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Nitrogen Fertilization of Wheat No-Till Planted in Alfalfa Stubble

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Research Question

Conservation tillage practices can significantly reduce soil erosion, improve water distribution, and decrease environmental concerns in furrow-irrigated fields. Developing fertilizer management practices that optimize crop yields after legumes in these systems will aid their adoption. This study evaluated the N fertilizer requirement of wheat planted in herbicide-killed alfalfa stubble.

Literature Summary

The N available after legumes is sufficient for maximum crop yields in many cropping systems. Fertilizing without accounting for the "extra" N mineralized from legume residues can contribute to high nitrate-N concentrations in the soil during crop production and increase nitrate-N leaching potential. Tillage practices also affect the physical, biological, and chemical nature of the soil, changing the N mineralization rates and N fertilizer requirements.

Study Description

Two soft white winter wheat (var. Stephens) experiments and one hard red spring wheat (var. Bronze Chief) experiment were conducted in southern Idaho between 1984 and 1987 on a furrow-irrigated silt loam soil. The wheat was no-till planted with a conventional double disk opener drill into alfalfa stubble, killed by spraying the fall regrowth with a mixture of 1 qt glyphosphate and 2 qt 2,4-D. Nitrogen fertilizer (ammonium nitrate) was surface broadcast in the spring at rates between 0 and 200 or 240 lb/acre.

Applied Question

Does wheat no-till planted in herbicide-killed alfalfa stubble require N fertilization for maximum grain yields?

Nitrogen fertilization increased grain yields in all three field experiments (Table 1). The N fertilizer response occurred because sufficient N had not mineralized from soil and legume sources before the wheat plant started rapid N uptake (Fig. 1). Nitrogen uptake rates by the wheat between jointing and soft dough growth stages were approximately twofold larger than soil N mineralization rates. This rapidly depleted the available nitrate-N in the rooting zone when fertilizer N was not applied. About 109 lb N/acre were taken up by the wheat plants at soft dough growth stage from soil and legume residue sources. The apparent N fertilizer recovery was 76%.

In general, we recommend that other crops be planted in the herbicide killed alfalfa stubble instead of cereals if early spring leaching is not a problem. The N uptake patterns of potato, corn, and sugarbeet are substantially later than wheat's (Fig. 1). This allows more nitrate-N to accumulate in the root zone from mineralization before crop N uptake starts and uses more of the N mineralized in late summer and early fall, reducing the potential for subsequent nitrate-N leaching.

Full scientific article from which this summary was written begins on page 404 of this issue.

Table 1. Spring N fertilization effects on grain protein concentration and yield of wheat no-till planted in herbicide-killed alfalfa.

Experiment, variety	N rate	Yield*	Protein concentration*
	lb/acre	bu/acre	%
1. Stephens, soft white winter wheat	0	70a	9.8a
	50	90b	10.4ab
	100	99c	11.3ab
	200	101c	11.8b
2. Bronze Chief, hard red spring wheat	0	30a	16.0a
	50	47b	16.1a
	1020	56c	16.4a
	240	66d	18.0b
3. Stephens, soft white winter wheat	0	86a	9.2a
	50	115b	10.0a
	100	131c	10.0a
	200	142c	11.7b

* Treatments significantly different at the 0.05 probability level if followed by different letters within an experiment (Duncan's multiple range test).

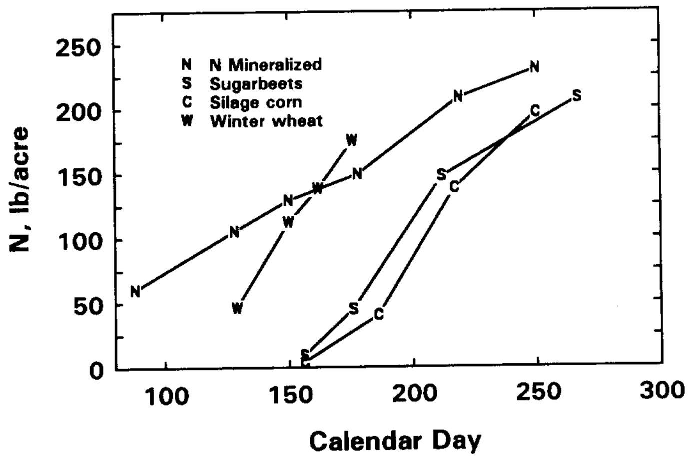

Fig. 1. The relationship between soil N mineralization and N uptake by selected irrigated crops.

