Predicting N Fertilizer Rates for Corn

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SUMMARY

Sixteen N rate experiments were carried out in farmer fields in 1995 and 1996. The objective was to measure optimum N fertilizer rates and see whether they could be reliably predicted ahead of time. Yield response to N was measured in each experiment along with soil N measurements (planting and sidedress), and tissue N and chlorophyll meter reading at sidedress time. A very wide range of economically optimum N fertilizer rates was found, fairly evenly spread from 0 to 200 lb N/acre, with an average of 84 lb N/acre. Yield at the optimum N rate averaged 152 bu/acre. Both yields and optimum N rates were higher in 1996 than in 1995. There was a surprisingly small difference in average optimum N rate between sites that had an organic N source (manure or alfalfa) and ones that did not (68 vs. 94 lb N/acre). Even more surprising, sites with corn the previous year had a significantly lower average optimum N rate than sites with soybeans the previous year (61 vs. 103 lb N/acre). This would seem to indicate that there was carryover of N fertilizer from the previous corn crop in some cases. The variability in optimum N rate was so wide that fertilizing to the average optimum N rate was a poor strategy. We tried to see whether in-field measurements could be used to tell which fields needed more N fertilizer and which fields needed less. Soil N measurements, tissue N at sidedress, and chlorophyll meter reading at sidedress were all clearly related to optimum N rate--the higher the test result, the lower the optimum N rate. Only two recommendation systems tested significantly increased profit (by $7 to 8/acre) relative to N rates used by farmers in these fields: 1) subtracting credits for both manure, alfalfa, or soybean history and preplant soil nitrate from current University of Missouri recommendations, or 2) using sidedress tissue N content to predict sidedress N rate. Three other systems reduced N rates significantly relative to farmer N rates without reducing profits: 1) chlorophyll meter, 2) sidedress soil nitrate test with the critical value adjusted for a wet spring, and 3) University of Missouri recommendations with history credits only.

INTRODUCTION

Experiments were carried out in farmer fields in 1995 and 1996 with the objective of evaluating or developing field-specific tests to optimize N fertilizer rates for corn. Because the greatest potential for nitrogen fertilizer savings comes when manure or alfalfa is in the cropping system, and because some of the soil nitrate tests seem to work differently under these conditions, most farms had pairs of experiments, one with an organic N source and the other with none. Descriptions of the experimental locations are given in Table 1.

Table 1. Descriptions of experimental locations

Location	Year	County	Previous crop	Organic N source	Organic N history
Hauck 1	1995	Callaway	corn	hog lagoon water	>10 years lagoon water
Hauck 2	1995	Callaway	corn	none	lagoon water in 1989
Hoff	1995	Cooper	DC soybean	none	none
Lenz 1	1995	Cooper	corn	solid dairy manure	>10 years dairy manure
Lenz 2	1995	Cooper	corn	none	turkey manure in 1992, alfalfa killed spring 1994
Rothermich 1	1995	Callaway	soybean	injected hog slurry	none
Rothermich 2	1995	Callaway	soybean	none	none
Boland 1	1996	Saline	corn	surface hog slurry	20 years hog slurry
Boland 2	1996	Saline	corn	none	none
Kurtz 1	1996	Holt	soybean	solid hog manure	none
Kurtz 2	1996	Holt	soybean	none	none
Milne 1	1996	Holt	alfalfa	alfalfa, plowed	5 years alfalfa
Milne 2	1996	Holt	corn	none	none
Echelmeier	1996	Callaway	soybean	none	none
Rothermich 3	1996	Callaway	wheat	none	none
Sommer	1996	Callaway	wheat	none	none

PROCEDURES

Except for nitrogen fertilization, farmers used their normal cultural practices in all experiments. Due to an extremely wet spring in 1995, most experiments were planted in early June, and even then conditions were wet enough to cause significant stand losses. Most 1996 experiments were planted in late April and stands were good.

Nitrogen rate treatments were applied to small plots at the first thirteen locations in Table 1 (hand-applied ammonium nitrate) and to large strips at the last three locations (sidedressed anhydrous ammonia or UAN solution). For the 1995 experiments N was applied at sidedress in 50 lb increments, following 0 or 50 lb N/acre at planting. For the 1996 small-plot experiments, N was applied in 25 lb increments either preplant, sidedress, or 100 lb at planting followed by sidedress N rates. For the 1996 strip-plot experiments N was sidedressed in 50 lb increments. Rates ranged from 0 to 350 or 400 lb/acre in the small-plot experiments, and 0 to 150 or 200 lb/acre in the strip-plot experiments. Although the 300+ lb N rates are impractically high for farmers, they help to establish the yield plateau accurately, which is in turn important in establishing the optimum N rate accurately. Measuring the optimum N rate and seeing whether it can be predicted using field-specific tests is the main objective of this research.

