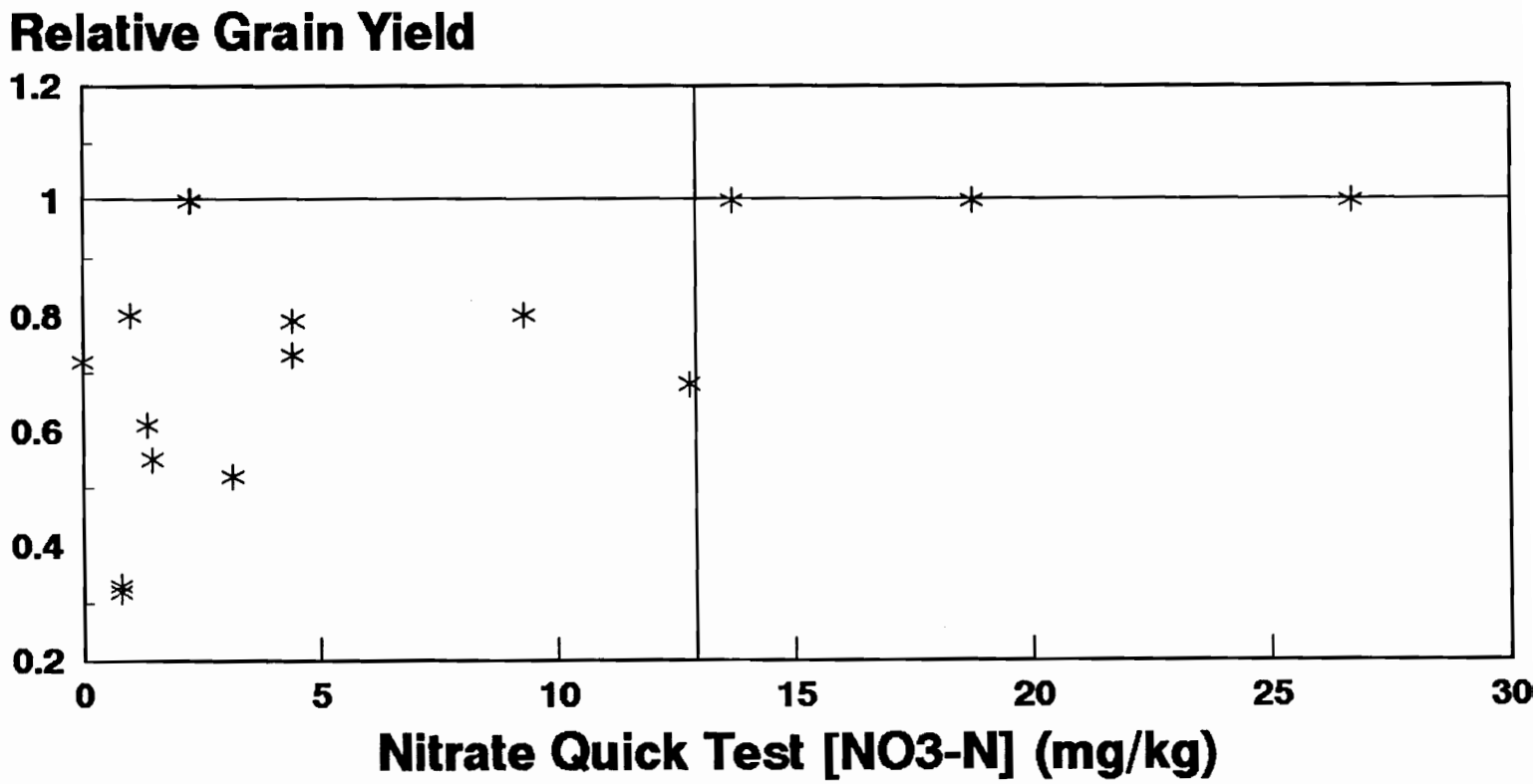


* Data from Kentland Research Farm and Northern Piedmont Agricultural Experiment Station 1992-1993.

Figure 56. Relative Yield vs. Soil NO3-N*

At Corn Eight-Ten Leaf Stage

Soil Sample Depth 0 - 15 cm

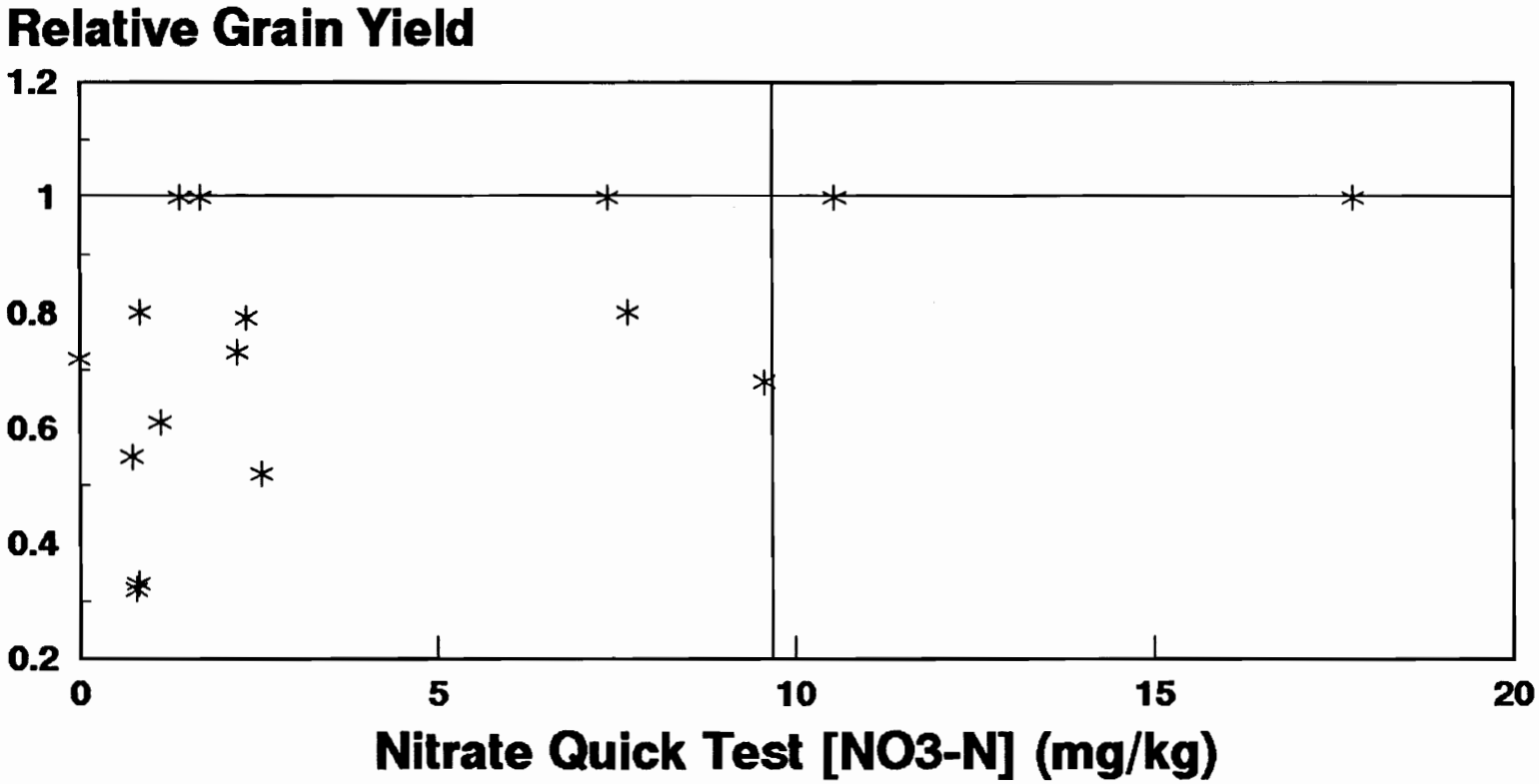


* Data from Kentland Research Farm and Northern Piedmont Agricultural Experiment Station 1992-1993.

Figure 57. Relative Yield vs. Soil NO3-N*

At Corn Eight-Ten Leaf Stage

Soil Sample Depth 0 - 30 cm



* Data from Kentland Research Farm and Northern Piedmont Agricultural Experiment Station 1992-1993.

4. Conclusions

It is evident from the results of the cover crop data that treatments including rye can accumulate amounts of N similar to vetch on soils with high amounts of residual N. Additionally, rye in rye+vetch cover crops may reduce the growth of the vetch portion of the mix on high N soils through competition. It is also apparent that on soils of limited residual N, rye+vetch cover crops can produce N yields intermediate to rye alone and vetch alone cover crops. Additionally, the overall C/N ratio of a rye+vetch cover crop is intermediate to the C/N ratio of rye alone or vetch alone.

Vetch is very sensitive to environmental conditions, whereas rye is able to better tolerate stress (i.e. drought, weed competition). Furthermore, rye is able to compensate for stand differences through tillering. Overall, biomass and N contents from the three cover crops were similar to those reported in the literature. However, rye N accumulation in 1992 surpasses the majority of current reports. Allowing rye containing cover crops to accumulate biomass at levels similar to those in 1992 can retard early season corn growth and limit corn yield potential.

Soil N concentrations appear to reach a maximum at either the four to five or eight to ten leaf stage of corn, regardless of cover crop system. This corresponds with the onset of maximum corn N uptake and supports the corn four to five leaf stage as an appropriate time to sample for recommending

sidedress N. With the exception of the KRF in 1992, vetch plots produced the highest amount of plant available soil N. Additionally, plant available soil N was concentrated predominately in the top 15 cm of the soil where the plant residues were located.

The Nitrate Quick Test is an accurate method of determining soil [NO_3-N]. However, the test is not designed to measure very low (less than 10 mg/kg) soil [NO_3-N] and therefore the accuracy of the test decreases as the actual soil NO_3-N concentration decreases.

As indicated by the corn N data at silking, fallow and vetch treatments produced the most plant available N where vetch was an insignificant part of the rye+vetch blend, but when vetch is a contributor to biomass and N content in the mix, vetch and rye+vetch produce the most plant available N. Corn grain and silage yields were higher in the fallow and vetch plots due to a combination of greater N availability and better early season mineralization and higher early season soil temperatures. Additionally, rye and rye+vetch plots require greater amounts of N to reach maximum yield due to N immobilization by the rye. All cover crop treatments that responded to fertilizer N demonstrated very small corn yield increases with the last increments of supplemental N. Therefore, a corn yield goal less than maximum yield would be more economically and environmentally sound than a corn yield goal of maximum yield when corn follows cover crops.

Soil sampling at corn four to five leaf growth stage for predicting corn N needs is the best method where corn follows cover crops. Soil N values have very likely peaked at this time and critical values are within the reported range. Although the data is limited, sampling just the top 15 cm of the soil may be adequate (when sampling for NO_3-N) since the this is where the plant residues are located in a no-till cover crop system. Additionally, total soil mineral N is an accurate predictor N availability or sufficiency. Sampling two weeks after the recommended time may be an alternative method of sampling since cover crop N release is still occurring and critical values fall within the reported range.

Critical values were lower than the published range of values for separating N responsive and N nonresponsive sites when the Nitrate Quick Test was utilized to determine soil [NO_3-N]. The test was designed to measure soil NO_3-N concentrations within the critical value range of the PSNT, but the majority of soil NO_3-N concentrations measured in this study were lower than the critical range of the PSNT. Therefore, although the data is limited, it is likely the Nitrate Quick Test can be a useful tool for making fertilizer N recommendations for corn in cover crop systems since an accurate soil NO_3-N concentration is not required when soil NO_3-N is low.

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Chapter III.
Influence of Cover Crop Desiccation Time and Residue Management on N Availability to Corn.

ABSTRACT

Winter cover crops are integral parts of whole farm systems including corn (*Zea mays* L.), but little research examining the influence of cover crop management on cover crop N release and corn yield exists. A field study was established to determine the effect of rye (*Secale cereale* L), hairy vetch (*Vicia villosa* Roth), and rye+hairy vetch spring desiccation time (early boot stage of rye, early flowering stage of vetch) and residue management (control, residue mowed, residue mowed and disked) on cover crop biomass and N accumulation and on corn N concentration and yield. All cover crops increased in biomass accumulation but only vetch increased in nitrogen content between desiccation times. Vetch plots contained more plant available N than treatments including rye. Early desiccation resulted in higher plant available N but lower soil moisture than late desiccation. Mow+disk plots had higher early season plant available N but lower soil moisture than mow or control treatments. Corn yielded higher in vetch plots than in treatments including rye and higher in early desiccated treatments than late desiccated treatments. Cover crop mowing is an alternative cover crop management technique for enhancing cover crop N release, soil moisture conservation, and corn yield.

1. Introduction

The majority of cover crop-corn research has focused on corn that is planted into chemically desiccated cover crop residue using no-tillage practices (1, 2, 3, 5, 8, 9, 10, 11, 14, 15, 19). However, only a portion of cover crop N is available to a succeeding corn crop due to a lack of synchrony between cover crop N mineralization and corn N uptake (11).

Studies suggest that cover crop N release is slightly faster under conventional tillage than no-tillage (20, 21, 22, 27). However, the synchrony of cover crop N release with corn N uptake is reported to be similar under both systems (20, 21, 22, 27). Cover crop N mineralization seems to be more dependent on precipitation than tillage (20, 21, 22, 27).

Wagger (25, 26) studied the influence of cover crop spring desiccation time relative to corn planting [early desiccation/early plant (EE), early desiccation/late plant (EL), and late desiccation/late plant (LL)]. Delaying desiccation increased cover crop N content in legume systems only. Cover crop N release patterns were similar between kill times. However, corn did not respond to N following hairy vetch in the EE or LL system or following crimson clover in the EL treatment, indicating greater synchrony between cover crop N release and corn N uptake in these systems.

The objectives of this study were (i) to determine the effect of several cover crop combinations on total cover crop biomass and N accumulation; (ii)

to determine the effect of desiccation timing on cover crop biomass, N content, and N mineralization (as measured soil nitrate and ammonium), and on corn N concentration and grain yield; (iii) to determine the effect of cover crop mowing and disking on cover crop N mineralization (as measured soil nitrate and ammonium) and on corn N concentration and grain yield; and, (iv) to determine the optimum soil sampling time for predicting corn N needs in alternative cover crop management systems.

2. Materials and Methods

2.1 Field Plot Specifications

Field studies were conducted at the Kentland Research Farm (KRF) in Blacksburg, Virginia, from fall 1991 to fall 1993. The study was conducted on two soil series - a McGary silt loam (fine, mixed, mesic, Typic Argiaquolls) from fall 1991 to fall 1992 and a Shottower cobbly loam (clayey, kaolinitic, mesic, Typic Paleudults) from fall 1992 to fall 1993. See Tables 1-3 for field plot histories and climatological data.

This study employed a split-split plot design. Three cover crop treatments, hairy vetch (*Vicia villosa* Roth), rye (*Secale cereale* L. var. Wheeler), and a rye-hairy vetch mix, were established in fall 1991 and fall 1992 as main plots. The split plot treatments were two spring kill (by herbicide application) times: the early flag leaf stage of rye or the early flowering stage of hairy vetch (flowering of rye). The split-split plot treatments were of three residue management practices implemented after each respective kill time. The residue management techniques included no further treatment, cover crop residue mowed, and cover crop residue mowed and lightly disked into the top 3 to 6 cm of the soil. Main plots were replicated four times each year.

Land preparations before cover crop planting consisted of moldboard plowing and disking. Additionally, an application of 5.8 l ha^{-1} Gramoxone [1,1'-dimethyl-4,4'-bypyridinium ion] plus 1.17 l ha^{-1} nonionic surfactant [Alkyly aryl

Table 1. Kentland Research Farm Field Plot History - Study Year 1991-1992.

Time Period	Crop Grown	Amendment(s) Applied
Spring/Summer 1989	Alfalfa	--
Fall/Winter 1989	Small Grain	73 kg N, 140 kg P_2O_5, 140 kg K_2O ha^{-1}.
Spring/Summer 1990	Fallow	--
Fall/Winter 1990	Fallow	--
Spring/Summer 1991	Fallow	--

Table 2. Kentland Research Farm Field Plot History - Study Year 1992-1993.

Time Period	Crop Grown	Amendment(s) Applied
Spring/Summer 1990	Sod	--
Fall/Winter 1990	Sod	--
Spring/Summer 1991	Sod	--
Fall/Winter 1991	Sod	--
Spring/Summer 1991	Sod	--

Table 3. Kentland Research Farm Climatological Data.

Year	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG
	Month											
	Temperature (°C)											
1991-1992	19	13	7	4	2	4	6	11	14	18	23	20
1992-1993	18	11	7	1	3	0	3	10	17	20	25	22
	Precipitation (cm)											
1991-1992	1.2	0.7	7.6	14.0	7.5	8.8	8.3	13.8	10.8	15.8	23.8	10.9
1992-1993	4.4	5.5	9.6	6.0	8.4	8.2	17.6	8.6	11.1	9.1	8.4	8.3

polyethoxy ethanol phosphates and organic phosphatic acids] was required in the 1992-1993 study year to kill an established sod. Phosphorus and potassium were applied according to a soil test recommendations (4) prior to cover crop planting and prior to corn planting. Neither phosphorus nor potassium was needed in the study year 1991-1992. In the study year 1992-1993, 134 kg ha^{-1} of each P_2O_5 and K_2O was applied on 18 SEP 1992 and 67 kg ha^{-1} of each P_2O_5 and K_2O was applied on 10 MAY 1993.

Rye and "common" hairy vetch were seeded at 101 kg ha^{-1} (303 seeds m^{-2}) and 28 kg ha^{-1} (117 seeds m^{-2}), respectively (23) (Tables 4-5). The rye-hairy vetch mix rate was planted at 67 kg ha^{-1} (201 seeds m^{-2}) rye and 19 kg ha^{-1} (80 seeds m^{-2}) hairy vetch (18) (Tables 4-5). All cover crops were planted with a grain drill with a row spacing of 17.8 cm. Soon after cover crop emergence an electric fence was erected around the vegetative covers in order to prevent deer damage.

The vegetative covers were killed at each respective kill time with an application of 1.75 l ha^{-1} Gramoxone plus 1.17 l ha^{-1} nonionic surfactant (24) (Tables 4-5). Several days after the herbicide application the respective treatments were mowed and disked (Tables 4-5). Mowing was accomplished using a tractor mounted rotary mower. Disking was accomplished by running a tandem or an offset disk over the plots one to five times until the required residue incorporation was achieved. A cultipacker was rolled over the cover

Table 4. Field Work Log Kentland Research Farm Study Year - 1991-1992.

Date	Activity
4 OCT 1991	Seeded cover crops.
17 MAR 1992	Counted plant populations.
29 APR 1992	Sampled soil and cover crops in early desiccation plots. Sprayed early desiccation plots with Paraquat.
1 MAY 1992	Mowed and disked necessary plots of dead cover crop residue.
22 MAY 1992	Sampled soil and cover crops in late desiccation plots. Sprayed late desiccation plots with Paraquat.
27 MAY 1992	Sampled soil in early desiccated plots.
28 MAY 1992	Mowed and disked necessary plots of dead cover crop residue in late desiccation plots.
2 JUN 1992	Rolled over covers with cultipacker and planted corn.
3 JUN 1992	Applied weed control.
9 JUL 1992	Measured soil temperatures.
16 JUL 1992	Sampled soil.
17 JUL 1992	Sampled whole corn plants.
20 JUL 1992	Measured soil temperatures.
27 JUL 1992	Sampled soil and corn leaves.
14 AUG 1992	Sampled majority of corn ear leaves. Remaining leaves were sampled the following two weeks as silks became apparent.
12 OCT 1992	Harvested grain.

Table 5. Field Work Log Kentland Research Farm Study Year - 1992-1993.

Date	Activity
15 SEP 1992	Seeded cover crops.
14 APR 1993	Counted plant populations.
29 APR 1993	Sampled soil and cover crops in early desiccation plots. Sprayed early desiccation plots with Paraquat.
3 MAY 1993	Mowed and disked necessary plots of dead cover crop residue.
17 MAY 1993	Sampled soil and cover crops in late desiccation plots.
19 MAY 1993	Sprayed late desiccation plots with Paraquat.
20 MAY 1993	Sampled soil in early desiccated plots.
21 MAY 1993	Mowed and disked necessary plots of dead cover crop residue in late desiccation plots. Rolled over covers with cultipacker and planted corn.
24 MAY 1993	Applied weed control.
24 JUN 1993	Sampled soil and whole corn plants.
25 JUN 1993	Measured soil temperatures.
8 JUL 1993	Sampled soil and corn leaves.
9 JUL 1993	Measured soil temperatures.
5 AUG 1993	Sampled corn ear leaves.
1 OCT 1993	Harvested grain.

crops that had not been mowed or mowed and disked to simplify no-till corn (*Zea mays* L. var. Pioneer 3154) planting into the heavy cover crop residues (Tables 4-5). This corn variety was chosen because of its high yield potential and its resistance to gray leaf spot (*Cercospora zeae-maydis* and *C. sorghi* var. *maydis*), a commonly observed disease at the KRF location. The corn was planted at a population of 65,600 plants ha^{-1} with a row spacing of 74.1 cm. The corn was thinned to a population of 54340 plants ha^{-1} several weeks after emergence.

In the 1991-1992 study year, the main plot dimensions were 8.2 m by 27.4 m, the split plot dimensions were 8.2 m by 13.7 m, and the split-split plot dimensions were 4.6 m by 8.2 m. In the 1992-1993 study year, the main plot dimensions were 8.5 m by 27.4 m, the split plot dimensions were 8.5 m by 13.7 m, and the split-split plot dimensions were 4.6 m by 8.5 m. Split-split plots contained six rows of corn each year.

Corn seed was treated with 51.4 g Kernal Guard [Lindane, Captan, and Diazinon; Gamma isomer of 1,2,3,4,5,6-hexachloro-cyclohexane; cis-*N*-Trichloromethylthio-4-cyclohexane-1,2-dicarboximide; O,O-diethyl O-(2-isopropyl-4-methyl-6-pyrimidinyl) phosphorothioate] per 22.7 kg seed by mixing in the planter box to prevent seedcorn maggot (*Delia platura* Meigen) infestations (24). Scouting for cutworms (*Agrotis ipsilon* Hufnagel and *A. gladiaria* Morrison), armyworm (*Pseudaletia unipuncta* Haworth), stalk borers

(*Papaipema nebris* Guen.), and slugs (*Agriolimax reticulatus* Muller) was done according to IPM recommendations (24).

Weeds were controlled with various combinations of herbicides applied after corn planting (Tables 4-5) and based on Virginia Cooperative Extension recommendations (Table 6) (24).

2.2 Field Plot Sampling

Soil was sampled after cover crop planting to determine residual soil N content. Fifteen two cm diameter soil cores were collected at depths of 0 to 15 cm, 15 to 30 cm, and 30 to 60 cm from the study area. Soil samples were immediately frozen with dry ice and remained frozen until laboratory N extraction and analysis was performed.

Cover crop plant populations were measured after winter dormancy to determine plants per meter^2 (Tables 4-5). Plants (plus tillers in the plots containing rye) were counted in 30 cm sections of row at predetermined plot locations. Rye and vetch were counted separately in the rye-vetch mix plots. Four counts per main plot were taken, averaged, and used to calculate plants meter^{-2}.

Cover crop tissue was sampled before each respective cover crop desiccation time to determine N content and biomass accumulation (Tables 4-5). An open-ended sheet metal cylinder 47.5 cm in diameter was used as a

Table 6. Herbicide Combinations Used to Control Weeds.

Date	Herbicides Applied		Composition
3 JUN 1992	5.6 l ha^{-1} Bicep	Atrazine:	2-chloro-4-ethylamino-6-isopropylamino-*s*-triazine
		Metolachlor:	2-chloro-*N*-(2-ethyl-6-methylphenyl)-*N*-(2-methoxy-1-methylethyl) acetamide
	3.1 l ha^{-1} Princep	Simazine:	2-chloro-4,6-bis(ethylamino)-*s*-triazine
	1.75 l ha^{-1} Gramoxone	Paraquat:	1,1'-dimethyl-4,4'-bipyridinium ion
	1.17 l ha^{-1} Surfactant	Surfactant:	Alkyly aryl polyethoxy ethanol phosphates and organic phosphatic acids
24 MAY 1993	9.3 l ha^{-1} Roundup	Glyphosate:	Isopropyl amine salt of N-(phosphono-methyl) glycine
	7 l ha^{-1} Lasso	Alachlor:	2-chloro-2'-6'-diethyl-N-(methoxymethyl)-acetamide
	1.68 kg ha^{-1} Atrazine		See above
	1.12 kg ha^{-1} Princep		See above
	2.34 l ha^{-1} Surfactant		See above

sampling tool. The covers were sampled by cutting the plants inside the cylinder at ground level. Rye and vetch in the rye-vetch mix plots were hand separated immediately. Two random samples were taken per split plot.

Soil was also sampled before cover crop desiccation to determine initial soil N concentration (Tables 4-5). Ten two cm diameter soil cores were collected at depths of 0 to 15 cm and 15 to 30 cm from each split plot. Inorganic soil N was tracked throughout the season to determine periodic soil N concentration (Tables 4-5). Soil samples were taken in every early killed plot at corn planting and in every plot at the four to five leaf stage (approximately 4 weeks after emergence) and the eight to ten leaf stage (approximately 6 weeks after emergence). Five two cm diameter soil cores were taken at depths of 0 to 15 cm and 15 to 30 cm in each split-split plot on each occasion. All soil samples were immediately frozen with dry ice and remained frozen until laboratory N extraction and analysis were performed.

Soil temperatures were measured during the season to aid in interpreting differences in soil N mineralization, corn N uptake, and corn growth patterns (Tables 4-5). Measurements were made in the top 3 cm of soil at the 4 to 5 and the 8 to 10 leaf stage of corn. Data collection was accomplished using a two channel sensor and inserting a connecting thermocouple into the soil. Five measurements were made per split-split plot on each occasion.

Corn tissue was sampled during the season to determine N uptake and estimate relative N availability (Tables 4-5). Whole plant samples were collected at the 4 to 5 leaf stage by cutting 4 plants at ground level in each plot. Leaf samples were taken at the 8 to 10 leaf stage and by sampling the uppermost mature leaf from 6 different plants in each split-split plot. Leaf samples were also collected at corn silking by cutting the leaf opposite and below corn ear from 6 different plants in each split-split plot.

Corn yields were estimated by sampling corn ears from 3 m of the center two rows in each split-split plot (Tables 4-5). Corn grain was weighed and subsampled in the field for moisture determination.

2.3 Laboratory Analysis

Soil moisture was determined by weighing the field moist samples, drying the samples in a forced air oven at 105 °C until constant weight was achieved, and reweighing. Sample weighing and moisture calculations were done according to Gardner (6).

Soil nitrate (NO_3^-) and exchangeable ammonium (NH_4^+) were extracted from thawed, moist soil samples with 2M KCl in an approximate ratio of 1 part soil to 10 parts extractant (12). Extracts were centrifuged, instead of filtered to remove particulates, in order to avoid extract contamination from filter papers (17).

Nitrate concentrations in soil extracts were determined colorimetrically with a QuikChem Automated Ion Analyzer according to QuikChem Method No. 12-107-04-1-B (13), a Griess-Ilosvay procedure. Ammonium concentrations in the soil extracts were also determined colorimetrically with the same instrument using QuikChem Method No. 12-107-06-2-A (13), an indophenol method, modified by substituting salicylic acid for phenol. Soil sample extractions were duplicated and repeated when differences exceeded 1.0 mg N kg^{-1} soil or 10 percent deviation from the mean, whichever was less.

