THESIS

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CORN GRAIN AND NITROGEN YIELD RESPONSE TO LEGUME COVER CROP KILL DATE AND SUBIRRIGATION

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CORN GRAIN AND NITROGEN YIELD RESPONSE TO LEGUME COVER CROP KILL DATE AND SUBIRRIGATION

By

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ABSTRACT

A field study was conducted to determine the effect of timing of killing a legume cover crop on the yield and N uptake of a following corn crop in subirrigated and non-irrigated systems. Corn grain yield following red clover (RC) with no N fertilizer applied was similar to grain yield with no cover crop and 140 kg N ha^{-1} applied. A ten day difference in killing the RC cover crop had no effect on grain yields or total N uptake of a following corn crop. Soil water contents at the time of corn planting were higher in the early- than in the late-kill RC systems. Timing of RC kill may be an effective technique for managing soil water content in spring without sacrificing N contribution. The legume based cropping systems were as profitable as systems with no cover crop. Subirrigation did not significantly affect corn grain yields.

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INTRODUCTION

Including legume cover crops in a cropping system may provide benefits of reduced soil erosion (Smith et al, 1987), increased water infiltration (McVay et al. 1989), improved soil tilth (Marten and Touchton, 1983), contribution of biologically fixed nitrogen (Heichel et al, 1985), and increased yield of a subsequent crop (Baldock et al., 1981, Holderbaum et al., 1990). The N contributed by legume cover crops is often the most important reason growers include them in cropping systems.

Two common methods of measuring the N contributed by a legume to a cropping system are total N content of the legume biomass (TNLB) and the fertilizer replacement value (FRV) (Hesterman, 1988). For red clover, alfalfa, and hairy vetch the TNLB at the time of incorporation is commonly reported to exceed 100 kg/ha (Wagger, 1989; Oyer and Touchton, 1990) and has been reported as high as 350 kg/ha (Groya and Scheaffer, 1985). Because the TNLB method measures only that N present in the plant biomass at the time of incorporation into the soil, Griffin and Hesterman (1989) modified the TNLB method to include the N content of the legumes prior to winter dieback. The plowdown N yield

(PDN) was defined as N contained in herbage and roots in the fall plus N contained in herbage at the time of spring incorporation. The FRV is defined as "the quantity of fertilizer N required to produce a yield in a crop that does not follow a legume that is identical to that produced by incorporation of the legume" (Hesterman, 1988). Reported FRVs typically are in the 70-170 kg N/ha range (Oyer and Touchton, 1990; Utomo et al. 1990) and have been reported to be as high as 225 kg N/ha (Harris, 1993). Corn yield increases of up to 100 percent (Holderbaum et al., 1990; Voss and Shrader, 1979) have been reported following plowdown of a legume compared to corn grown under similar conditions without the legume.

Non-legume crops following a legume do not always show yield increases, and under certain conditions legume cover crops actually can have a negative effect upon a subsequent crop. Under water-limiting conditions, corn crops following a legume cover crop have exhibited reduced emergence (Holderbaum et al., 1990a; Hesterman et al., 1992), limited early growth (Holderbaum et al., 1990a; Corak et al., 1991; Hesterman et al., 1992), and reduced grain and stover yield (Touchton and Whitwell, 1984; Hesterman et al. 1992). The likely cause of this negative effect is depletion of soil water by an actively growing legume (Ebalhar et al., 1984; Frye et al., 1988; Badarrudin and Meyer, 1990; Hesterman et al., 1992).

Corak et al. (1991) reported that, in Kentucky, a hairy vetch winter cover crop compared to a no cover crop control reduced soil water in the top 30 cm by approximately 30% at the time of no-till corn planting in the spring. Ebalhar et al. (1984) compared four winter cover crops in a no-tillage system in Kentucky and found that, compared to corn residue, hairy vetch depleted soil water in the 7.5 to 15 and 15 to 30 cm soil profiles by 16 and 25%, respectively. The other cover crops they studied, each of which produced less biomass than hairy vetch, did not significantly deplete soil water content. The results of these studies with vetch in the Eastern and South-eastern U.S. may not be directly applicable to a conventionally tilled system in the north-central U.S. because of the importance of climate (Briggs and Shantz, 1916) and plant species (Fairbourn, 1982) in determining moisture utilization and soil moisture depletion. Information about the extent, dynamics, and affect of legume cover crops on soil water depletion in the north-central U.S. is limited.

Irrigation may be effective at alleviating legume induced soil water deficits without sacrificing legume nitrogen contribution. Corak et al. (1991) used irrigation to successfully alleviate moisture stress in corn which followed a hairy vetch cover crop.

Killing a cover crop two to three weeks prior to planting a subsequent crop has also been recommended by several researchers (Hargrove and Frye, 1987; Utomo et al., 1987; Munawar et al., 1990) as a way to minimize the risk of yield loss from cover crop induced soil water deficits. Munawar et al. (1990) found timing of killing a rye cover crop to have no effect on soil water content at the time of no-tillage corn planting. However, beginning one week after corn planting soil water contents were greater with early-killed than late-killed rye. These researchers attributed the differences in soil water content to the early killed rye, which flattened against the soil surface, being a more effective barrier than the late killed rye, which remained standing.

Terminating spring growth of a legume cover crop will limit biomass and N accumulation (Ngalla and Eckert, 1987; Ebalhar et al., 1984). The effects of early termination of legume growth may be especially pronounced in northern climates, where active spring growth is characterized by rapid increases in dry matter accumulation and nitrogenase activity (Rice, 1980). Holderbaum et al. (1990) reported that hairy vetch grown in Maryland added 2 kg N/ha/day between the onset of spring growth and early to mid-May. Although incorporating a larger quantity of N results in a potentially larger available N pool, changes in chemical composition associated with maturity may reduce the rate of decomposition, resulting in similar quantities of N being available to a subsequent crop (Wagger, 1989)

Timing of cover crop desiccation or incorporation may be an effective technique for managing green manure water use. When water is plentiful, cover crops could be allowed to grow until the desired time of planting a subsequent crop. Under conditions of water surplus, cover crop spring growth may actually reduce soil water content, potentially reducing leaching of NO_3-N (McCracken et al., 1988) and allowing earlier field operations. During years when water is expected to be limited, terminating cover crop growth earlier could minimize soil water depletion by the cover crop.

Subirrigation

Water table management using combined sub-surface drainage-irrigation (subirrigation) systems is a method of regulating soil water conditions for improved crop growth. Reported effect of subirrigation on corn grain yields has varied. Nemon et al. (1987) reported that subirrigating corn on a sandy soil increased grain yields by 40 and 86% in two years. Belcher (1992) reported a 26% increase in corn grain yields averaged across 16 year/locations in Michigan. In contrast, Chieng et al. (1987) found subirrigation to have little effect on corn grain yields during three years of research. Woodruff et al. (1987) reported lower corn yields with a 0.35- and 0.70- compared to 1-m water table depth with 0 or 112 kg N ha^{-1} applied but no difference in yield with 224 or 336 kg N ha^{-1}. The varied effects of subirrigation on corn yield may be due to different soil types and/or precipitation.

Subirrigation systems are easily adapted to existing tile drain systems and can be particularly effective in some humid areas where uneven seasonal rainfall distribution leads to water surpluses and deficits during the same season (Nemon et al. 1987). Potential advantages of subirrigation compared to other methods of irrigation include efficiency at providing water to crops growing on soils having low water holding capacities, low labor requirements, minimal evaporative loss (Criddle and Kalisvaart, 1967), and reduced energy requirements (Strickland et al. 1981). The potential disadvantages of subirrigation include possible limitation of crop choice dependent upon rooting characteristics and the limited adaptability to sites with a relatively flat soil surface and a naturally high water table or a water impermeable soil layer close to the soil surface (Criddle and Kalisvaart, 1967).

Subirrigation may result in a considerably different soil environment than that found under rain-fed conditions. Chieng et al. (1987) stated that the soil environment created by subirrigation will result in reduced leaching of nutrients from the upper root zone. However, Woodruff et al. (1984) found reduced N uptake by fertilized corn and lower concentrations of soil NO_3-N when water tables were maintained at 35 or 70 cm in comparison to 100 cm depths.

Because soil water content strongly affects microbial reaction rates (Paul and Clark, 1989), rates of legume decomposition, N mineralization, and denitrification may be altered under subirrigated conditions. Slower rates of legume decomposition under wet conditions have been reported for laboratory (Bartholomew and Norman, 1946) and field (Wagger, 1989) experiments. The potential for subirrigation to alter rates of legume decomposition and the movement of N within a system may result in differing relative performance of legume- versus fertilizer-N based systems under subirrigated compared to non-irrigated systems. Previous research on subirrigation has concentrated on the management of the subirrigation system for optimizing crop production in fertilizer-N based systems.

Objectives

The goal of this research was to determine the effect that timing of killing a legume cover crop had on grain yield and N uptake of a following corn crop in subirrigated and non-irrigated systems.

Specific objectives were to i) compare the N contributed by early- and late-kill red clover cover crops, ii) compare grain yield and N uptake of corn following early- and late-kill red clover cover crops, iii) determine the effect of subirrigation on grain yield and N uptake of corn grown in red clover- and fertilizer-N based cropping systems, iv) quantify water content in the soil surface layers prior to corn planting and during early season growth, and v) determine which crop sequence/management combination provided the highest net revenue.

MATERIALS AND METHODS

This research was conducted in 1992 and 1993 on a cooperating farmer's field near Pigeon, Huron County, Michigan. Soil type was Kilmanagh loam (fine-loamy, mixed, nonica, mesic Aeric Haplaquepts). The field was chosen because of existing subsurface drainage and reverse-flow subirrigation systems. Drain lines were at 7.6-m intervals. Two parallel experiments were established. One experiment received irrigation water through the reverse flow subirrigation (SI) system and the second experiment was non-irrigated (NI). Subirrigation was not a randomized treatment. Water table depths in both experiments, measured weekly during the period the subirrigation system was used, are shown in Figures 1 and 2. Water table measurements were taken between 11:00 am and 1:00 pm. Measurements reported are the average of one reading taken a tile line and one reading taken midway between two tile lines.

The entire field had been planted to sugar beets, dry beans, and barley in 1989, 1990, and 1991, respectively. To break an existing hardpan a shank was used to subsoil the field to a depth of 45 cm after barley harvest in 1991. No N fertilizer was applied in 1991. Results from soil tests

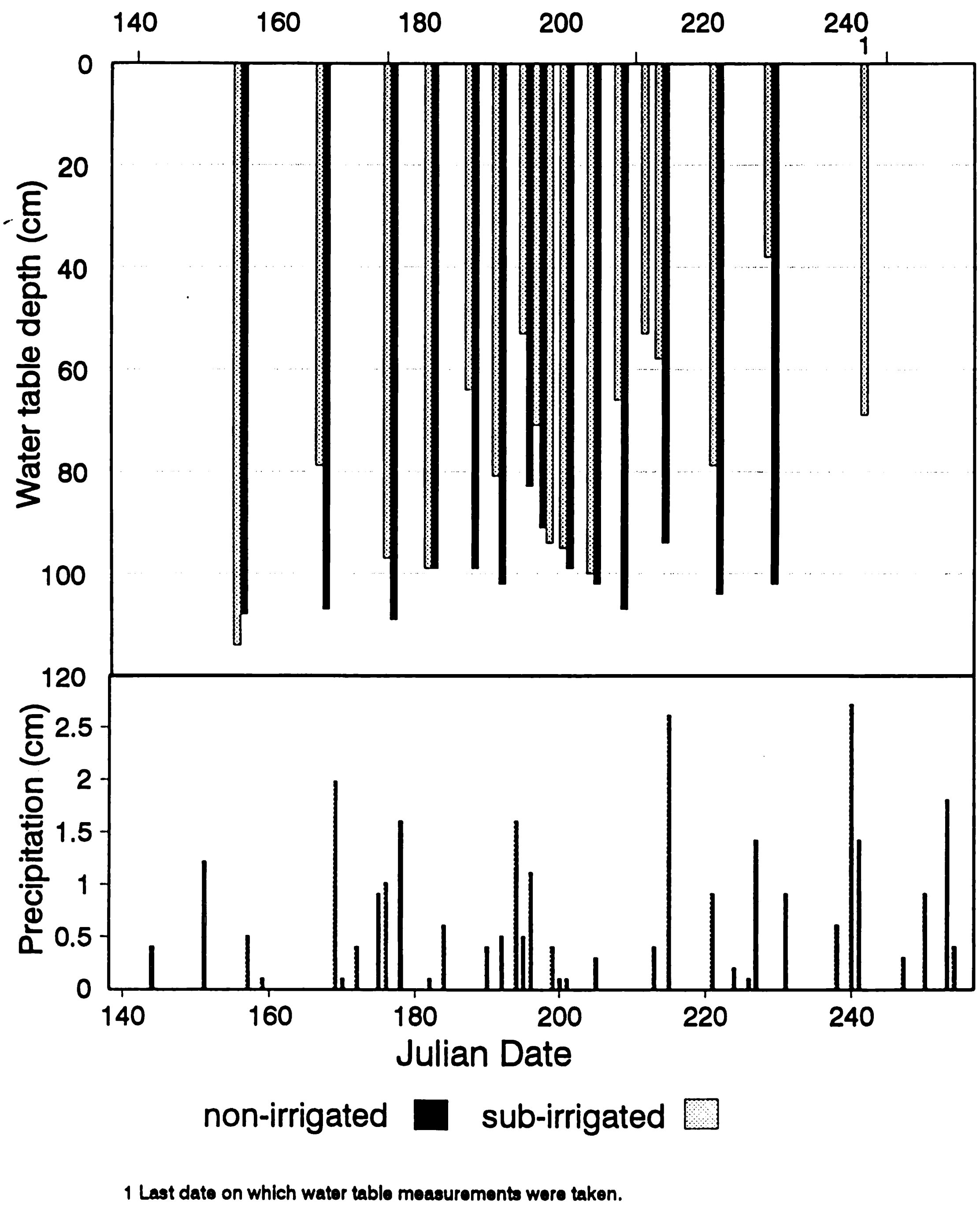


Figure 1 Daily precipitation and subirrigated and non-irrigated water table depths from 19 May through 12 September 1992.