Soil samples were taken at planting and again at sidedress to a depth of 3 feet in 1 foot increments and analyzed for ammonium and nitrate. Whole-plant tissue samples were taken at sidedress time and analyzed for total nitrogen content. SPAD chlorophyll meter readings were also taken at sidedress time, and stalk samples were collected at harvest for nitrate analysis. Sidedress samples were taken both in plots receiving no N at planting and separately in plots receiving either 50 lb N/acre (1995) or 100 lb N/acre (1996) at planting. Small plots were hand-harvested, shelled, weighed, and yield was calculated corrected to 15% moisture. Population in the harvest area was recorded. Strip plots were combined, weighed, and yield was calculated corrected to 15% moisture.

In experiments where the relationship between yield and population in the harvest area was significant, plot yields were corrected to the mean population of the experiment. This was done separately for plots that were nitrogen-limited and plots that were not at locations with a yield response to N. A nearest-neighbor technique was used to account for spatial yield variability due to variations in soil properties within the experiment (Scharf and Alley, 1993). Corn yield response to nitrogen fertilizer rate was modeled using quadratic-plateau or non-responsive models calculated using SAS. At one location, a linear-plateau model was used because it fit the data substantially better than a quadratic-plateau model.

Economic response to N was calculated as (yield at given N rate) x $2.80/bu - N rate x $0.25/lb N - $200/acre other production costs. Yield at a given N rate was obtained from the best-fitting yield response function.

Economic optimum N rate (the rate giving the highest return) at each location was regressed against site measurements (soil test values, tissue test N, SPAD meter reading) to see whether any of them were related strongly enough to optimum N rate to be used in making N rate recommendations. The N rate recommended at each experiment was calculated for a large number of possible recommendation systems, including some that are currently in use in other states, and the economic performance of each system was compared over all sites where we had the measurements to test it.

RESULTS AND DISCUSSION

Yields and optimum N rates

Yields in 1995 were good considering the extremely late planting dates and reduced stands (caused by wet planting conditions), and yields in 1996 were excellent. Both years had good rainfall distribution through the summer.

Corn yield response to nitrogen rate for all experimental locations is shown in Figure 1. Economically optimum N rates were calculated from these yield response curves using a corn price of $2.80/bu and an N price of $0.25/lb N. Changing these prices would change the profit estimates quite a bit, but would change the optimum N rate only a little (Baethgen et al., 1989). Since our main