Cover crop and corn tissue samples were dried in a forced air oven at 65 °C until constant weight was achieved. Cover crop and 4 to 5 leaf stage corn samples were weighed to calculate biomass accumulation and N content. Dried samples were ground in a 20.3 cm mill until they passed through a 10 holes cm^{-2} mesh. Cover crop samples and 4 to 5 leaf stage corn samples were ground further by rolling 24 hours on a conveyor in glass jars containing 10 to 12 stainless steel rods.

Total Kjeldahl Nitrogen (TKN) was determined by digesting ground plant tissue and analyzing the digests for ammonium using a QuikChem Automated Ion Analyzer. The procedure QuikChem Method No. 13-107-06-2-B (13) was modified to obtain a higher digestion temperature. This was done by digesting 0.10 g tissue with 0.75 g of a catalyst mixture (K_2SO_4 and HgO in a 25 to 1 ratio (Pope Kjeldahl Mixtures, #1 pumice, Dallas, Texas)) and with 1.25 ml H_2SO_4.

The color reagent was also diluted to expand the effective range of the method to cover the anticipated range of sample N contents. Data quality was maintained with frequent analysis of a U.S. Department of Commerce, National Institute of Standards and Technology plant tissue sample (SRM 1547) of a known N content. All samples were digested and analyzed in duplicate and repeated when differences exceeded 0.10 percent N or 10 percent deviation from the mean, whichever was less.

Corn grain was dried in a forced air oven at 65 °C until constant weight was achieved. Moisture was calculated and yields were corrected and expressed for grain at 15.5% moisture.

2.4 Data Analysis

Data was analyzed using the General Linear Model (GLM) procedure of the Statistical Analysis System (16). Mean comparisons were done according to Gomez and Gomez (7). All data was separated for analysis by sample time and/or sample depth (where applicable) to avoid unbalanced data and to aid in mean comparison determinations.

3. Results and Discussion

3.1 Cover Crop Data

Cover crop treatments that included rye were very similar in total biomass and nitrogen (N) production in 1992, accumulating more biomass and nitrogen (N) than vetch at both kill times (Table 7). This indicates that rye can be an excellent scavenger of soil N with high biomass production potential on soils with large amounts of residual N (Table 8). C/N ratios were also relatively low reflecting high N uptake by rye relative to biomass production (Tables 9-10).

Rye in the rye alone treatments and rye in the rye+vetch treatments were not significantly different in biomass or nitrogen yields even though rye in the rye+vetch mix was seeded at a lower rate than rye alone. This displays rye's ability to compensate for plant population differences. The vetch portion of the mix contributed very little biomass or nitrogen at either desiccation time. Visual observations indicated vetch was probably smothered because of the vigorous growth of the rye portion of the mix on the high N soil.

Vetch biomass and nitrogen yields were significantly lower than either of the other cover crop treatments at both kill times, most likely due to poor fall germination and growth. Precipitation in September and October of 1991 was extremely low (Table 3), therefore inhibiting vetch germination and fall growth. Spring 1992 plant populations reflect this, exhibiting lower vetch plant

Table 7. Effects of Cover Crop Treatments on Rye and Hairy Vetch Biomass and N Accumulation - 1992.

Cover Crop	Biomass			Nitrogen		
	Rye	Vetch	Total	Rye	Vetch	Total
	Mg/ha			kgN/ha		
	Early Desiccation					
Rye	5.39	---	5.39	104	---	104
Vetch	---	0.31	0.31	---	14	14
Rye+Vetch	5.81	0.03	5.84	121	1	122
	Late Desiccation					
Rye	10.37	---	10.37	124	---	124
Vetch	---	2.18	2.18	---	86	86
Rye+Vetch	9.84	0.11	9.95	121	4	125
LSD	1.72*	0.18*	1.19**	NS	4*	35*

* Differences among means within columns are significant at the 0.01 probability level.

** Differences among means within columns are significant at the 0.05 probability level.

Table 8. Residual Fall Soil N Data.

Year	Soil Depth	$[NO_3\text{-}N]$	$[NH_4\text{-}N]$	$[NO_3\text{-}N]+[NH_4\text{-}N]$
	-----cm-----	----------mg/kg----------		
1991	0-15	40.77	4.03	44.80
	15-30	40.86	4.11	44.97
	30-60	5.94	7.96	13.90
1992	0-15	17.35	12.25	29.60
	15-30	9.27	10.30	19.57
	30-60	6.64	4.37	11.01

Table 9. Effects of Cover Crop Treatments on Cover Crop C/N Ratios.

Cover Crop	1992	1993
	-Early Desiccation-	
Rye	23	28
Vetch	10	15
Rye+Vetch	21	23
	-Late Desiccation-	
Rye	38	56
Vetch	11	12
Rye+Vetch	34	33
LSD	4*	5*

* Differences among means within columns are significant at the 0.01 probability level.

Table 10. Effects of Cover Crop Treatments on Rye and Hairy Vetch C/N Ratios.

Treatment	Rye	Vetch	Total	Rye	Vetch	Total
	----------1992----------			----------1993----------		
Cover Crop						
Rye	30	---	30	42	---	42
Vetch	---	10	10	---	13	13
Rye+Vetch	28	12	28	34	15	28
LSD	NS	1**	4*	3*	NS	4*
Desiccation Time						
Early	22	12	18	26	15	22
Late	37	11	28	50	13	34
LSD	2*	NS	1*	3*	NS	3*

* Differences among means within columns are significant at the 0.01 probability level.
** Differences among means within columns are significant at the 0.05 probability level.

populations than in 1993 (Table 11). Visual observations indicated vetch did not really begin to grow and rapidly accumulate biomass and N until after the first desiccation time.

Treatments that included rye nearly doubled in total biomass production from the early desiccation time to the late desiccation time. Carbon accumulated rapidly between kill times but N uptake had largely ceased by the early desiccation time, as indicated by the significantly higher C/N ratios at late kill.

Vetch biomass and nitrogen in the vetch alone treatments increased substantially between kill times, but vetch in the rye+vetch mix increased very little. Again, visual observations indicated vetch in the rye+vetch blend was smothered by the rapid overwhelming growth of the rye part of the mix on the high N soil. Although the increase in vetch biomass and N content in the vetch alone plots during the short interval between kill times was impressive, it is likely spring growth was limited by poor vetch germination.

Cover crop production was quite different during 1993 (Table 12). Rye biomass and nitrogen yields were much lower than in 1992 because of the low residual soil N (Table 8). Rye still produced the highest biomass yields, but nitrogen assimilation by rye was the lowest of all cover crop treatments. C/N ratios were relatively high, also reflecting low N assimilation relative to biomass production (Tables 9-10).

Table 11. Spring Cover Crop Plant Populations.

Cover Crop	Rye	Vetch	Total
	----------plants*/m²----------		
	----------1992----------		
Rye	1839	---	1839
Vetch	---	38	38
Rye+Vetch	1308	41	1349
	----------1993----------		
Rye	678	---	678
Vetch	---	121	121
Rye+Vetch	399	58	457

* Plants=tillers for rye.

Table 12. Effects of Cover Crop Treatments on Rye and Hairy Vetch Biomass and N Accumulation - 1993.

Treatment	Biomass			Nitrogen		
	Rye	Vetch	Total	Rye	Vetch	Total
	Mg/ha			kgN/ha		
Cover Crop						
Rye	5.08	---	5.08	55	---	55
Vetch	---	2.27	2.27	---	84	84
Rye+Vetch	3.73	0.51	4.24	50	17	67
LSD	NS	1.01*	0.91*	NS	30*	11**
Desiccation Time						
Early	3.48	0.91	2.92	59	30	59
Late	5.33	1.87	4.80	46	71	78
LSD	0.73*	NS	0.89*	NS	NS	NS

* Differences among means within columns are significant at the 0.01 probability level.

** Differences among means within columns are significant at the 0.05 probability level.

Rye in the rye alone treatments and rye in the rye+vetch treatments were not significantly different in biomass or nitrogen yields even though rye in the rye+vetch mix was seeded at a lower rate than rye alone. Again, this displays rye's ability to compensate for plant population differences. The vetch portion of the mix accumulated significantly higher biomass and nitrogen than in 1992, placing the rye+vetch mixture as an intermediate nitrogen producer between rye alone and vetch alone. This was also reflected in the C/N ration of the mixture, placing it between the C/N ratios of rye alone and vetch alone. Visual observations indicated vetch was able to compete better than in 1992 with the rye portion of the mixture since rye growth was lower and slower on the low N soil.

Vetch biomass yields were significantly lower than either of the other cover crop treatments. Biomass production may have been limited due to the competition by weeds. Weeds were very vigorous in the early spring probably because this land had been plowed the previous fall after years in pasture, thereby triggering germination of many dormant weed seeds. Despite lower biomass yields than the other cover crops, nitrogen accumulation by vetch was higher than either rye or rye+vetch in 1993.

Rye biomass significantly increased from the early desiccation time to the late desiccation time, yet nitrogen content did not increase. Carbon

accumulated rapidly between kill times but N uptake had largely ceased by the early desiccation time, as indicated by the significantly higher C/N ratios at late kill.

Vetch biomass and nitrogen did not increase between kill times. Again, biomass production was limited due to the competition by weeds. Weed competition increased between kill times due to warming temperatures and more vigorous weed growth.

In summary, cover crops including rye can produce higher biomass yields than vetch. Rye+vetch cover crops can assimilate N in intermediate amounts to vetch alone and rye alone where residual soil N is limited. Delaying desiccation increased the biomass production of all cover crops, but increased nitrogen accumulation in vetch only. Furthermore, C/N ratios increased between kill times in plots including rye.

3.2 Soil N Data

Soil N concentration was influenced by soil sample depth both years. Soil N concentrations were higher in the 0-15 than in the 15-30 cm soil depth. However, effects of cover crop, desiccation time, and cover crop residue management on soil N were similar between soil depths. Therefore, only the 0-15 cm soil depth will be discussed in the following text. Soil N concentrations in the 15-30 soil depth can be seen in Appendix B.

Soil NO_3-N and total mineral N concentrations were relatively low in 1992 at early desiccation (Table 13). Vetch soils had higher NO_3-N and total mineral N concentrations than plots including rye. Rye and rye+vetch plots were very similar in NO_3-N and total N content. Soil [NH_4-N] was not significantly different between treatments and averaged 3.06 mg/kg. Soil N concentrations at late desiccation were not significantly different among treatments and averaged 0.76, 3.71, and 4.47 mg/kg for soil [NO_3-N], soil [NH_4-N], and total soil N, respectively.

Soil N concentrations had increased by corn planting in the early desiccated plots, indicating that cover crop N mineralization had begun (Figure 1). The soil had a higher [NO_3-N] in the vetch plots than the other cover crops tested, likely due to nitrification of residual soil N since vetch biomass and N were extremely low at early desiccation. However, total soil mineral N concentrations were not different between cover crops.

Soil N concentrations continued to increase by the four to five leaf stage of corn (Figure 2). Vetch plots contained higher concentrations of soil NO_3-N and total soil N than treatments including rye, likely due to high amounts of residual soil N carried over from the previous fall rather than the low-yielding vetch. Soil NH_4-N comprised a greater proportion of total mineral N in treatments including rye than in vetch alone treatments, indicating that

Table 13. Soil N Data at Early Desiccation - 1992. 0-15 cm Soil Depth.

Cover Crop	[NO3-N]	Total N
	---------mg/kg---------	
Rye	0.39	3.44
Vetch	2.53	6.10
Rye+Vetch	0.24	2.79
LSD	1.24*	2.06*

* Differences among means between columns are significant at the 0.01 probability level.

Figure 1. Soil N Data at Corn Planting - 1992

Early Desiccated Plots

0-15 cm Soil Depth

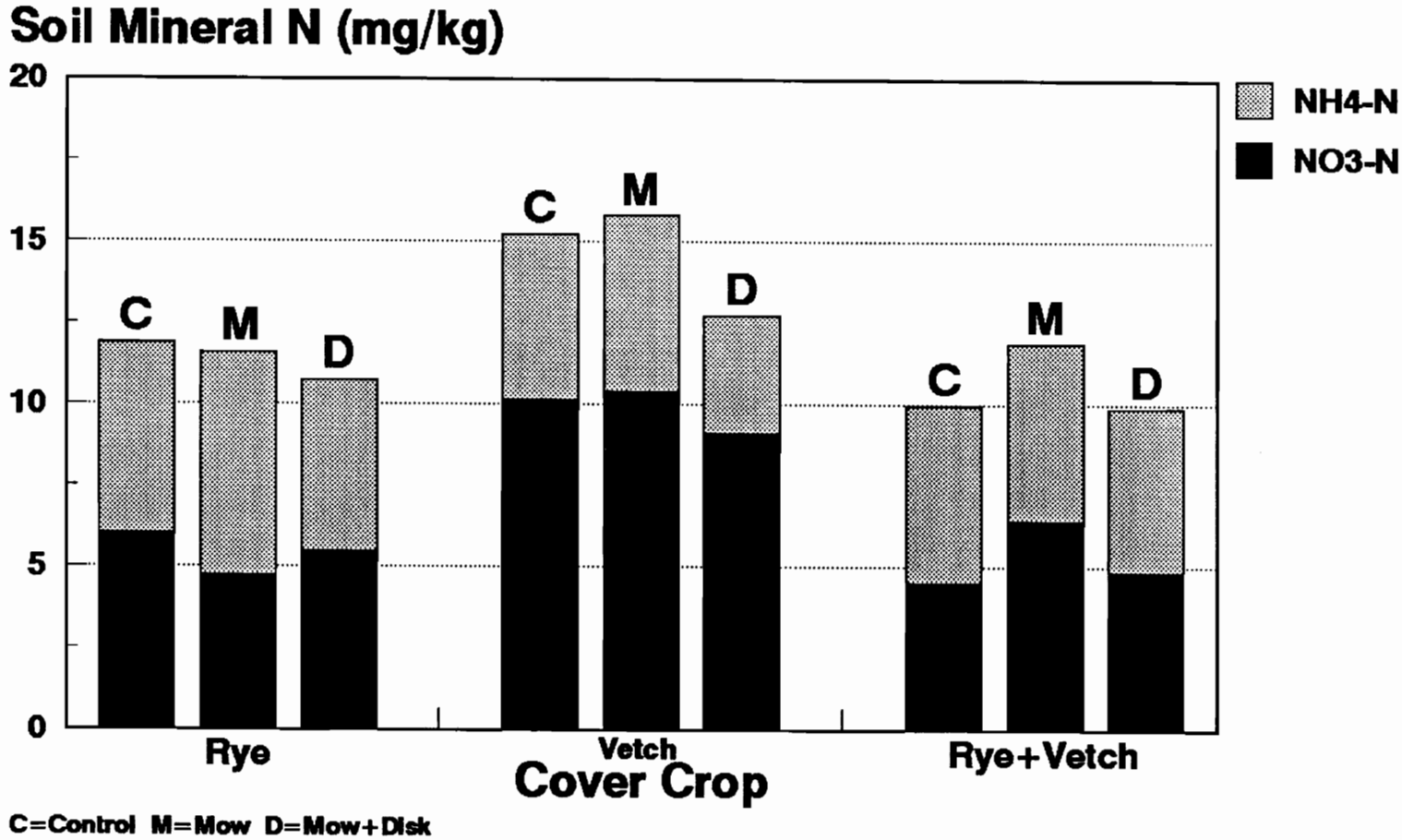
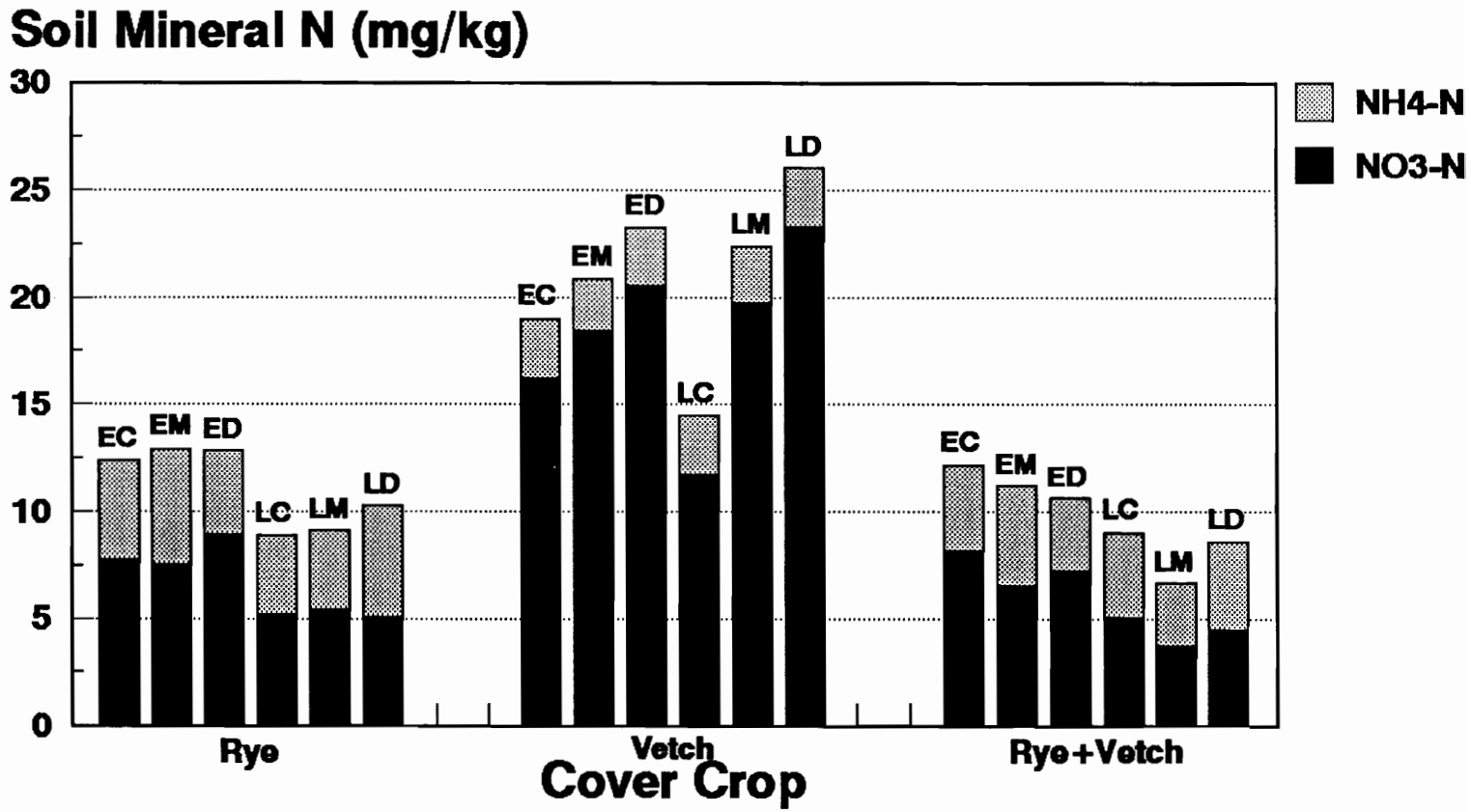


Figure 2. Soil N Data - 1992

At Corn Four to Five Leaf Stage

0-15 cm Soil Depth



E = Early Desiccation L = Late Desiccation
C = Control M = Mow D = Mow+Disk

nitrification was limited, possibly due to increased moisture in the rye containing plots.

Soil N concentrations increased in vetch plots while they decreased slightly in rye containing treatments at the eight to ten leaf stage of corn (Figure 3). Soil NO_3-N and total soil N concentrations were higher in vetch than rye containing plots at this sample time. Additionally, soil NH_4-N values were higher in treatments including rye. Therefore, similar to the previous sample time, nitrification was limited in rye containing plots, possibly due to increased moisture in these treatments.

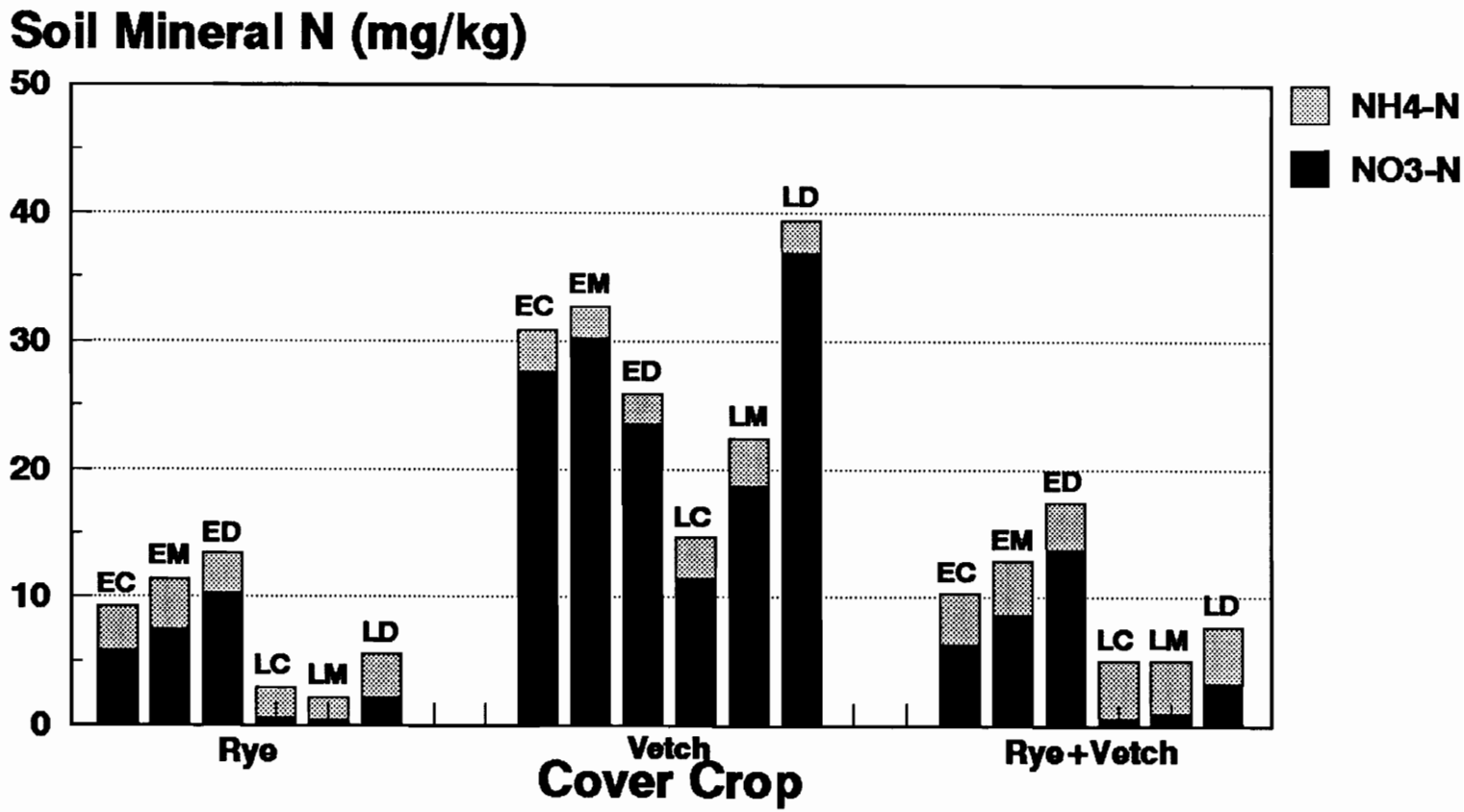
Early desiccated plots had higher soil NO_3-N and total soil N concentrations than late desiccated plots at the eight to ten leaf stage of corn. The exception was the late desiccated mow+disk plots, which were similar to early desiccated treatments. This indicates that mowing and disking can increase soil N availability to corn when the cover crop is allowed to grow until corn planting.

In the 1993 study year soil N concentrations were not significantly different between treatments at early desiccation and averaged 0.06, 11.61, and 11.67 mg/kg for soil [NO_3-N], soil [NH_4-N], and total soil N, respectively. Similarly, no significant differences existed between soil N concentrations at late desiccation. Soil N concentrations averaged 0.05, 10.14, and 10.19 mg/kg for soil [NO_3-N], soil [NH_4-N], and total soil N, respectively.

Figure 3. Soil N Data - 1992

At Corn Eight to Ten Leaf Stage

0-15 cm Soil Depth



E = Early Desiccation L = Late Desiccation
C = Control M = Mow D = Mow+Disk

Soil N concentrations had increased in the early desiccated plots by corn planting, although most treatments were still dominated by the NH_4-N form of N (Figure 4). All control and mow treatment plots were very similar in N concentration, whereas mowing and disking had enhanced N release and mineralization. The mow+disk treatment in the vetch plots caused plant available N to almost double, while mow+disk treatments in plots including rye also caused available N to increase significantly. In the overall mow+disk treatments, vetch N concentrations were highest, rye N concentrations were lowest, and rye+vetch N concentrations were intermediate to rye and vetch. This indicates that mowing and disking can increase early season plant available N and that a rye+vetch cover crop has the potential to release N in amounts intermediate to rye and vetch.

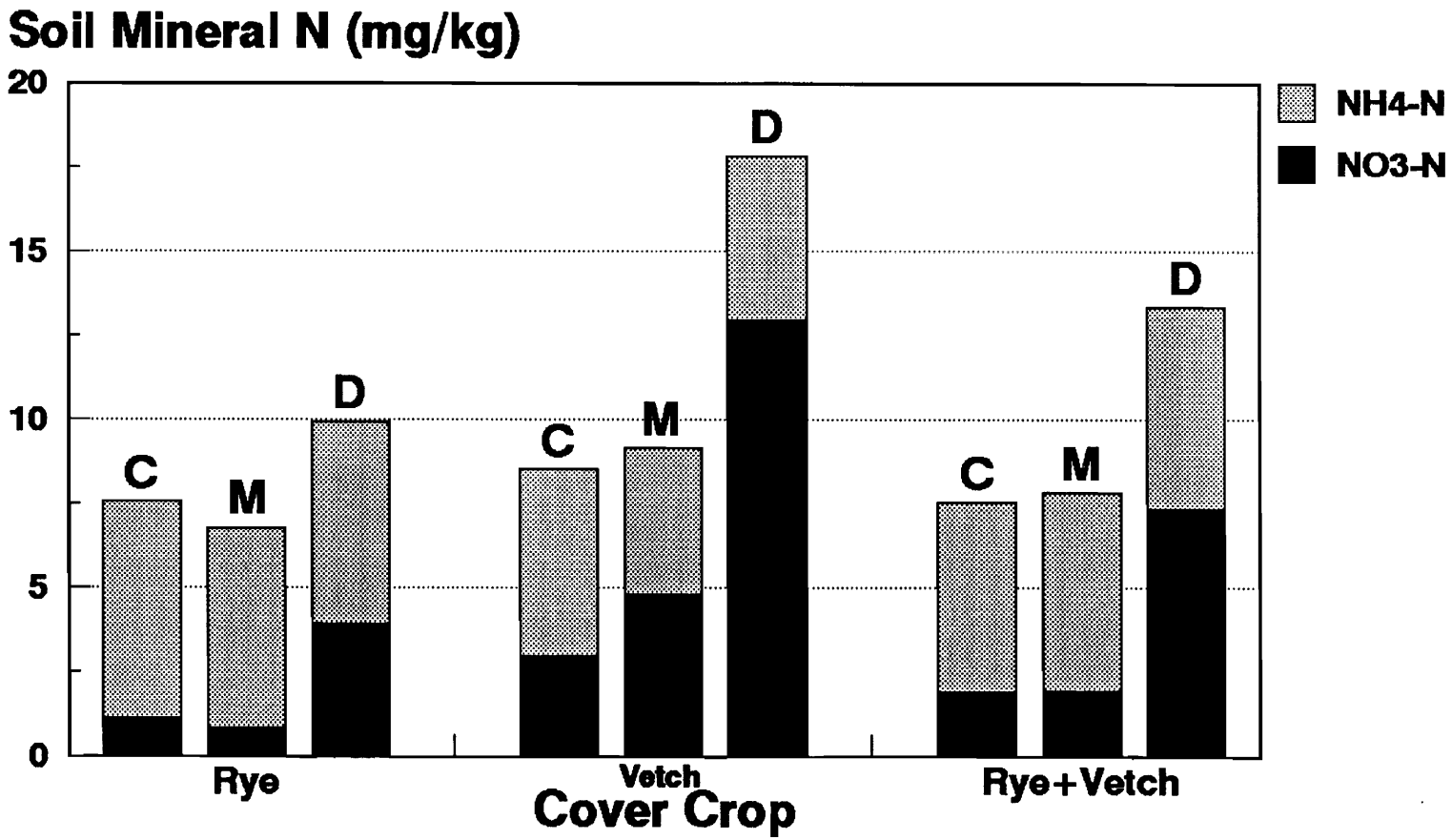
All treatments peaked in N concentrations at the four to five leaf stage of corn (Figure 5). Vetch treatments contained higher concentrations of soil NO_3-N and total soil N than plots including rye. This was probably due to the high N vetch residue that enhanced mineralization and nitrification in these plots. Rye and rye+vetch plots were very similar in [NO_3-N] and total soil N, but rye was slightly higher in [NH_4-N] than rye+vetch.