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D. T. Westermann* and S. E. Crothers

Conservation tillage practices significantly reduce soil erosion, improve water distribution, and decrease environmental concerns in furrow-irrigated fields. Developing optimum N fertilization practices after legumes in these systems will help their adoption. We conducted three field studies on a silt loam soil to determine if N fertilizer is required for furrow-irrigated wheat (*Triticum aestivum* L.) planted in herbicide killed alfalfa (*Medicago sativa* L.) stubble. Fall regrowth of alfalfa was sprayed with a mixture of 1 qt glyphosphate and 2 qt 2,4-D/acre. 'Stephens', a soft white winter wheat was planted with a double disk opener drill in two experiments and 'Bronze Chief', a hard red spring wheat in a third experiment. Nitrogen fertilizer (ammonium nitrate) was spring broadcast at four rates from 0 to 200 or 240 lb N/acre. The buried plastic bag technique estimated available N (EAN); above ground whole plant samples estimated root zone nitrate-N; and grain plot yields estimated with a combine. Nitrogen fertilization increased grain yield in all experiments because sufficient N had not mineralized from soil and legume residues before uptake needs of the wheat. The wheat plant at the soft dough growth stage contained about 109 lb N/acre from N mineralized from soil and legume residue sources. The apparent N fertilizer recovery calculated by a combined regression relationship between N uptake and fertilizer rates was 76%. The average plant recovery of mineralized N at maximum grain yields was calculated at 78%. Crops planted in herbicide killed alfalfa should be selected so sufficient nitrate-N can accumulate from mineralization before maximum crop uptake and for N uptake ability in late summer. Nitrogen fertilizer applications should be based on a spring soil test for nitrate-N in this no-till system. Both practices will reduce the potential for nitrate-N leaching losses.

LEGUME RESIDUES can be important sources of available N to crops. The recovery of N by the following crop depends upon the amount of N in the legume residue returned to the soil, the availability of N from the decomposing legume residue, tillage practices, and the nonlegume crop being grown. Only 15 to 25% of the N in legume residue is recovered by a nonlegume crop the first cropping year using ^{15}N methods (Heichel, 1985). This additional N was sufficient for maximum corn (*Zea mays* L.) yield the first year after alfalfa, birdsfoot trefoil (*Lotus corniculatus* L.), and red clover (*Trifolium pratense* L.) (Fox and Piekielek, 1988). Legume residues can also contribute significant amounts of N for crop use over time. Nitrogen uptake by corn over five cropping years from an area previously in alfalfa was 341 lb/acre greater than that from an uncropped soil area (Boawn et al., 1963). Crop sequence after legumes can also have a significant role in capturing the N mineralized. In one study, it was estimated that one-half of the nitrate-N in the subsurface drainage water from an irrigation tract came from fields where beans (*Phaseolus vulgaris* L.) followed alfalfa in the rotation (Robbins and Carter, 1980). Fertilizer N recommendations that do not consider the N supplied from legume residues can contribute to high soil nitrate-N concentrations during crop production (El-Hout and Blackmer, 1990).

Soil erosion is a major problem on furrow irrigated lands in the western USA. Sediment losses can be as large as 45 tons/acre in an irrigation season (Carter, 1990). Soil erosion reduces crop yields and decreases water quality from suspended particulates. Crop residue management with conservation tillage successfully reduces wind and water erosion problems in the Great Plains. Until recently, few attempts were made to apply these practices to irrigated lands. Conservation tillage of furrow-irrigated lands can reduce erosion and sediment losses 80 to 90% (Carter, 1990).

Conservation tillage practices under furrow irrigation can be successfully initiated when beans, corn, or cereals follow alfalfa in the rotation (Carter and Bert, 1991). Herbicides are available to control vegetation so crops can be seeded directly into alfalfa stubble (Buhler and Mercurio, 1988). Optimum N fertilization rates can increase when producers change from conventional to no- or reduced-tillage systems (Jacobsen and Westerman, 1988). This partially occurs because soil N mineralization rates are smaller under reduced tillage practices (Destain et al., 1989). Tillage also affects the physical, biological, and chemical nature of the soil (Doran, 1980).

Establishing the N fertilizer requirement of crops grown after legumes in conservation tillage systems will aid the adoption of this practice. It will also help maintain or increase crop yield, while minimizing the environmental impact. This study's objective was to determine if N fertilizer is required for furrow-irrigated wheat planted directly into herbicide killed alfalfa stubble.