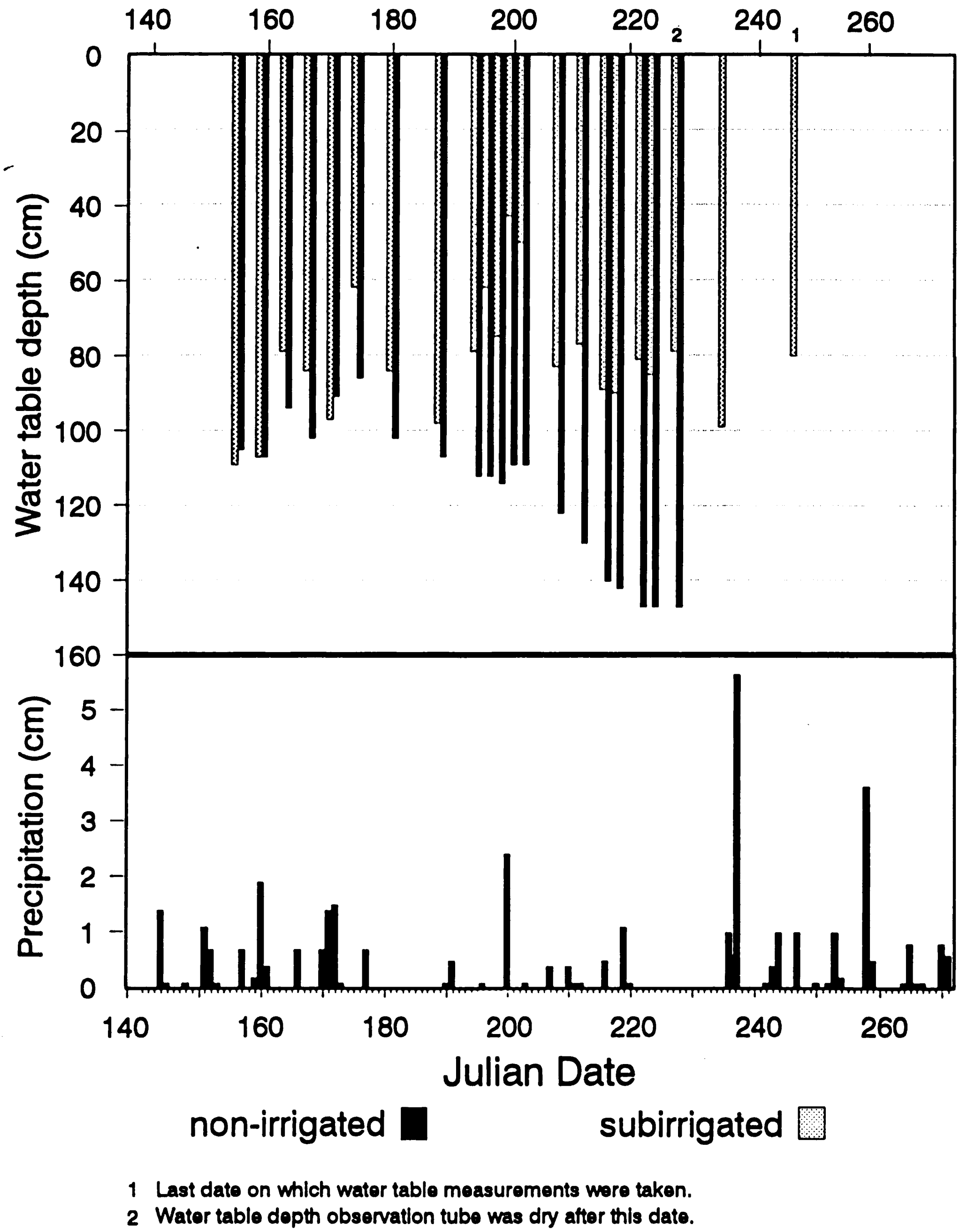


Figure 2 Daily precipitation and subirrigated and non-irrigated water table depths 19 May through 27 September 1993.

performed on samples taken during the fall of 1991 and spring of 1993 are in Table 1. No P, K, or lime were added because soil tests indicated that P, K, and pH were suitable to obtain maximum grain yields.

Precipitation data were collected from a weather station located on site during the 1992 season (Figure 1) and from a location five miles north of the site during the 1993 season (Figure 2).

Cropping Systems and Experimental Design

Five 2-year cropping systems were studied. Each system was defined by the cropping sequence and management of the cover crop. The five cropping systems were:

i) wheat (no-cover crop)-corn
ii) wheat (RC-FS early-kill)-corn
iii) wheat (RC-FS late-kill)-corn
iv) wheat (RC-DR early-kill)-corn
and v) wheat (RC-DR late-kill)-corn

where RC = red clover cover crop
FS = frost seeding used to establish red clover
DR = drilling used to establish red clover,
early-kill = red clover killed 13 days prior to planting corn
late kill = red clover killed three days prior to planting corn

Table 1 Phosphorous and potasium content and pH of soil sampled from the subirrigated and non-irrigated experiments in fall 1991 and spring 1993.

Experiment	Time of sampling	P†	K	pH
		--- kg/ha	---	
Subirrigated	Fall 1991	115	305	7.5
	Spring 1993	120	260	7.5
Non-irrigated	Fall 1991	155	280	6.8
	Spring 1993	145	230	6.7

† Phosphorous measured as Bray P-1.

Data from a complete cycle of each cropping system were collected from spring 1992 through fall 1993. In this complete cycle, winter wheat was planted in October 1991, and harvested in July 1992, RC was seeded in spring 1992 and killed in spring 1993, and corn was planted after RC kill in May 1993. In addition, data were collected and are presented for corn grown in 1992 and wheat grown in 1993. These two crops were not part of a complete cropping system cycle.

Comparing methods of red clover establishment was not a specific objective of this study. In May 1992 drilling was used to establish a second set of RC plots in each block. It was intended that the two sets of RC plots would be used for the early- and late-kill treatments. However, plant populations in fall 1992 were significantly higher in the FS than DR plots. To avoid confounding the effect of RC kill date with plant population, RC-DR and RC-FS plots were kept separate. Early- and late-kill treatments were established by splitting each RC plot. For statistical analysis, early- and late-kill treatments were treated as whole plots. Red clover-DR and RC-FS data were used to determine effects of kill date.

Each of the two experiments (SI and NI) was a randomized complete block split-plot design with four blocks. Whole plots were cover crop management (no-cover, RC-FS early-kill, RC-FS late-kill, RC-DR early-kill, and RC-

FS late-kill). Four rates of fertilizer N, 0. 70, 140, and 210 kg N ha^{-1}, were applied to corn plots as a split treatment. No-cover plots were 13.4 by 15.2 m, RC plots were 13.4 by 7.6 m. Split plots were 3.35 by 15.2 m for no-cover treatments and 3.35 by 7.6 m for RC treatments.

Crop Management and Sampling

Winter Wheat Wheat (*Triticum aestivium* L. var. 'Frankenmuth') was drilled at 0.17 m row spacing at 200 kg/ha in early October of each year. In the fall of 1991, the entire field was planted with wheat, and wheat growing in plots to be planted with corn was killed by tillage in the spring of 1992. Three wheat plots per replication remained during the 1992 season; one plot was wheat only, red clover was drilled into one plot, and red clover was frost-seeded into the remaining plot. In 1992, all wheat plots were fertilized with 67 kg N/ha applied on June 10, after grain heads had formed. No herbicide was applied to wheat plots. Wheat was harvested on 28 July 1992. Grain yields were determined by sampling three 1-m^2 quadrats from each plot.

For the 1993 growing season, two wheat plots per replication were established; one plot was not interseeded and red clover was frost-seeded into the other plot. In 1993 wheat plots received 28 kg N/ha on October 11, 1992 and 100 kg N/ha on April 11, 1993. No herbicide was applied to wheat plots. On 28 July 1993, wheat grain yields were determined by machine harvesting a 1.15 by 15.2-m strip from each plot.

Red Clover Red Clover (*Trifolium pratense* L. 'medium') was frost-seeded using a fertilizer spreader into one wheat plot per replication on 28 March in 1992. Red clover was drilled into the RC-DR plots on 13 May 1992. Equipment for all seedings was calibrated to apply 16.8 kg seed/hectare. However, in 1992 the fertilizer spreader used to broadcast the seed leaked, and the estimated seeding rate was 22.4 kg seed/ha. Red clover was inoculated with the appropriate inoculant two weeks before planting. At the beginning of the second season of RC growth, early- and late-kill clover treatments were established by splitting each RC plot. The RC early-kill plots in both experiments were sprayed with 3.5 L glyphosate + 2.3 L crop oil concentrate ha^{-1} on 6 May 1993. Glyophosate was also applied to the no-cover treatment in the NI. No herbicide was applied to late-kill plots. In 1992, the entire field was moldboard-plowed on 17 May 1993.

Red clover crops established in the spring of 1992 were sampled after a hard frost and apparent cessation of growth on 17 October 1992. Spring sampling occurred on 4 May and 14 May 1993. The earlier sampling date was two days prior to early-kill, the later sampling date was three days prior to late-kill.

In 1993, RC was frost seeded into one wheat plot per replication on 28 March. Seeding rate for frost-seeded RC was 16.8 kg/ha. Red clover was inoculated with the appropriate inoculant two weeks before planting. Red clover established in the spring of 1993 was sampled after a hard frost and apparent cessation of growth on 17 October 1993.

In both years, RC biomass was sampled by hand-harvesting three 0.33 x 0.33-m quadrats per plot. Plants were excavated to a depth of 0.3 m. Plant herbage and roots-crowns were separated by cutting 3 cm above the crowns. Root-crown samples were washed with tapwater to remove soil. Plant populations were determined by counting the number of plants within each quadrat and are reported as number of plants m^{-2}. All samples were dried at 60°C to constant water content.

<u>Corn</u> Corn (*Zea mays* L. Pioneer cv. 3751) was planted in 55-cm rows at 71,500 seeds/ha on 14 May in 1992 and 20 May in 1993. In both years, weed control was achieved by cultivation. In 1993, hand hoeing augmented machine cultivation. Each year, four rates of ammonium-nitrate granular fertilizer; 0, 70, 140, and 210 kg N ha^{-1}, were applied as a split treatment to all corn plots. Nitrogen fertilizer was broadcast at planting. Corn grain was

harvested from a 6.1 and 4.6-m section of the center two rows in each split plot in 1992 and 1993, respectively. Grain yields were adjusted to 155 g kg^{-1} moisture. Plant populations were determined by counting the number of plants in this yield area and calculating populations on a per hectare basis. Corn stover was sampled by harvesting ten stalks from the yield rows of each subplot. These stalks were weighed, and three stalks were subsampled. Subsamples were dried at 60°C to constant water content. Dried stalks were ground and analyzed for total N. Corn ear-leaves from two (1992) or three (1993) randomly selected plants from each plot in the 0 and 140 kg N ha^{-1} plots were sampled when plants were at silking. Corn ear-leaves were analyzed for N concentration.

Plant Analysis and N Calculation

All wheat, red clover, and corn samples were weighed before and after drying and moisture content was calculated to express yield measurements on a dry matter (DM) basis. After drying, all samples were ground to pass through a 1-mm screen using a cyclone mill. Total N concentration of ground samples was determined by micro-Kjeldahl digestion of 0.100 g plant material in 12 M H_2SO_4 with 1.5 g K_2SO_4 and 0.075 g Se catalyst. Following digestion, total $NH4^+$ in samples was determined by Lachat Quik-Chem Method no. 10-107-06-2-E (Lachat Chemicals, Inc. Mequon, WI). Total N content of materials was calculated as the product of DM content and N concentration.

Red clover plowdown nitrogen (PDN) was calculated according to Griffin and Hesterman (1991) using equation 1:

$$PDN = fall(herbage + root)N + spring\ herbage\ N \quad [1]$$

Grain yield-based FRV of the RC cover crops was calculated by setting the regression equation describing the N fertilizer response of corn grain yield with no-cover equal to the corn grain yield following RC with no N fertilizer applied. The regression equation was then solved for N. The calculated N value equals the FRV. Fertilizer replacement values based on corn grain N content and total plant N content were calculated in a similar manner.

Soil Water Measurements

Volumetric soil water content (VWC) under no-cover and RC-FS early- and late-kill treatments were measured using a Tektronics model 1502B time domain reflectometer [TDR] (Topp and Davis, 1985). For each TDR reading, dielectric constants and associated soil water contents were calculated using equations developed by Topp et al. (1980).

In fall 1992, parallel pair transmission lines (rods) made from 4.96 mm diameter stainless steel were installed vertically, 5 cm apart, to 14.5, 29.5, and 44.5 cm depths in each no-cover and RC-FS late-kill plot. Rods were pushed or hammered into the soil using a wooden frame as a guide. Pairs of rods were placed approximately 10 cm apart from each other. All rod pairs were placed in corn rows. On 1 May 1993 all rods were re-established to proper depth and TDR readings were initiated. On 11 May, four days after RC early-kill, rods were installed in each RC early-kill plot. All rods were removed from the field on 17 May before plowing and corn planting. On 20 May, after corn was planted, rods were reinstalled in the 0 and 210 kg N-rate split plots in corn following three cover crop treatments; no-cover, RC-FS early-kill, and RC-FS late-kill. Because of variability in measurements of VWC in the 14.5 to 29.5 and 29.5 to 44.5-cm soil layers data from these layers were integrated and analyzed as a single soil layer. Results of analysis of data from two soil layers, 0 to 14.5-cm and 14.5 to 44.5-cm, are presented.

Soil Samples

In 1992, soil was sampled from the 0 to 15, 15 to 30, and 30 to 45-cm layers from the 0 and 140 kg N/ha treatments of each corn plot on July 22, October 12, and November 11. In 1993, soil was sampled from the 0 to 15, 15 to 30, and 30 to 45 cm layers from the 0 N-rate corn plots of NC and FS-RC early and late-kill plots on five dates: 14 May, 2 June, 24 June, 20 July, and 12 September. Soil was sampled using a

2.5 cm diameter soil corer. Two or three cores were taken from each plot sampled. Inorganic nitrogen (NH_4^+ and NO_3^-) was extracted from the soil samples by shaking 20 g dry soil in 100 ml of 2 M KCl for one hour. Inorganic N in filtered KCl extracts was assayed colormetrically on a Lachat flow injector analyzer using Lachat QuikChem Method 12-107-04-1-A. Only total inorganic-N data are presented. Soil samples were pooled by treatment across replication prior to analysis, precluding statistical analysis of the data.

Economic Analysis

The net income of each cropping system/N fertilizer combination was calculated by subtracting selected variable costs from gross income. Selected variable costs included the cost of red clover seed, N fertilizer, fertilizer application, operation, maintenance, and depreciation of the subirrigation system. Gross income was calculated by multiplying corn grain yield from each treatment by the 1993 government target price for corn grain. The costs of N fertilizer and fertilizer application were obtained from the Huron County, MI Cooperative Extension Service. The hauling and drying costs are from Schwab, 1994. Shrinking of grain caused by drying was not accounted for. Depreciation cost was calculated by dividing the \$740 ha^{-1} cost of installing the subirrigation system by the 20 year expected life of the system. Operation, maintenance, and installation costs, and expected life of the subirrigation system are from Belcher (1992).

Statistical Analysis

Each of the two experiments (SI and NI) was analyzed as a randomized complete block split-block design with four blocks. Cover crops were whole plots. In 1993, N-rates were applied across early- and late-kill treatments within each RC plot. Because N-rate was not applied as a randomized treatment within each early- and late-kill plot, N-rate was analyzed as a split block treatment. When more than one sub-sample was analyzed, the mean of the sub-samples was used for statistical analysis.

Data was analyzed using analysis of variance (ANOVA). Soil VWC data were analyzed separately by date and soil layer. Comparisons between VWC treatment means were made using the Least Significant Difference test (LSD) (Petersen, 1985) when the ANOVA indicated a significant F ($P < 0.05$). Corn ear-leaf N concentration, grain and stover dry matter, N concentration and N content, and total plant N content means were partitioned using orthogonal contrasts. The contrasts were RC versus no-cover crop and RC early-kill vs RC late-kill. The REG procedure of SAS was used to test the significance of linear and quadratic equations describing the response of corn grain yield, dry matter, and total N content to N fertilizer applied. A t-test was used to compare data from the SI experiment to data from the NI experiment.

RESULTS AND DISCUSSION

Red Clover Biomass and N Content

Interseeding red clover into a standing wheat crop did not significantly affect wheat grain yields or grain N concentration in either the SI or NI experiment (Table 2). These results are similar to results reported by Hesterman et al. (1992), Janke et al. (1987), and Ngalla and Eckart (1987), but contrast with Brandt et al. (1989) who reported that interseeding subterranean clover into winter wheat had a significant effect upon wheat grain yield. Results reported by Brandt et al. (1989) may have been due to either not fertilizing the wheat or aggressive growth of the interseeded legume. The data reported here corroborate the conclusion reached by Hesterman et al. (1992), that interseeding a small seeded forage legume into a standing small grain crop may be an effective method of incorporating a legume cover crop into a rotation without sacrificing a revenue-producing grain crop during the establishment phase.

Killing RC early limited the quantity of N accumulated in RC shoots by as much as 70 kg ha^{-1} (Table 3). Lower spring RC shoot N content resulted in significantly and near-significantly ($P<0.07$) lower PDN in the early- compared

Table 2 Grain dry matter yield and N concentration of wheat grown with and without interseeded red clover (RC)[†] in subirrigated and non-irrigated experiments in 1992 and 1993.