Soil NO_3-N was higher and soil NH_4-N was lower in the early desiccated plots than in the late desiccated plots. This indicates more rapid mineralization and nitrification on early desiccated plots than late desiccated plots. Plant

Figure 4. Soil N Data at Corn Planting - 1993

Early Desiccated Plots

0-15 cm Soil Depth

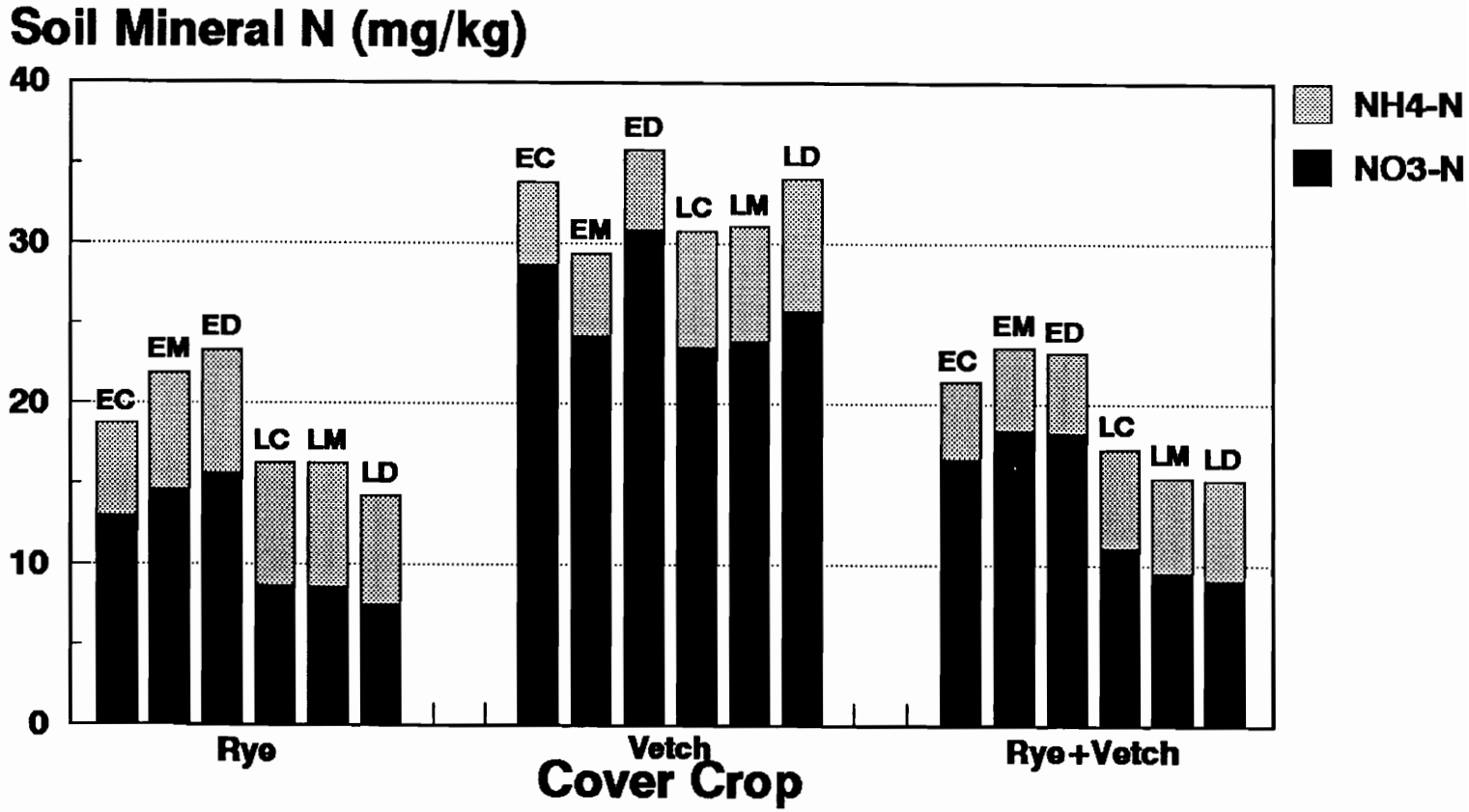


C=Control M=Mow D=Mow+Disk

Figure 5. Soil N Data - 1993

At Corn Four to Five Leaf Stage

0-15 cm Soil Depth



E = Early Desiccation L = Late Desiccation
C = Control M = Mow D = Mow+Disk

material having a lower C:N ratio at early desiccation than late desiccation was likely the reason.

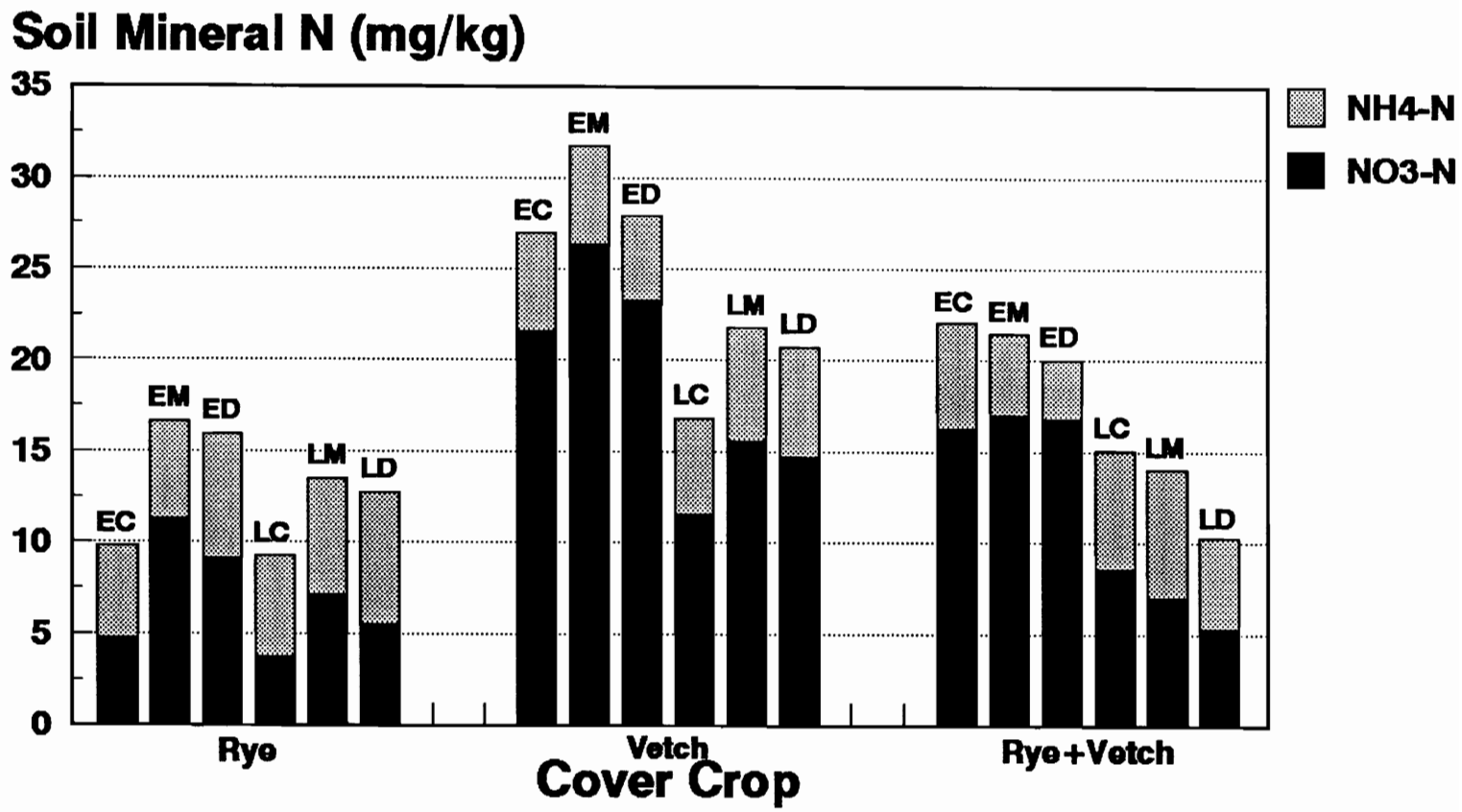
Soil N concentrations decreased slightly by the eight to ten leaf stage of corn, but trends remained similar. Vetch still produced higher concentrations of NO_3-N and total soil N with rye+vetch treatments yielding concentrations intermediate to vetch and rye alone plots (Figure 6). The concentration of NH_4-N was higher in the mow+disk treatment where rye was grown alone, yet was lower where rye was grown in combination with vetch. Possibly the rye alone plots took longer to mineralize N due to the higher carbon content than the rye in the rye+vetch cover crop. Cover crop desiccation also influenced all forms of soil N. Soil NO_3-N and total N levels were higher in the early killed plots, while soil NH_4-N levels were higher in the late killed plots. Again, these results indicate greater mineralization and nitrification in the early desiccated treatments due to lower C/N ratio plant material and longer reaction time.

In summary, vetch treatments contain more plant available N than rye or rye+vetch throughout the early growing season. However, when a rye+vetch cover crop accumulates N in intermediate amounts to vetch and rye, it can release plant available N in intermediate amounts also. Additionally, cover crop residue mowing and disking and early cover crop desiccation can increase soil N availability to corn. Cover crop N release peaked at the corn four to five leaf stage in the majority of treatments. Mowing cover crop residues can enhance

Figure 6. Soil N Data - 1993

At Corn Eight to Ten Leaf Stage

0-15 cm Soil Depth



E = Early Desiccation L = Late Desiccation
C = Control M = Mow D = Mow+Disk

N release by placing the residues in a better position for decomposition than just spraying, i.e. reduced particle size, soil-residue contact. However, additionally disking may cause cover crop N release prior to corn N uptake because residues decompose quicker when incorporated into the soil.

3.3 Soil Moisture Data

Soil moisture was influenced by soil sample depth both years. Soil moisture was higher in the 0-15 than in the 15-30 cm soil depth. However, cover crop, desiccation time, and cover crop residue management effects were similar between soil depths. Therefore, only the 0-15 cm soil depth will be discussed in the following text. Soil moisture content in the 15-30 soil depth can be seen in Appendix C.

Soil moisture contents were not significantly different between treatment means at early desiccation in 1992 and averaged 224.21 g/kg. By late desiccation vetch plots were lower in soil moisture than plots including rye, likely due to the lack of cover on the vetch plots that allowed for moisture evaporation from the soil surface (Table 14). Furthermore, at corn planting, early desiccated vetch plots were lower in soil moisture than rye containing plots, again likely due to a lack of cover that allowed for moisture evaporation from the soil surface (Figure 7).

Table 14. Soil Moisture Data at Late Desiccation. 0-15 cm Soil Depth.

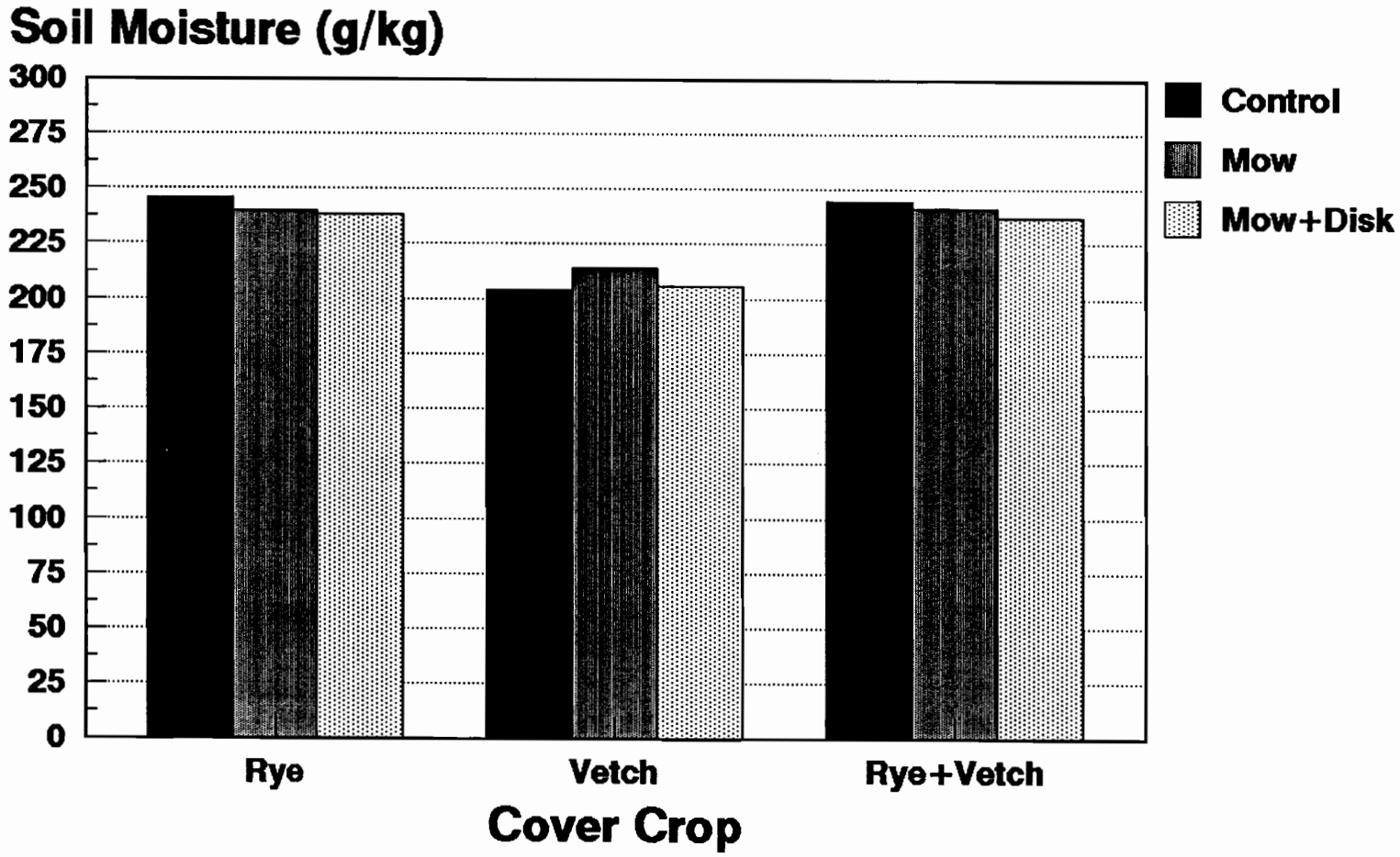
Cover Crop	--1992--	--1993--
	----------g/kg----------	
Rye	247.30	135.53
Vetch	239.93	153.23
Rye+Vetch	251.65	130.68
LSD	10.11*	10.75*

* Differences among means within columns are significant at the 0.01 probability level.

Figure 7. Soil Moisture at Corn Planting - 1992

Early Desiccated Plots

0-15 cm Soil Depth



Moisture contents at the four to five and eight to ten leaf stage of corn reflected important effects from all treatments (Figures 8-9). Vetch was much lower in moisture than plots including rye, likely due to the high amount of moisture retaining rye mulch. Late desiccation also resulted in increased moisture retention, also due to an increased amount of water retaining cover crop mulch with the delayed kill. Finally, at the corn four to five leaf stage, a decrease in soil water conservation was observed with an increase in cover crop residue manipulation. It seemed that the more resistant the cover crop was to decomposition, the more water was conserved.

Soil moisture contents were not significantly different between treatment means at early desiccation in 1993 and averaged 176.55 g/kg. By late desiccation vetch plots were higher in soil moisture than plots including rye, likely due to higher soil moisture use on plots including rye (Table 14). The early desiccated plots at corn planting were similar in soil moisture content, likely due to precipitation before soil sampling that masked management effects (Figure 10).

Rye containing plots had higher soil moisture contents than vetch treatments at the four to five and eight to ten leaf stage of corn (Figures 11-12). Additionally, the mow+disk treatments at the eight to ten leaf stage of corn resulted in less soil water than the other residue management practices. It is