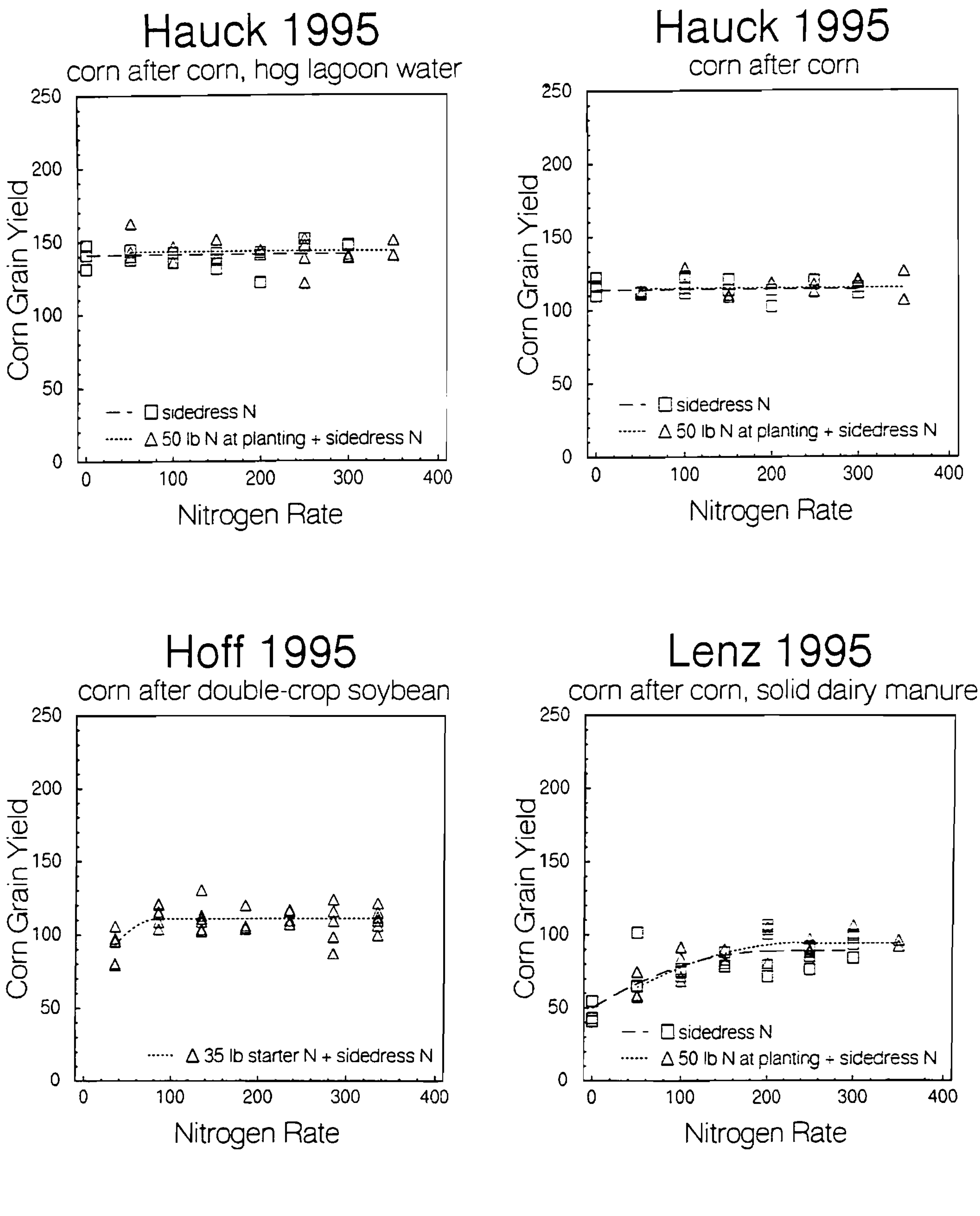
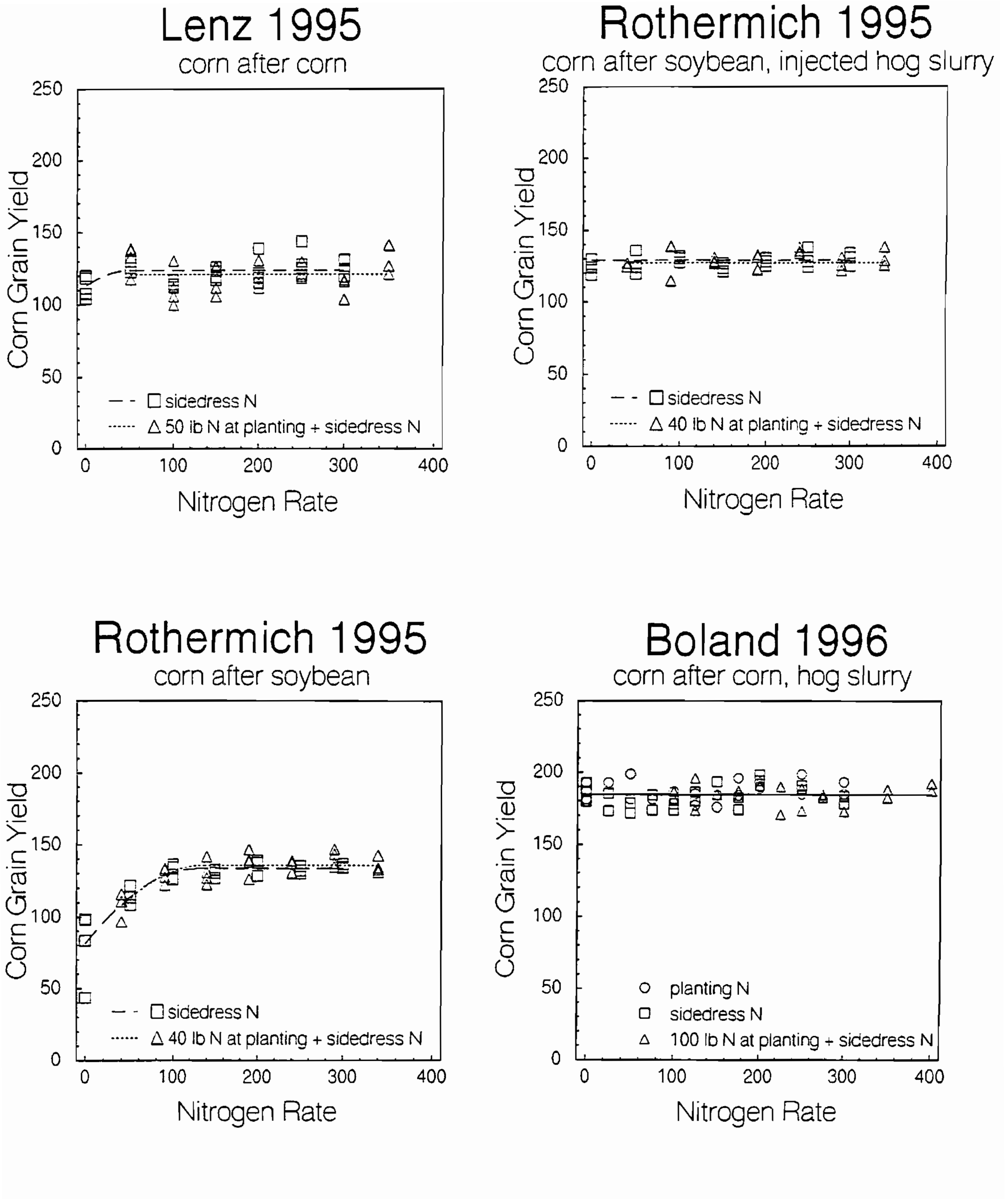


Figure 1. Corn yield response to nitrogen fertilizer in 16 farmer fields in Missouri.