Experiment	Seeded	1992 DM	1992 N	1993 DM	1993 N
		Mg/ha	%	Mg/ha	%
Subirrigated	Without RC	2.2	2.1	7.0	1.6
	With RC	2.4	1.9	7.7[*]	1.5
	Significance	NS	NS	NS	NS
	CV(%)	10.6	6.2	10.4	4.6
Non-irrigated	Without RC	2.6	1.8	7.3	1.6
	With RC	2.3	1.6	6.7	1.6
	Significance	NS	NS	NS	NS
	CV(%)	10.9	8.4	5.4	2.5

[†] Red clover was frost-seeded on 28 March in 1992 and 1993.
[*] Significant difference (t-test, $P<0.05$) between subirrigated and non-irrigated experiments.

Table 3 Effect of seeding method and time of kill on red clover plant population, shoot and root N content in fall, 1992, and shoot and root dry matter, N concentration, and N content in spring 1993, and calculated plowdown N (PDN)[1] for subirrigated and non-irrigated experiments.

				Fall, 1992		Spring, 1993						
				Shoots	Roots	Shoots			Roots			
Experiment	Seeding Method	Time of Kill	Plant population*	Total N	Total N	DM	N	N Uptake	DM	N	N Uptake	PDN
			plants/m^2	kg/ha	kg/ha	Mg/ha	%	kg/ha	Mg/ha	%	kg/ha	kg/ha
Subirrigated												
	Frost Seeded	early	260	143	51	1.0	4.2	42	1.2	3.1	36	235
		late	-	-	--	3.1	3.6	111	1.5	2.5	37	305
	Drilled	early	120	122	46	1.9	4.1	78	1.6	3.2	51	248
		late	-	-	--	3.3	3.8	123	1.7	2.5	43	291
	Significance											
		Seeding method	**	ns	ns	ns	ns	*	*	ns	*	ns
		Time of kill	--	--	--	***	**	***	ns	***	ns	**
		CV (%)	37	12.3	28.8	24.6	5.3	24.0	14.8	5.1	17.8	9.0
Non-Irrigated												
	Frost Seeded	early	245	128	58	1.5	4.2	62	1.5	2.9	42	243
		late	-	-	--	3.0	3.7	111	1.4	2.4	35	297
	Drilled	early	81	138	54	2.4	4.1	98	1.8	3.2	57	293
		late	-	-	--	3.6	3.7	134	1.6	2.5	40	328
	Significance											
		Seeding method	***	ns	ns	ns	ns	ns	ns	ns	ns	ns
		Time of kill	--	--	--	**	**	**	ns	***	*	ns
		CV (%)	43	18.2	23.0	26.1	5.1	25.6	22.5	8.1	21	15.1

*, **, *** Significant at the 0.05, 0.01, and 0.001 levels, respectively.

[1] Plowdown N was calculated as N content in fall(shoots + roots) + spring shoots.

to late-kill RC system in the SI and NI experiments, respectively. However, timing of RC kill did not significantly affect corn ear-leaf N concentrations in 1993 (Table 4), or corn grain yield and grain N content (Table 5 and 6) in 1993 suggesting that kill date did not affect the N available to the succeeding corn crop. Wagger (1989) also reported no effect of cover crop kill date on the yield and N status of a following corn crop. Possible reasons that lower PDN may not have resulted in less N being available to the succeeding corn crop are (i) more N was immobilized by microbial activity in the late- than early-kill system, (ii) more N was leached from the late- than early-kill system, (iii) changes in RC chemical composition resulting from advanced maturity resulted in late-kill RC to be more resistant to decomposition and N contained in the late-kill RC to be less available than N contained in early-kill RC (Wagger, 1989), and (iv) the higher N content of late-kill RC shoots may have resulted from uptake of soil N rather than biologically fixed atmospheric N (Rice, 1980). That early-kill did not limit the amount of N available to the succeeding corn crop suggests that, in systems where a cover crop accumulates the majority of N the season before incorporation, there may be a large range in the period of time during which a cover crop could be killed without limiting the N available from that cover crop. These results are in contrast to warnings made by several

Table 4 Effect of N fertilizer (1992) and cover crop/N fertilizer combinations (1993) on corn ear-leaf N concentration in the subirrigated and non-irrigated experiments.

Experiment	Cover crop	N-rate	N concentration 1992	1993
		kg/ha	-------- % N	-------
Subirrigated	No-cover	0	1.32	1.27[‡]
		140	2.43	2.54
	RC-early[†]	0	--	2.42
		140	--	2.81
	RC-late	0	--	2.43
		140	--	2.89
	Significance			
	No-cover vs RC		--	***
	RC-early vs -late		--	NS
	N-rate		***	***
	(No-cover vs RC) x Nrate		--	**
	CV (%)		4.9	9.8
Non-irrigated	no-cover	0	1.27	1.50
		140	2.40	2.61
	RC-early	0	--	2.48
		140	--	2.75
	RC-late	0	--	2.30
		140	--	2.78
	Significance			
	No-cover vs RC		--	***
	RC-early vs -late		--	NS
	N-rate		***	***
	(No-cover vs RC) x Nrate		--	***
	CV (%)		4.3	5.2

, * Significant at the 0.01 and 0.001 levels, respectively.

† Red clover (RC) was frost seeded. RC-early was sprayed with glyphosate 13 days before planting corn. Both RC-early and RC-late were moldboard plowed on 17 May 1993, three days before planting corn.

‡ Significant ($P<0.05$, determined by t-test) difference between subirrigated and non-irrigated experiment.

Table 5 Effect of cover crop treatment and N fertilizer on corn grain and stover dry matter, N concentration, and N content, and total N in above ground biomass at harvest for the subirrigated experiment in 1993.

Cover crop[‡]	N-rate	Grain			Stover			Plant N
		DM	N	N	DM	N	N	
	kg/ha	Mg/ha	%	kg/ha	Mg/ha	%	kg/ha	kg/ha
no-cover	0	3.6	1.2	37	4.5	0.42†	19†	56
	70	6.6	1.0	57	5.7†	0.50†	29	86
	140	8.6	1.1	80	5.8	0.77	41	121
	210	10.4	1.2	105	5.8	0.66	41	145
RC-FS early	0	8.5	1.3	91	6.1	0.61	39	132
	70	9.6	1.4	112	5.5†	0.75	41	152
	140	11.5	1.4	134	7.5	0.82	60	194
	210	10.5	1.3	113	6.3	0.81	50	164
RC-FS late	0	8.4	1.4	99	6.4†	0.76	48	147
	70	10.4	1.3	116	6.0	0.72	44	159
	140	10.9	1.4	126	6.7	0.88	59†	185†
	210	11.3	1.2	117	8.2	0.70	59	176
RC-DR early	0	8.2	1.1	79	6.2	0.82	50	129
	70	10.1	1.3	114	5.9	0.61	36	150
	140	10.0	1.4	115	5.9	0.80	47	161
	210	10.2	1.3	115	6.1	0.86	52	167
RC-DR late	0	8.6	1.3	94	6.6†	0.67	45	139
	70	10.5	1.3	118	7.0	0.85	61	179
	140	9.6	1.2	101	6.1	0.76	45	147
	210	11.1	1.3	126	8.4†	0.82	70	195
Significance								
N-rate		*	NS	NS	NS	NS	NS	NS
no-cover vs RC		***	**	***	NS	NS	NS	*
RC-E vs RC-L		NS	NS	NS	NS	NS	NS	NS
N-rate X cover crop		*	NS	*	NS	NS	NS	NS
CV (%)		13	11	15	19	19	26	15
LSD for cover crops[§]		0.6	0.11	16	--	--	--	50
LSD for N-rates[¶]		1.4	0.28	38	--	--	--	56

*, **, *** Significant at the 0.05, 0.01, and 0.0001 levels, respectively.

† Significant difference (t-test, P<0.5) between subirrigated and non-irrigated experiments, compared within a treatment.

‡ RC-FS, RC-DR stand for red clover frost seeded and drilled into winter wheat, respectively. Early kill was sprayed with glyphosate 13 days before planting corn. Both early- and late kill were moldboard plowed on 17 May, 3 days before planting corn.

§ Least significant difference to compare cover crop treatment means within a N-rate.

¶ Least significant difference to compare N-rate means within a cover crop treatment.

Table 6 Effect of cover crop treatment and N fertilizer on corn grain and stover dry matter, N concentration, and N content, and total N in above ground biomass at harvest for the non-irrigated experiment in 1993.

Cover crop[‡]	N-rate	Grain DM	Grain N	Grain N	Stover DM	Stover N	Stover N	Plant N
	kg/ha	Mg/ha	%	kg/ha	Mg/ha	%	kg/ha	kg/ha
no-cover	0	4.8	0.95	46	4.2	0.72[†]	30[†]	76
	70	7.2	0.91	65	4.2[†]	0.76[†]	32	98
	140	9.6	1.02	99	4.9	0.82	40	139
	210	9.5	1.16	111	5.0	0.67	33	144
RC-FS early	0	9.2	1.10	100	4.1	0.81	33	133
	70	9.9	1.18	116	5.3[†]	0.76	41	156
	140	10.6	1.10	115	6.3	0.72	46	162
	210	9.9	1.15	114	5.5	0.83	46	160
RC-FS late	0	9.2	1.16	107	4.7[†]	0.91	43	150
	70	10.5	1.14	119	5.0	0.72	36	155
	140	10.0	1.09	110	5.1	0.73	37[†]	146[†]
	210	11.1	1.12	124	5.2	0.86	45	169
RC-DR early	0	8.8	1.07	95	5.1	0.60	31	124
	70	9.3	1.10	104	5.5	0.74[†]	40	144
	140	9.8	1.18	116	5.3	0.82	42	158
	210	9.2	1.07	99	5.2	0.97	50	150
RC-DR late	0	8.4	1.04	88	5.2[†]	0.72	37	125
	70	9.5	1.09	105	5.1	0.78	41	145
	140	9.9	1.14	114	5.5	0.83	46	159
	210	10.5	1.08	114	5.1[†]	0.80	41	154
Significance								
N-rate		NS	NS	NS	NS	NS	NS	NS
no-cover vs RC		NS	NS	NS	NS	NS	NS	NS
RC-E vs RC-L		NS	NS	NS	NS	NS	NS	NS
N-rate X cover crop		***	NS	**	NS	NS	NS	NS
CV(%)		10	9	14	17	19	28	12
LSD for cover crops[§]		2.2	--	28	--	--	--	--
LSD for N-rates[¶]		2.0	--	35	--	--	--	--

*, **, *** Significant at the 0.05, 0.01, and 0.0001 levels, respectively.

† Significant difference (t-test, P<0.5) between subirrigated and non-irrigated experiments, compared within a treatment.

‡ RC-FS, RC-DR stand for red clover frost seeded and drilled into winter wheat, respectively. Early kill was sprayed with glyphosate 13 days before planting corn. Both early- and late kill were moldboard plowed on 17 May, 3 days before planting corn.

§ LSD to compare cover crop treatment means within a N-rate.

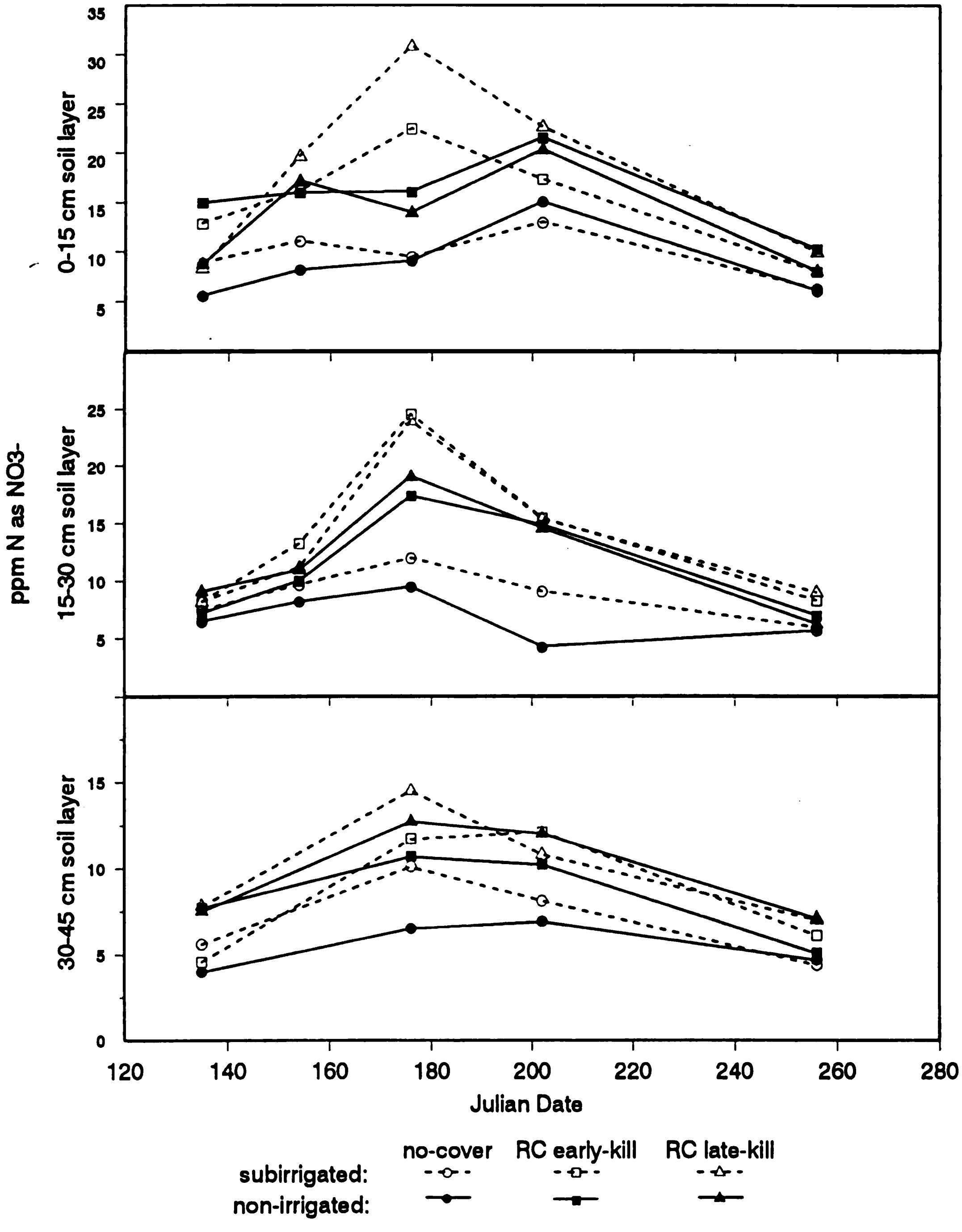
¶ LSD to compare N-rate means within a cover crop treatment.

researchers (Ebalhar et al., 1984; Ngalla and Eckert, 1987) that early kill of a cover crop may limit the N benefit derived from that cover crop.

Soil N Content

Nitrate-N concentrations of soil sampled on 14 May (Julian date 135), prior to RC incorporation, from the 0 to 15 cm layer of the RC-FS early-kill, RC-FS late-kill and no-cover plots were 15, 8.8, and 5.6 ppm, respectively, in the SI experiment, and 12.9, 8.4, and 8.9 ppm, respectively, in the NI experiment (Figure 3). The higher nitrate-N concentrations in the RC early-kill indicate that N in the early-kill RC began to be mineralized prior to the time corn was planted (Figure 3). Although earlier mineralization of early-killed cover crops may increase the potential for N to leach from the system, in this study increased inorganic concentrations were measured in only the surface 0 to 15 cm layer. Similarly, Sarrantonio and Scott (1988) found N from legume cover crops was mineralized within 7 days of killing but that the N remained in the surface soil layer. Prior to incorporating the cover crops, inorganic N concentrations were similar in the late-kill RC and no-cover systems.