Figure 8. Soil Moisture - 1992

At Corn Four to Five Leaf Stage

0-15 cm Soil Depth

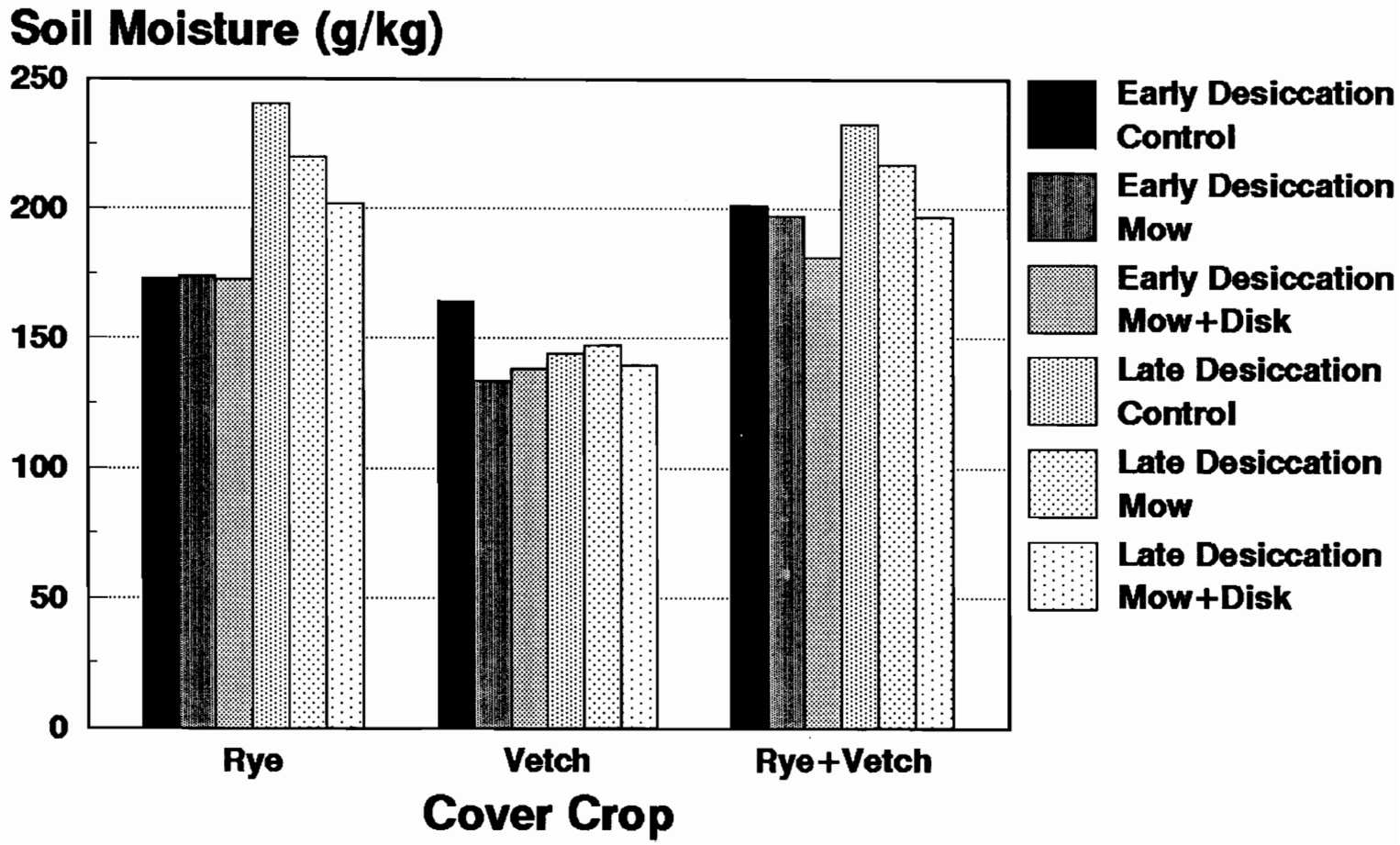


Figure 9. Soil Moisture - 1992

At Corn Eight to Ten Leaf Stage

0-15 cm Soil Depth

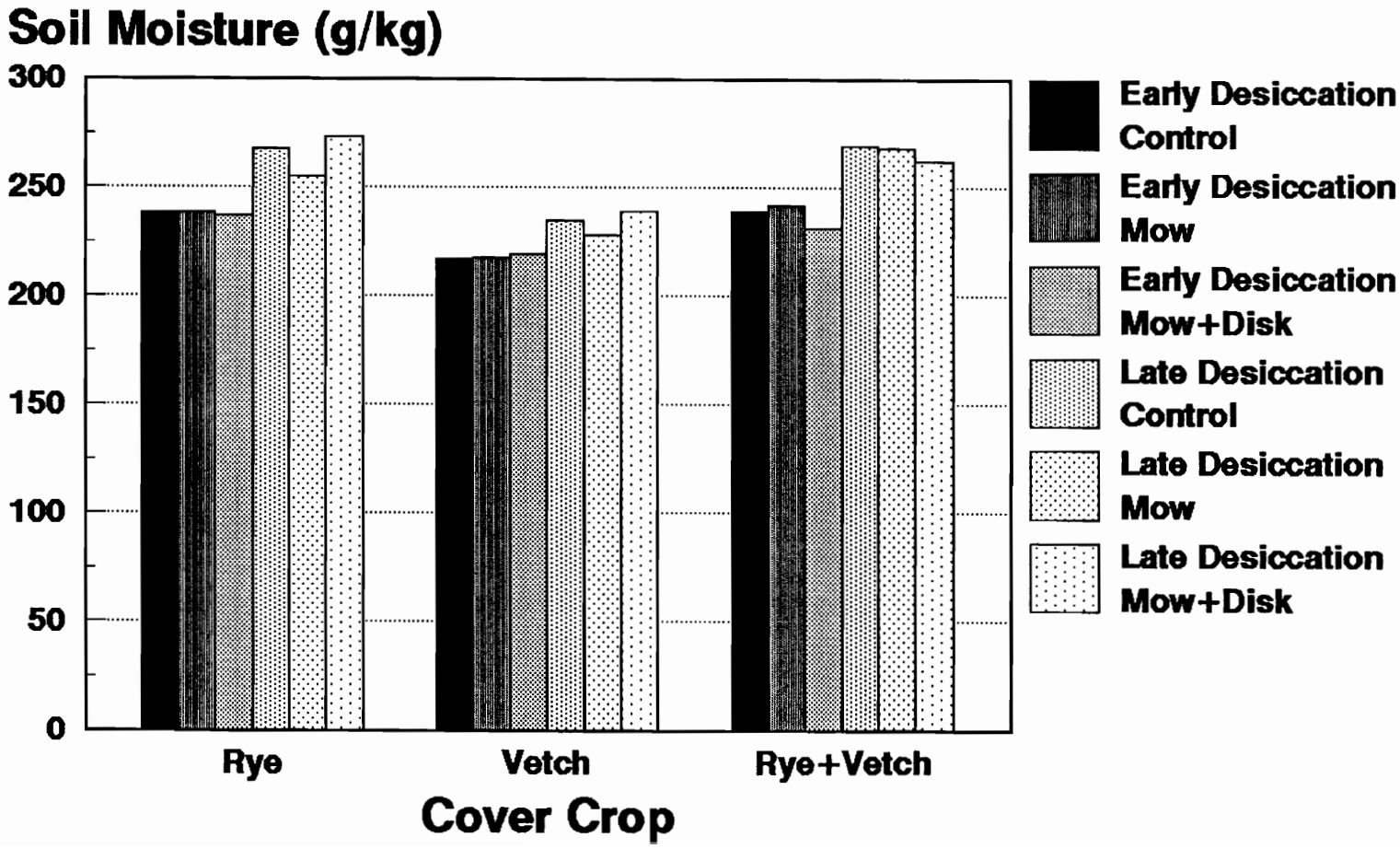


Figure 10. Soil Moisture at Corn Planting - 1993

Early Desiccated Plots

0-15 cm Soil Depth

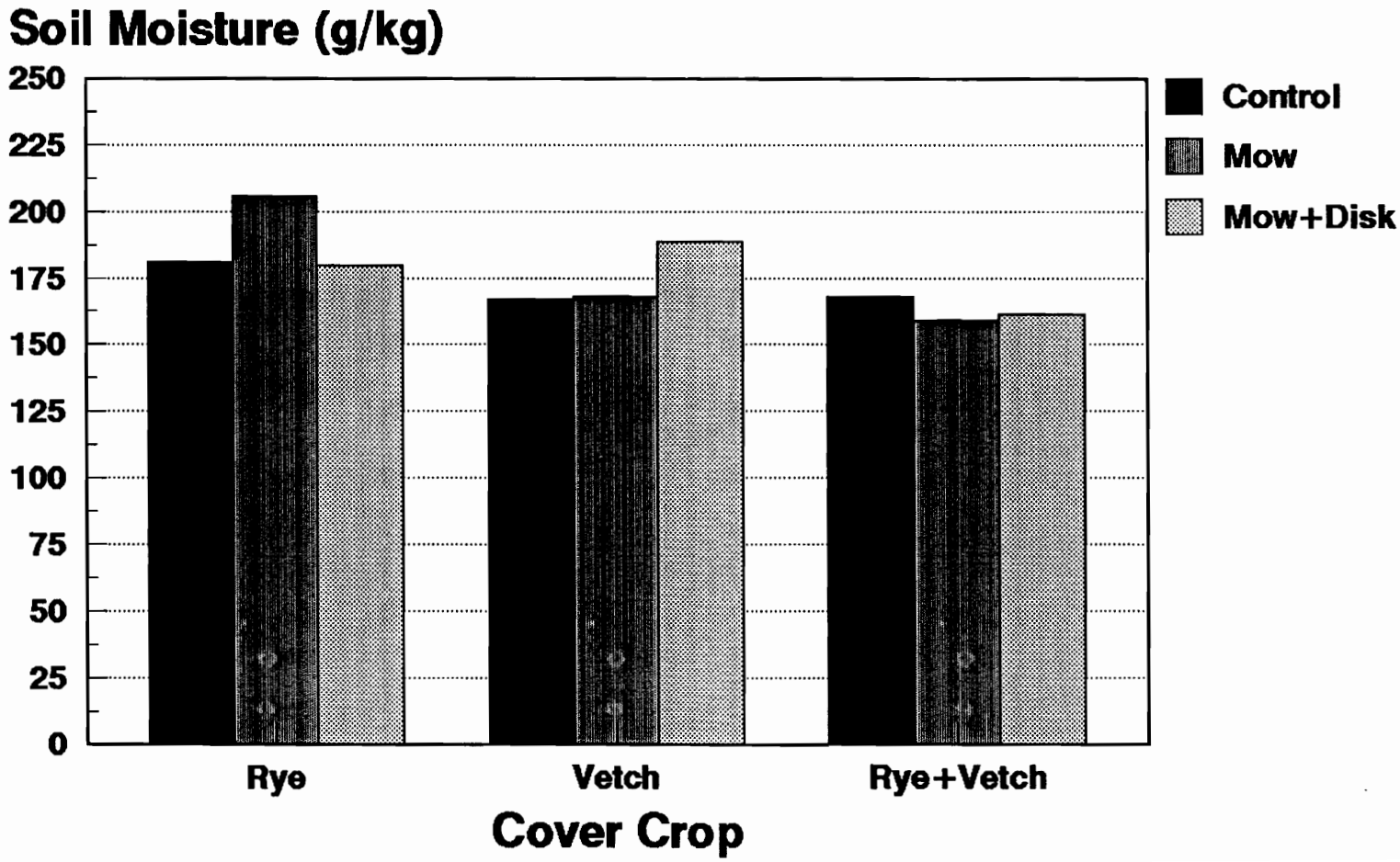


Figure 11. Soil Moisture - 1993

At Corn Four to Five Leaf Stage

0-15 cm Soil Depth

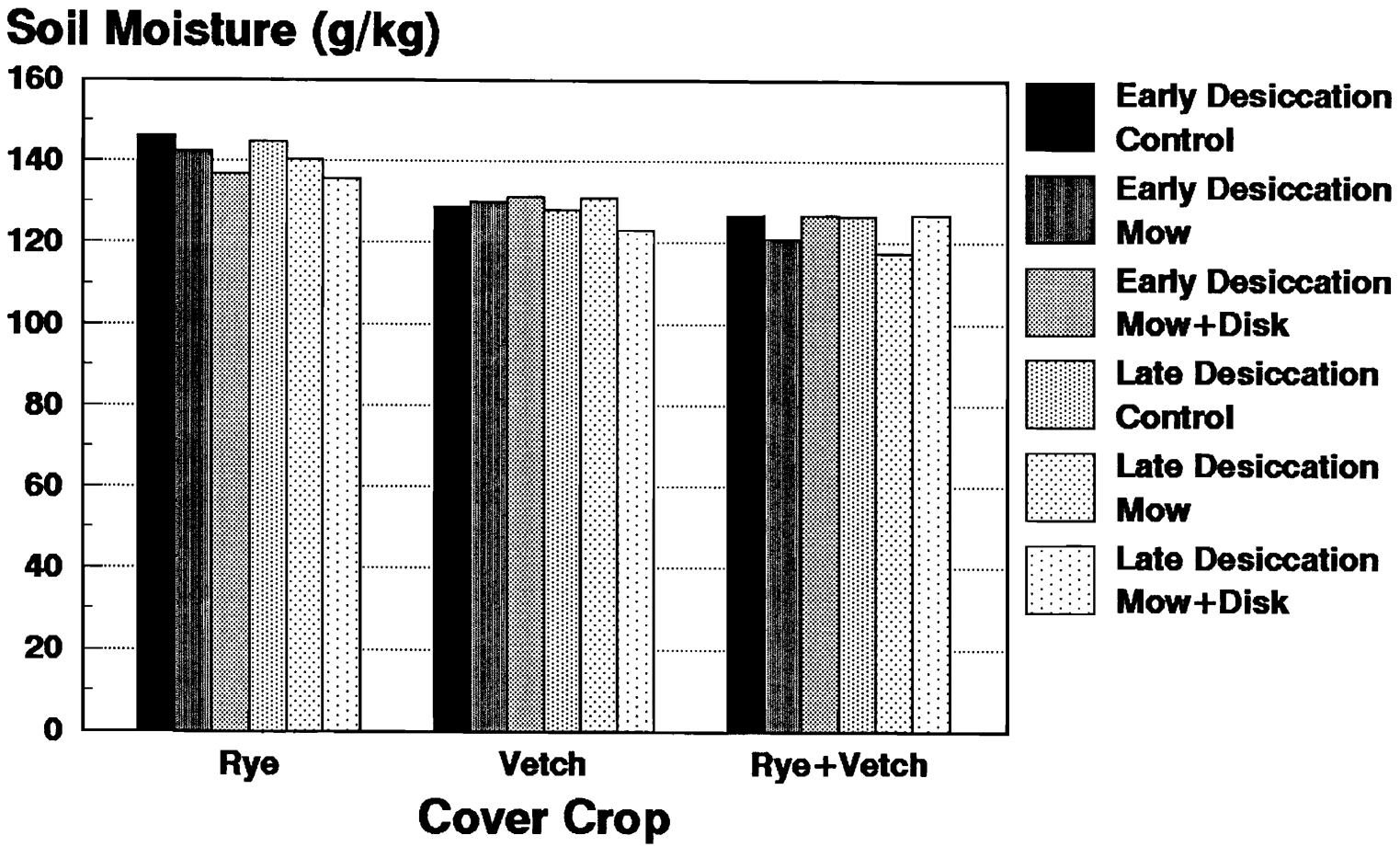
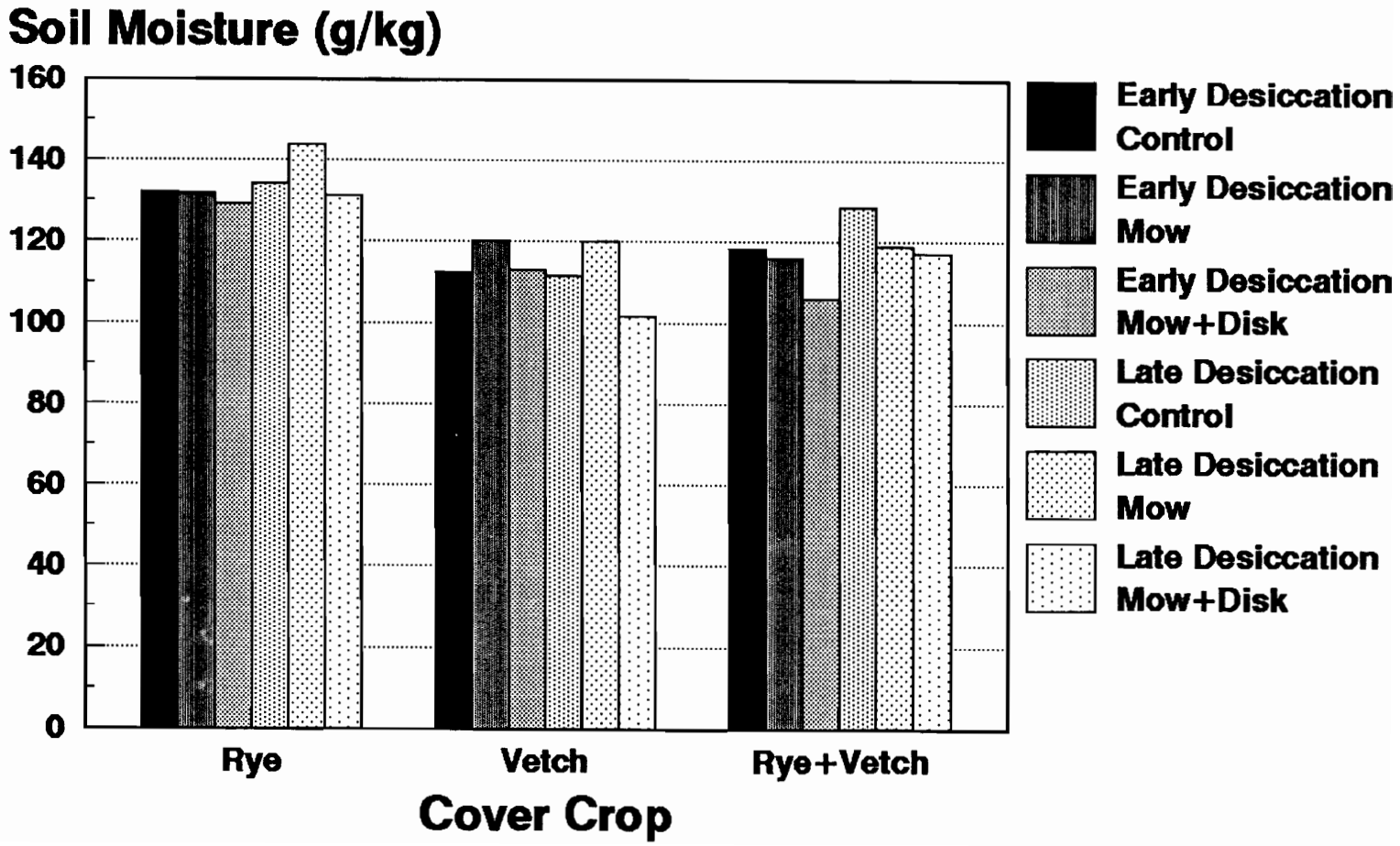


Figure 12. Soil Moisture - 1993

At Corn Eight to Ten Leaf Stage

0-15 cm Soil Depth



likely the cover crop residue in these treatments had decomposed substantially by this sample time and that little residue remained for water conservation.

3.4 Soil Temperature Data

Soil temperatures were higher in vetch treatments than plots containing rye at the four to five and eight to ten leaf stages during both years of this study (Figures 13-16). This was due to higher amounts of cover crop residue in treatments including rye which decreased heat penetration to the soil surface compared to vetch plots. This lower soil temperature in rye containing plots likely limited mineralization and nitrification compared to vetch (Figures 2-3 and 5-6).

Soil temperatures were also higher in early desiccated than late desiccated treatments at both sample times (Figures 13-16). This was due to higher amount of cover crop residue in late desiccated treatments which decreased heat penetration to the soil surface compared to early desiccated plots. Additionally, cover crop residue in early desiccated treatments had lower C/N ratios than residues in late desiccated treatments and therefore were less resistant to decomposition. Cover crop residue in early desiccated plots also had a longer time to decompose than residue in late desiccated plots. This lower soil temperature in late desiccated plots likely limited mineralization and nitrification compared to early desiccated treatments (Figures 2 and 5-6).

Figure 13. Soil Temperature - 1992

At Corn Four to Five Leaf Stage

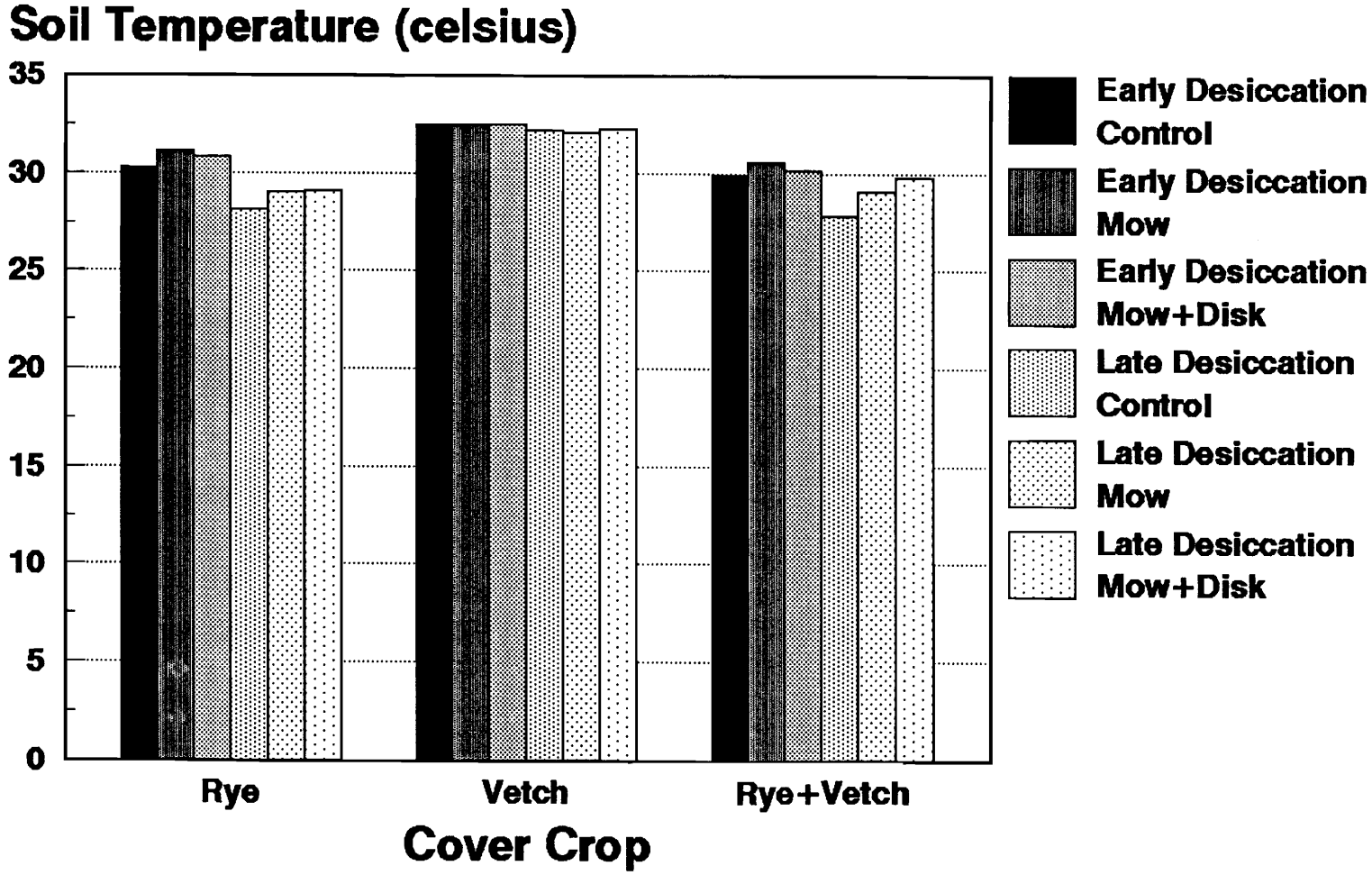


Figure 14. Soil Temperature - 1992

At Corn Eight to Ten Leaf Stage

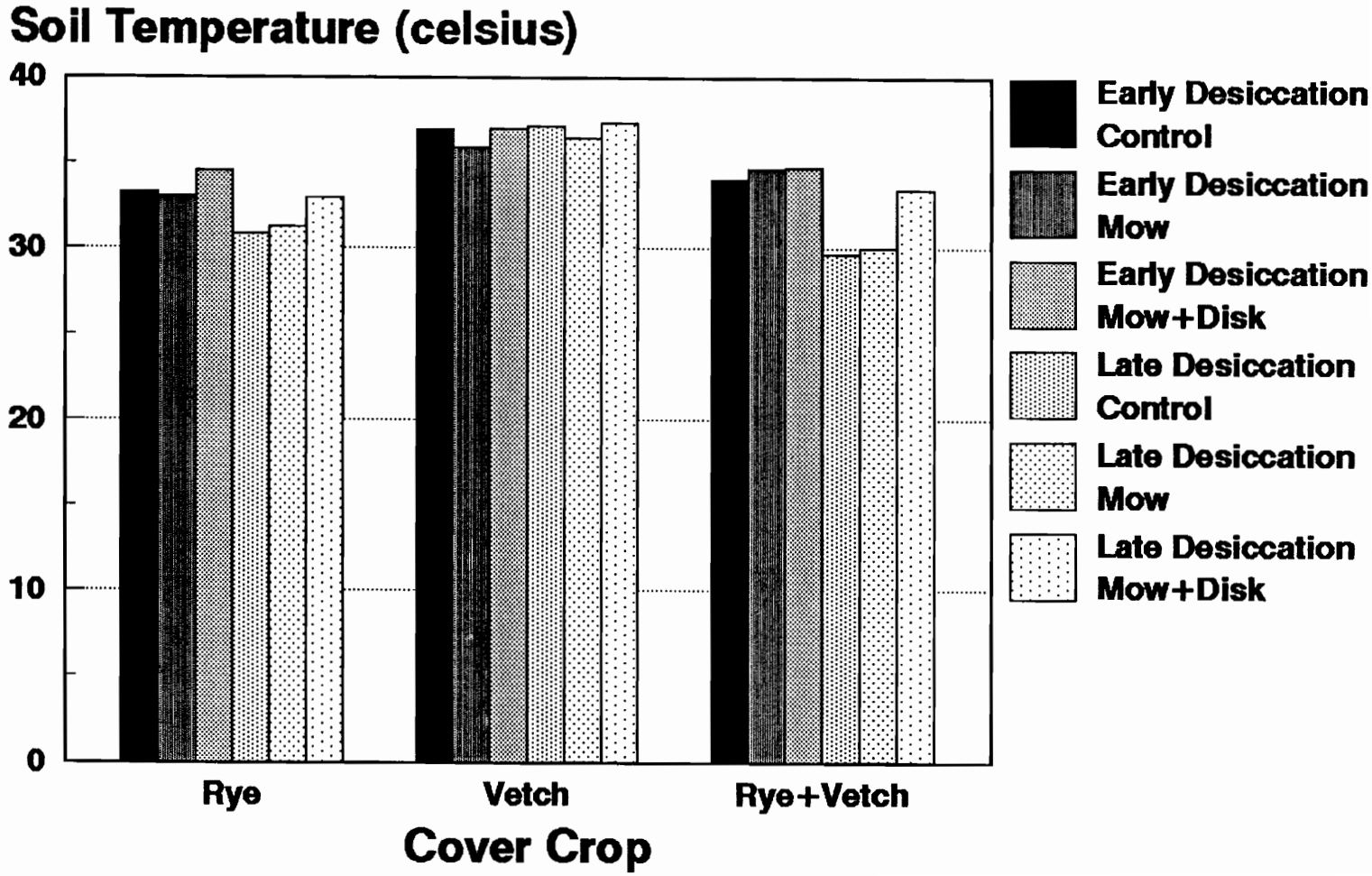


Figure 15. Soil Temperature - 1993

At Corn Four to Five Leaf Stage

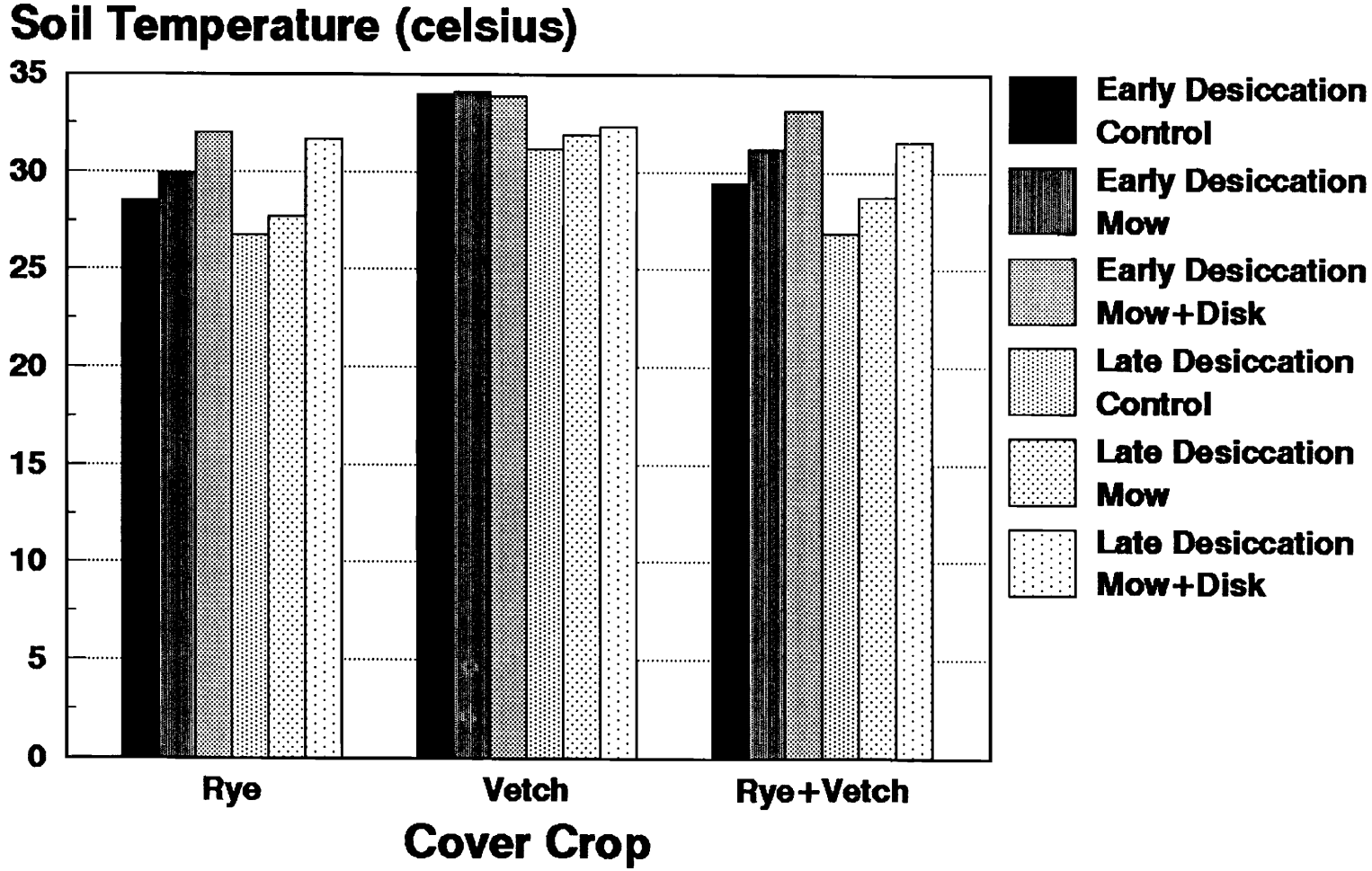
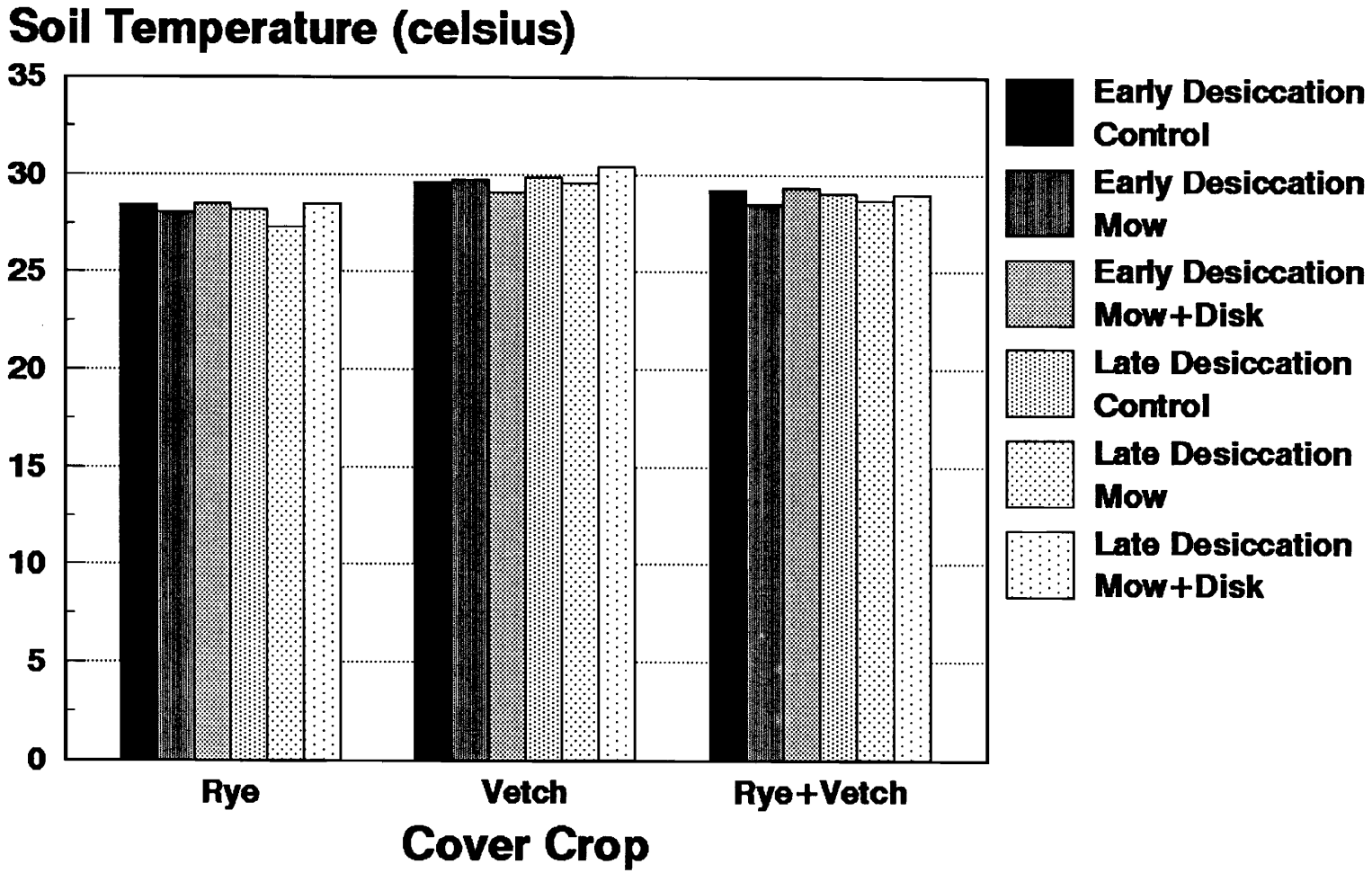


Figure 16. Soil Temperature - 1993

At Corn Eight to Ten Leaf Stage



Soil temperatures were also higher in mow+disk treatments than other residue management plots at the four to five and eight to ten leaf stages during both years of this study (Figures 13-16). This was due to faster cover crop decomposition in these treatments where residues had been slightly incorporated. Additionally, the soil surface was bare in places where cover crop residues had been soil incorporated in the mow+disk plots. These two factors combined to cause increased heat penetration to the soil surface in the mow+disk plots compared to other residue management treatments. This higher soil temperature in mow+disk plots likely enhanced mineralization and nitrification compared to control and mow (Figure 3).