METHODS AND MATERIALS

Three field experiments were conducted from 1984 through 1987 on a Portneuf silt loam (coarse-silty, mixed,

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Abbreviation: EAN, estimated available N.

Table 1. Varieties and timing of experimental operations.

Expt.	Wheat variety†	Soil nitrate-N‡	Herbicide applied	Crop planted	N applied	Crop harvested
1	Stephens, sww	11.6	04 Oct. 84	11 Oct. 84	05 Aug. 85	07 Aug. 85
2	Bronze Chief, hrs	7.6	22 Oct. 85	26 Mar. 86	03 Apr. 86	19 Aug. 86
3	Stephens, sww	8.7	13 Oct. 86	14 Oct. 86	30 Mar. 87	11 Aug. 87

† sww = soft white winter; hrs = hard red spring.
‡ Average ppm soil nitrate-N in 0 to 24 in. before spring N fertilizer applications.

mesic Durixerollic Calciorthids) near Kimberly, ID (Table 1). This soil has a calcic horizon at about 18 in. that restricts root growth of some plants but not water movement. Alfalfa stands were three or more years old and included some invading grass species. After the third forage cutting was removed and some regrowth was visible, a mixture of 1 qt glyphosphate (Roundup) and 2 qt 2,4-D was applied in approximately 30 gal water/acre. Wheat was planted with a conventional double disk opener drill with press wheels directly into the sprayed alfalfa stubble at seeding rates of 100 to 120 lb/acre. A soft, white winter wheat variety was planted in Experiments 1 and 3; a hard red spring wheat variety in Experiment 2 (Table 1). Existing furrows (30-in. spacing) were cleaned in the spring before the first irrigation. If needed, additional 2,4-D applications (1-2) were made to the wheat crop to control alfalfa regrowth and broadleaf weeds. Irrigation water ($\sim$0.1 ppm nitrate-N) was applied in every furrow when about 50% of the plant-available water in the top 18 in. of soil was depleted. Each irrigation applied about 3 in. of water in 12 h.

Spring soil samples from the top 24 in. of soil were extracted for available plant nutrients before any fertilizer was applied. Phosphorus was surface applied as monocalcium phosphate (0-45-0) when needed. Ammonium nitrate (34-0-0) was broadcast on the soil surface in the spring (Table 1). Each experiment had four N rates between 0 and 200 or 240 lb N/acre (Table 2). Nitrogen mineralization bags (representing 18 in. of topsoil, including legume root residues) EAN (Westermann and Crothers, 1980). They were installed in the non-N fertilized treatment the fall after planting Experiment 1, but in the spring of the cropping year for the two other experiments. One bag per plot was removed at each plant sampling and once after grain harvest to monitor N mineralization. In addition, Experiment 1 had one fall sampling after installation. Ten soil cores, 0.75 by 18 in., also were taken and composited from each non-N fertilized plot when a mineralization bag was removed. All soil samples were air-dried at about 100°F and analyzed for nitrate-N with an ion selective electrode (Milham et al., 1970).

Plant stand counts were visibly estimated in the spring on ten 2.7-sq-ft areas per experiment. Ten whole plant tops were excised at the ground level and used to estimate N uptake at jointing (Feekes, F6–7), flag leaf (F9), flowering (F10.5), and soft dough (F11.2) growth stages. All plant samples were dried at 140°F, ground to pass a 0.025 sq in. mesh screen, and analyzed for total N (Bremner and Mulvaney, 1982).

Table 2. Spring N fertilization effects on grain protein concentrations and yields of wheat no-till planted in herbicide-killed alfalfa.*

Experiment†	N rate	Yield	Protein
	lb/acre	bu/acre	%
1. Stephens, sww	0	70a	9.8a
	50	90b	10.4ab
	100	99c	11.3ab
	200	101c	11.8b
2. Bronze Chief, hrs	0	30a	16.0a
	60	47b	16.1a
	120	56c	16.4a
	240	66d	18.0b
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	50	115b	10.0a
	100	131c	10.0a
	200	142c	11.7b

* Significant differences within an experiment shown by different letters at the 0.05 probability level (Duncan's multiple range test).
† sww = soft white winter, hrs = hard red spring.

Grain yields were estimated by harvesting an 8- by 42-ft strip through the center of each plot with a combine. After cleaning, this grain sample was weighed and subsampled for bushel weights. Total N (Bremner and Mulvaney, 1982) also was determined on grain samples and multiplied by 5.7 to convert %N to protein.