Nitrate-N concentration in soil sampled from the 0 to 15 and 15 to 30 cm layers from early- and late-kill RC systems on 24 June were 17 and 17 ppm respectively, in the SI experiment, and 24 and 28 ppm, respectively in the NI



1 Early-kill RC was sprayed with glyphosate 13 days before corn planting. Both early- and late-kill RC were moldboard plowed on 17 May, three days before planting corn.

Figure 3 Nitrate-N concentrations of soil sampled between 14 May and 12 September 1993 from 0 to 15, 15 to 30, and 30 to 45 cm soil layers of corn following no cover crop and early- and late-kill[1] frost seeded red clover cover crops with no N fertilizer applied in the subirrigated and non-irrigated experiments.

experiment. In the SI experiment, nitrate-N concentrations from the RC 0 N-rate systems were lower than the 21 ppm pre-sidedress soil nitrate test critical level. Corn grain yields (Table 5) from the RC-FS early- and late-kill 0 N-rate plots in the SI experiment were significantly lower than yields from the fertilized plots (Table 5). Nitrate-N concentration in soil from the NI experiment exceeded the pre-sidedress soil nitrate test critical level of 21 ppm (Fox et al., 1989; Bundy and Andrasski, 1993), indicating that in both early- and late-kill RC systems there was no need for additional fertilizer to be applied to the corn crop. In the NI experiment, corn grain yields from RC-FS early- and late-kill 0 N-rate systems were not significantly lower than grain yields from the fertilized plots (Table 6). In the no-cover systems soil nitrate-N concentrations were 9 ppm in both SI and NI experiments. In both experiments, corn grain yields from the no-cover systems responded significantly to fertilizer N. In this study, the 21 ppm nitrate-N critical level was an effective predictor of the availability of soil N to corn grown in both legume- and fertilizer-N based cropping systems.

<u>Corn Dry Matter and N Yield and Legume N Contribution</u>

In 1992, ear-leaves from corn grown with 140 kg N ha^{-1} had significantly higher N concentrations than ear-leaves sampled from corn that was not fertilized (Table 4). In

1993, N-rate significantly affected the N concentration of ear-leaves from corn grown in both the no-cover and RC-FS systems (Table 4). Time of RC kill did not significantly affect ear-leaf N concentration in any case. The significant interactions between cover crop and N-rate reported for both experiments are a result of the greater response of ear-leaf N concentration to N fertilizer in the no-cover than in the RC systems.

Corn ear-leaf N concentration has been reported by several researchers as a means of assessing the N status of corn (James et al., 1967; Melsted et al., 1969; Asghari and Hanson, 1984; Cerrato and Blackmer, 1991). Reported corn ear-leaf N concentrations at which grain yield is maximized (the critical level) are generally above 2.75% (James et al., 1967; Asghari and Hanson, 1984; Melstead et al. 1969). Some researchers have suggested that a corn ear-leaf N concentration of 2.75% overestimates the quantity of N necessary to achieve maximum yield (Cerrato and Blackmer, 1991) while data from Asghari and Hanson (1984) suggest that critical values may be difficult to determine for legume-N based systems. In the SI experiment in this study, maximum corn grain yields (Table 5) were not obtained when corn earleaf N concentration was below 2.75% (Table 4), suggesting the 2.75% critical level was appropriate. In the NI experiment corn earleaf N concentrations from the no-cover 140 kg N ha^{-1} N-rate and RC-FS 0 N-rate systems were below the 2.75% critical level (Table 4) but corn grain yields from these systems were not significantly different from maximum yields (Table 6), suggesting that the 2.75% critical level was too high.

The response of corn grain dry matter and grain N content, and total N in above ground biomass at harvest to fertilizer N-rate in 1992 indicate that available soil N limited corn growth (Figures 4, 5, and 6, respectively, and Table 7). Corn grain dry matter in the SI experiment in 1992 was not different with 210 compared to 140 kg N ha^{-1} applied (Table 8). In contrast, grain N content and total plant N were higher with 210 kg N ha^{-1} than with 140 kg N ha^{-1} applied. Greater response of grain N (Hargrove, 1986, Hesterman et al., 1992) and total plant N content (Hesterman et al., 1992) reflect the greater sensitivity of these parameters to available N.

In the SI experiment in 1993 there was a highly significant difference in corn grain yield and grain N content between no-cover and RC systems but no difference between early- and late-kill RC systems (Table 5). The significant N-rate by cover crop interaction for corn grain dry matter yield and N content in the SI experiment reflects the greater response of corn grain to fertilizer N in the no-cover system than the RC systems (Figure 7 and 8, respectively, and Table 7). Total plant N was not significantly affected by N-rate (Figure 9 and Table 7) but was significantly higher in the RC systems than in the no-cover system.

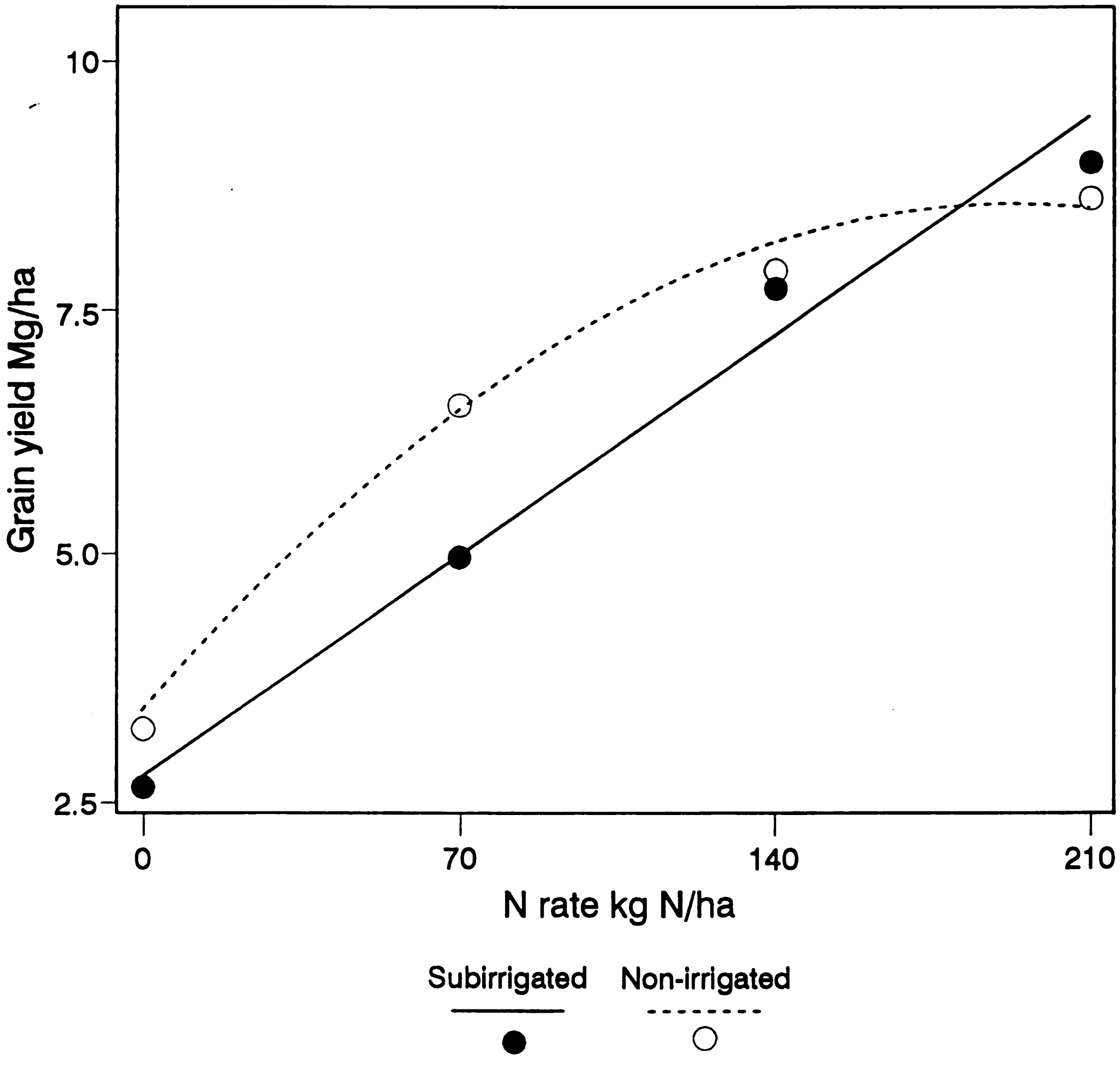


Figure 4 Corn grain yield response to fertilizer N in subirrigated (SI) and non-irrigated (NI) experiments in 1992. Plotted points are means of six replications for the SI experiment and eight replications for the NI experiment.

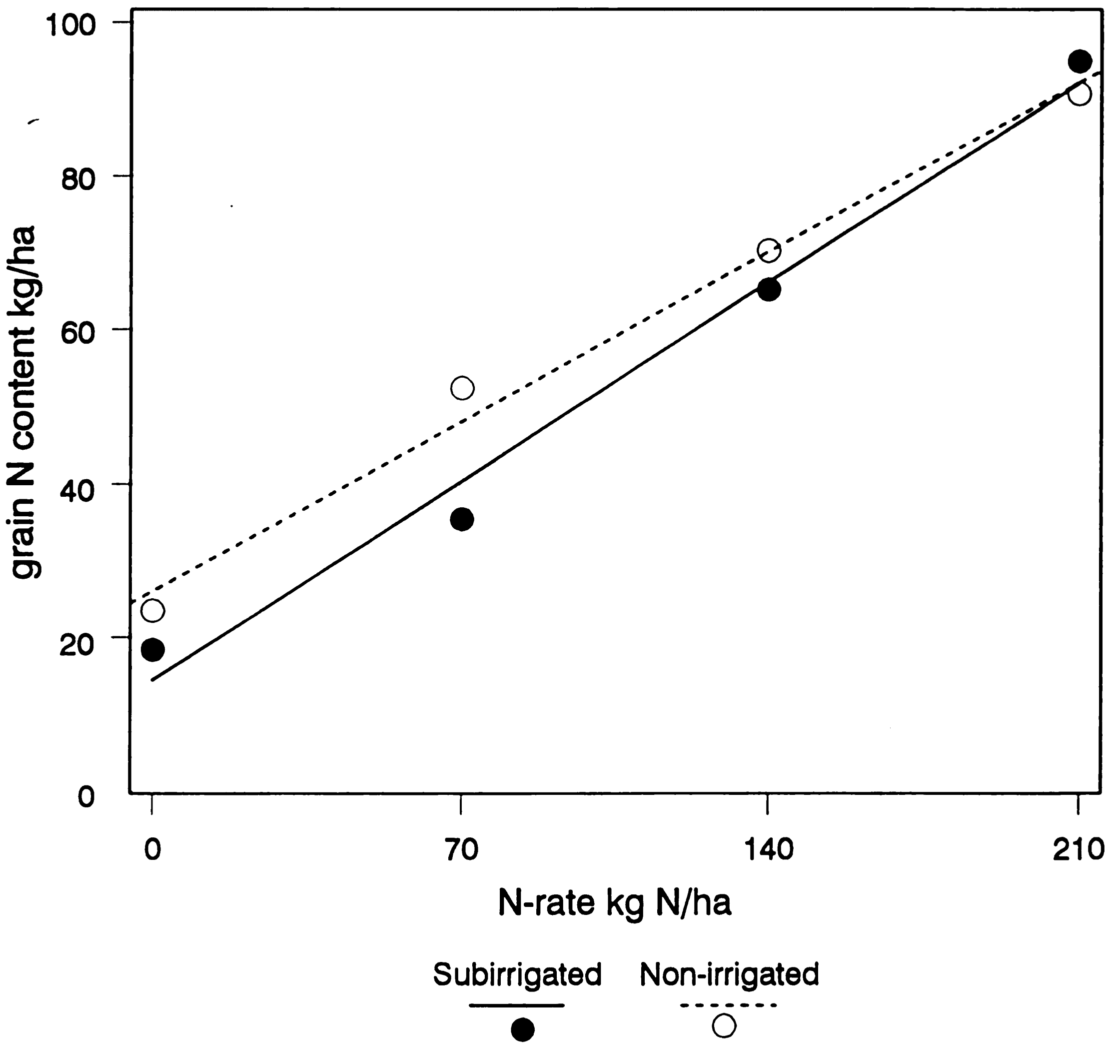


Figure 5 Corn grain N content reponse to fertilizer N in subirrigated (SI) and non-irrigated (NI) experiments in 1992. Plotted points are the means of six replications for the SI experiment and eight replications for the NI experiment.

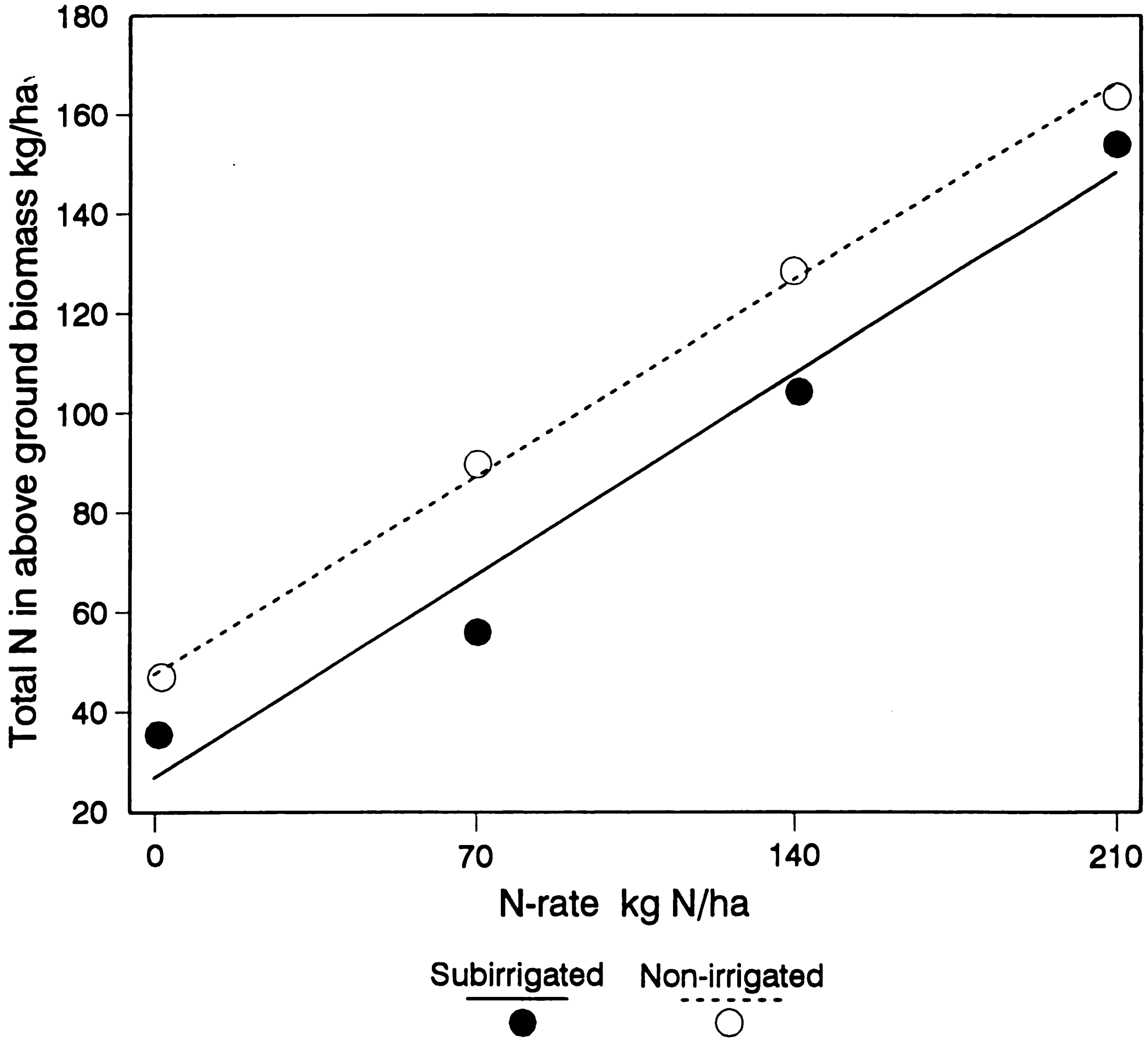


Figure 6 Total N in above ground biomass at harvest response to fertilizer N in subirrigated (SI) and non-irrigated (NI) experiments in 1992. Plotted points are the means of six replications in the SI experiment and eight replications in the NI experiment.