3.5 Corn N Data

Although corn N concentration at corn four to five leaf stage in 1992 was similar or higher in the rye and rye+vetch than in the vetch treatments in the late desiccated plots (Table 15), corn plants in the rye and rye+vetch plots were significantly smaller in size than the corn plants in the vetch plots. This was because the rye was allowed to grow too large before desiccation in the spring. The heavy rye mulch reduced sunlight and heat penetration to the soil which caused corn plants to be stunted (Figure 13). This cool early season soil temperature stunted the growth of the corn in the plots containing rye.

Table 15. Corn N Concentration at Four to Five Leaf Stage.

Cover Crop	1992 Desiccation Time Early	1992 Desiccation Time Late	1993 Desiccation Time Early	1993 Desiccation Time Late
	g/kg			
Rye	23.0	26.1	40.6	35.8
Vetch	24.3	21.5	41.0	41.1
Rye+Vetch	21.0	24.3	40.0	38.3
LSD	3.9*		1.5*	

* Differences among means within columns are significant at the 0.05 probability level.

Table 16. Corn N Concentration at Four to Five Leaf Stage - 1992.

Residue Management	[N]
	-g/kg-
Control	24.4
Mow	23.6
Mow+Disk	22.1
LSD	2.0*

* Differences among means within columns are significant at the 0.01 probability level.

Therefore, the differences in corn N concentration are most likely due to dilution of plant N by biomass accumulation rather than soil N availability.

A decrease in corn N concentration with an increase in cover crop residue manipulation was also observed in 1992 at the corn four to five leaf stage (Table 16). However, corn N uptake values indicate no difference between residue management treatments (Table 17). Additionally, corn plants on vetch plots had similar or higher N contents than the other treatments. Therefore, differences in corn N concentration are most likely due to differences in corn plant size than soil N availability.

Visual observations indicated sampling at the eight to ten leaf stage of corn allowed some time for the size differences between corn plants to decrease, yet corn plants in the vetch plots were still significantly larger than those in the rye and rye+vetch plots. However, corn N concentrations were higher in vetch plots in early desiccated treatments, indicating more available N on these plots and more uniform corn plant size between early desiccated cover crop treatments (Table 18). Cover crop plots were not significantly different in the late desiccated treatments, likely due to differences in corn plant size rather than soil N availability.

A decrease in corn N concentration with an increase in cover crop residue manipulation was also observed at the eight to ten leaf stage of corn (Table 19). Similarly, visual observations indicated larger corn plants on

Table 17. Corn N Uptake at Four to Five Leaf Stage - 1992.

Cover Crop	Residue Management: Control	Mow	Mow+Disk
	kg N/ha		
Rye	13.7	12.8	12.6
Vetch	19.7	14.9	18.5
Rye+Vetch	13.1	16.8	12.7
LSD		4.2*	

* Differences among means within columns and rows are significant at the 0.05 probability level.

Table 18. Corn N Concentration at Eight to Ten Leaf Stage - 1992.

Cover Crop	Desiccation Time: Early	Late
	g/kg	
Rye	21.7	22.1
Vetch	25.6	23.6
Rye+Vetch	21.5	21.3
LSD	2.5*	

* Differences among means within columns and rows are significant at the 0.05 probability level.

Table 19. Corn N Concentration at Eight to Ten Leaf Stage.

Residue Management	1992	1993
	g/kg	
Control	23.6	35.3
Mow	22.5	35.9
Mow+Disk	21.7	34.6
LSD	0.7**	1.1*

* Differences among means within columns are significant at the 0.01 probability level.

** Differences among means within columns are significant at the 0.05 probability level.

mow+disk than other residue management treatments. Additionally, soil N concentrations were higher in mow+disk than control or mow treatments (Figure 3). Therefore, corn N concentrations were again likely due to dilution of plant N by biomass accumulation rather than soil N availability.

Corn N concentrations were higher in vetch treatments than in treatments including rye at corn silking (Table 20). Additionally, corn plants in early desiccated plots had higher N concentrations than those in late killed plots, indicating higher N availability (as soil N values did, Figures 1-3) on these plots (Table 21).

Corn N concentration in 1993 at the four to five leaf stage of corn produced different results than the previous year. Early desiccation made soil N availability similar within all cover crop treatments, showing that killing a cover crop including rye with a low C:N ratio will enhance early season N release and availability (Table 15). In contrast, delayed killing of cover crops including rye caused lower corn N concentration values in those plots, due to N immobilization by the high carbon rye. Additionally, vetch plots had higher N concentrations across all residue management treatments except mow+disk (Table 22). Therefore, mowing and disking a cover crop that includes rye can result in early season soil N availability similar to vetch.

Corn N contents were similar between early desiccated cover crop treatments (Table 23). Delaying desiccation reduced corn N uptake in

Table 20. Corn N Concentration at Silking in Three Cover Crop Systems.

Cover Crop	1992	1993
	----------g/kg----------	
Rye	16.7	16.2
Vetch	28.7	22.2
Rye+Vetch	17.9	18.5
LSD	4.2*	2.5*

* Differences among means within columns are significant at the 0.05 probability level.

Table 21. Corn N Concentration at Silking.

Treatment	[N] --g/kg--
----------1992----------	
Desiccation Time	
Early	23.2
Late	19.0
$LSD_{0.01}$	2.7
----------1993----------	
Residue Management	
Control	18.9
Mow	20.4
Mow+Disk	17.7
$LSD_{0.01}$	2.0

Table 22. Corn N Concentration at Four to Five Leaf Stage - 1993.

Cover Crop	Residue Management: Control	Mow	Mow+Disk
	kg N/ha		
Rye	36.2	38.9	39.4
Vetch	41.1	41.8	40.3
Rye+Vetch	38.7	39.3	39.6
LSD		2.2*	

* Differences among means within columns and rows are significant at the 0.01 probability level.

Table 23. Corn N Uptake at Four to Five Leaf Stage - 1993.

Cover Crop	Desiccation Time	Residue Management: Control	Mow	Mow+Disk
		kg N/ha		
Rye	Early	3.2	4.2	4.9
Rye	Late	0.7	0.8	1.7
Vetch	Early	4.7	5.4	5.5
Vetch	Late	3.5	3.9	8.0
Rye+Vetch	Early	3.4	3.8	5.9
Rye+Vetch	Late	1.1	1.4	3.5

treatments including rye compared to early desiccation, indicating lower N availability in these plots. However, where cover crops were desiccated late, mowing and disking increased early season soil N availability and uptake. This indicates that mowing and disking may be an option to enhance cover crop N release when desiccation must be delayed.

In contrast, at the eight to ten leaf stage of corn the opposite effect was observed (Table 19). Cover crop treatments that were mowed and disked had lower corn N concentrations than the other residue management treatments. Corn plant size was uniform between treatments, therefore it is probable that this treatment may result in the majority of cover crop N being released prior to maximum corn N need and uptake.

The corn silking stage showed significantly higher N concentrations in vetch plots than in rye and rye+vetch plots, indicating (as the soil N figures did, Figures 4-6) higher N availability in vetch treatments (Table 20). Additionally, corn plants in the plots that had been mowed had higher N concentrations than those that were additionally disked (Table 21). It was possible that mowing and disking caused cover crop N release too early for maximum corn N uptake.

3.6 Corn Yield Data

Yields were higher in vetch plots from both years of this study, while yields were not different between plots including rye (Table 24). This was

Table 24. Corn Grain Yield in Three Cover Crop Systems.

Cover Crop	--Mg/ha--
----------1992----------	
Rye	3.44
Vetch	6.93
Rye+Vetch	3.89
LSD	2.03*
----------1993----------	
Rye	5.71
Vetch	7.98
Rye+Vetch	6.32
LSD	1.29**

* Differences among means within columns are significant at the 0.01 probability level.

** Differences among means within columns are significant at the 0.05 probability level.

Table 25. Corn Grain Yield Data - 1992.

Cover Crop	-Desiccation Time- Early	Late
	--------Mg/ha--------	
Rye	4.51	2.36
Vetch	6.76	7.11
Rye+Vetch	4.34	3.43
LSD	2.12	

* Differences among means within columns and rows are significant at the 0.01 probability level.

probably due to higher soil N availability and better early season growing conditions in vetch plots. Furthermore, late cover crop desiccation reduced yields in rye treatments in 1992, most likely due to retarded early season corn growth that decreased corn yield potential (see section 3.5) (Table 25). High residual soil N availability (Table 8) caused similar corn yields between early and late desiccation in vetch plots even though vetch N content increased significantly between kill times.

Corn yields were similar between all late desiccated plots and early desiccated control plots in 1992 (Table 26). Again, early season corn growth was stunted and corn yield potential was reduced in late desiccated plots because cover crop biomass was so abundant in these treatments. In contrast, cover crop biomass was lower at early desiccation. Therefore, corn yield potential was greater in early than late desiccated plots. Additionally, yields with early desiccated mow and mow+disk treatments were higher than with the other combinations of desiccation time and residue management.

No cover crop disturbance increased corn yields above mowing and disking in early desiccated plots during 1993 (Table 26). It is likely mowing and disking caused the release of cover crop N prior to maximum corn N uptake (Figures 4-6). Additionally, mow+disk treatments had lower soil moisture than control or mow due to a lack of water conserving mulch caused by disking (Figures 11-12). This could also have reduced the yield potential in mow+disk treatments

Table 26. Corn Grain Yield Data - Residue Management vs. Desiccation Time.

Residue Management	Mg/ha Early Desiccation	Late Desiccation
	1992	
Control	4.45	4.33
Mow	5.55	4.36
Mow+Disk	5.61	4.22
LSD	0.87*	
	1993	
Control	7.34	5.63
Mow	7.24	6.98
Mow+Disk	6.50	6.34
LSD	0.81*	

* Differences among means within columns and rows are significant at the 0.05 probability level.

Late desiccated control treatments had lower yields than early desiccated control or mow plots in 1993. Late desiccated cover crops had much higher C/N ratios than early desiccated cover crops, therefore corn yields were likely limited by N immobilization. However, late desiccated mow treatments had higher yields than control plots and had similar yields to early desiccated control and mow treatments. This indicates that mowing can enhance cover crop N release and corn yield potential when cover crop desiccation must be delayed. Late desiccated mow+disk plots yielded similar to early desiccated mow+disk plots, likely due to a lack of synchrony between cover crop N release and corn N uptake and low soil moisture.

4. Conclusions

It is evident from the results of the cover crop data that cover crops including rye can assimilate amounts of N similar to vetch on soils with high amounts of residual N. Additionally, rye in rye+vetch cover crops can inhibit the growth of the vetch part of the mix on high N soils. It is also apparent that on soils of limited residual N, rye+vetch cover crops can produce N yields intermediate to rye alone and vetch alone cover crops. Additionally, the overall C/N ratio of a rye+vetch cover crop was intermediate to the C/N ratio of rye alone or vetch alone.

Delaying cover crop desiccation increased the biomass yields of all cover crops, but increased nitrogen yields of vetch only. Additionally, C/N ratios increased between kill times in plots including rye. Therefore, desiccating a cover crop including rye early will enhance the N releasing potential of the cover.

Vetch can provide higher amounts of plant available N than rye or rye+vetch. A rye+vetch cover crop with N contents intermediate to vetch and rye can also provide intermediate levels of plant available N. Mowing and disking cover crop residue increased early season plant available soil N; however, mowing only increased plant available N later in the growing season, but still within the period of maximum corn N need and uptake. Early desiccation of cover crops that included rye increased plant available soil N. Plant available soil N concentrated predominately in the top 15 cm of the soil where the plant residues were located. Soil N concentrations peaked at corn four to five leaf stage in the majority of treatments.

Cover crops including rye conserved more soil moisture than a vetch cover crop. Additionally, delaying cover crop desiccation increased the soil moisture retaining capability of the residue mulch. Severe cover crop disturbance, such as mowing and disking, decreased the ability of the residue to conserve soil moisture. However, a mowed cover crop can retain similar amounts of soil water as an undisturbed cover crop.

Corn yielded higher in vetch than in cover crops including rye. Early desiccation of cover crops including rye resulted in higher corn yields than late desiccation of cover crops including rye. Additionally, mowing and mowing plus disking can increase corn yields in early desiccated cover crop treatments by enhancing the release of plant available N. However, mowing plus disking can decrease corn yields in either early or late desiccated cover crop plots by limiting soil moisture availability. Mowing cover crop residue increased corn yields both years. Mowing increased cover crop N release and soil N availability while maintaining soil moisture conservation.

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Chapter IV. Summary and Conclusions.

It is evident that vetch is less tolerant than rye to environmental stress. When vetch growth was severely limited by the lack of precipitation or weed competition, rye growth continued with little symptom of stress. Additionally, due to environmental factors that limited vetch growth and/or high residual soil N, it is inconclusive whether vetch is adaptable and/or should be recommended for the Ridge and Valley and Piedmont physiographic provinces of Virginia.

Rye growth was so dominate in the rye+vetch cover crop mixtures that a cover crop containing similar biomass amounts of both rye and vetch was unattainable. It is likely that altering seeding rates or varieties planted may be necessary to produce a rye+vetch cover crop that contains similar biomass quantities of both rye and vetch. Although vetch biomass accumulation was limited by rye during 1993, a rye+vetch cover crop could accumulate intermediate N contents to rye alone and vetch alone.

Soil N availability was higher in vetch and fallow plots than in treatments containing rye. Moreover, early desiccation of cover crops including rye resulted in higher soil N availability than late desiccation. Rye+vetch cover crop plots were intermediate in soil N availability to rye alone and vetch alone. Therefore, when rye+vetch accumulates N in amounts intermediate to rye alone and vetch alone that soil N availability is also intermediate to the two cover

crops. This is an indication of the potential of this cover crop combination for uniting the benefits of nonlegumes and legumes.

Although mowing and disking resulted in higher early season soil N availability than the other residue management treatments tested, the majority of all cover crop, desiccation time, and residue management combinations studied resulted in peak soil N concentrations at the four to five leaf stage of corn. This indicates that N mineralization is more dependent on time and heat units than cover crop or cover crop management technique.

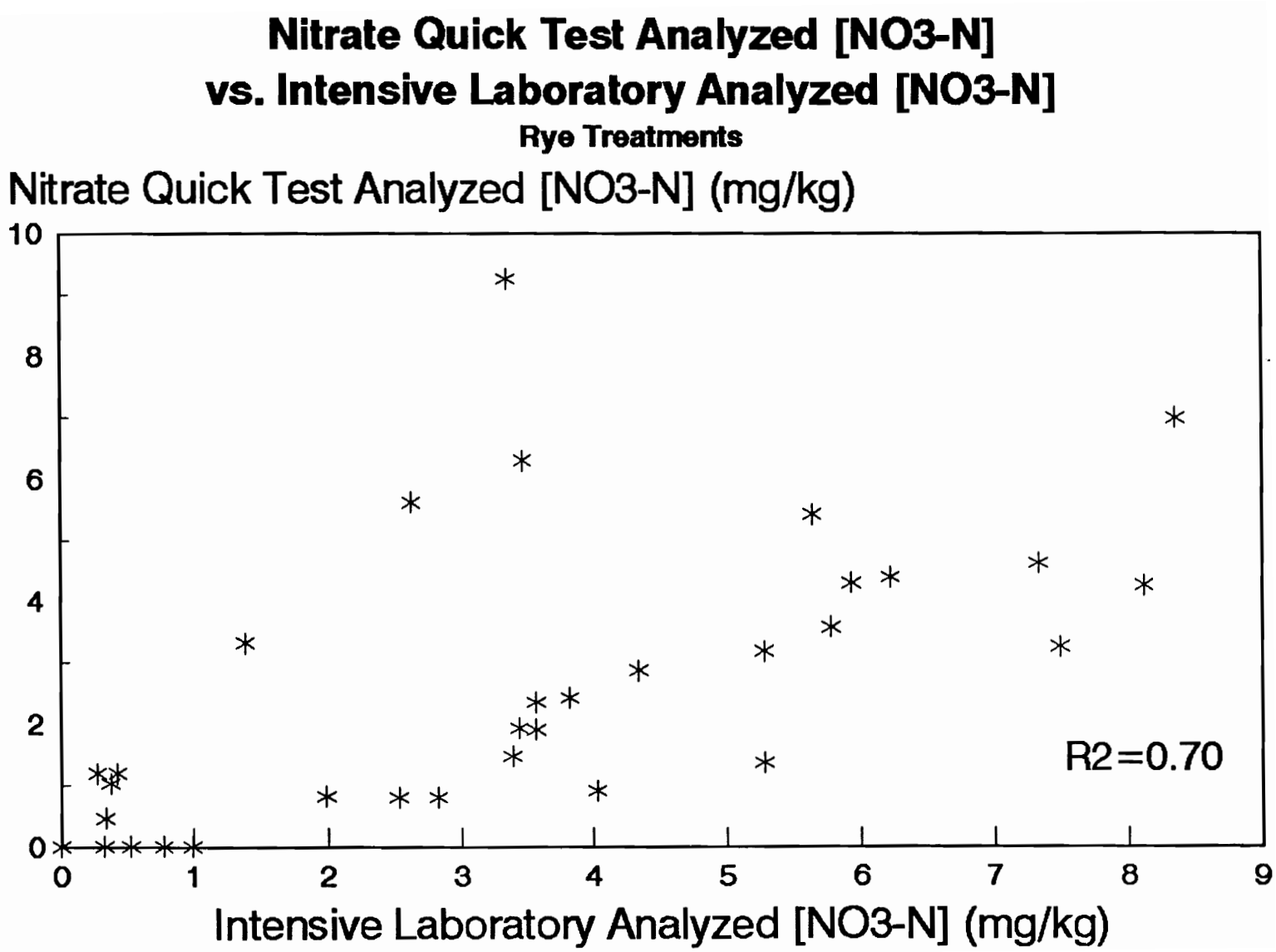
Cover crop mowing produced maximum corn yields during both study years. Mowing cover crop residue enhanced cover crop N release and moisture conservation to a greater extent than the other cover crop management methods tested. However, it is unlikely cover crop mowing is viable at this time because the cost of spraying and mowing is greater than the cost of spraying and applying fertilizer N.

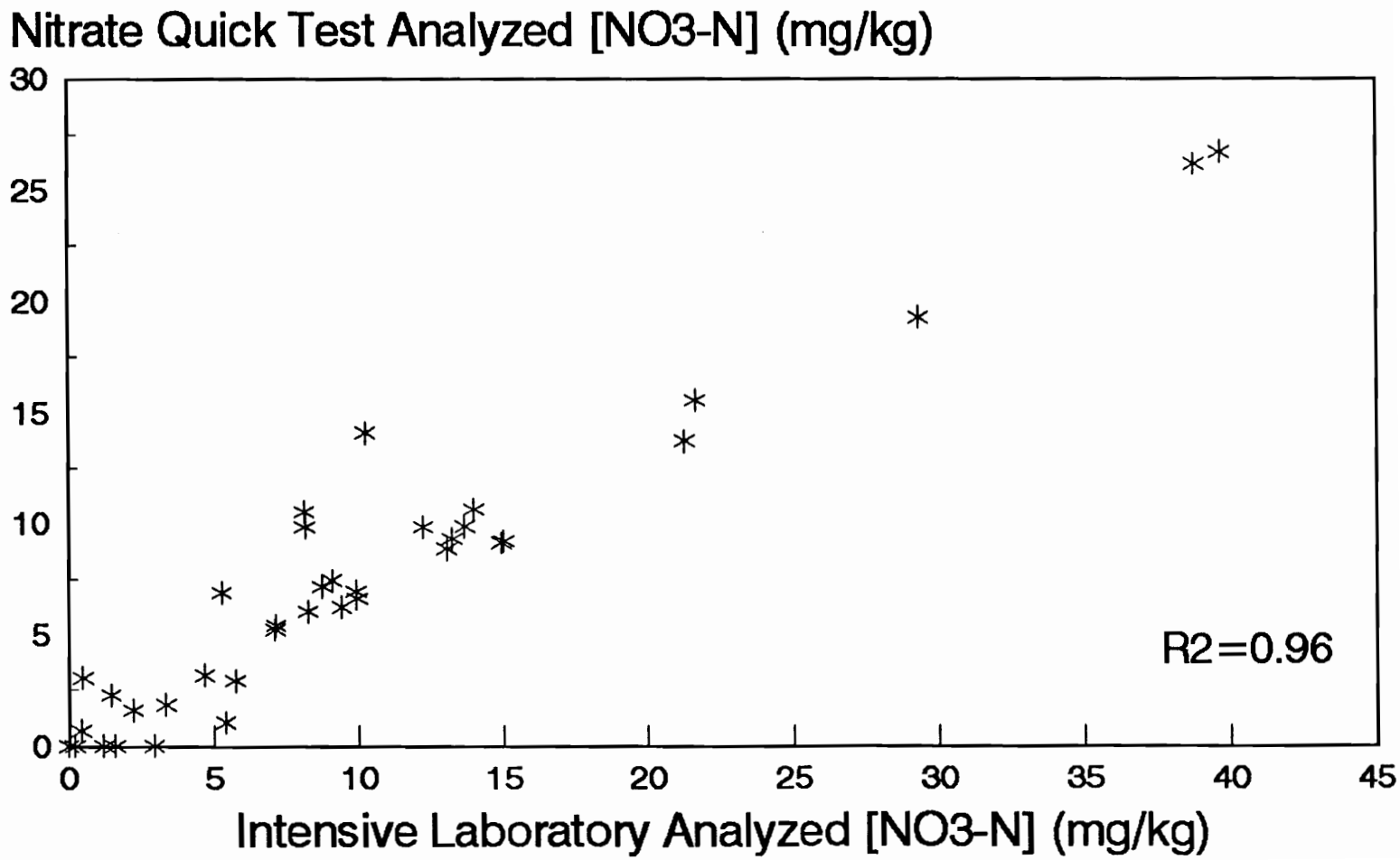
The pre-sidedress soil nitrate test (PSNT) for predicting corn N sufficiency is a viable tool in cover crop-corn systems. However, sampling to a depth of 15 cm may be adequate for making supplemental fertilizer N recommendations based on published norms. Additionally, sampling two weeks later than normal and/or using total soil mineral N may be alternative techniques for separating N responsive and N nonresponsive sites. This indicates that flexibility in the time of soil sampling exists for the use of the

PSNT in cover crop-corn systems. Although this PSNT research produced valuable results, the actual number of site years was limited. Additional research will be required to refine critical values in cover crop-corn systems.

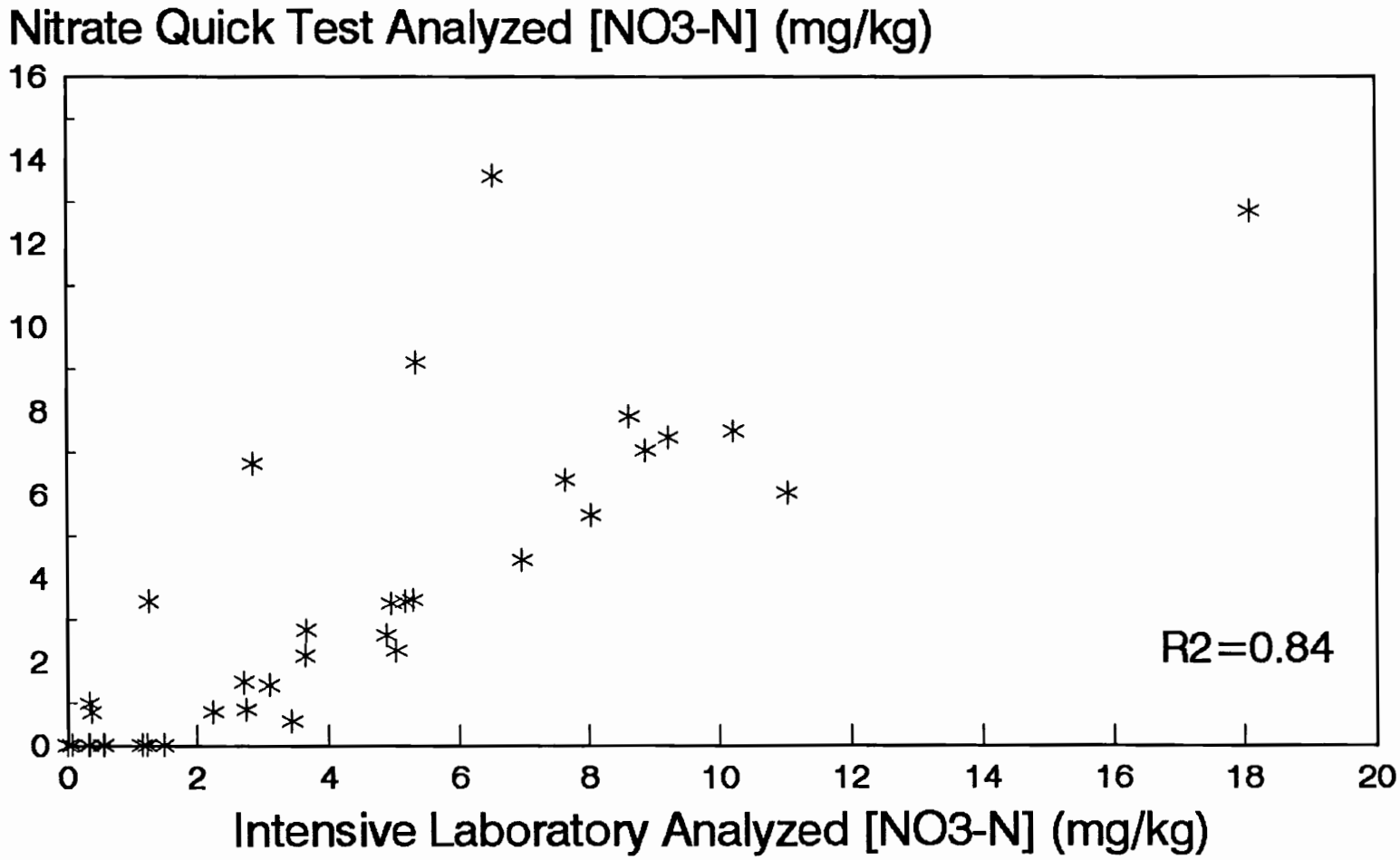
The Nitrate Quick Test is a viable tool for making fertilizer N recommendations in cover crop-corn systems. Additionally, the test may be valuable for determining soil [NO_3-N] prior to cover crop planting. An estimate of soil [NO_3-N] prior to cover crop planting could aid in deciding the species of cover crop to be grown. Therefore, problems with abundant rye biomass (as in 1992) could be avoided.