Individual plots were 20 by 50 ft and arranged in a randomized complete block design with four replications in each experiment. Data were analyzed statistically with procedures outlined by the SAS Institute (SAS, 1982). Duncan's multiple range test separated means if treatments were significantly different. In this study, optimum N fertilization is defined as the rate where additional N did not significantly ($Pr > F = 0.05$) increase grain yields.

RESULTS AND DISCUSSION

The N fertilizer credit the first year after an established legume is generally between 80 and 130 lb N/acre (Fox and Piekielek, 1988; Heichel, 1985; Hesterman et al., 1986); this includes N mineralized from indigenous soil organic matter. The nitrate-N that accumulated in the mineralization bags by the soft dough plant sampling was

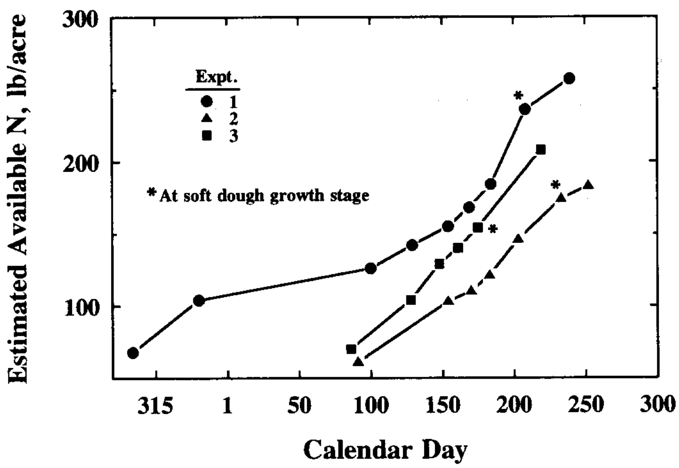

Fig. 1. The estimated available N (EAN) measured with the buried plastic bag technique for each of the three experiments. Data points marked with an (*) correspond to the soft dough growth stage within each experiment.

between 155 and 240 lb N/acre (Fig. 1). This N was from the mineralization of both alfalfa plant residues and other soil organic N sources. Studies with ^{15}N-labelled legume residues shows that about 15 to 25% is available to the next crop (Heichel, 1985). The N content of root plus crown residues from established alfalfa stands is typically estimated to be between 125 and 175 lb N/acre. A maximum of 44 lb N/acre would be available for later crop N uptake, if the plant recovered 25% of the N in the alfalfa residue. This suggests that considerable soil organic N was mineralized from other sources in this study, i.e., between 110 and 195 lb N/acre. This is in the same range as that reported in an irrigated sugarbeet (*Beta vulgaris* L.) study on similar silt loam soils (Carter et al., 1976).

Nitrogen fertilization significantly increased grain yields in all three experiments (Table 2). In the two winter wheat experiments (1 and 3), the grain yield increased up to 100 lb N/acre. In contrast, the yield of the hard red spring wheat continued to increase up to the highest fertilizer N rate (240 lb N/acre). This variety of hard red spring wheat (Bronze Chief) produces high protein grain, but has limited production compared with better adapted varieties in southern Idaho. Nitrogen fertilization increased the grain protein concentration in all studies, particularly at the highest N rate (Table 2).

The above ground plant N uptake at soft dough was linearly related to the N fertilization rate in all experiments (Fig. 2). Separate linear regression analysis for each experiment had slopes of 0.71, 0.77, and 0.81, and intercepts of 132, 110, and 88 lb N/acre for Experiments 1, 2, and 3, respectively. The calculated average y-intercept was 109 lb N/acre for the combined data (Fig. 2). The apparent average N fertilizer recovery was 76% (slope of combined regression line, Fig. 2). This is appreciably higher than N fertilizer use efficiencies (40 to 70%) from studies using ^{15}N labeling techniques (Hauck and Bremner, 1976).

The N in the tops at soft dough was 212, 285, and 175 lb/acre at optimum N for grain yield in the three experiments, respectively. These amounts are similar to the EAN after day 200 in Experiments 1 and 3 (Fig. 1 vs. Fig. 2); yet N fertilizer responses occurred in both experiments. This happened because some of the N was mineralized after N uptake terminated (Fig. 3, data represents the two other experiments). The N uptake for the optimum yield treatment (100 lb N/acre) crossed the EAN (via mineralization bags) on about calendar day 170. At that point, there was very little soil nitrate-N left in the root zone in the control treatment (Fig. 3). Nitrogen uptake curves for lower N fertilization rates (i.e., < 100 lb N/acre) never crossed the EAN, while that for the higher N fertilization rate did.