Table 7 Regression equations for corn grain yield (GR), grain N content (GRN), and total N in aboveground biomass at harvest (TN) as a function of N fertilizer applied (x) for the subirrigated and non-irrigated experiments during 1992 and 1993.

Experiment	Year	Cover Crop	Equation	R^2	Significance
Subirrigated					
	1992	No-cover	GR = $2.7 + .032(x)$	0.88	.0001
			GRN = $14 + 0.37(x)$	0.90	.0001
			TN = $27 + 0.58(x)$	0.83	.0001
	1993	No-cover	GR = $4.0 + .031(x)$	0.67	.0001
			GRN = $30 + 0.28(x)$	0.66	.0001
			TN = $56 + 0.44(x)$	0.72	.0001
		RC-DR-early	GRN = $68 + 0.45\ (x) - 0.0017(x^2)$	0.63	.0015
		RC-DR-late	GRN =		NS
		RC-FS-early	GRN = $76 + 0.48(x) - 0.0018(x^2)$	0.61	.0022
		RC-FS-late	GRN =		NS
		RC combined†	GR = $8.5 + .026(x) - 7.3*10^{-5}(x^2)$	0.50	.0001
			TN = $142 + 0.18(x)$	0.25	.0001
Non-Irrigated					
	1992	No-cover	GR = $3.4 + .053(x) - .00014(x^2)$	0.83	.0001
			GRN = $26 + 0.31(x)$	0.87	.0001
			TN = $48 + 0.57(x)$	0.86	.0001
	1993	No-cover	GR = $4.7 + .052(x) - .00013(x^2)$	0.88	.0001
			GRN = $39 + 0.27(x)$	0.86	.0001
			TN = $77 + 0.35(x)$	0.80	.0001
		RC combined	GR = $9.1 + .060(x)$	0.17	.0006
			GRN = $86 + 0.06(x)$	0.12	.0054
			TN = $137 + 0.117(x)$	0.21	.0002

† RC combined represents frost seeded and drilled early and late kill red clover, except for GRN in the subirrigated experiment in which RC drilled early kill (RC-DR-early) in which grain yield was significantly lower than when corn follwoed other covers. There were no significant differences between any of the red clover cover crop systems at any N rates for GRN or TN.

Table 8 Effect of N fertilizer on corn grain and stover dry matter, N concentration, and N content, and total N in above ground biomass at harvest for the subirrigated and non-irrigated experiments in 1992.

Experiment	N-rate	Grain			Stover			Plant N
		DM	N	N	DM	N	N	
	kg/ha	Mg/ha	%	kg/ha	Mg/ha	%	kg/ha	kg/ha
Subirrigated								
	0	2.6	0.9‡	22	4.3	.37‡	16	38
	70	4.9	0.9†	42‡	6.6	.35‡	23	60‡
	140	7.8	1.0	77	7.3	.47	28	109†
	210	9.1	1.2	112	7.7	.66	43	164
Significance								
N-rate		***	***	***	***	***	*	***
CV (%)		16	6.1	19	11	15	21	18
LSD		1.8	0.1	15	1.3	.01	9	24
Non-irrigated								
	0	3.3	0.9‡	28	4.5	.43‡	19	44
	70	6.7	0.9†	62‡	6.6	.43‡	30	92‡
	140	8.0	1.0	83	8.1	.55	45	128†
	210	8.6	1.3	107	7.7	.83	64	164
Significance								
N-rate		***	***	***	***	***	***	***
C.V.(%)		15	7.5	18	15	20	27	13
LSD		1.6	0.1	14	1.6	0.18	11	14

*,*** Significant at 0.05, 0.001 probability levels, respectively, NS = not significant at P=0.05.

†, ‡ Significant difference at 0.05, 0.01 probability levels (t-test) between subirrigated and non-irrirrigated experiments.

In the NI experiment in 1993 there was a highly significant N-rate by cover crop interaction for corn grain yield and grain N content (Table 6). This interaction reflects the significant response of grain yield to fertilizer N in the no-cover system and the lack of response where corn followed RC (Figure 7 and 8, Table 7). Asghari and Hanson (1984b), Hargrove (1986), and Hesterman et al. (1992) all reported no response of yields from grain crops when those crops followed a legume. The lack of yield response is most likely a result of the RC contributing sufficient N to supply the N demand of the corn crop. In the NI experiment, total plant N was not significantly affected by N-rate or cropping system (Table 6 and Figure 9).

In 1993, corn grain yield, grain N content, and total N differed significantly between corn grown in the no-cover crop system and corn grown in the RC systems where no fertilizer N was applied, allowing FRV of the red clover to be calculated based on each of these parameters. Fertilizer replacement values based on grain yield are more commonly reported (Baldock et al. 1981, Ebalhar et al. 1984, Hesterman et al. 1986) but FRV based on grain N content (Hargrove, 1986, Hesterman et al., 1992) or total plant N (Hesterman et al. 1992) may be more sensitive to N available from a cover crop. There were no consistent patterns relating FRVs to RC seeding method or kill date (Table 9).

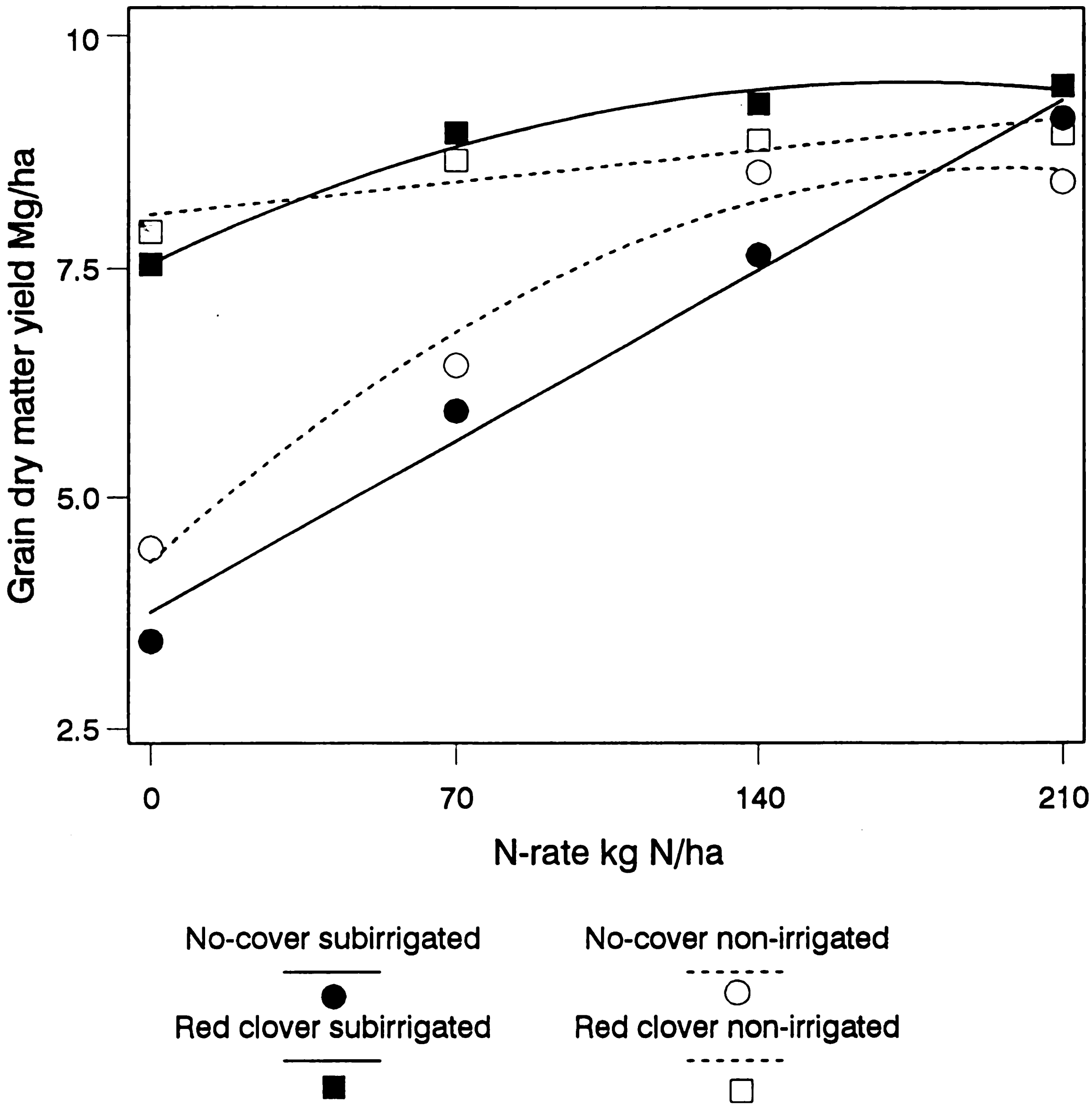


Figure 7 Corn grain yield response to fertilizer N in subirrigated and non-irrigated experiments, 1993. Corn followed either no-cover crop or red clover cover crop. Plotted points of red clover are means of early- and late-kill, drilled and frost seeded treatments. No-cover crop points are means of four replications.

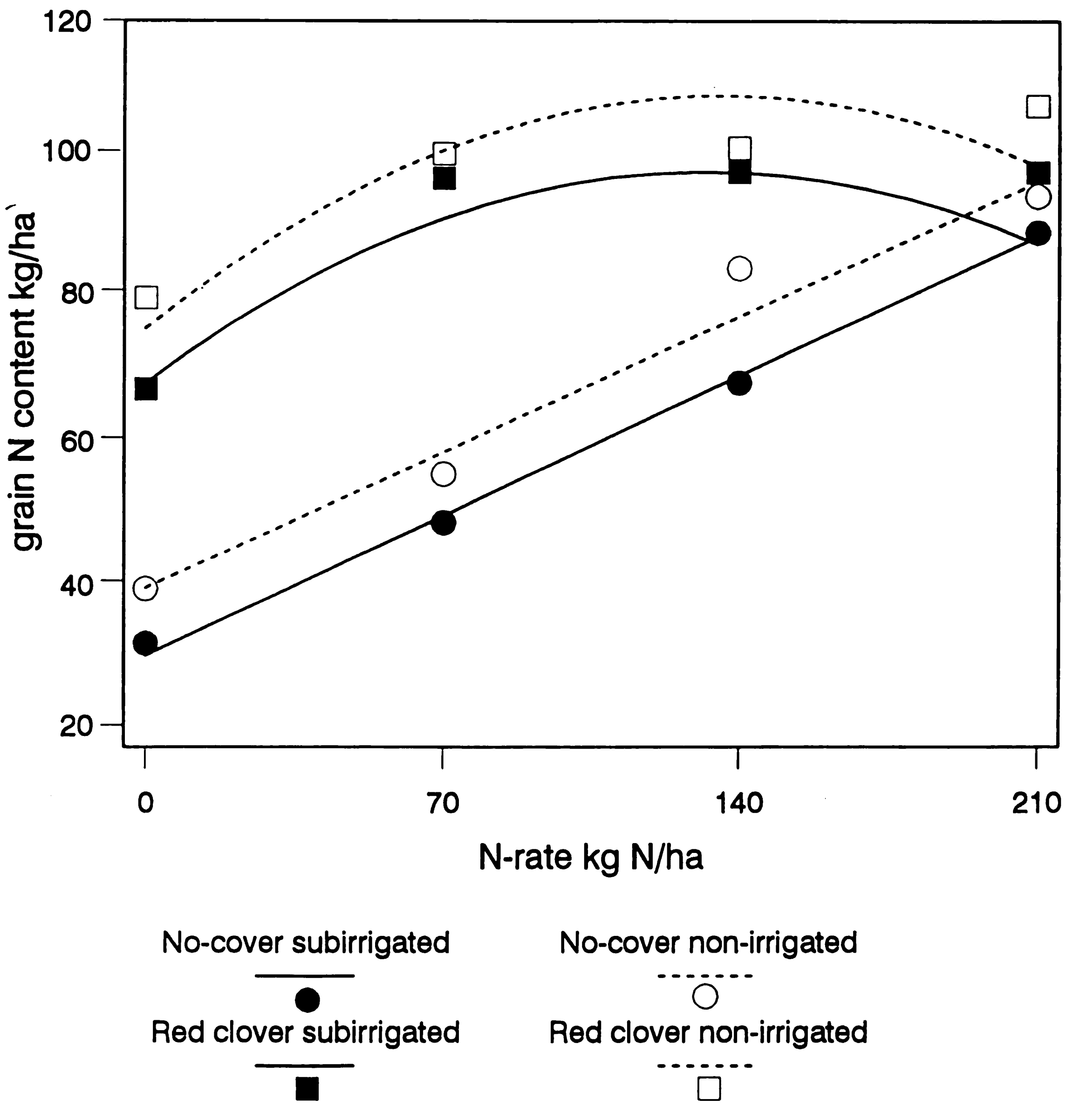


Figure 8 Corn grain N content response to fertilizer N in subirrigated and non-irrigated experiments, 1993. Corn followed either no-cover crop or red clover cover crop. Plotted points for red clover are means of early- and late-kill, drilled and frost seeded treatments. No-cover crop points are means of four replications.