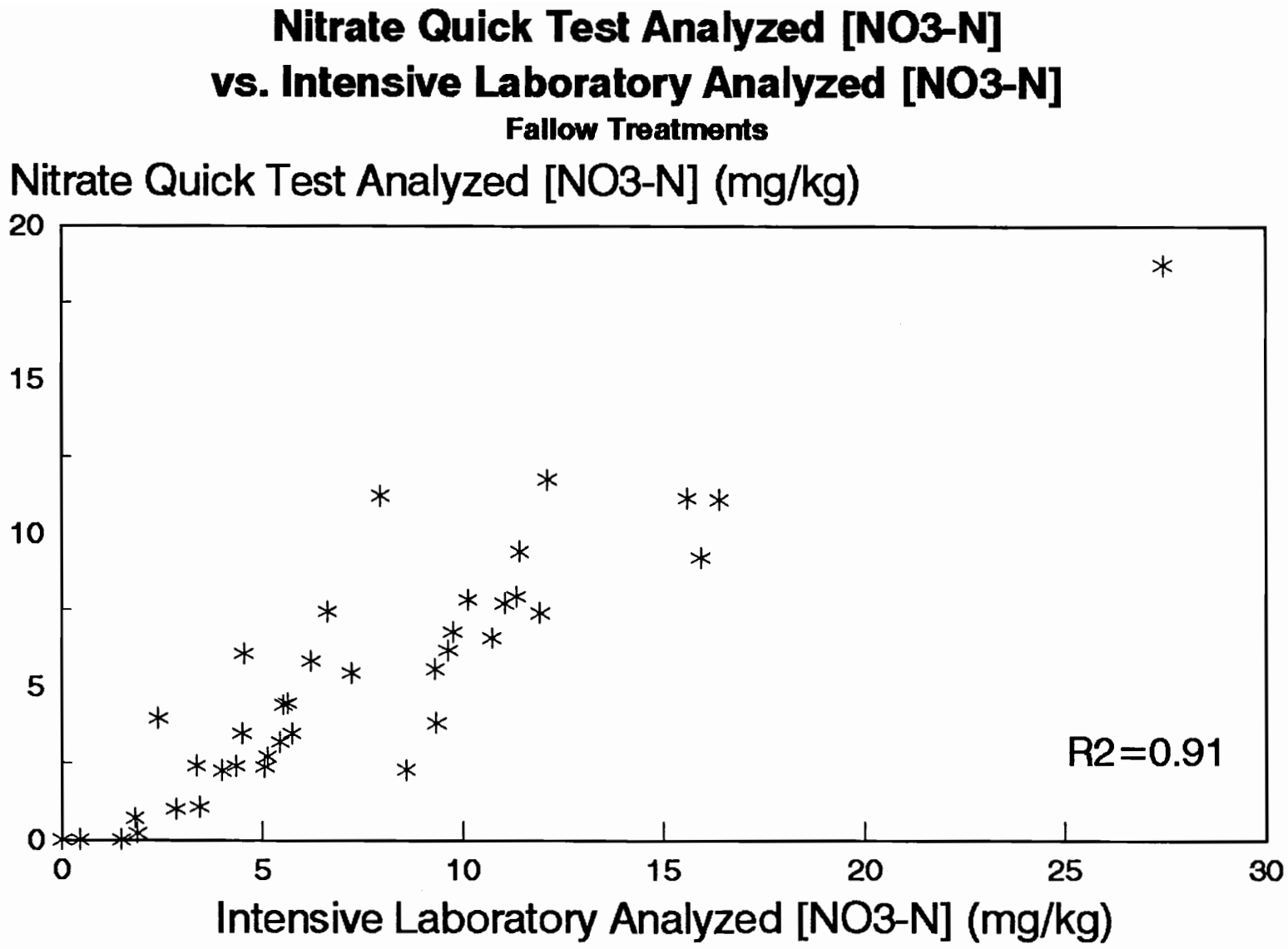
APPENDIX A. Nitrate Quick Test Analyzed [NO_3-N] vs. Intensive Laboratory Analyzed [NO_3-N].

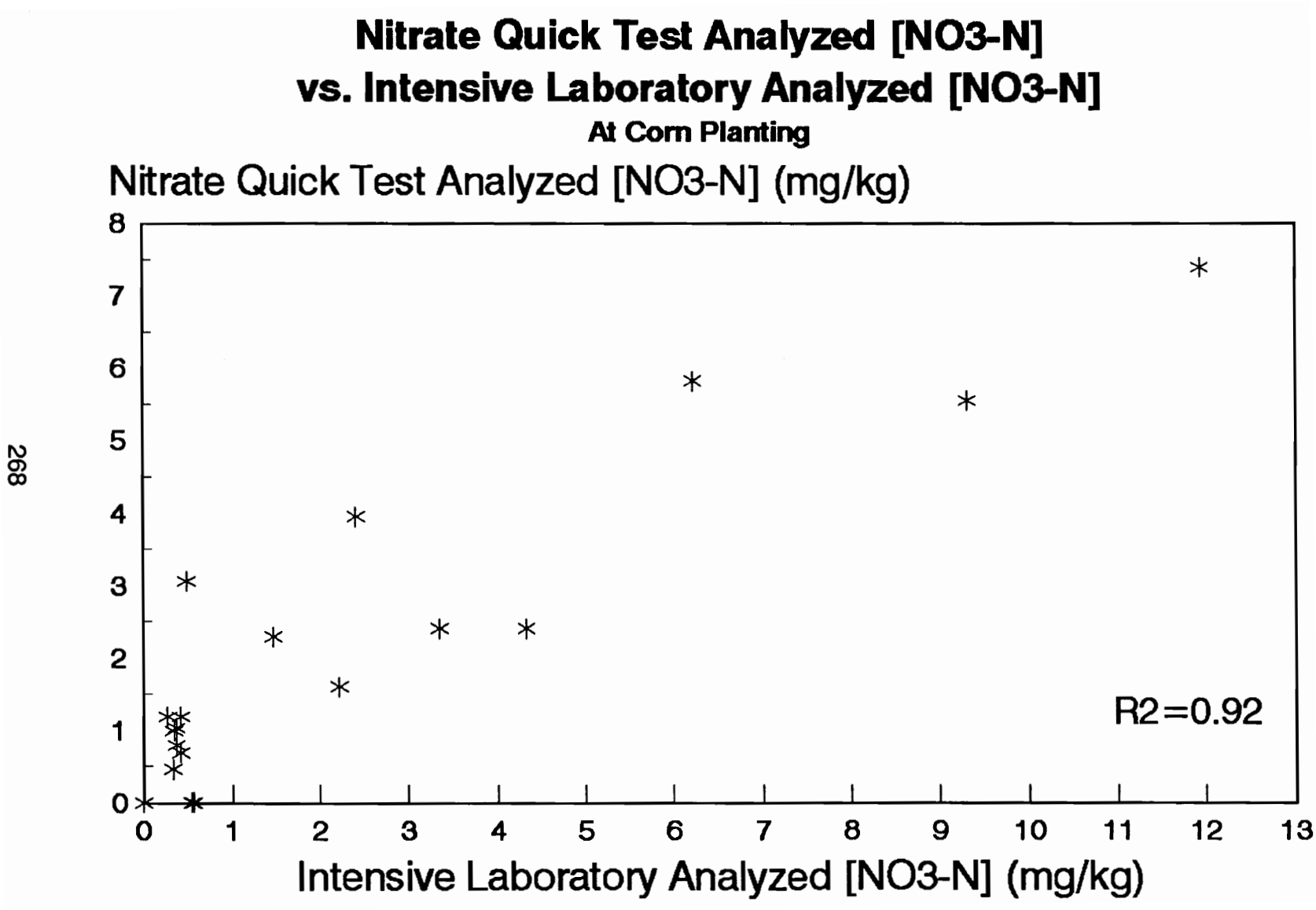

Nitrate Quick Test Analyzed [NO3-N]
vs. Intensive Laboratory Analyzed [NO3-N]
Rye Treatments
Nitrate Quick Test Analyzed [NO3-N] (mg/kg)
10
8
6
4
2
0
0
1
2
3
4
5
6
7
8
9
R2=0.70
Intensive Laboratory Analyzed [NO3-N] (mg/kg)


Nitrate Quick Test Analyzed [NO3-N]
vs. Intensive Laboratory Analyzed [NO3-N]
Vetch Treatments
Nitrate Quick Test Analyzed [NO3-N] (mg/kg)
30
25
20
15
10
5
0
0
5
10
15
20
25
30
35
40
45
R2=0.96
Intensive Laboratory Analyzed [NO3-N] (mg/kg)

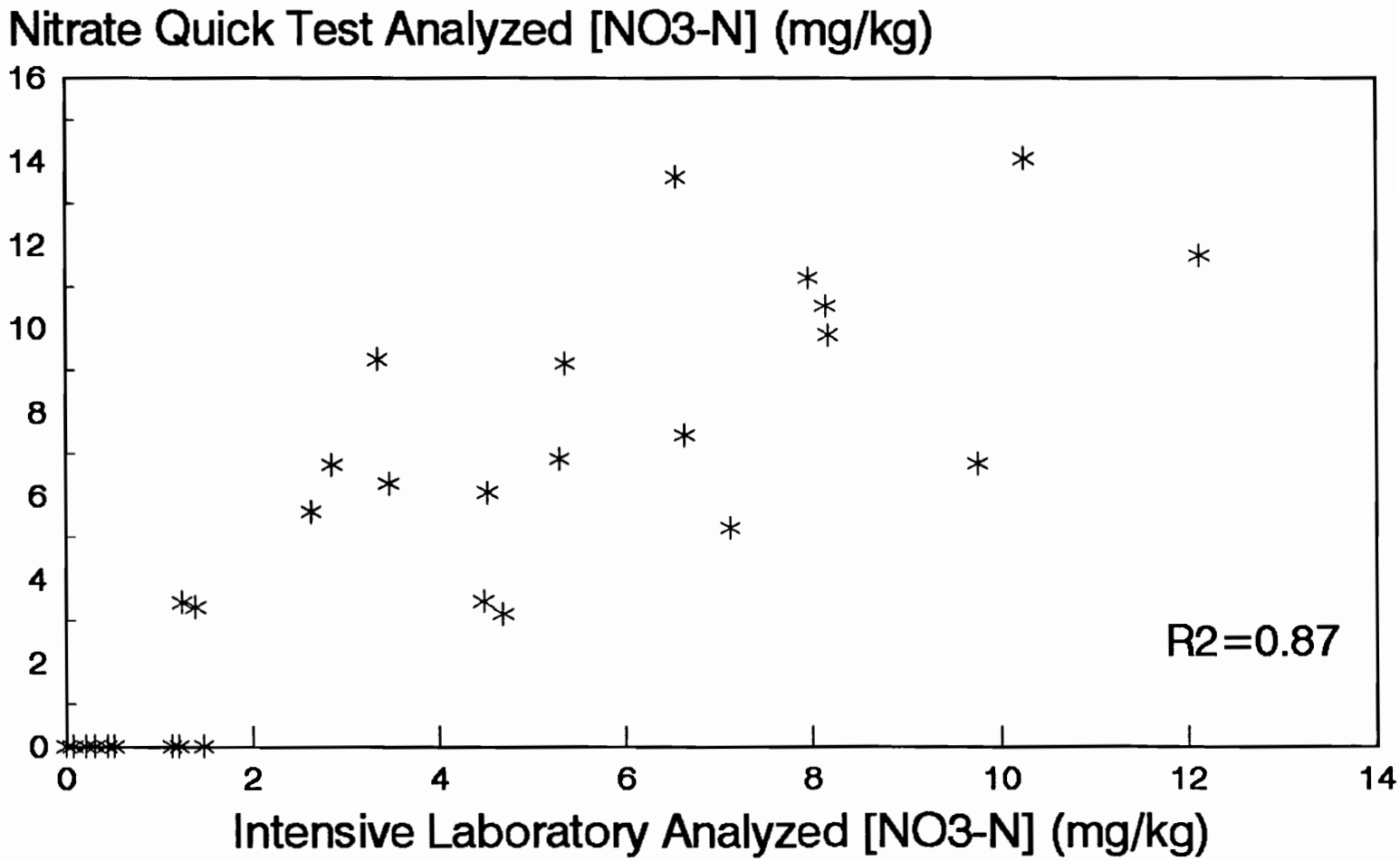
Nitrate Quick Test Analyzed [NO3-N]
vs. Intensive Laboratory Analyzed [NO3-N]
Rye+Vetch Treatments

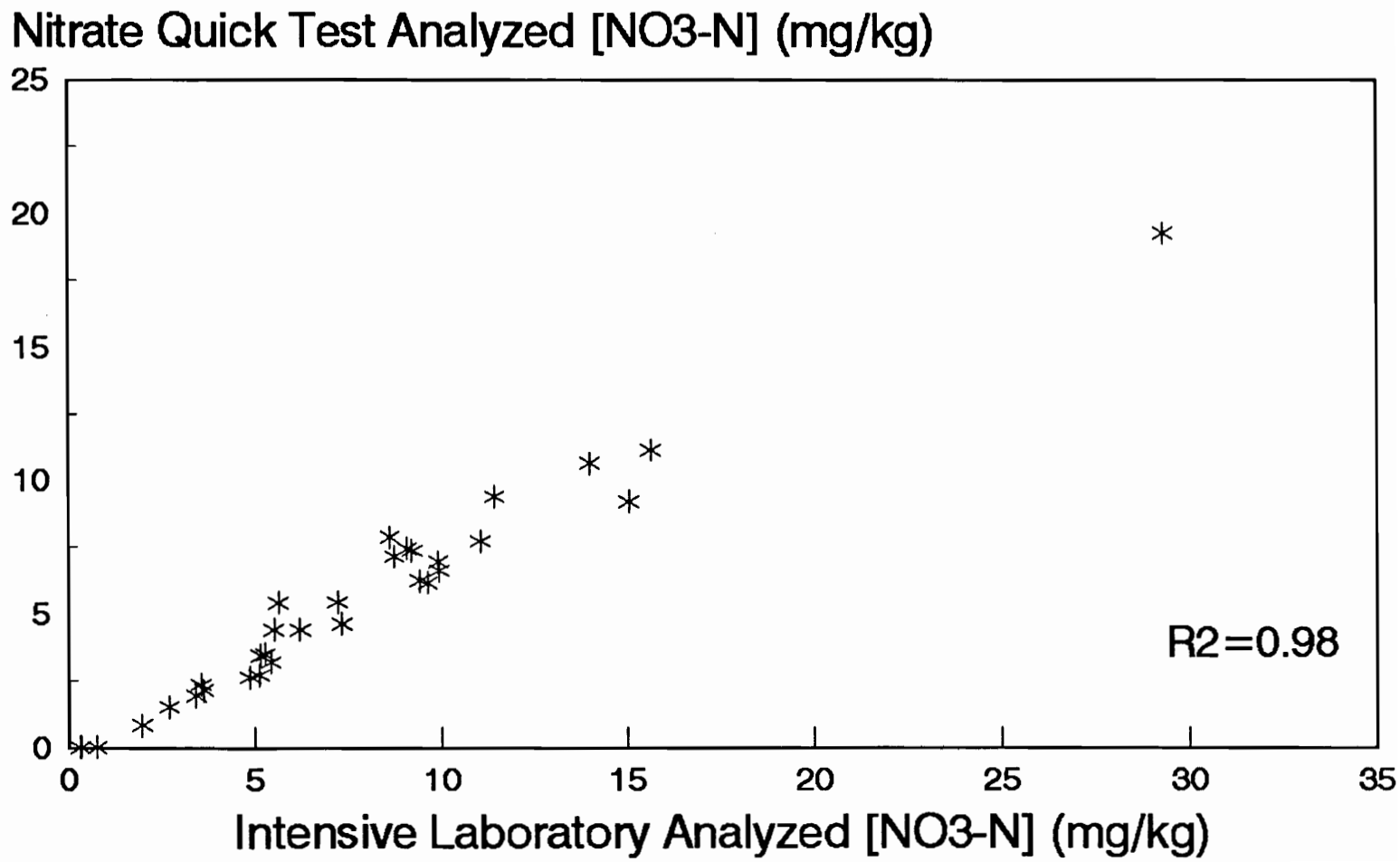


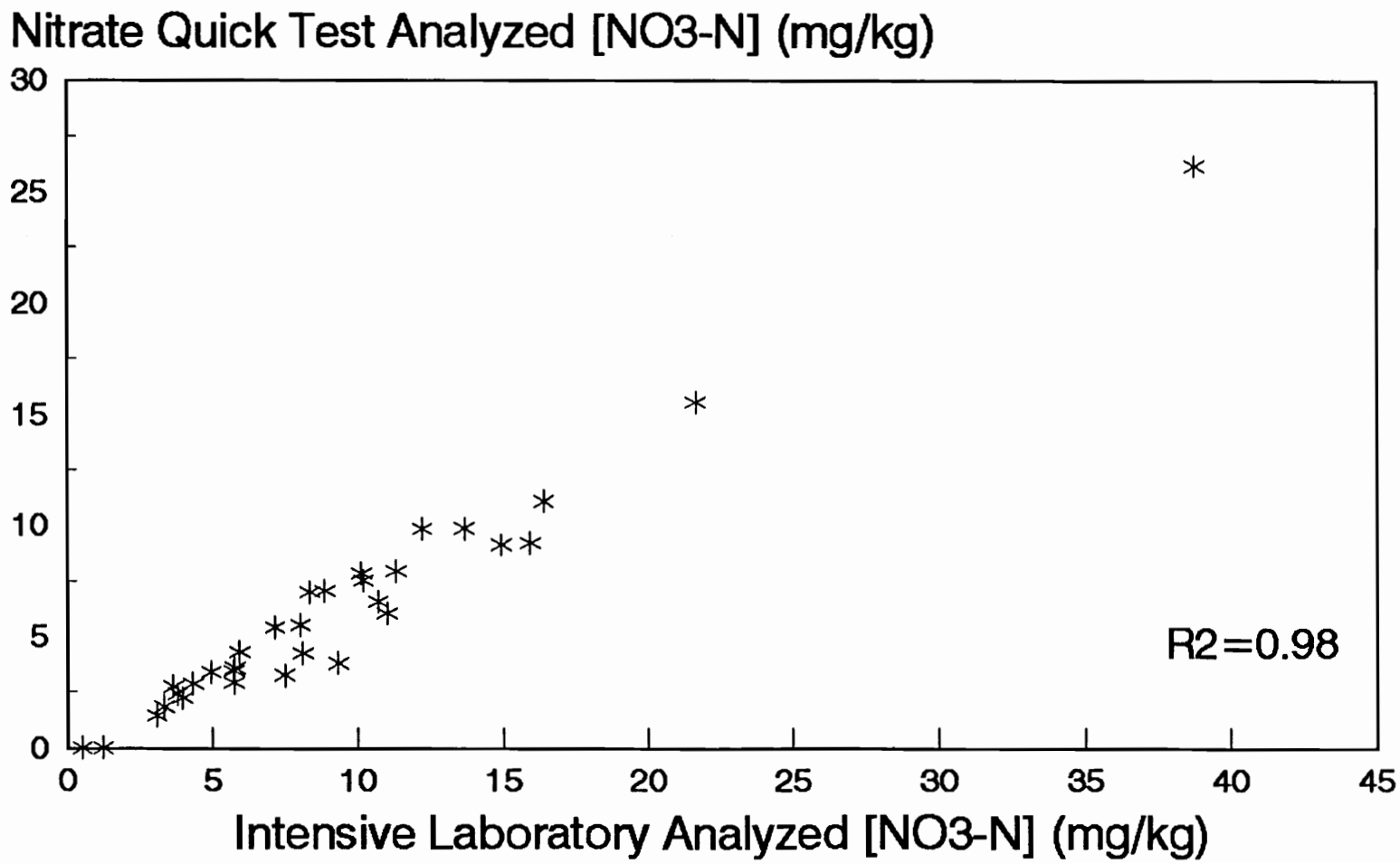

Nitrate Quick Test Analyzed [NO3-N]
vs. Intensive Laboratory Analyzed [NO3-N]
Fallow Treatments
Nitrate Quick Test Analyzed [NO3-N] (mg/kg)
20
15
10
5
0
0
5
10
15
20
25
30
R2=0.91
Intensive Laboratory Analyzed [NO3-N] (mg/kg)

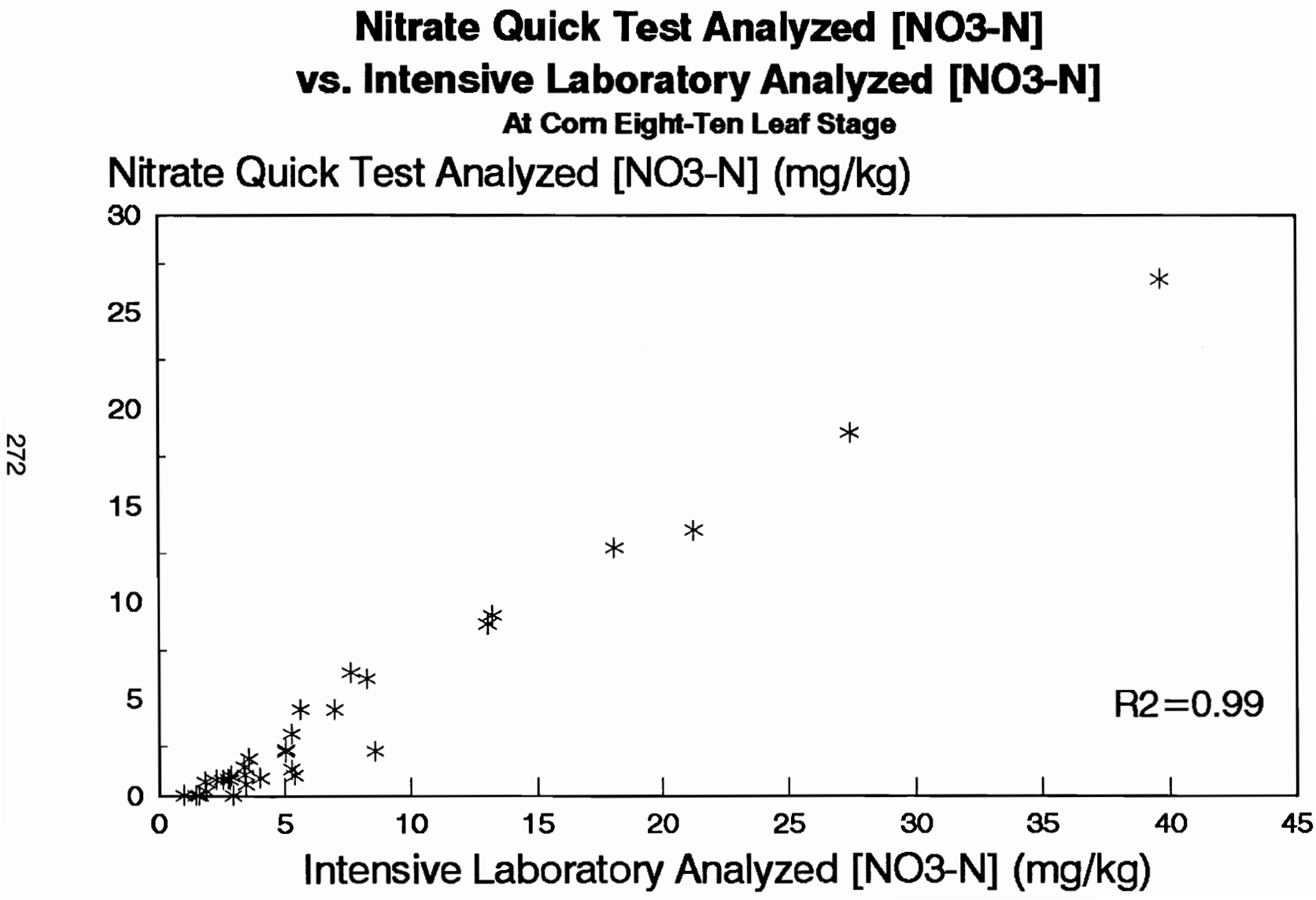

Nitrate Quick Test Analyzed [NO3-N]
vs. Intensive Laboratory Analyzed [NO3-N]
At Corn Planting
Nitrate Quick Test Analyzed [NO3-N] (mg/kg)
Intensive Laboratory Analyzed [NO3-N] (mg/kg)
R2=0.92
0
1
2
3
4
5
6
7
8
9
10
11
12
13

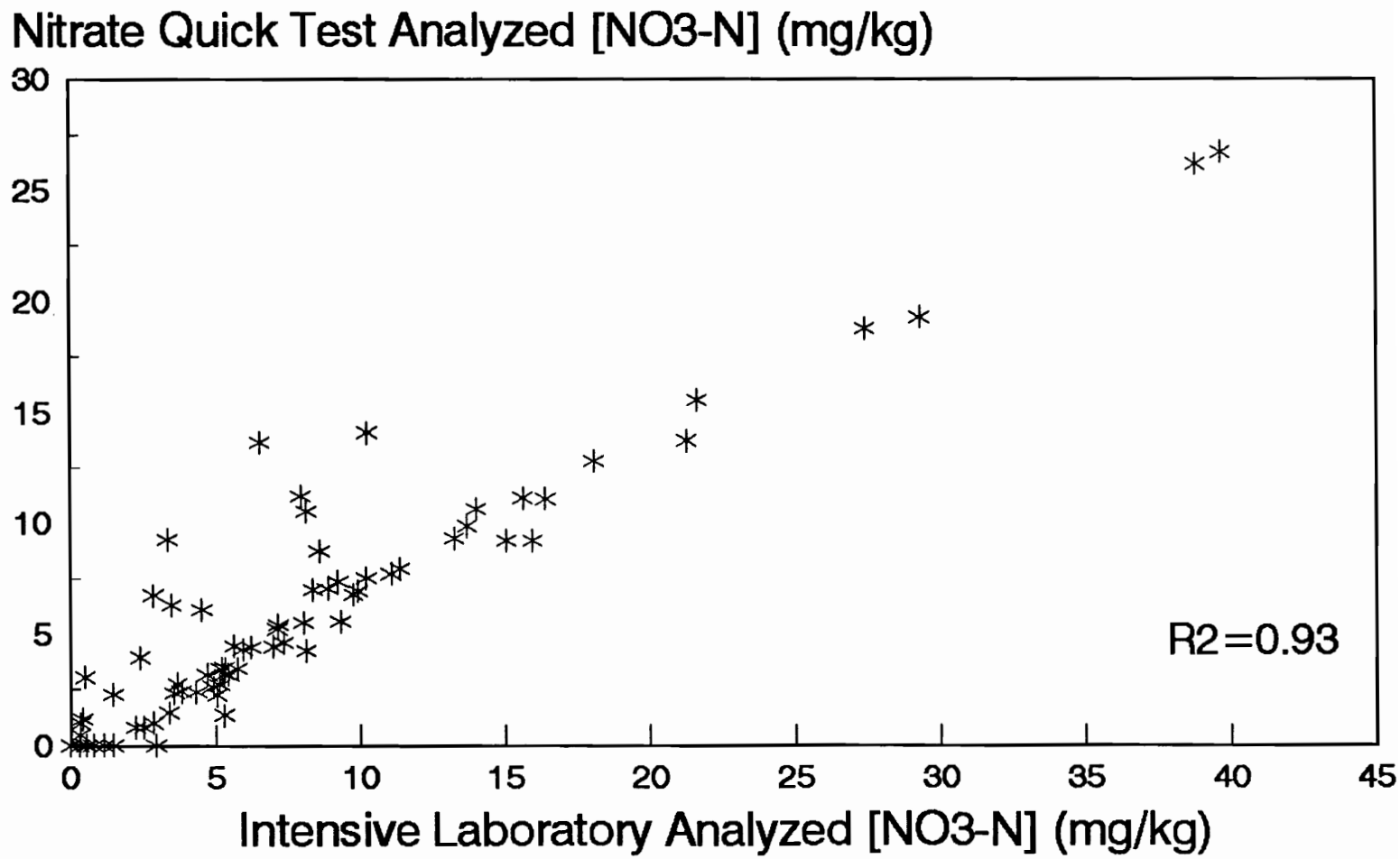
Nitrate Quick Test Analyzed [NO3-N]
vs. Intensive Laboratory Analyzed [NO3-N]
At Corn Emergence