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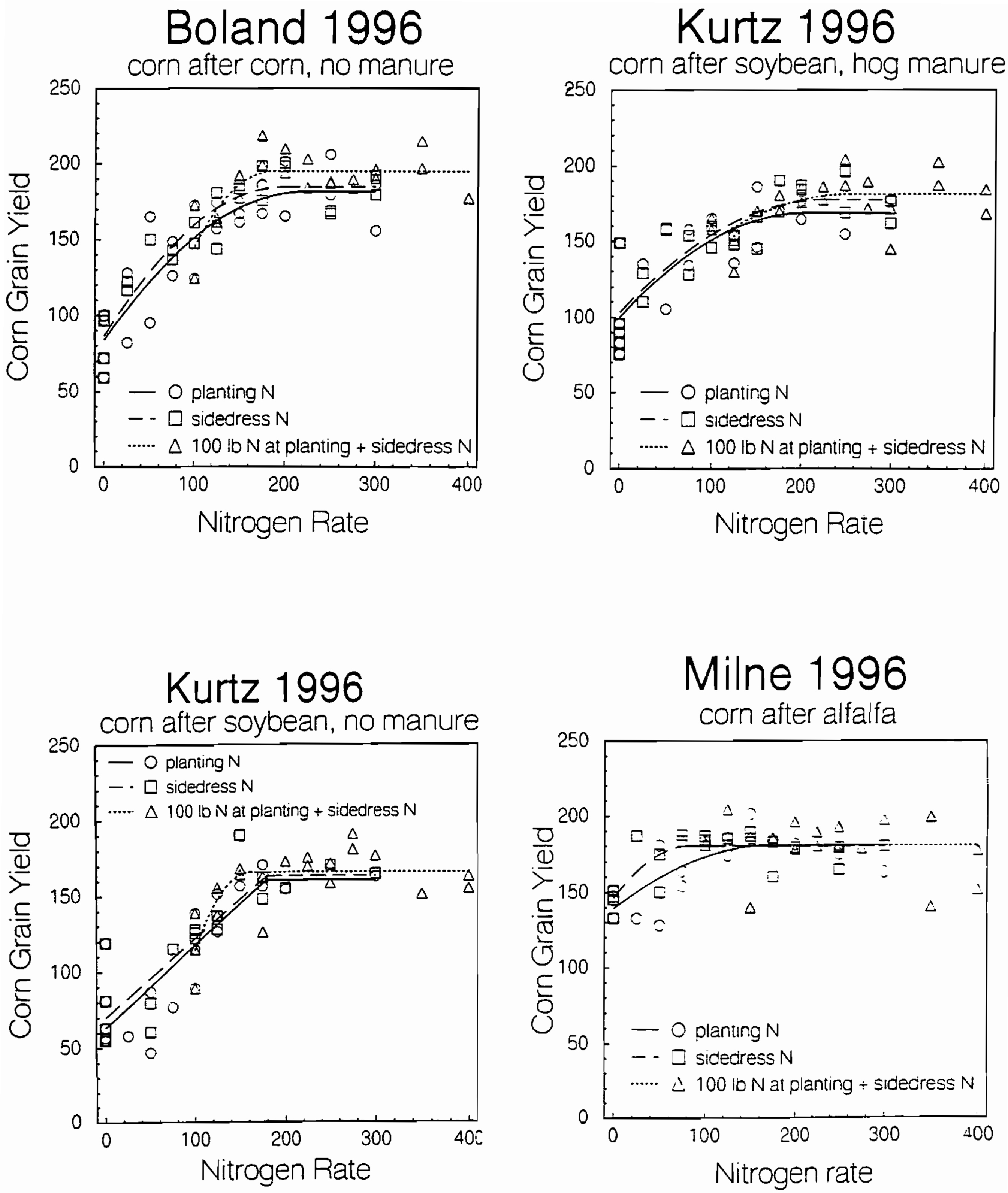