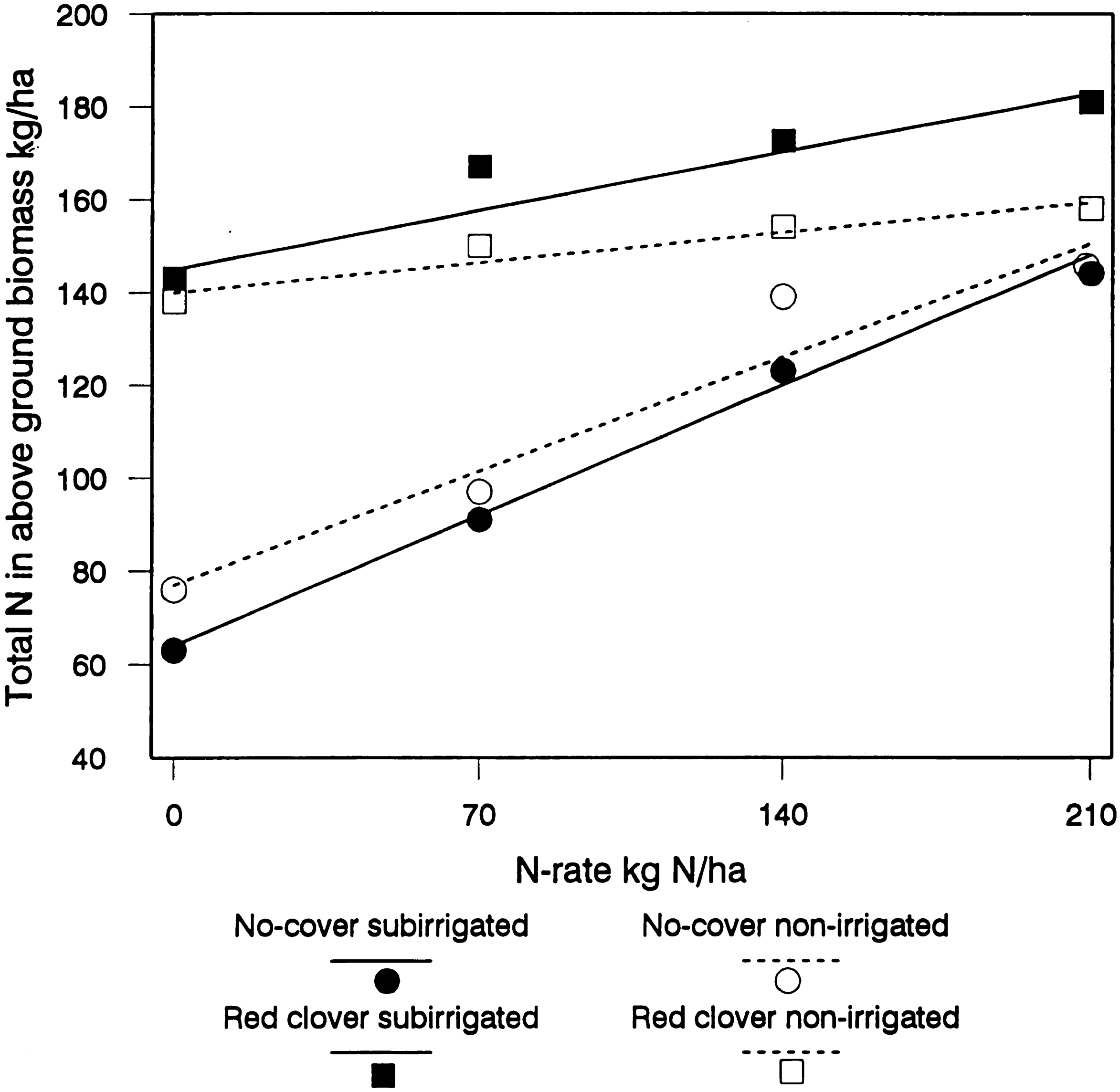


Figure 9 Nitrogen in above ground corn biomass at harvest response to fertilizer N in subirrigated and non-irrigated experiments in 1993. Corn followed either no-cover or red clover cover crop. Plotted points for red clover are means of early-and late-killed, drilled and frost seeded treatments. No-cover crop points are means of four replications.

Table 9 Fertilizer replacement values of red clover cover crops in 1993 based on corn grain yield, grain N content, and total plant N content at harvest.

Red clover Management[†]	FRV based on:	Subirrigated experiment			Non-irrigated experiment		
		Grain Yield	Grain N Content	Total Plant N	Grain Yield	Grain N Content	Total Plant N
		kg N/ha					
FS early-kill		146	170	175	131	186	167
FS late-kill		142	194	223	138	205	167
DR early-kill		138	133	148	114	173	155
DR late-kill		150	179	168	95	154	144
early-kill mean		142	152	162	123	180	162
late-kill mean		146	187	196	117	180	156
Significance							
Early- vs late-kill		NS	*	NS	NS	NS	NS

† FS, DR stand for red clover frost seeded and drilled into wheat, respectively. Early kill was sprayed with glyphosate 13 days before planting corn. Both early- and late-kill were molboard plowed on 17 May, 3 days before planting corn.
* Significant at 0.05 probablity level.

The lower FRVs from the NI experiment are a result of higher grain yields from the no-cover system in the NI than in the SI experiment.

The effect of subirrigation on corn grain yield and N uptake were similar for the no-cover systems in both 1992 and 1993. At lower N rates, corn grain yield, N content, and total plant N were consistently lower in the SI than the NI system (Tables 5 and 6), suggesting either a loss of N from or lower N availability in the SI system. Decreased corn grain yield and N concentration were reported by Chaudhary et al. (1975) when water table depths were at 60 or 90 cm compared to 120 cm depths and by Woodruff et al. (1984) when water tables depths were 0.70 m or less. Measured water table depths in the SI experiment in this study varied between 0.38 m and 1.1 m in 1992 (Figure 1) and 0.45 and 1.1 m in 1993 (Figure 2). Woodruff et al. (1984) concluded that less N was available to corn with higher water table depths due to loss of N from denitrification or leaching.

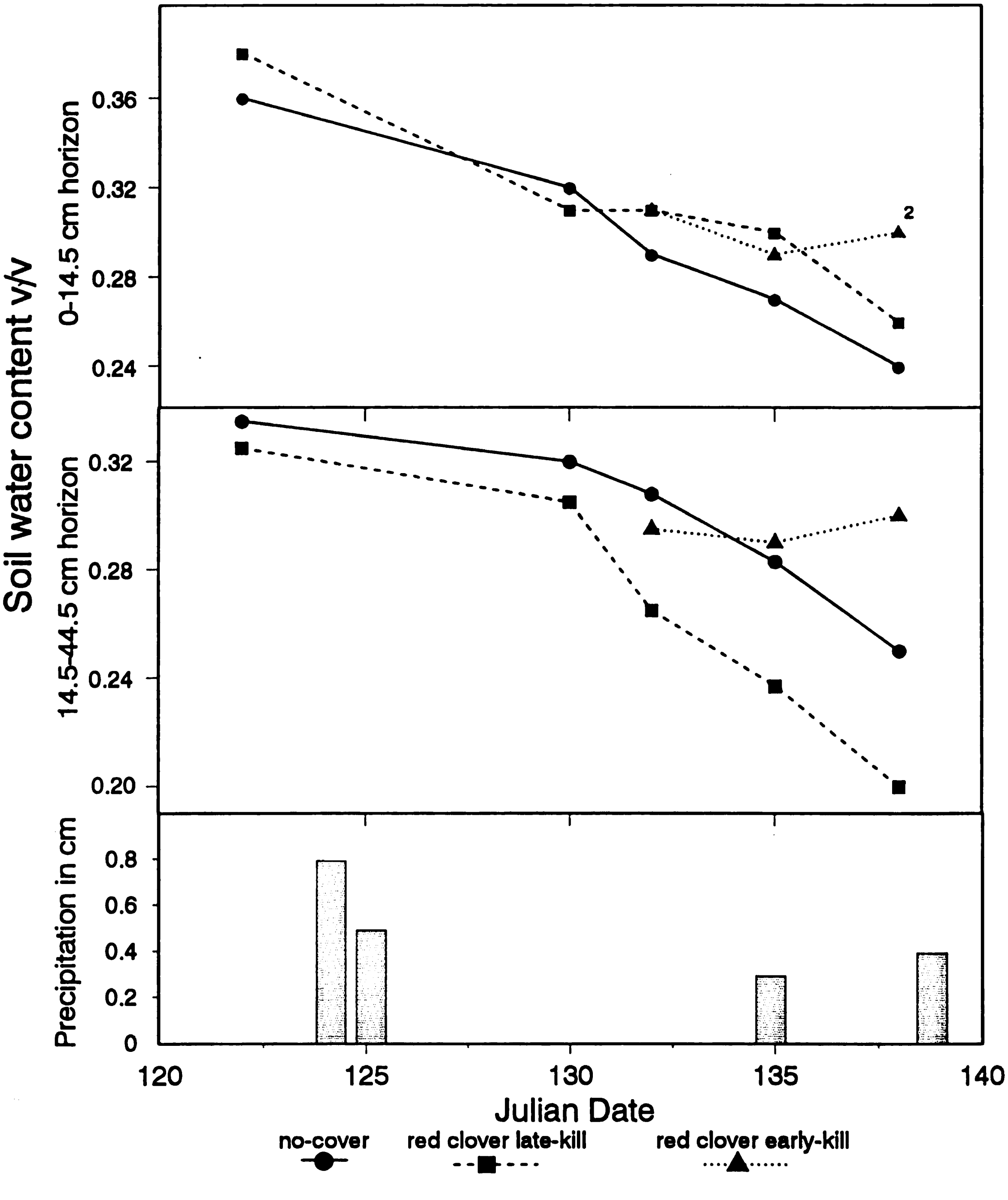
In the RC systems in 1993 corn grain yields and corn grain N content differed little between the SI and NI systems (Table 5 and 6). Chieng et al. (1987) also reported little effect of subirrigation upon corn grain yields. These results contrast with the 26% increase in corn yields averaged across 16 year/locations reported by Belcher (1992); although, during some years yield increases reported by Belcher were minor. Higher grain yields may not have occurred in the SI experiment in this study due to precipitation and soil storage supplying sufficient water for corn to obtain maximum grain yields in the NI experiment.

Corn stover yields were consistently higher in the SI than the NI system (Tables 5 and 6). Higher stover yields are evidence of greater above ground vegetative growth in the SI experiment. It is possible that the greater above ground growth in the SI experiment resulted from a more consistent water supply or to less partitioning of C to below ground growth.

In 1992, corn plant population means were 66,500 and 67,500 plants ha^{-1} in the SI and NI experiments, respectively. In 1993, corn plant population means were 63,000 and 62,900 plants ha^{-1} in the SI and NI experiments, respectively. Fertilizer N-rate did not have a significant affect on plant population in either experiment in 1992 or 1993.

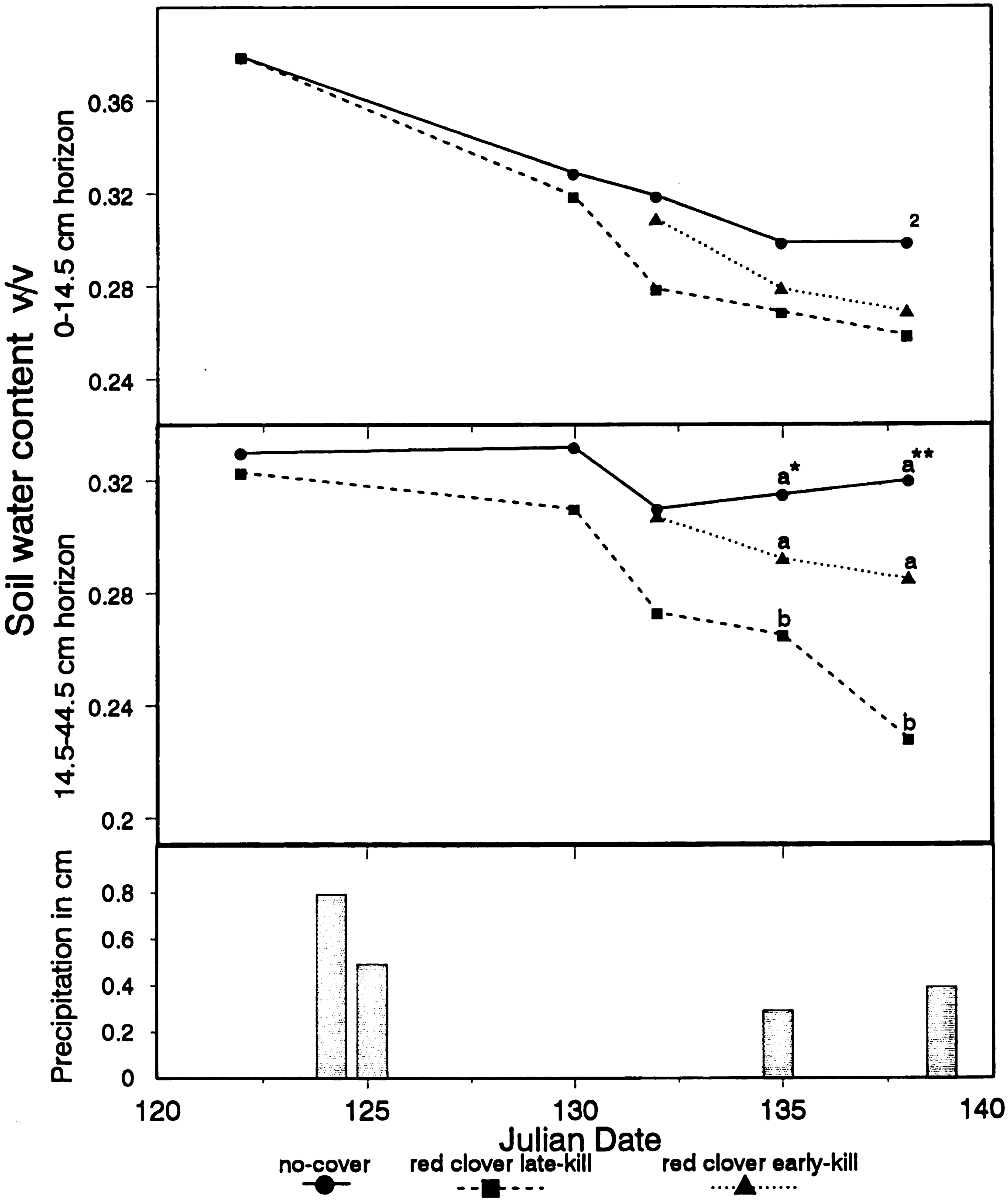
Soil Water Content

Prior to cover crop incorporation (Julian date 138), there was a tendency for soil water content to be lower in the RC late-kill plots than in either the RC early-kill or no-cover plots, particularly in the lower soil layer (Figures 10 and 11). Water content in the surface soil layer of the RC plots may not have been significantly less than VWC in the no-cove plots due to greater water evaporation from the



1 Red clover was frost seeded. Red clover early-kill was sprayed with glyphosate on 7 May. The field was moldboard plowed on 17 May (Julian date 137).
2 Only one measurement for no-cover, mean of two measurements for red clover at each horizon on this date.

Figure 10 Volumetric soil water content in the 0 to 14.5 and 14.5 to 44.5 cm soil layers for no-cover, red clover early-kill, and red clover late-kill cover crop treatments[1] and daily precipitation between 1 May and 19 May 1993 in the subirrigated experiment. Each point is the mean of four measurements, unless noted otherwise.



1 Red clover was frost seeded. Red clover early-kill was sprayed with glyphosate on 7 May. The field was moldboard plowed on 17 May (Julian date 137).
2 Mean of three measurements at each horizon for no-cover on this date.
*, ** Data points labeled with the same letter within each sampling date and horizon are not significantly different at P=0.10 and 0.05, respectively, according to pairwise comparisons using Fisher's LSD.