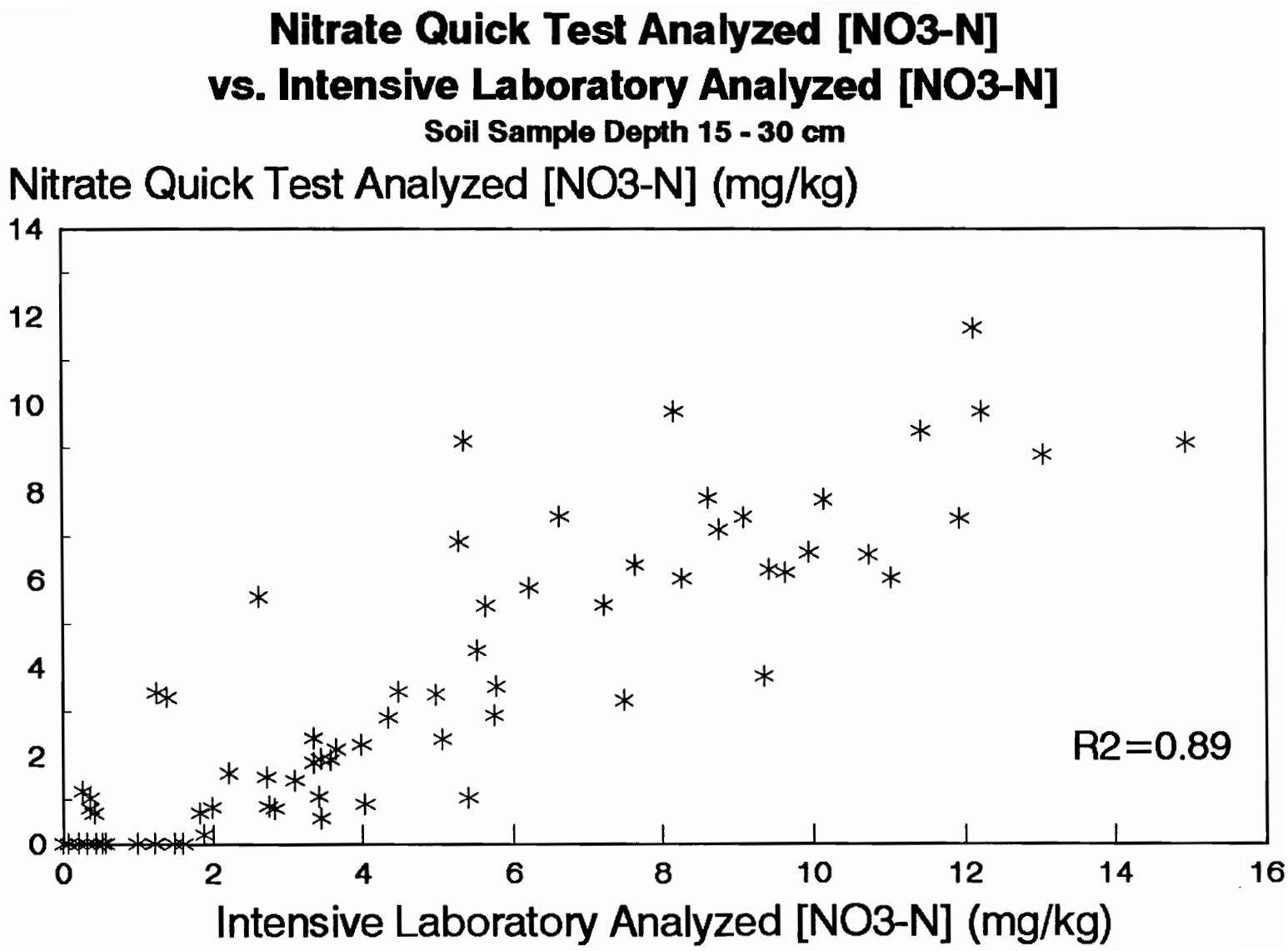



Nitrate Quick Test Analyzed [NO3-N]
vs. Intensive Laboratory Analyzed [NO3-N]
At Two Weeks After Corn Emergence
Nitrate Quick Test Analyzed [NO3-N] (mg/kg)
25
20
15
10
5
0
0
5
10
15
20
25
30
35
R2=0.98
Intensive Laboratory Analyzed [NO3-N] (mg/kg)


Nitrate Quick Test Analyzed [NO3-N]
vs. Intensive Laboratory Analyzed [NO3-N]
At Corn Four-Five Leaf Stage
Nitrate Quick Test Analyzed [NO3-N] (mg/kg)
30
25
20
15
10
5
0
0
5
10
15
20
25
30
35
40
45
R2=0.98
Intensive Laboratory Analyzed [NO3-N] (mg/kg)


Nitrate Quick Test Analyzed [NO3-N]
vs. Intensive Laboratory Analyzed [NO3-N]
At Corn Eight-Ten Leaf Stage
Nitrate Quick Test Analyzed [NO3-N] (mg/kg)
30
25
20
15
10
5
0
0
5
10
15
20
25
30
35
40
45
R2=0.99
Intensive Laboratory Analyzed [NO3-N] (mg/kg)


Nitrate Quick Test Analyzed [NO3-N]
vs. Intensive Laboratory Analyzed [NO3-N]
Soil Sample Depth 0 - 15 cm
Nitrate Quick Test Analyzed [NO3-N] (mg/kg)
30
25
20
15
10
5
0
0
5
10
15
20
25
30
35
40
45
R2=0.93
Intensive Laboratory Analyzed [NO3-N] (mg/kg)


Nitrate Quick Test Analyzed [NO3-N]
vs. Intensive Laboratory Analyzed [NO3-N]
Soil Sample Depth 15 - 30 cm
Nitrate Quick Test Analyzed [NO3-N] (mg/kg)
14
12
10
8
6
4
2
0
0
2
4
6
8
10
12
14
16
R2=0.89
Intensive Laboratory Analyzed [NO3-N] (mg/kg)

APPENDIX B. Soil N Data. Soil Sample Depth 15-30 cm.

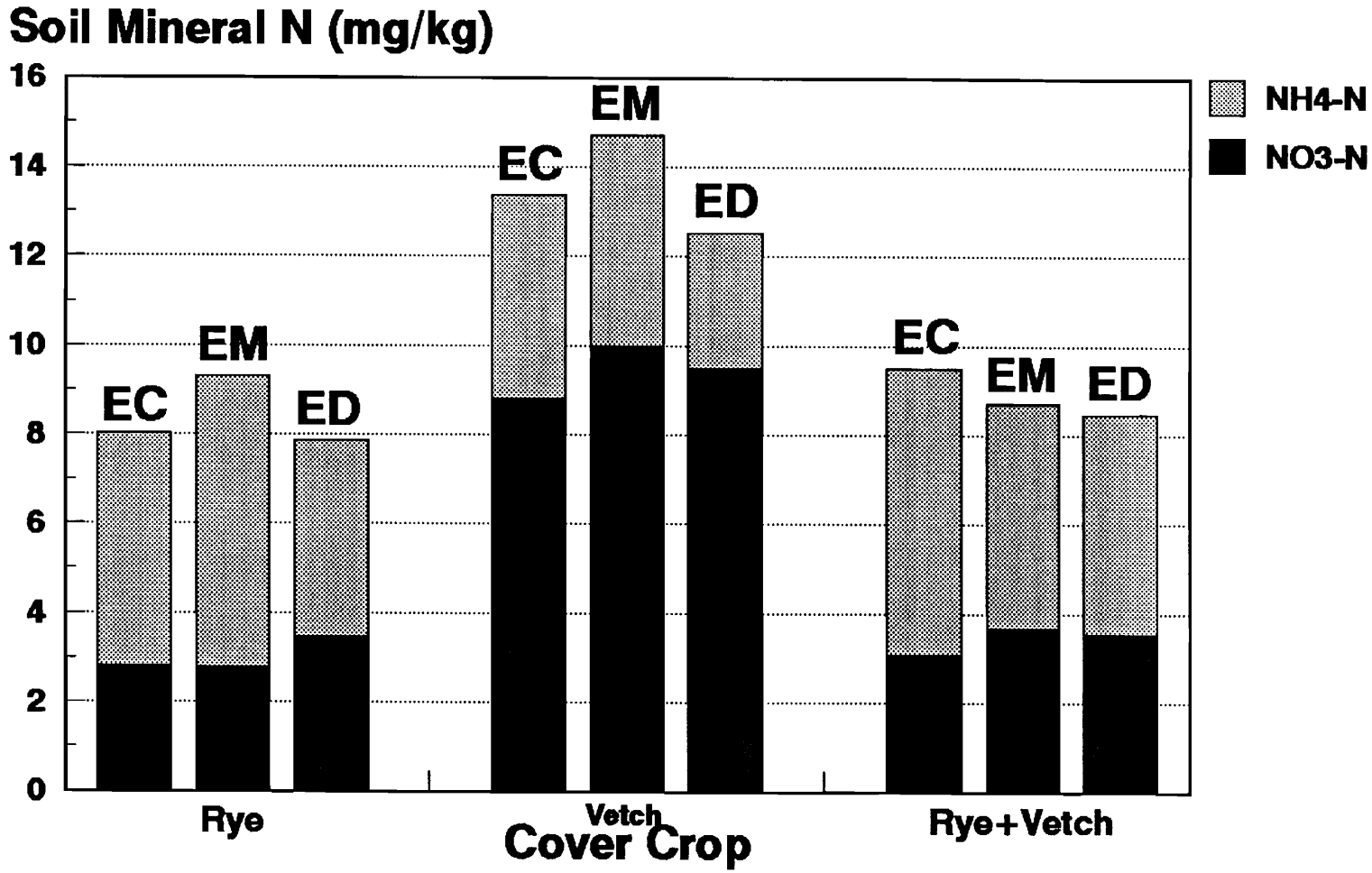
Soil N Data - 1992

Cover Crop	[NO3-N]	[NH4-N]	Total N
	----------mg/kg----------		
	----------Early Desiccation----------		
Rye	0.27	2.58	2.85
Vetch	4.35	2.90	7.25
Rye+Vetch	0.25	2.98	3.23
	----------Late Desiccation----------		
Rye	0.37	2.53	2.90
Vetch	2.02	2.12	4.14
Rye+Vetch	0.61	4.49	5.10

Soil N Data - 1993

Cover Crop	[NO3-N]	[NH4-N]	Total N
	----------mg/kg----------		
	----------Early Desiccation----------		
Rye	0.09	7.84	7.93
Vetch	0.05	11.20	11.25
Rye+Vetch	0.02	9.05	9.07
	----------Late Desiccation----------		
Rye	0.00	5.03	5.03
Vetch	0.00	5.53	5.53
Rye+Vetch	0.00	3.58	3.58