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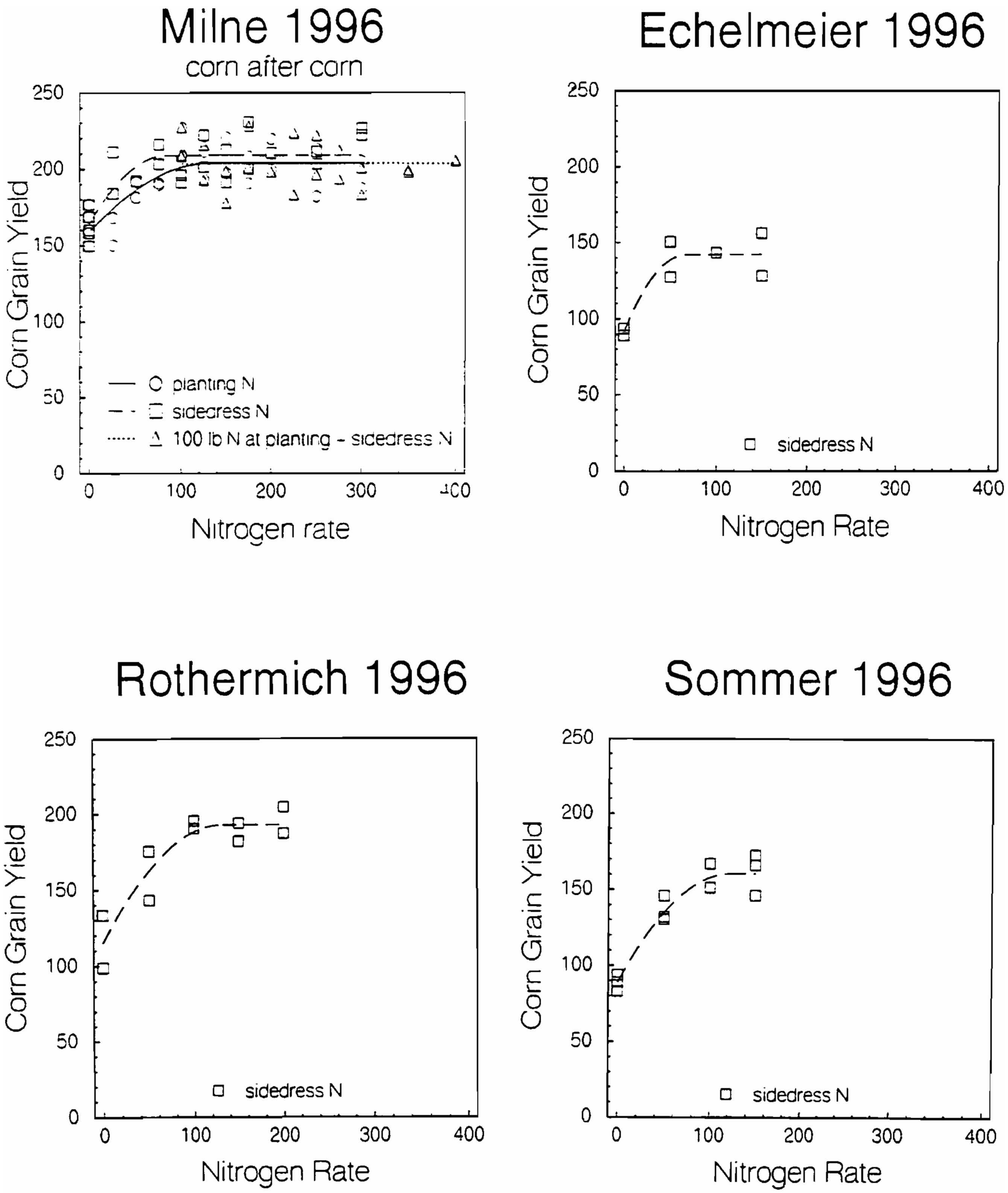

Figure 1 (continued)

interest is in predicting optimum N rates, price fluctuations won't have much effect on our ability to do this.

Timing of N fertilizer applications (planting, sidedress, or planting + sidedress) had very little effect on yield response (Figure 1). There were no cases where N at planting produced more yield than sidedress N. At the Boland 2 location, it appears that 100 lb N at planting followed by sidedressing gave higher yields than either planting or sidedress N applications. At the Milne 1 and Milne 2 locations, sidedressing gave the same optimum yields as N at planting, but did it at lower N rates.