We estimated the plant recovery of the EAN in each study by dividing the N uptake at soft dough for the control treatment by the difference between the EAN and the soil nitrate-N on the same sampling date. The results varied from 64 to 68%, averaging 66%. The plant recovery of the EAN also was estimated for the optimum N fertilized treatment in each experiment. The fertilizer N in the plant (assuming 0.76 for the N fertilizer recovery) was first subtracted from the N uptake in the above ground portion of the plant at soft dough. The remaining N was then divided by the difference between the EAN and the soil nitrate-N. The plant recovery of the EAN for this fertilized treatment was between 72 and 85%, averaging 78%. This percentage is similar to the apparent N fertilizer recovery (76%) determined by the regression slope (Fig. 2).

At the first plant sampling, day 129, the EAN was 102 lb N/acre, while the plant N uptake (at optimum fertilizer N) plus the soil nitrate-N was only 63 lb N/acre (Fig. 3). This indicates (i) possible antecedent loss of 39 lb/acre soil nitrate-N from the rooting zone via leaching, denitrification or immobilization, (ii) overestimating plant-available N by the mineralization bag technique, or (iii) underestimating plant N uptake. Nitrate would be particularly susceptible to leaching below 18 in. prior to the first plant sampling when plant root systems are relatively small. This N may be recovered during later plant development since winter and spring wheat plants extract water to about 5 and 3 ft deep on this soil, respectively. No attempt was made to estimate N losses from leach-

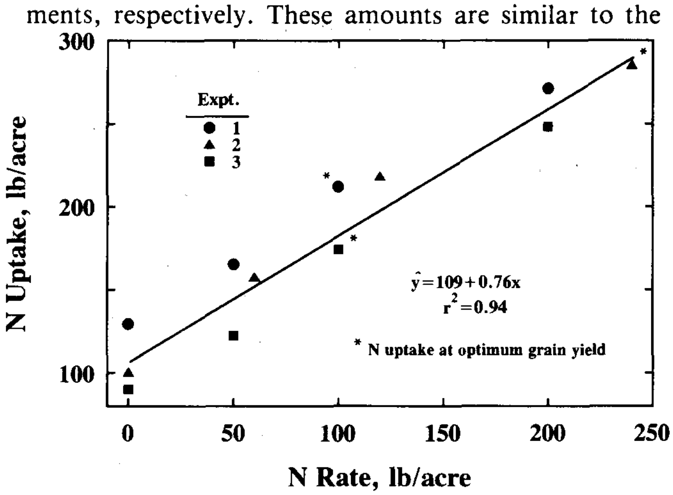

Fig. 2. The effect of N fertilization rate on above ground plant N uptake by wheat at the soft dough growth stage. Data points marked with (*) correspond to the optimum N fertilization rate within an experiment. Correlation of simple determination (r^2) significant at the 0.001 probability level.

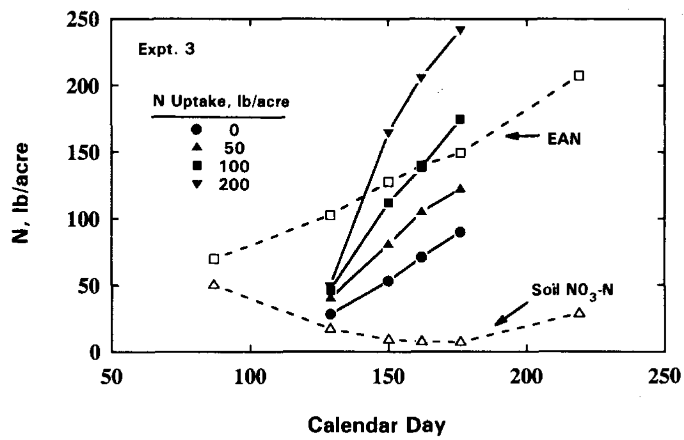

Fig. 3. The relationships between above ground plant N uptake for the N fertilization treatments, estimated avaliable N (EAN), and root zone soil nitrate-N content of the non-N fertilized treatment for Experiment 3.