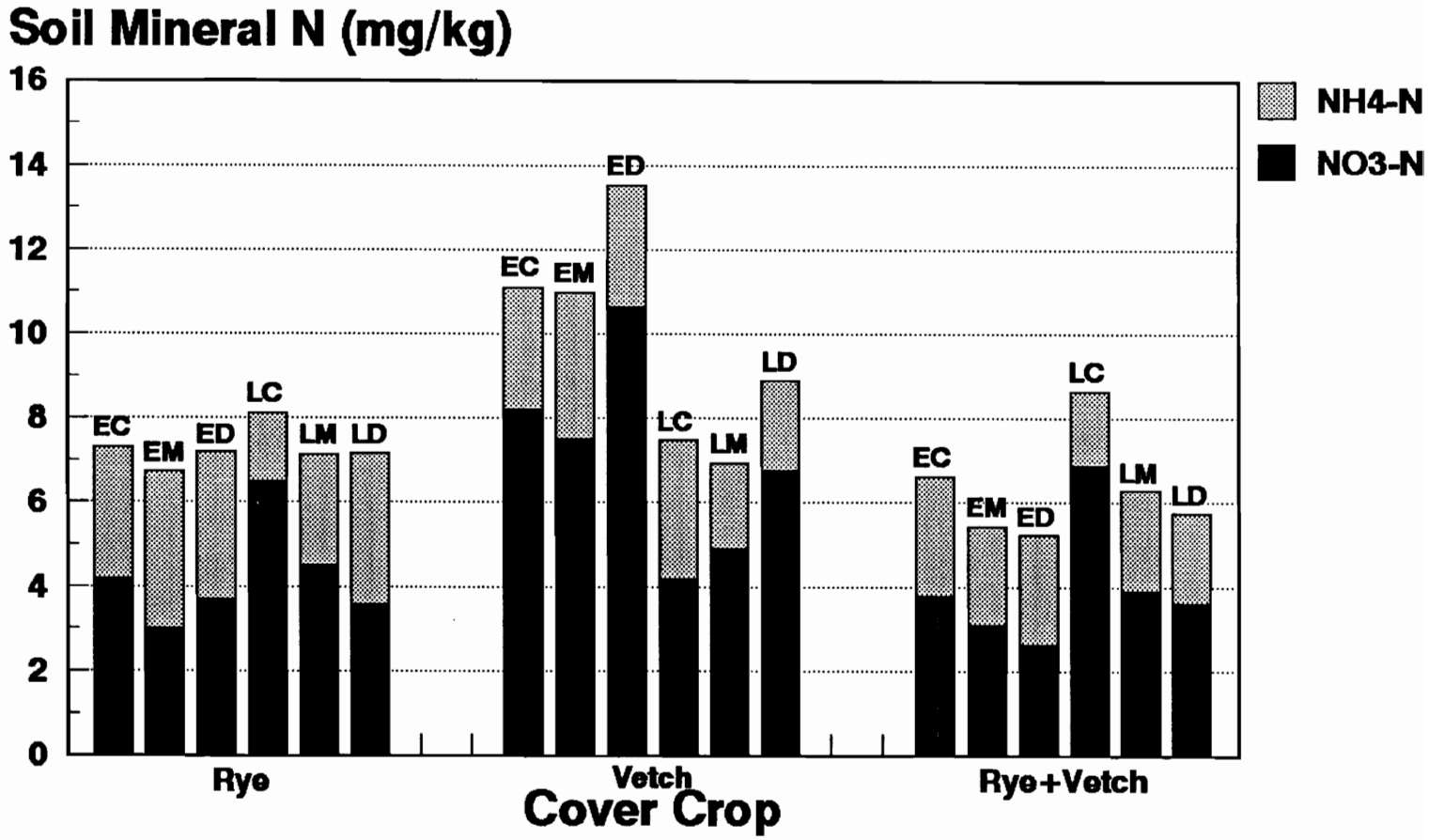
Soil N Data At Corn Planting - 1992



E = Early Desiccation
C= Control M = Mow D = Mow+Disk

Soil N Data - 1992

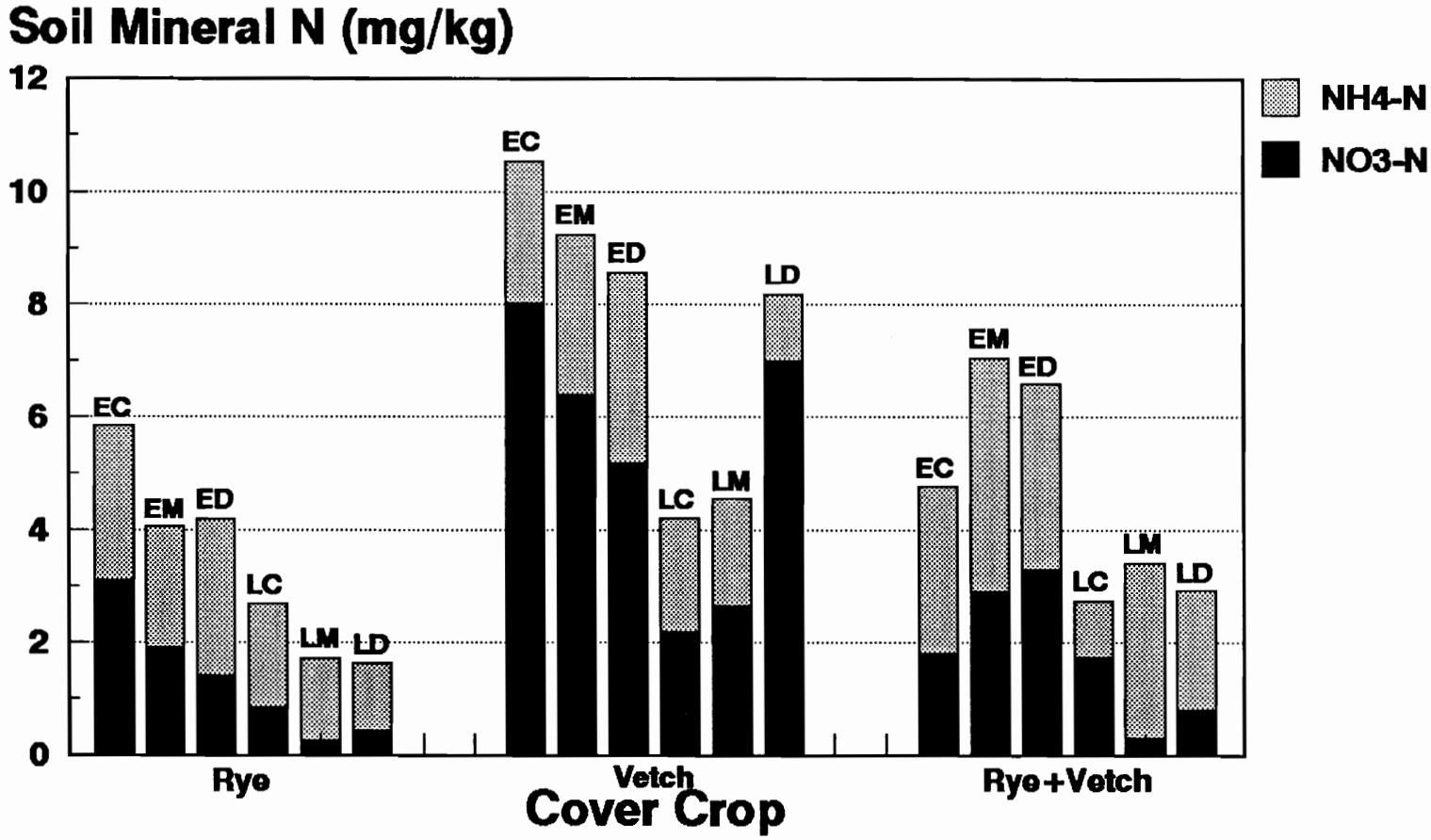
At Corn Four to Five Leaf Stage



E = Early Desiccation L = Late Desiccation
C = Control M = Mow D = Mow+Disk

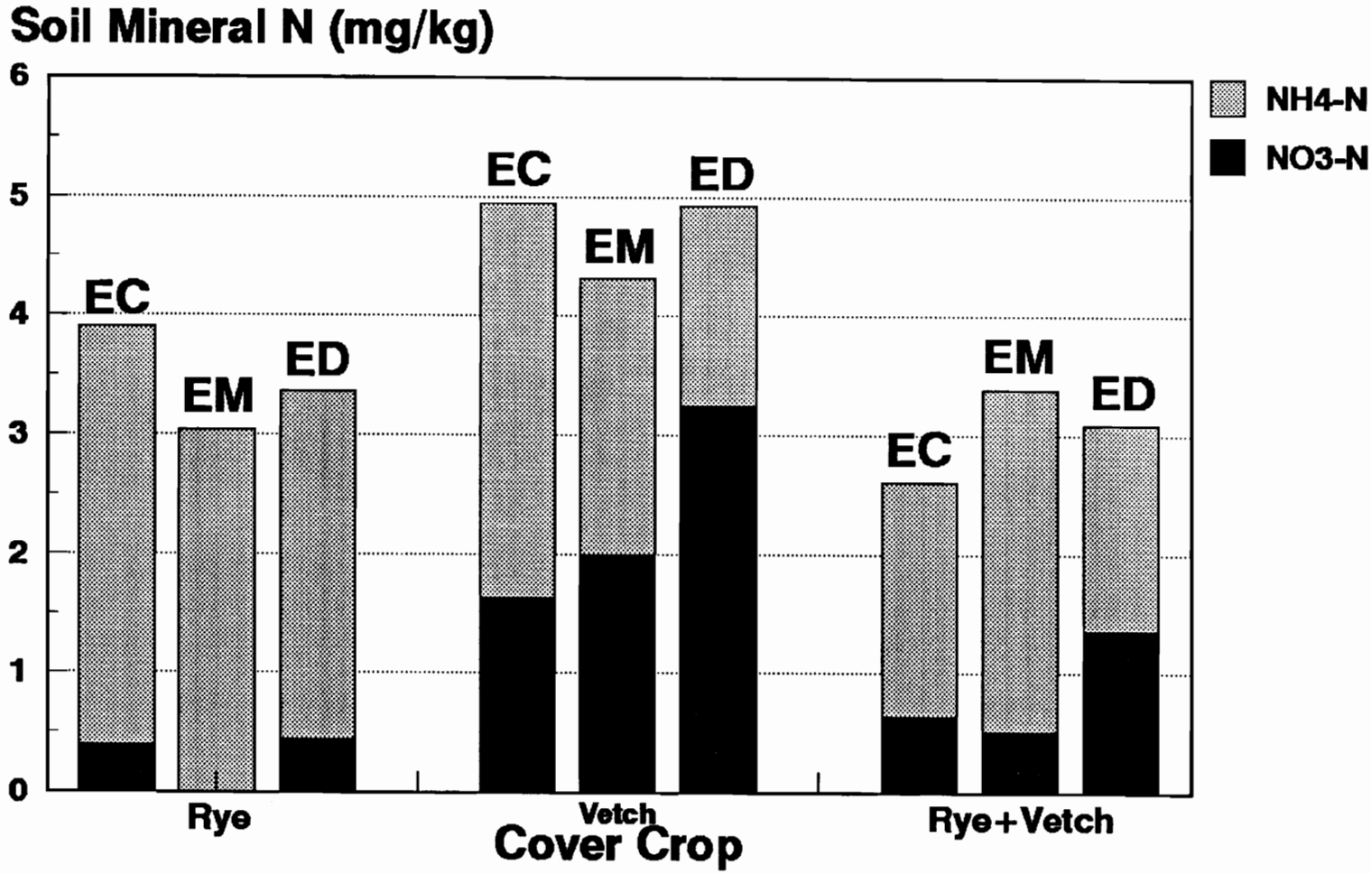
Soil N Data - 1992

At Corn Eight to Ten Leaf Stage



E = Early Desiccation L = Late Desiccation
C = Control M = Mow D = Mow+Disk

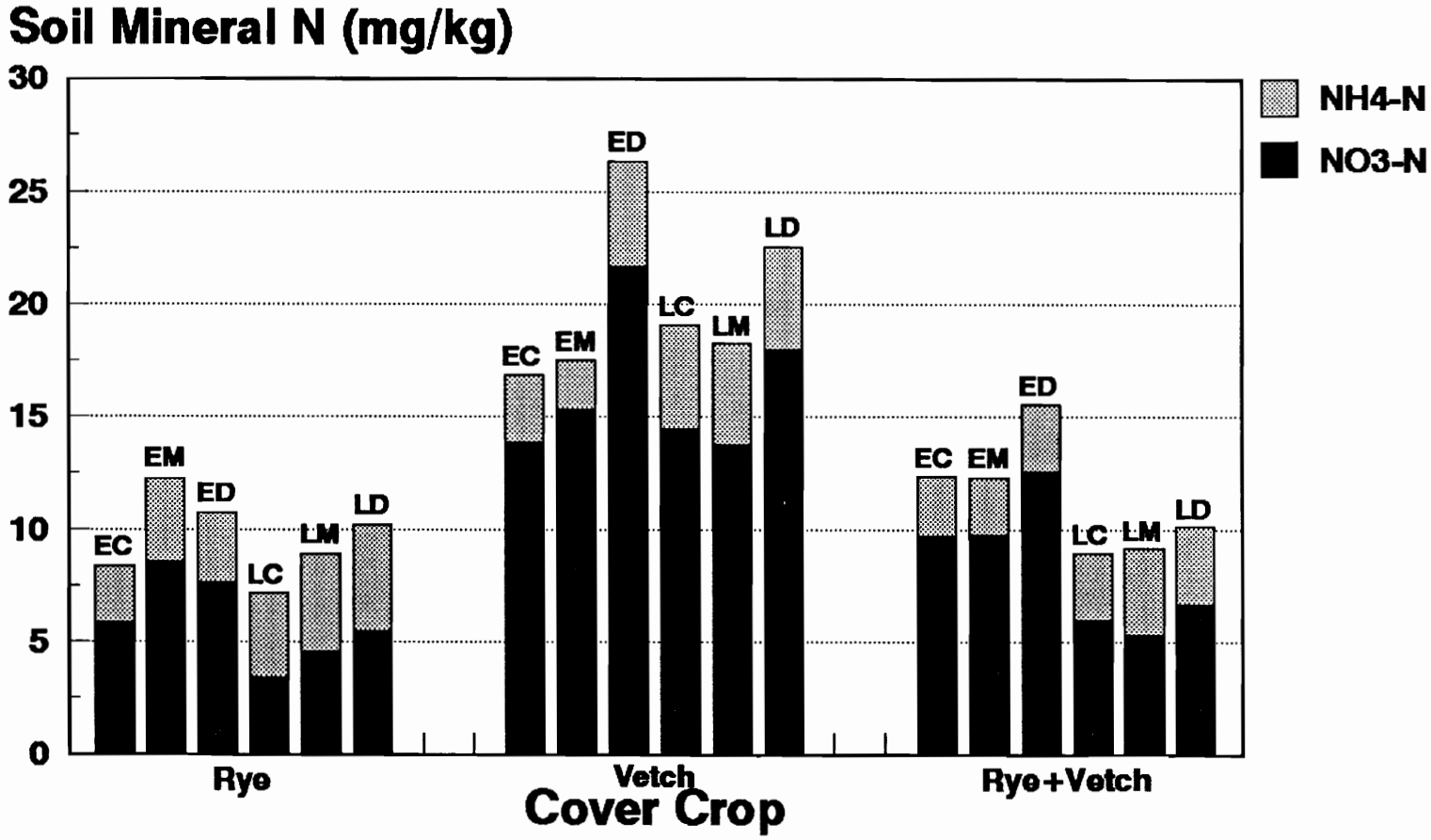
Soil N Data At Corn Planting - 1993



E = Early Desiccation
C = Control M = Mow D = Mow+Disk

Soil N Data - 1993

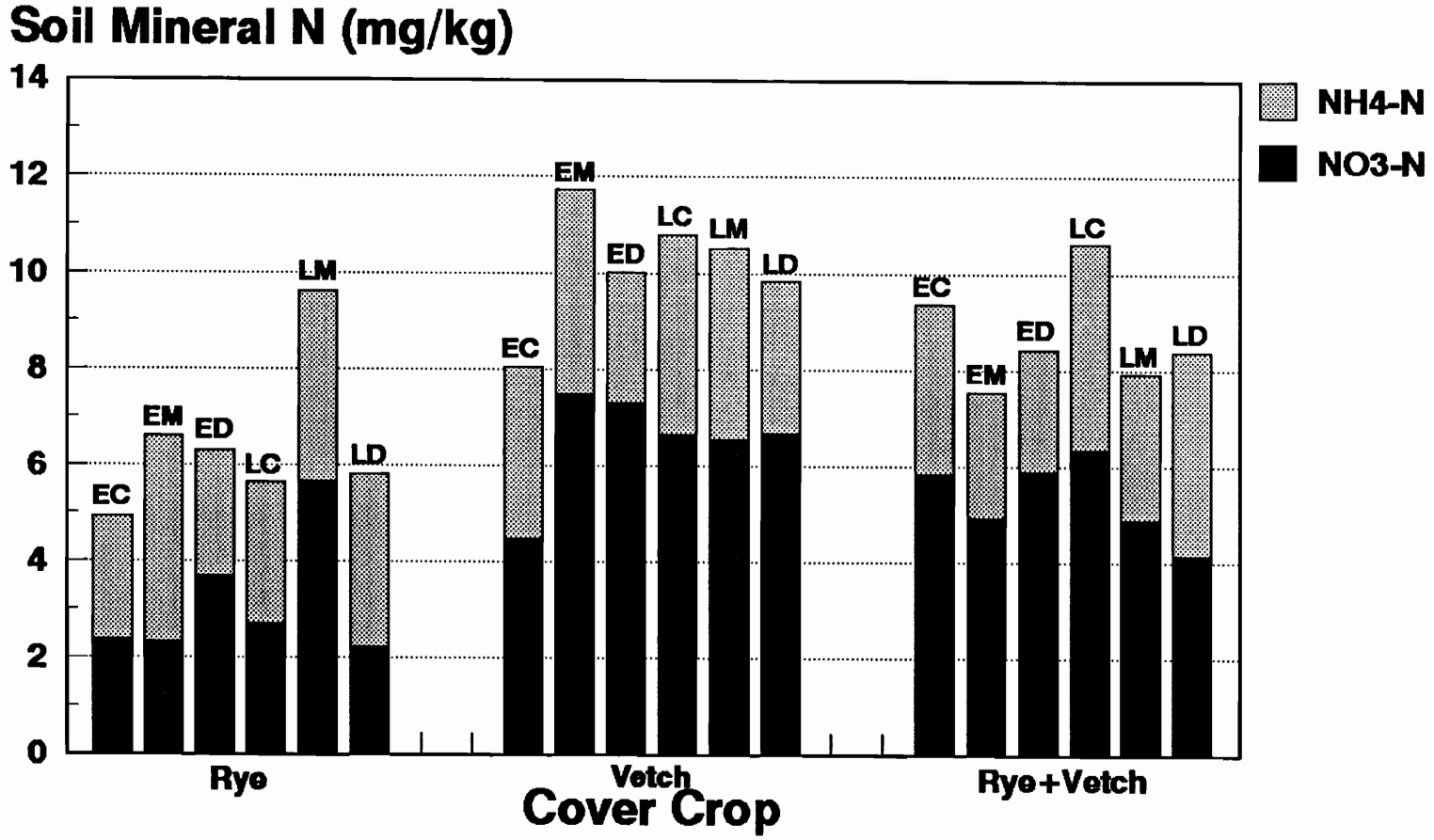
At Corn Four to Five Leaf Stage



E = Early Desiccation L = Late Desiccation
C = Control M = Mow D = Mow+Disk

Soil N Data - 1993

At Corn Eight to Ten Leaf Stage



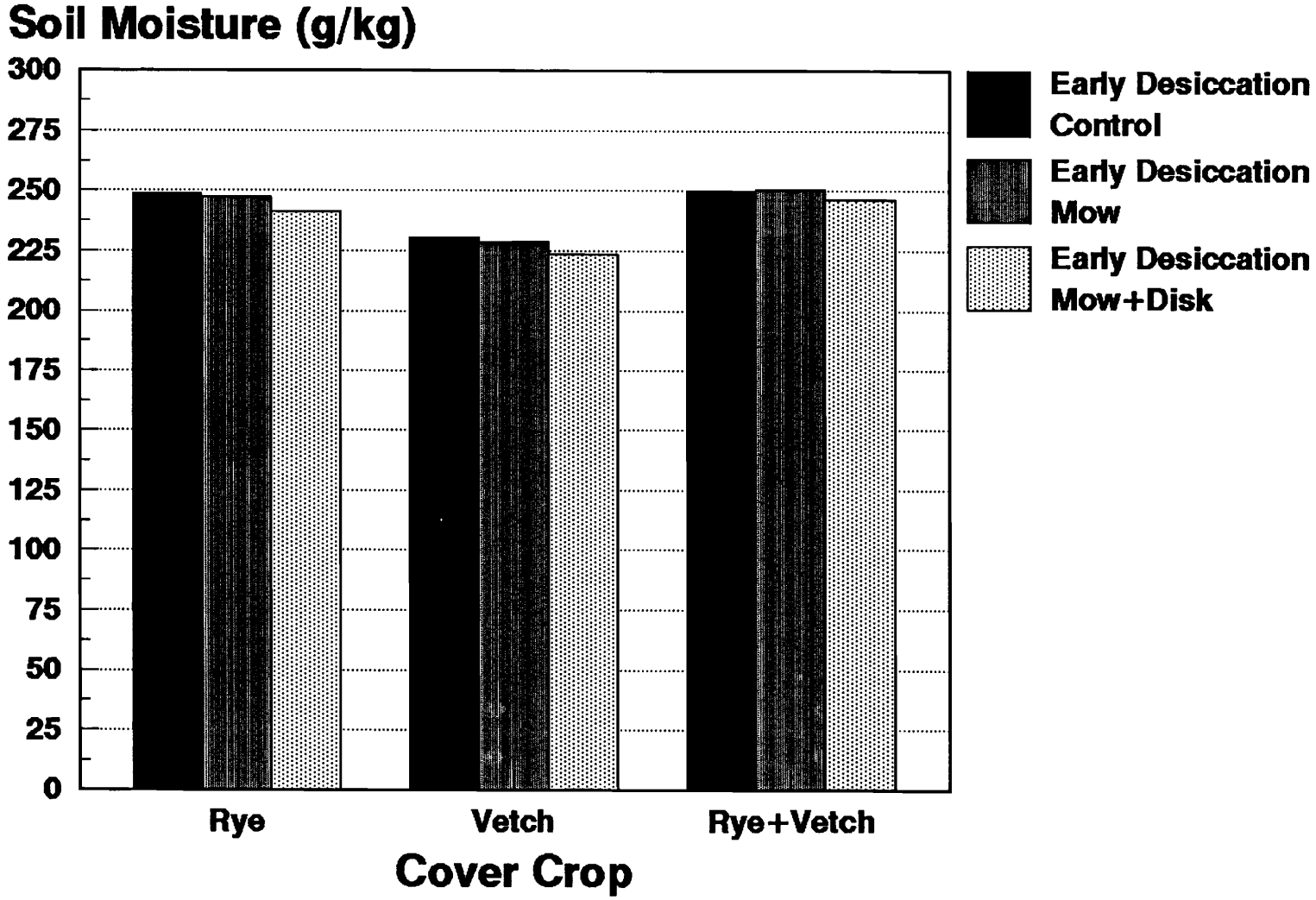
E = Early Desiccation L = Late Desiccation
C = Control M = Mow D = Mow+Disk

APPENDIX C. Soil Moisture Data. Soil Sample Depth 15-30 cm.

Soil Moisture Data

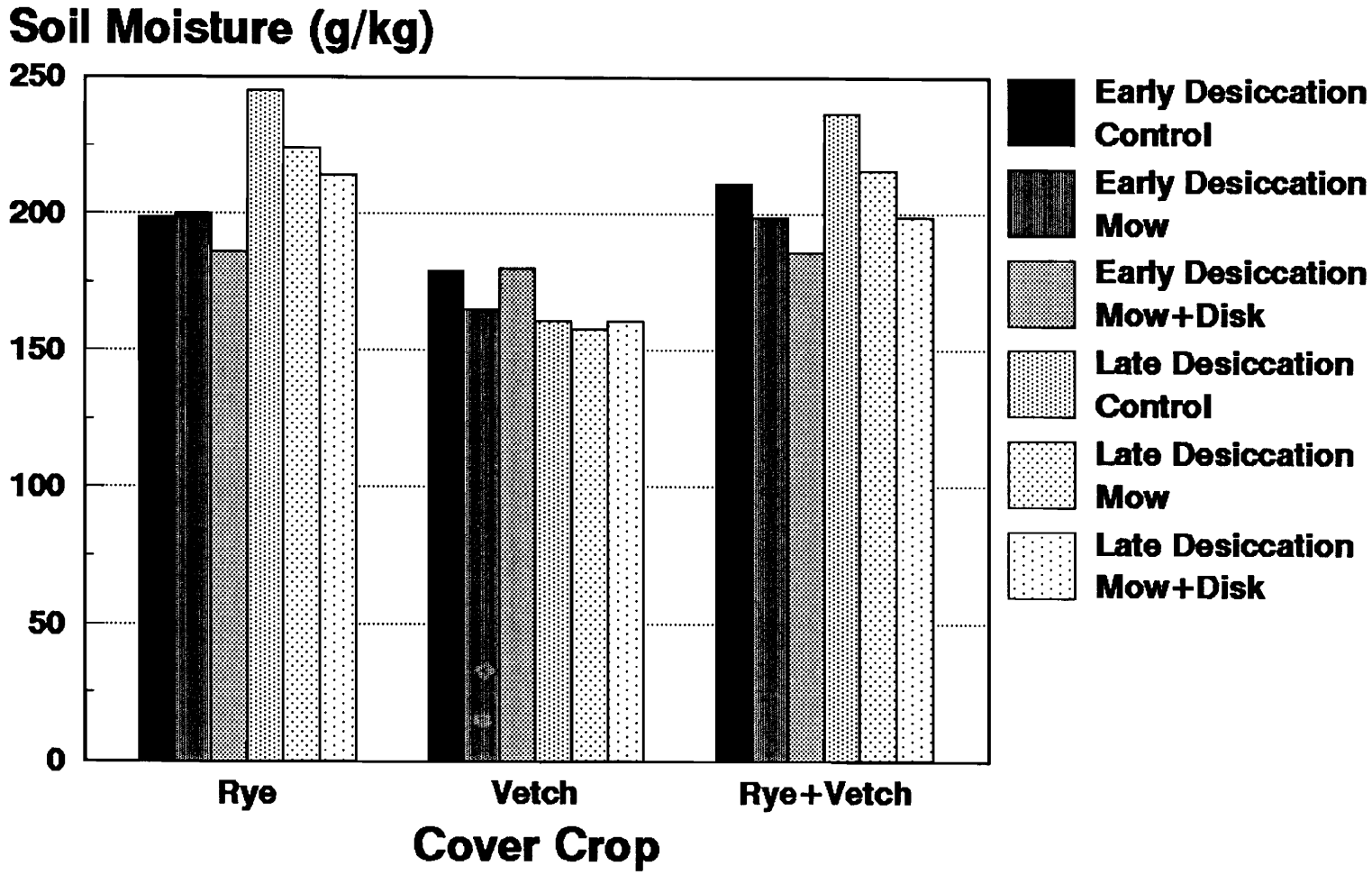
Cover Crop	1992	1993
	----------g/kg----------	
	-Early Desiccation-	
Rye	237.93	159.28
Vetch	234.63	174.33
Rye+Vetch	240.73	159.10
	-Late Desiccation-	
Rye	238.53	123.15
Vetch	237.95	142.90
Rye+Vetch	239.48	128.78

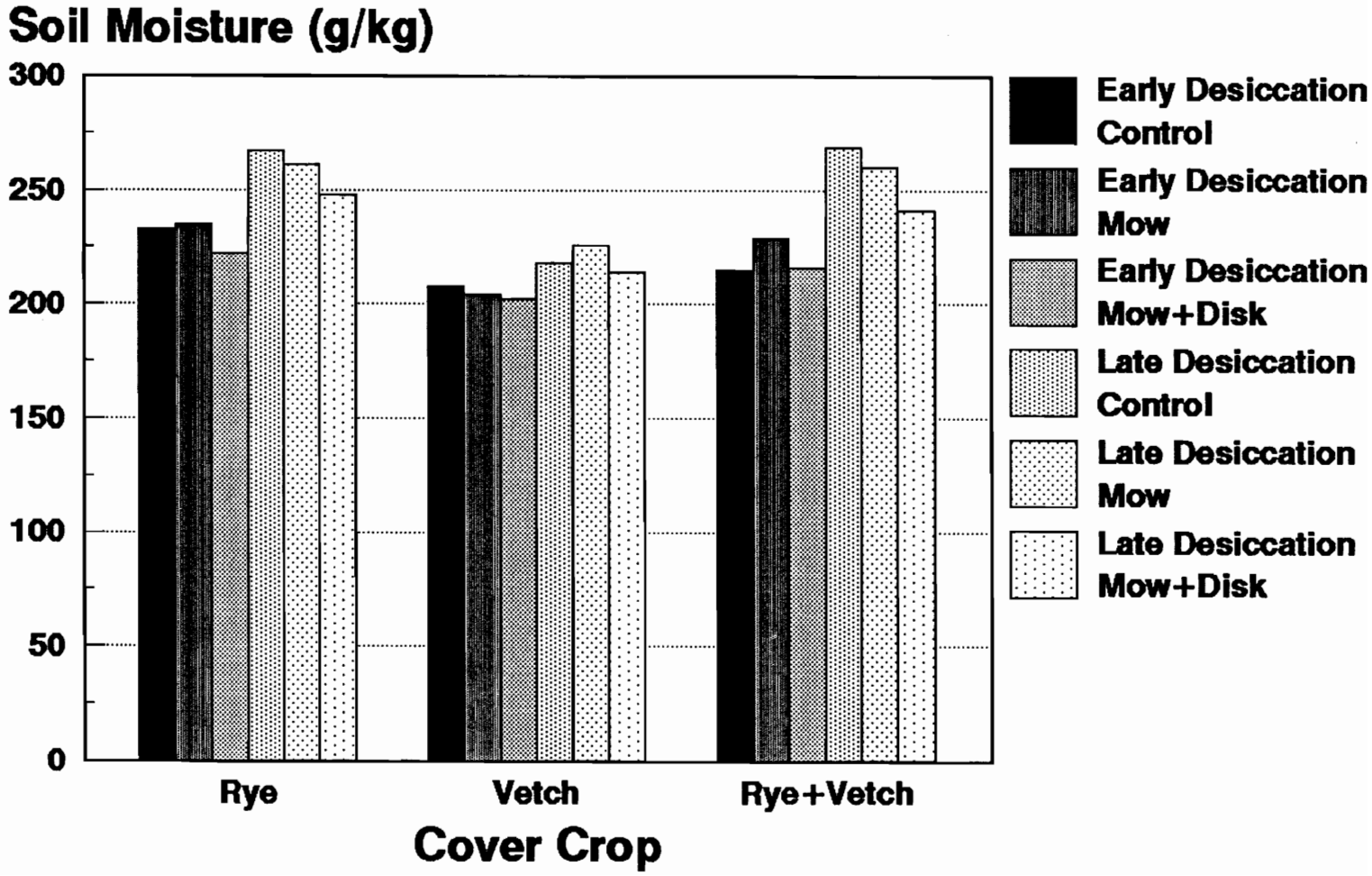
Soil Moisture at Corn Planting - 1992



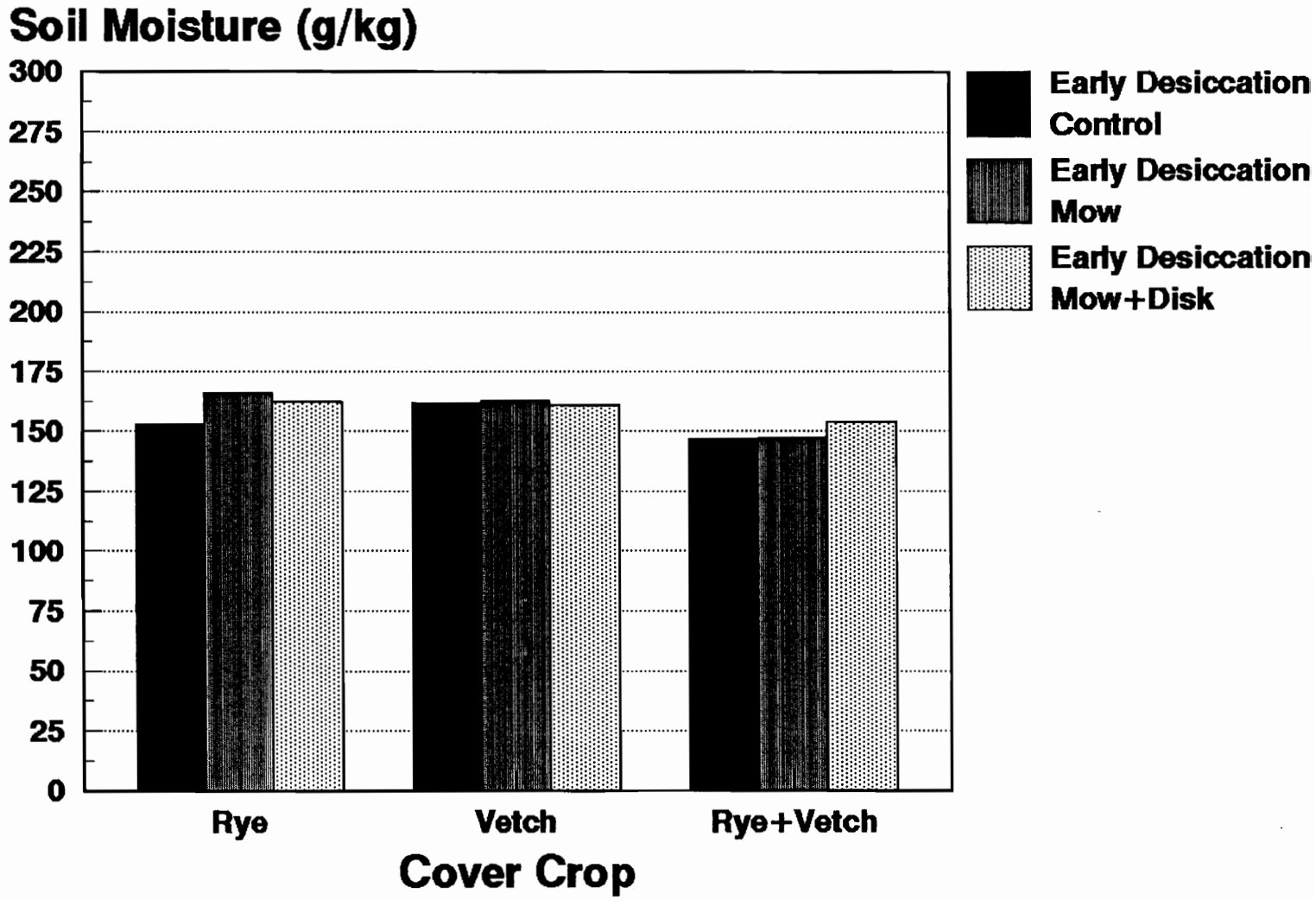
Soil Moisture - 1992

At Corn Four to Five Leaf Stage



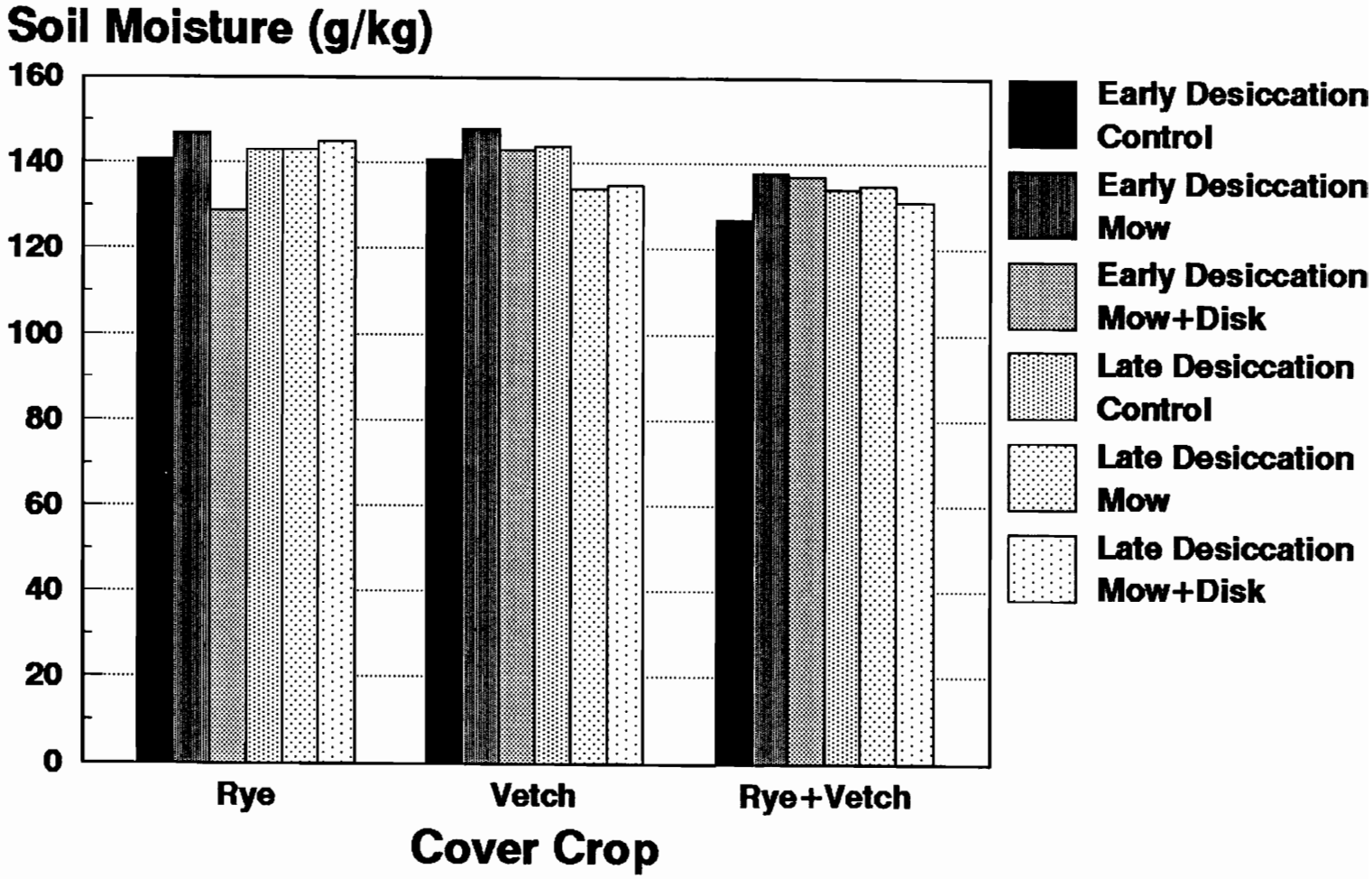

Soil Moisture - 1992
At Corn Eight to Ten Leaf Stage
Soil Moisture (g/kg)
300
250
200
150
100
50
0
Rye
Vetch
Rye+Vetch
Cover Crop
Early Desiccation Control
Early Desiccation Mow
Early Desiccation Mow+Disk
Late Desiccation Control
Late Desiccation Mow
Late Desiccation Mow+Disk

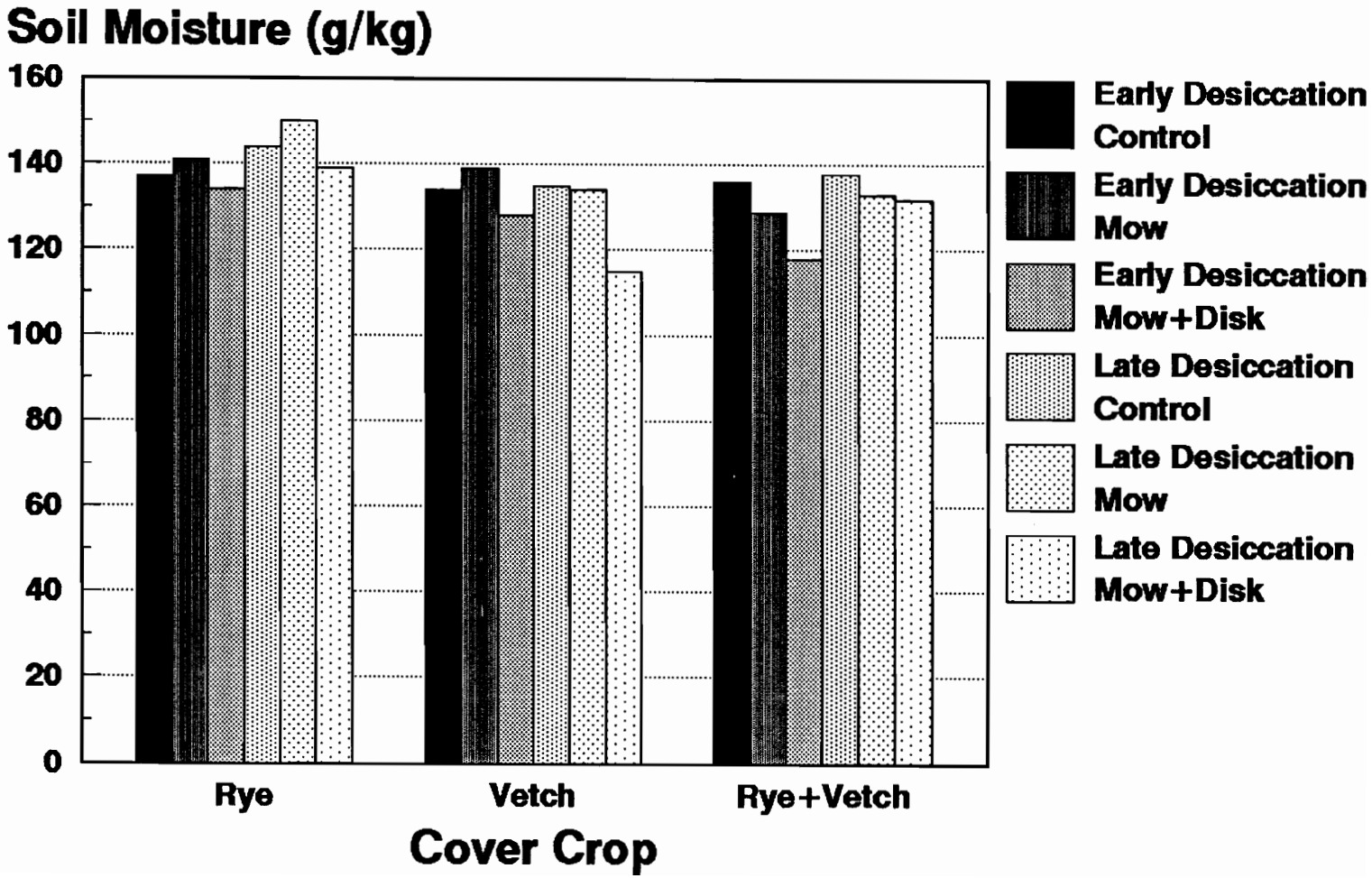
Soil Moisture at Corn Planting - 1993



Soil Moisture - 1993

At Corn Four to Five Leaf Stage




Soil Moisture - 1993
At Corn Eight to Ten Leaf Stage
Soil Moisture (g/kg)
160
140
120
100
80
60
40
20
0
Rye
Vetch
Rye+Vetch
Cover Crop
Early Desiccation Control
Early Desiccation Mow
Early Desiccation Mow+Disk
Late Desiccation Control
Late Desiccation Mow
Late Desiccation Mow+Disk

VITAE

Jeffrey David Vaughan was born in Raleigh, North Carolina, on June 28, 1969. He has lived in the Blacksburg, Virginia, area since October 1973. Jeff graduated with a B.S. in Agronomy at Virginia Tech in May 1991. He has a wife, Christene, and a daughter, Ruby.