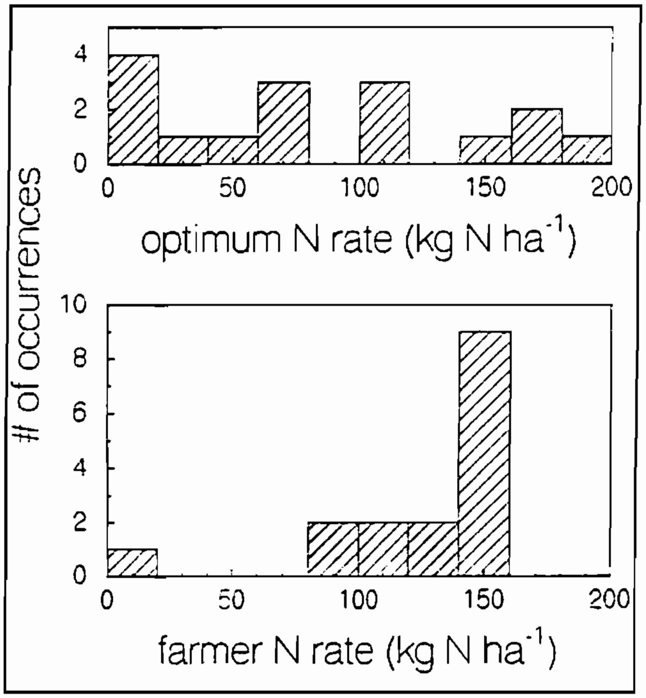

Figure 2. Distribution of optimum N rates and actual N rates used by farmers in 16 experimental corn fields.

Both yields and economically optimum N rates were higher in 1996 than in 1995 (Table 2). There was a very wide spread in optimum N rates in our experiments, but much less spread in the actual N rates used by the farmers in the surrounding fields (Figure 2). In general, the farmers put on more N than they needed and didn't vary their rates much because they had no way of knowing which fields might need less N, and the cost of putting on too little N is much higher than the cost of putting on too much. There is clearly an opportunity to do a better job of matching N fertilizer rates to crop need if a test (or tests) can be developed to reliably predict crop need in time to fertilize.

Although manure can often make a significant contribution to filling the N needs of a corn crop, manured fields sometimes need substantial amounts of fertilizer N to optimize yields as at the Lenz and Kurtz manured experiments (Table 2). A field-specific test that could identify which manured fields would respond to additional nitrogen fertilizer would be an important step toward crediting manure N. We found that only one of the cooperating farmers in this study normally gave any N credit for his manure applications. Cases where manure has failed to provide enough N for a corn crop when it "should have" will spread by word of mouth and influence the decisions of manure managers. A field-specific test to predict crop N needs could help to prevent many of these manure failures.

Table 2. Optimum N rates and yields derived from graphs in Figure 1.

location/ group	N timing	optimum total N rate	yield at opt. N rate	profit at opt. N rate	N rate used by farmer
		lb/acre	bu/acre	$/acre	lb/acre
Hauck 1	sidedress	0	141	195	150
Hauck 1	50 planting + sidedress	50	143	188	
Hauck 2	sidedress	0	114	119	150
Hauck 2	50 planting + sidedress	50	115	109	
Hoff	35 starter + sidedress	75	110	90	120
Lenz 1	sidedress	145	86	4	150
Lenz 1	50 planting + sidedress	175	91	11	
Lenz 2	sidedress	35	123	136	150
Lenz 2	50 planting + sidedress	50	121	126	
Rothermich 1	sidedress	0	127	156	0
Rothermich 1	50 planting + sidedress	50	129	151	
Rothermich 2	sidedress	110	133	144	110
Rothermich 2	50 planting + sidedress	115	134	147	
Boland 1	planting	0	185	317	150
Boland 1	sidedress	0	185	317	
Boland 1	100 planting + sidedress	100	185	292	150
Boland 2	planting	195	180	255	150
Boland 2	sidedress	180	184	269	
Boland 2	100 planting + sidedress	180	194	300	
Kurtz 1	planting	175	167	225	125
Kurtz 1	sidedress	190	175	244	
Kurtz 1	100 planting + sidedress	210	179	248	
Kurtz 2	planting	180	161	205	125
Kurtz 2	sidedress	180	164	213	
Kurtz 2	100 planting + sidedress	160	166	225	
Milne 1	planting	130	178	267	100
Milne 1	sidedress	70	180	285	
Milne 1	100 planting + sidedress	100	181	281	
Milne 2	planting	105	202	340	150
Milne 2	sidedress	70	208	365	
Milne 2	100 planting + sidedress	100	204	345	
Echelmeier	sidedress	60	142	186	150
Rothermich 3	sidedress	115	192	309	150
Sommer	sidedress	115	161	229	100
average all	sidedress	84	152	204	127
1995	sidedress	52	119	121	119
1996	sidedress	109	177	269	133
prev. corn	sidedress	61	149	201	150
prev. soybean	sidedress	103	142	172	105
prev. wheat	sidedress	115	176	269	125
organic N	sidedress	68	149	200	113
inorganic	sidedress	94	153	206	136

The number of sites with no major organic N source or organic N history but which had low N fertilizer needs was surprising. The Hauck 2, Lenz 2, Milne 2, Echelmeier, Rothermich 1996, and Sommer experiments all yielded at least 50 bu/acre higher than their optimum N rate in lb/acre. None of these fields had more than one manure application in the last ten years, or any manure since 1992. The Lenz location was in the second year coming out of alfalfa and that may have contributed some N to the corn crop. Normally we would recommend much higher N fertilizer rates to achieve these yields than what it actually took in these six cases. A way to identify fields like this ahead of time would save farmers money on N that is not giving them a return.