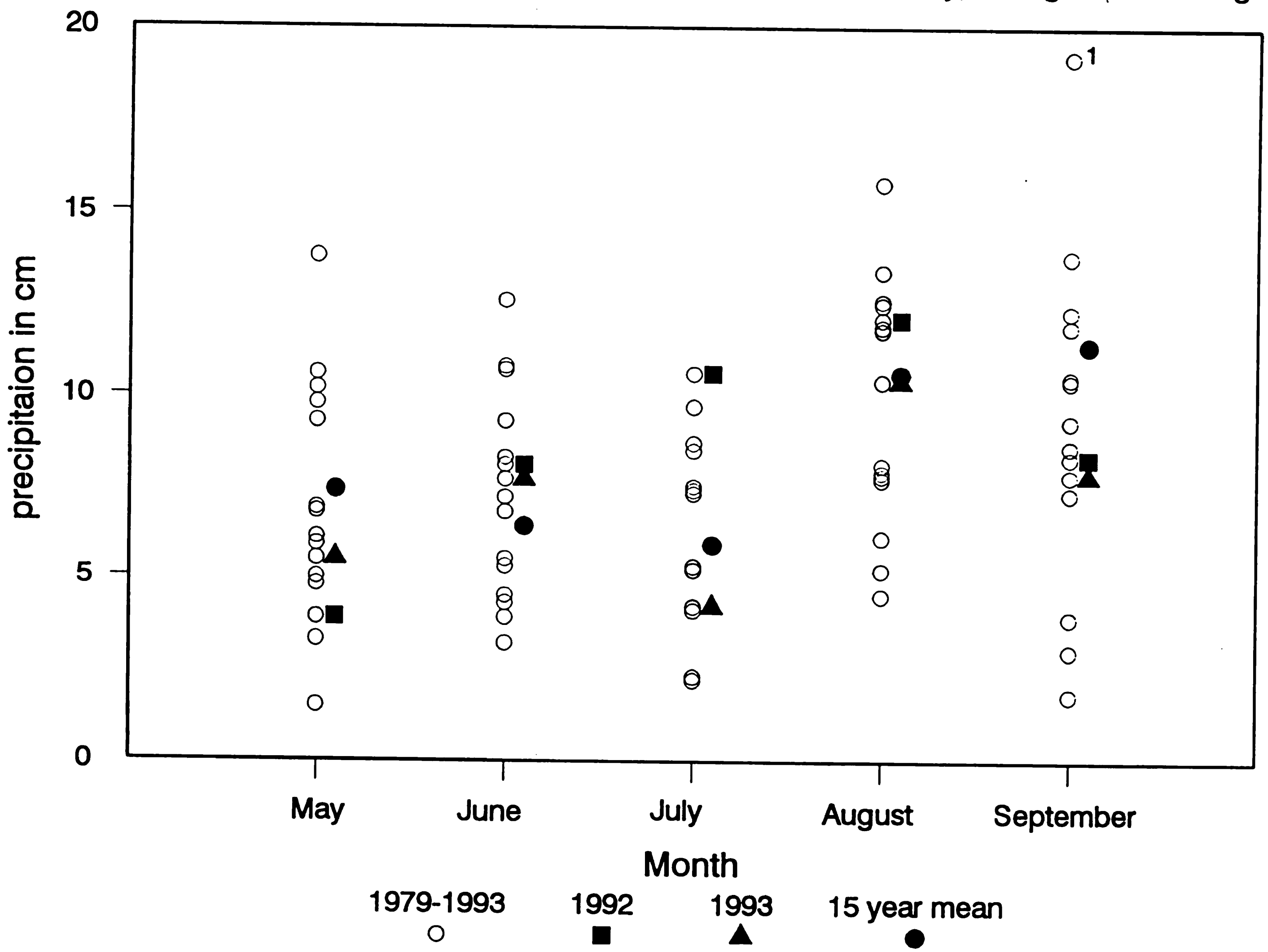
Figure 11 Volumetric soil water content in the 0 to 14.5 and 14.5 to 44.5 cm soil layers for no-cover, red clover early-kill and red clover late-kill cover crop treatments[1] and daily precipitaiton between 1 May and 19 May 1993 in the non-irrigated experiment. Each point is the mean of four measurements unless noted otherwise.

unprotected soil surface of the no-cover plots. The greater difference in water content in the deeper soil layer may also have been due to greater water uptake by RC roots from the deeper soil layer. Ebalhar et al. (1984) also reported a cover crop to affect the water contents of deeper soil layers greater than the surface layer.

The greatest difference in VWC in the different systems was between the no-cover and RC late-kill plots in the 14.5 to 44.5-cm layer in the NI experiment. This difference was approximately 30% of the total water content of that soil horizon, corresponding to 3 cm of water. Precipitation in May, 1993 was 1.2 cm less than the ten year average (Figure 12) and less than May precipitation during 9 of the past 15 years in this area of Michigan. High early season precipitation in this part of Michigan suggests that a cover crop is seldom likely to reduce soil water contents to a level significantly lower than with no cover crop.

Prior to RC incorporation, there was a smaller difference between VWC in the late-kill RC and no-cover treatments in the SI experiment than in the NI experiment. The relative difference between treatments in the two experiments may be a result of not controlling weeds in the no-cover plots in the SI experiment. Corack et al. (1991) reported smaller differences in VWC between vetch cover crops and no cover crops in a year when weeds on the no-cover crop

Figure 12 Monthly precipitation during the growing season in Huron County, Michigan 1979 through 1993.

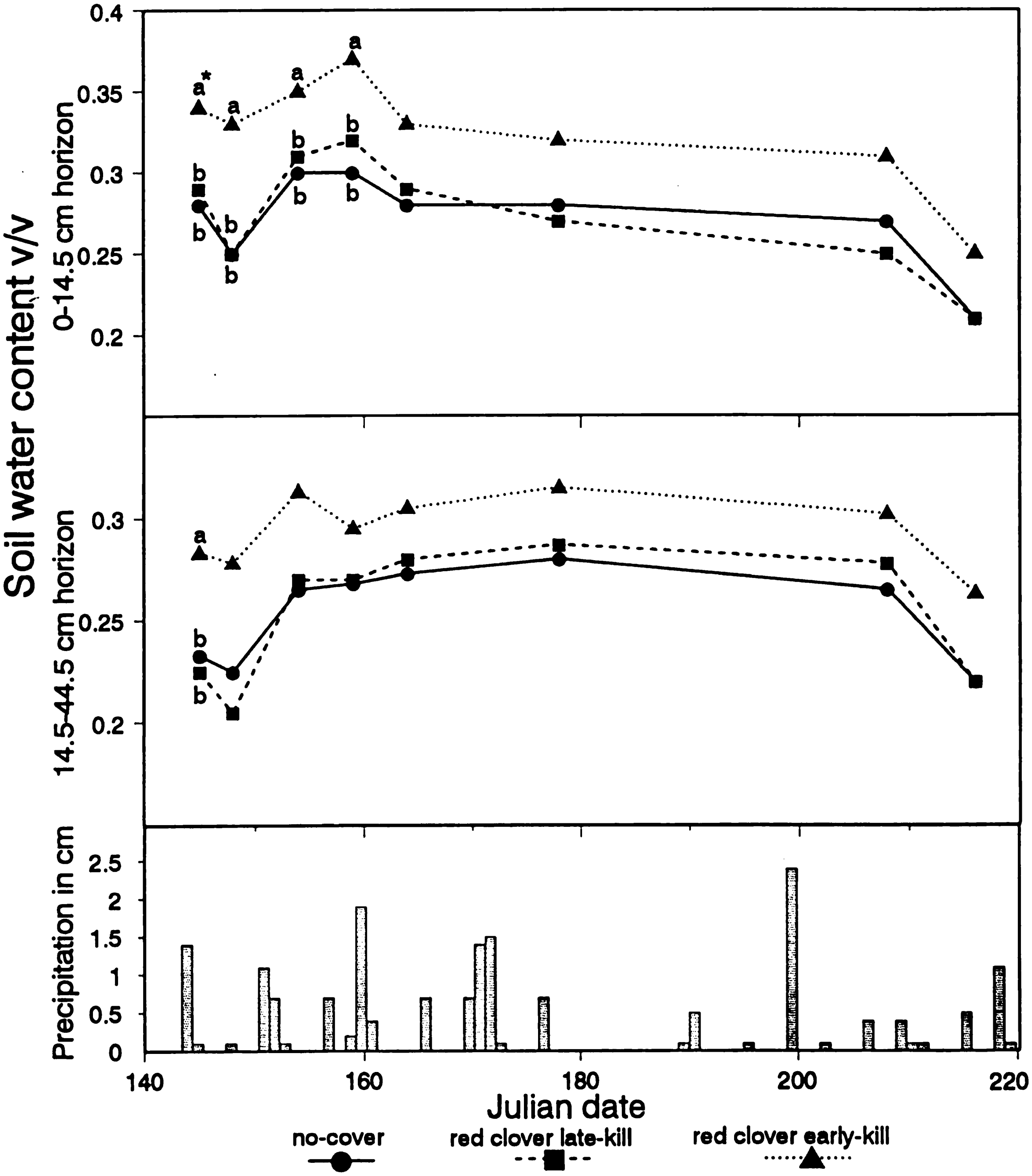


1 36.5 cm precipitation in 1986 is not included on plot

plots were not controlled than in two years when weeds were controlled.

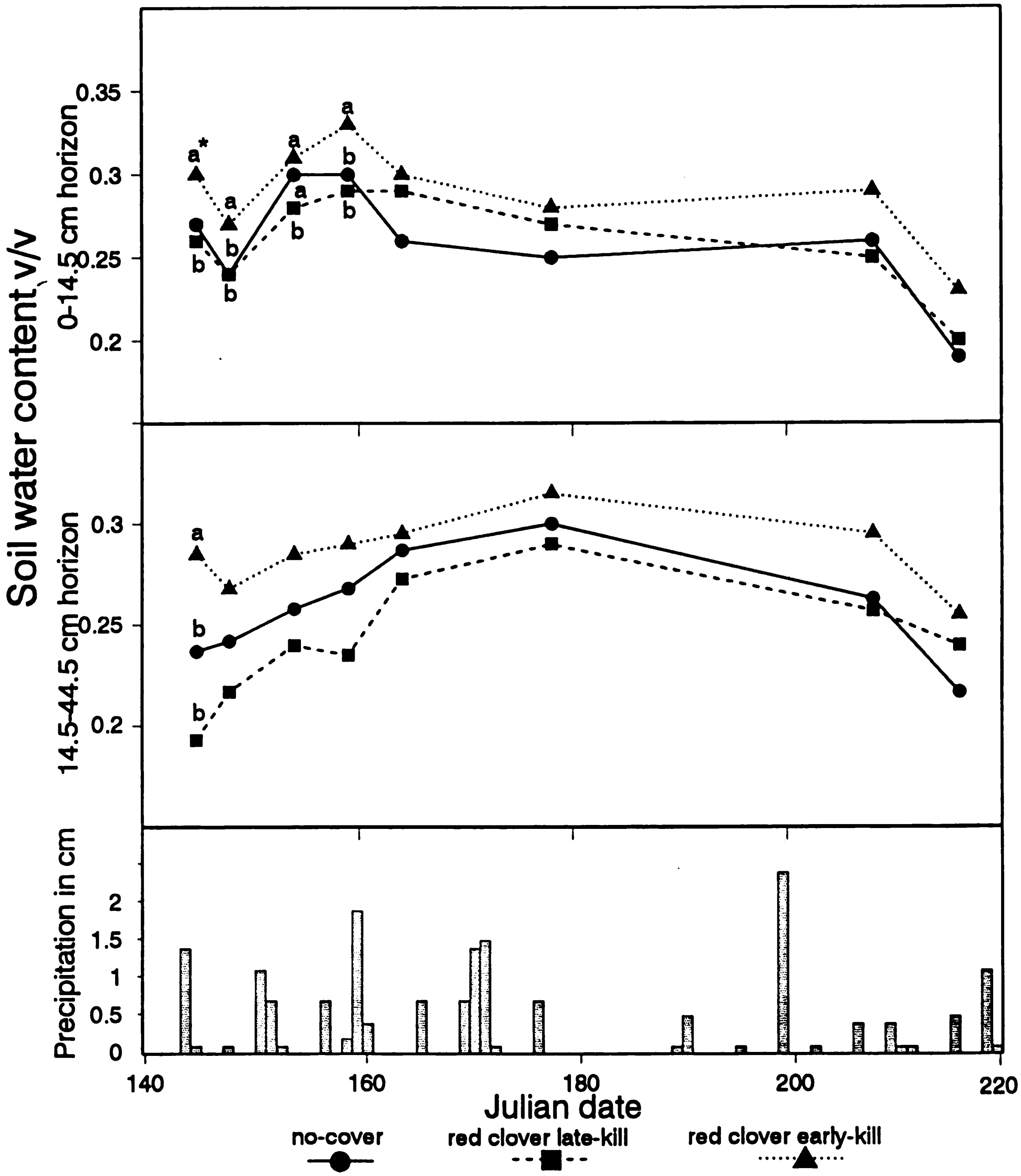
The difference in soil VWC between early- and late-kill RC suggests that killing cover crops early may be an effective means of limiting water use by spring growth. During dry years, an early-kill cover crop may conserve more water than no cover crop by providing a mulch which retards evaporation from the soil surface (Fry et al., 1988). In contrast, living covers may offer a management tool for removing excess water from the soil profile.

After corn planting (Julian date 141), VWC showed very similar trends in the different cropping systems within both the 0 to 14.5 and 14.5 to 44.5 cm soil layers. The trends were similar with either 0 or 210 kg N ha^{-1} applied within both the SI (Figures 13 and 14) and NI (Figures 15 and 16) experiments. Within each soil layer, VWC was lower after corn planting than before corn planting. Differences in VWC before and after corn planting likely resulted from changes in soil bulk density caused by moldboard plowing before planting. In the SI experiment VWC in the RC early-kill system was higher than in the no-cover or RC late-kill system, especially at the 0 kg ha^{-1} N-rate (Figure 14). During the period that VWC were measured, this difference deviated little at either soil horizon or N-rate. Since TDR rods were not moved after initial post corn planting installation, it is probable that this difference resulted



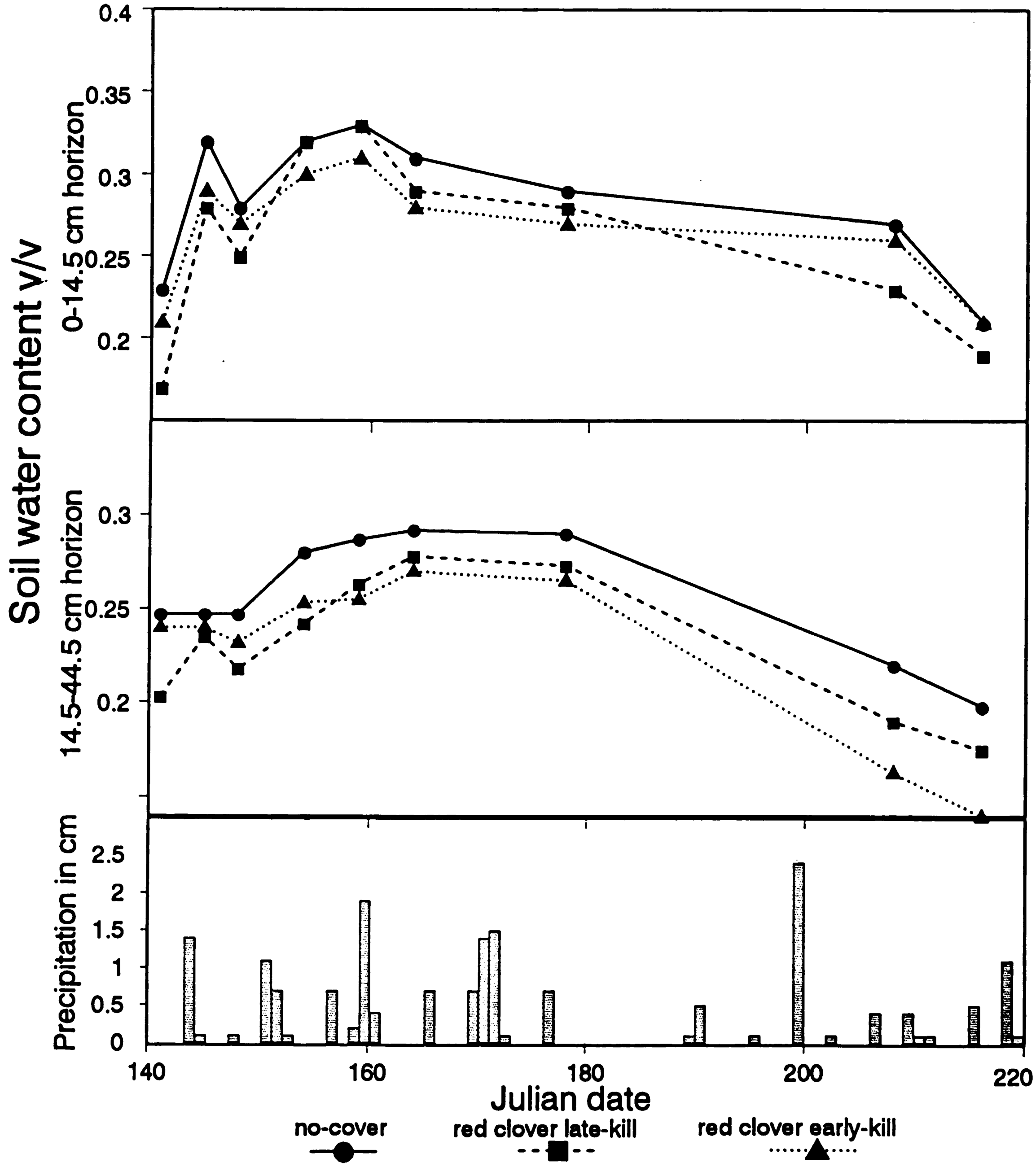
* Within each horizon and sampling date data points labeled with the same letter not significantly different (P=0.05) according to pairwise comparison using Fisher's LSD.
If no points are labeled, there were no significant differences between crops.