ing, denitrification, or immobilization in our experiments. We know that plant N uptake was underestimated because below ground roots were not measured. The roots comprise about 25% of the plant's dry matter at grain head emergence, decreasing to 10% at grain harvest (Russell, 1973). Root N may account for an additional 8 to 13 lb N/acre if the N concentration of the roots at soft dough is assumed to be 1%. Tillage is also known to increase the N mineralization rate (Destain et al., 1989; Levin et al., 1987). The soil in the mineralization bags was 'disturbed' in order to back-fill the plastic bags, while the wheat grew on soil not tilled. The mineralization bag technique should give a reasonable in situ estimate of mineralizable N for disturbed soil since the majority (>95%) of the mineralizable N is above the calcic layer in this soil (Carter et al., 1976). Other research showed that the nitrate-N in mineralization bags estimated the N available to potato (*Solanum tuberosum* L.) and corn during the growing season (Westermann and Crothers, 1980).

Several studies demonstrated that fertilizer N may not be required following a legume crop (Boawn et al., 1963; Carter et al., 1991; Fox and Piekielek, 1988). The N fertilizer requirement depends on (i) how well the N mineralization pattern synchronizes with the crop's N uptake pattern, and (ii) whether sufficient N has mineralized to satisfy the rapid N uptake requirement. We evaluated this crop effect by comparing the N uptake pattern of several crops commonly grown in western U.S. irrigated areas (Fig. 4): dry beans (Westermann et al., 1981), sugarbeet (Carter and Traveller, 1981), potato (Kleinkopf et al., 1981), and corn (D.T. Westermann, 1978, unpublished data). The N uptake for the spring wheat variety in our study was similar to that for winter wheat but delayed by about 5 to 10 d. The N uptake of other crops is substantially later than winter wheat (Fig. 4). This would (i) allow more nitrate-N to accumulate in the root zone before N uptake occurs during crop growth, and (ii) allow more use of N mineralized during the latter part of the growing season (Fig. 1). These comparisons show that potato, sugarbeet, and corn planted after alfalfa potentially can use more of the N mineralized from the soil and crop residues than wheat. This was demonstrated for corn on this soil where sufficient soil nitrate-N accumulated before rapid crop N uptake (Carter et al., 1991). Dry bean's total N uptake is smaller and should not be planted after alfalfa because of the potential for nitrate-N leaching losses (Robbins and Carter, 1980).

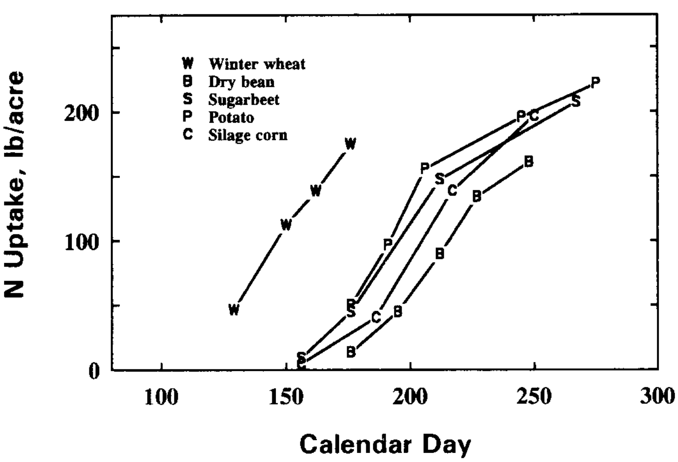

Fig. 4. A comparison of the N uptake of five irrigated crops during their growth and development.

Nitrogen mineralization will continue after N uptake by the wheat is complete if conditions are favorable (Fig. 3). Some of this N would be immobilized by subsequent straw decomposition processes but may also be susceptible to leaching loss. Planting a crop like corn or sugarbeet could significantly reduce the accumulation of soil nitrate-N during later summer and early fall.

Nitrogen fertilization increased the production of wheat no-till planted in alfalfa stubble fall-killed with herbicides. The optimum N fertilization rate was between 100 and 130 lb N/acre. This rate is similar to that recommended for irrigated wheat production after alfalfa in southern Idaho based on a spring soil nitrate-N test (Brown, 1989). It was not an adequate N fertilization rate for the high protein, hard red spring wheat used in this study. Early fall tillage and incorporation of legume residues may increase the timing and rate of N mineralized sufficiently to eliminate a N fertilizer application for optimum crop yields (Carter et al., 1991). Growers should spring soil test for residual nitrate-N and fertilizer according to established recommendations if they plant soft white wheat in alfalfa stubble fall killed with herbicides.

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