Although average optimum N rate was lower when an organic N source was present, and was lower when corn was the previous crop (compared to soybean), it was still extremely variable from site to site within these categories (Table 2; Figure 3). The differences in optimum N rate from one site to another could not be usefully predicted by previous crop or presence of an organic N source. Yield at the optimum N rate was not related to optimum N rate either (Figure 4), so using yield goal as a basis for N rate recommendations is also questionable.

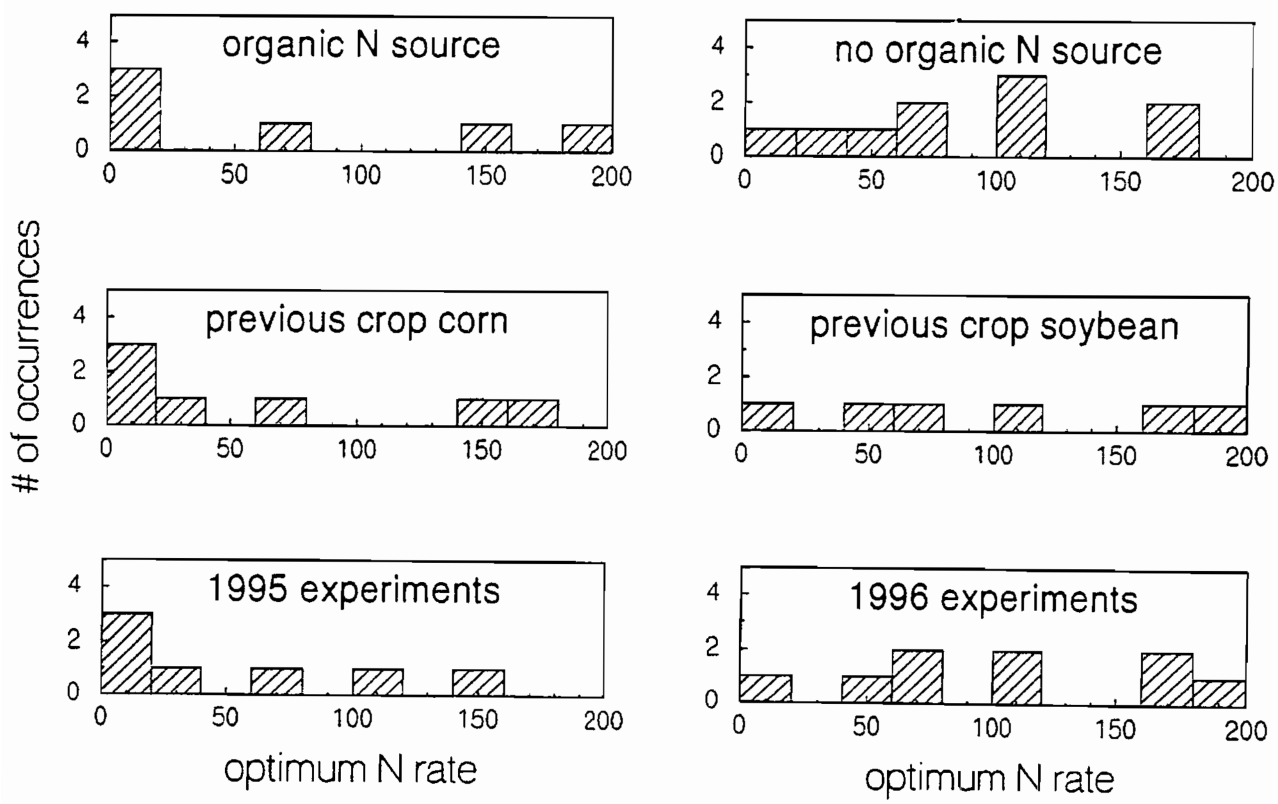

Figure 3. Distribution of economically optimum N rates for experiments in different categories. In all categories the optimum N rate ranges from 0 to at least 150 lb N/acre.

Relationships between field tests and optimum sidedress N rates

We'd like to be able to predict ahead of time what the optimum N fertilizer rate for each field will be. One way to do this is to see if any of the field tests (soil or plant measurements) are related to optimum measurements) are related to optimum fertilizer rate over a range of fields. To try this out, field test results were regressed against optimum sidedress N rate. Pretty much all of the tests were related to optimum N rate in a statistically significant way, but some were much more closely related than others (Table 3). Tissue nitrogen at V6 (6 collared leaves, normal sidedress time, about 12" high whorl) was the best predictor of optimum N rate, followed by chlorophyll meter reading of the top collared leaf at V6 (Table 3, Figures 5 & 6). Both tissue N and chlorophyll meter reading were much better predictors of optimum N rate at V6 than at V4/V5 (Table 3, Figures 5 & 6). Also, chlorophyll meter reading on the top collared leaf at V6 worked much better than a meter reading taken on the leaf above the top collared leaf (Figure 6).