Figure 13 Volumetric soil water contents in the 0 to 14.5 and 14.5 to 44.5 cm soil layers in the subirrigated experiment and daily precipitation between 20 May and 28 July 1993. Corn followed no-cover, red clover early-kill or red clover late-kill cover crop treatments. No fertilizer N was applied to corn. Each point is the mean of four measurements.



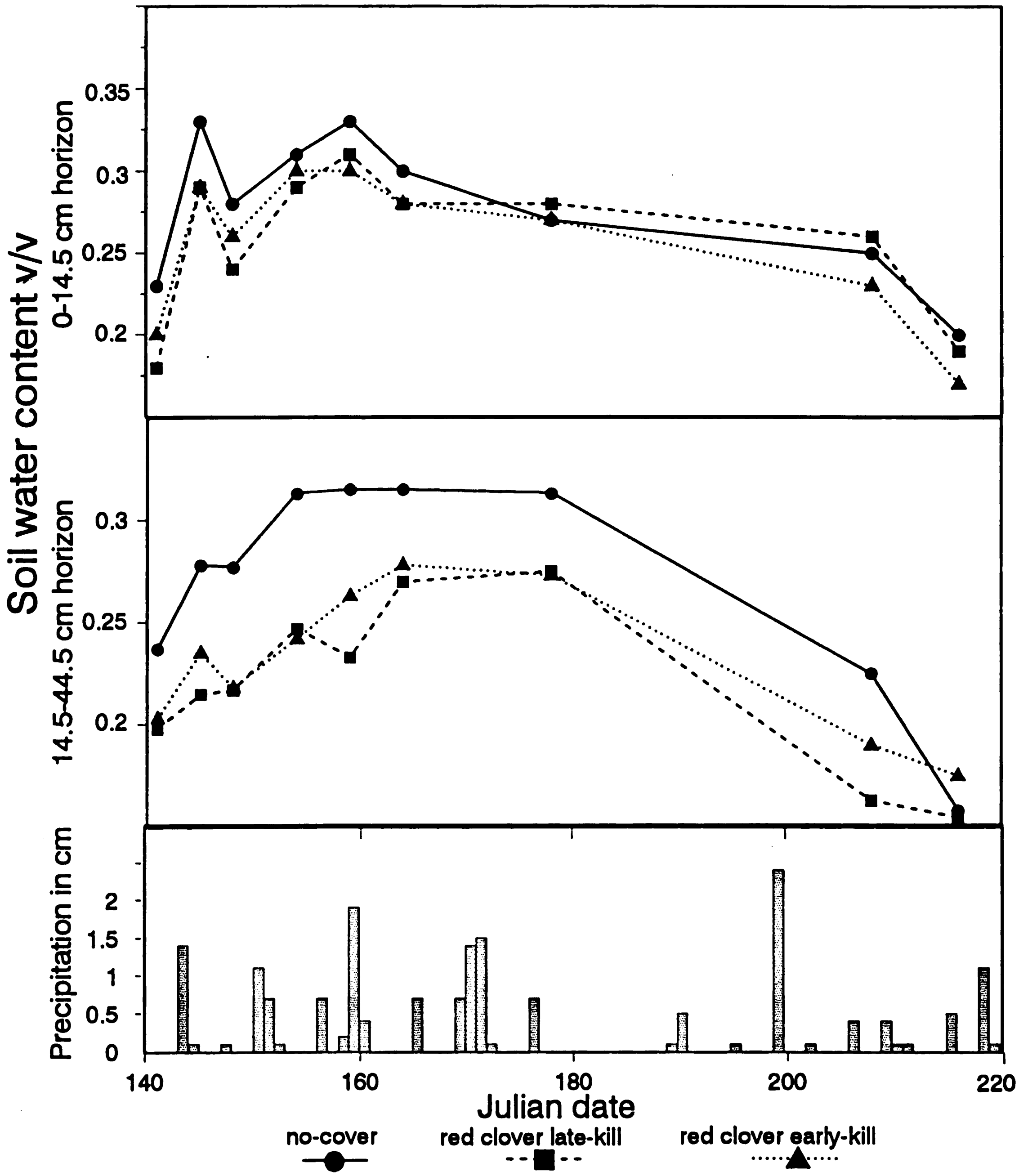
* Within each horizon and sampling date data points labeled with the same letter not significantly different (P=0.05) according to pairwise comparison using Fisher's LSD.

Figure 14 Volumetric soil water contents in the 0 to 14.5 and 14.5 to 44.5 cm soil layers in the subirrigated experiment and daily precipitation between 20 May and 28 July 1993. Corn followed no-cover, red clover early-kill or red clover late-kill cover crop treatments. Fertilizer N was applied to corn at 210 kg/ha. Each point is the mean of four measurements.



1 Within each horizon and sampling date data points labeled with the same letter not significantly different (P=0.05) according to pairwise comparison using Fisher's LSD.

Figure 15 Volumetric soil water contents in the 0 to 14.5 and 14.5 to 44.5 cm soil layers in the non-irrigated experiment and daily precipitation between 20 May and 28 July 1993. Corn followed no-cover, red clover early-kill or red clover late-kill cover crop treatments. No N fertilizer was applied to corn. Each point is the mean of four measurements.



1 Within each horizon and sampling date data points labeled with the same letter not significantly different (P=0.05) according to pairwise comparison using Fisher's LSD.

Figure 16 Volumetric soil water contents in the 0 to 14.5 and 14.5 to 44.5 cm soil layers in the non-irrigated experiment and daily precipitation between 20 May and 28 July 1993. Corn followed no-cover, red clover early-kill, or red clover late-kill cover crop treatments. Fertilizer N was applied to corn at 210 kg/ha. Each point is the mean of four measurements.

from the soil characteristics at the specific locations where VWC was measured.

A significant affect of N-rate on VWC during the later stages of corn growth was reported by Corak et al. (1991) and was expected in the NI experiment in this study. However, significant effects due to N rate occurred only during the first three weeks after planting in the surface horizon of the SI experiment (Table 10). The lack of a significant N-rate effect may be due to regular precipitation events, the amount of precipitation, and/or the shallow depth to which water contents were measured.

Economic Performance

In 1993, the RC-N system produced significantly higher net return than the no-cover system at the 0, 70, and 140 kg N ha^{-1} N-rates in the SI experiment and at the 0 and 70 kg N ha^{-1} N-rates in the NI experiment (Table 11). The differences in net return between the two systems were due to significantly higher gross revenues in the RC system. The SI system had lower economic returns than the NI system, except at the highest N rates. Differences between SI and NI systems were only significant with no N fertilizer applied. Doubling the price of fertilizer N (Table 12), from \$0.35 to \$0.70 kg^{-1}, had no effect on the relative performances of the cropping systems.

Table 10 Significance of cover crop treatment and N fertilizer on volumetric water content in the 0 to 14.5 and 14.5 to 44.5 cm soil layers after corn was planted[†] for the subirrigated and non-irrigated experiments in 1993.

Experiment	Soil horizon		Date								
		Julian date:	141	145	147	152	157	162	176	196	203
		Calendar date:	20 May	24 May	26 May	31 May	5 June	10 June	24 June	14 July	21 July
Irrigated											
	0-14.5 cm	Crop	-	**	***	*	**	NS	NS	NS	NS
		N-rate	-	*	NS	*	*	NS	NS	NS	NS
		Crop*N-rate	-	NS	NS	*	NS	NS	NS	NS	NS
	14.5-44.5 cm	Crop	-	*	NS	NS	NS	NS	NS	**	NS
		N-rate	-	NS	NS	NS	NS	NS	NS	NS	NS
		Crop*N-rate	-	NS	NS	NS	NS	NS	NS	NS	NS
Not-Irrigated											
	0-14.5 cm	Crop	NS	NS	NS	NS	NS	NS	NS	NS	NS
		N-rate	NS	NS	NS	NS	NS	NS	NS	NS	NS
		Crop*N-rate	NS	NS	NS	NS	NS	NS	NS	NS	NS
	14.5-44.5 cm	Crop	NS	NS	NS	NS	NS	NS	NS	NS	NS
		N-rate	NS	NS	NS	NS	NS	NS	NS	NS	NS
		Crop*N-rate	NS	NS	NS	NS	*	NS	NS	NS	NS

[†] Corn was planted on 20 May.

Table 11 Variable costs, gross revenue, and net return of subirrigated and non-irrigated corn produced in fertilizer (no-cover crop)- and red clover cover crop-N based cropping systems. Corn grain price was 1993 government support price, costs‡ were provided by the county extension service in Huron County, Michigan. Information is not provided for materials and activities which are common to all systems (eg corn seed, herbcide). Cost of N fertilizer is $.35 kg^{-1} N.

	1993							
	Fertilizer-N				Red clover-N§			
	0	70	140	210	0	70	140	210
Subirrigated	$ ha^{-1}							
Variable Costs								
Red clover seed	-	-	-	-	53	53	53	53
N-Fertilizer	-	25	49	74	-	25	49	74
Fertilizer application	-	8	8	8	-	8	8	8
Drying	15	27	35	42	34	41	46	44
Hauling	7	13	17	20	17	20	22	21
Depreciation	38	38	38	38	38	38	38	38
Electricity	38	38	38	38	38	38	38	38
Total variable costs	98	149	185	220	180	223	254	276
Income								
Gross Revenue	395*	715*	925*	1115	910*†	1080*	1215*	1180
Net Return	295*†	565*	740*	895	730*†	860*	960*	905
Non-Irrigated								
Variable Costs								
Red clover seed	-	-	-	-	53	53	53	53
N-Fertilizer	-	25	49	74	-	25	49	74
Fertilizer application	-	8	8	8	-	8	8	8
Drying	19	29	39	39	37	41	42	42
Hauling	9	14	19	19	18	20	20	21
Total variable costs	28	76	115	140	108	147	172	198
Income								
Gross Revenue	515*	780*	1045	1035	990*†	1095*	1115	1130
Net Return	485*†	705*	930	895	880*†	950*	945	930

§ Yields for legume N system are the mean of frost-seeded red clover early- and late-kill. Variable costs do not include the price of chemical or application for herbicide dessication in the early-kill system.

‡ Prices used were: corn grain $ 127 Mg^{-1} dry matter (equal to $2.75/bushel at 15.5% moisture). Red Clover seed, 17 kg ha^{-1} @ $ 3.10 kg. N-Fertilizer, @ $ .35 kg^{-1} N. Fertilizer application $7.70 ha^{-1}. Drying and hauling costs were calculated for grain harvested at 200 kg Mg^{-1} moisture. Depreciation was calculated as cost of system establishment divided by system life. Cost of establishment used was $740 ha^{-1} system life was considered to be 20 years. This method of calculating depreciation includes no return on investment. Cost and estimated life of system are from Belcher (1992). Installation cost was the lowest of the given range.

* Significant difference (P<0.05) between fertilizer and legume N systems within an N-rate, comparisons made using LSD.

† Significant difference (P<0.05) between SI and NI experiments, comparisons made using t-test.

Table 11 Variable costs, gross revenue, and net return of subirrigated and non-irrigated corn produced in fertilizer (no-cover crop)- and red clover cover crop-N based cropping systems. Corn grain price was 1993 government support price, costs[‡] were provided by the county extension service in Huron County, Michigan. Information is not provided for materials and activities which are common to all systems (eg corn seed, herbcide). Cost of N fertilizer is $.35 kg^{-1} N.

	1993							
	Fertilizer-N				Red clover-N[§]			
	0	70	140	210	0	70	140	210
Subirrigated	$ ha^{-1}							
Variable Costs								
Red clover seed	-	-	-	-	53	53	53	53
N-Fertilizer	-	25	49	74	-	25	49	74
Fertilizer application	-	8	8	8	-	8	8	8
Drying	15	27	35	42	34	41	46	44
Hauling	7	13	17	20	17	20	22	21
Depreciation	38	38	38	38	38	38	38	38
Electricity	38	38	38	38	38	38	38	38
	---	---	---	---	---	---	---	---
Total variable costs	98	149	185	220	180	223	254	276
Income								
Gross Revenue	395*	715*	925*	1115	910*†	1080*	1215*	1180
Net Return	295*†	565*	740*	895	730*†	860*	960*	905
Non-Irrigated								
Variable Costs								
Red clover seed	-	-	-	-	53	53	53	53
N-Fertilizer	-	25	49	74	-	25	49	74
Fertilizer application	-	8	8	8	-	8	8	8
Drying	19	29	39	39	37	41	42	42
Hauling	9	14	19	19	18	20	20	21
	---	---	---	---	---	---	---	---
Total variable costs	28	76	115	140	108	147	172	198
Income								
Gross Revenue	515*	780*	1045	1035	990*†	1095*	1115	1130
Net Return	485*†	705*	930	895	880*†	950*	945	930

§ Yields for legume N system are the mean of frost-seeded red clover early- and late-kill. Variable costs do not include the price of chemical or application for herbicide dessication in the early-kill system.

‡ Prices used were: corn grain $ 127 Mg^{-1} dry matter (equal to $2.75/bushel at 15.5% moisture). Red Clover seed, 17 kg ha^{-1} @ $ 3.10 kg. N-Fertilizer, @ $ .35 kg^{-1} N. Fertilizer application $7.70 ha^{-1}. Drying and hauling costs were calculated for grain harvested at 200 kg Mg^{-1} moisture. Depreciation was calculated as cost of system establishment divided by system life. Cost of establishment used was $740 ha^{-1} system life was considered to be 20 years. This method of calculating depreciation includes no return on investment. Cost and estimated life of system are from Belcher (1992). Installation cost was the lowest of the given range.

* Significant difference (P<0.05) between fertilizer and legume N systems within an N-rate, comparisons made using LSD.

† Significant difference (P<0.05) between SI and NI experiments, comparisons made using t-test.

CONCLUSIONS

Red clover incorporated the spring after the seeding year contributed between 235 and 328 kg N ha^{-1} when N contribution was measured as total N in legume biomass. Although early spring kill of RC limited the N content of RC biomass, no effect of RC kill date was seen on the grain dry matter or N yield of a following corn crop. It is possible that long term benefits of including a legume crop in a cropping system may be enhanced by greater spring growth and N accumulation. Early-kill RC also depleted soil water content less than RC late-kill. The effect of RC kill date on soil water content suggests that cover crop kill date may be effectively used for managing soil water contents in spring. These results also suggest that a delay in killing a legume cover increases the risk of soil water depletion by the cover crop and does not enhance the N contribution to a succeeding crop.

Subirrigating corn did not increase grain yields, most likely due to adequate rainfall and soil water storage supplying adequate water for corn to obtain maximum yields in the non-irrigated experiment. There was evidence for greater N loss from the subirrigated than from the non-irrigated experiment. Nitrogen loss from a subirrigated system may be minimized by maintaining a lower water table. The effect of subirrigation on grain yield and N uptake would likely be different during a year with lower precipitation.

The economic analysis suggested that at least in some years in both subirrigated and non-irrigated systems RC-N based cropping systems can be as profitable as systems which do not include a legume cover crop. In addition, the greater importance of high fertilizer inputs in the SI system should be considered when assessing the economics of these systems.

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