Soil nitrogen measurements were significantly related to optimum N rate, but this relationship was much weaker than with the plant measurements. At both planting and sidedress time, going deeper than 1 foot and/or adding

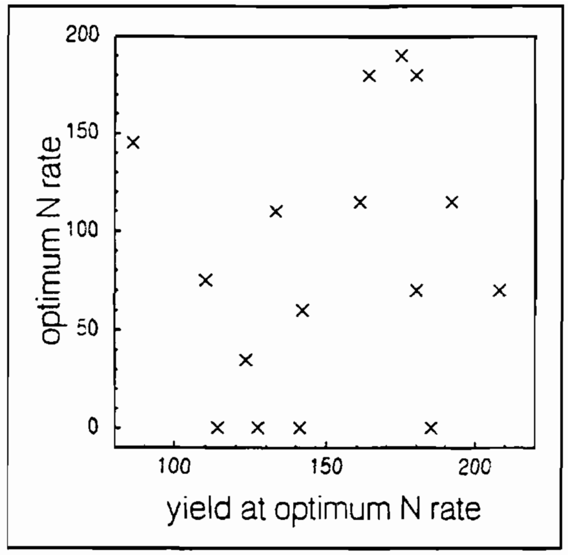

Figure 4. Yield was not a good predictor of how much N was needed.

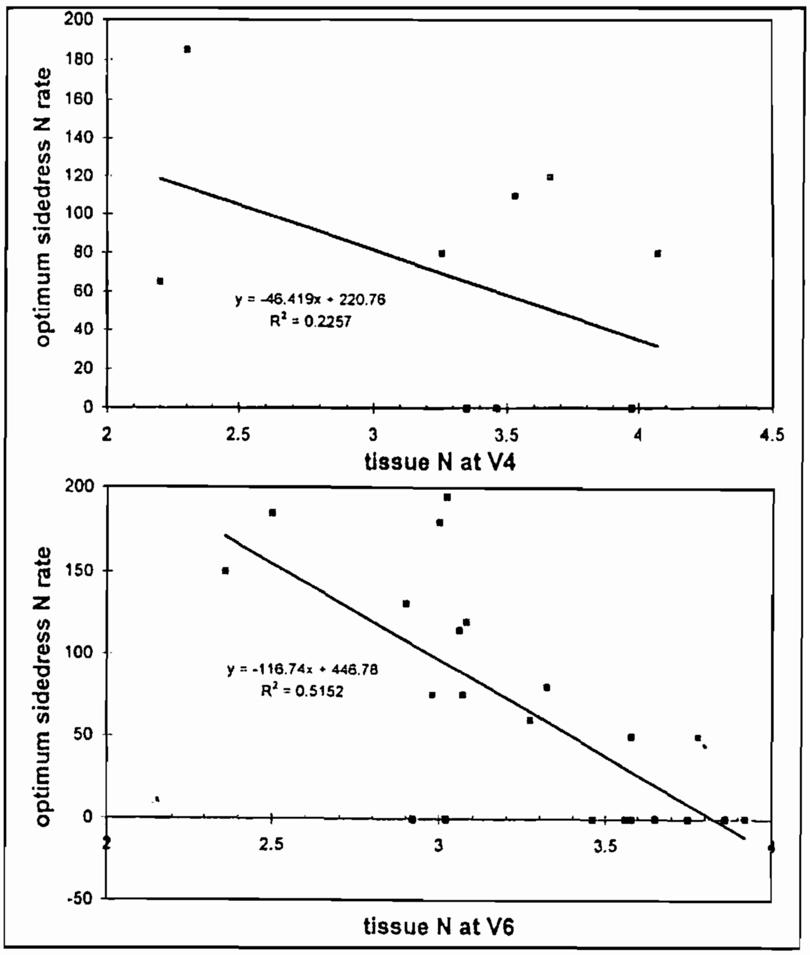

Figure 5. Total N in whole above-ground plants was already related to N need by growth stage V4, and much more strongly related at V6 (six collared leaves).

ammonium to the soil nitrate test increased the strength of the relationship, but not by very much (Table 3).

Table 3. Regression statistics for field tests vs. optimum N rates.

measurement	r^2	probability of no true relationship
planting soil NO_3^- to 1 foot	0.18	0.06
planting soil NO_3^- to 2 feet	0.26	0.02
sidedress soil NO_3^- to 1 foot	0.21	0.015
sidedress soil NO_3^- to 2 feet	0.24	0.01
sidedress soil NO_3^- + NH_4^+ to 2 feet	0.27	0.006
tissue N at V4/V5	0.22	0.16
tissue N at V6	0.52	0.0002
chlorophyll meter:		
top collared leaf at V4/V5	0.27	0.10
top collared leaf at V6	0.41	0.0009
leaf above top collared, V6	0.28	0.01

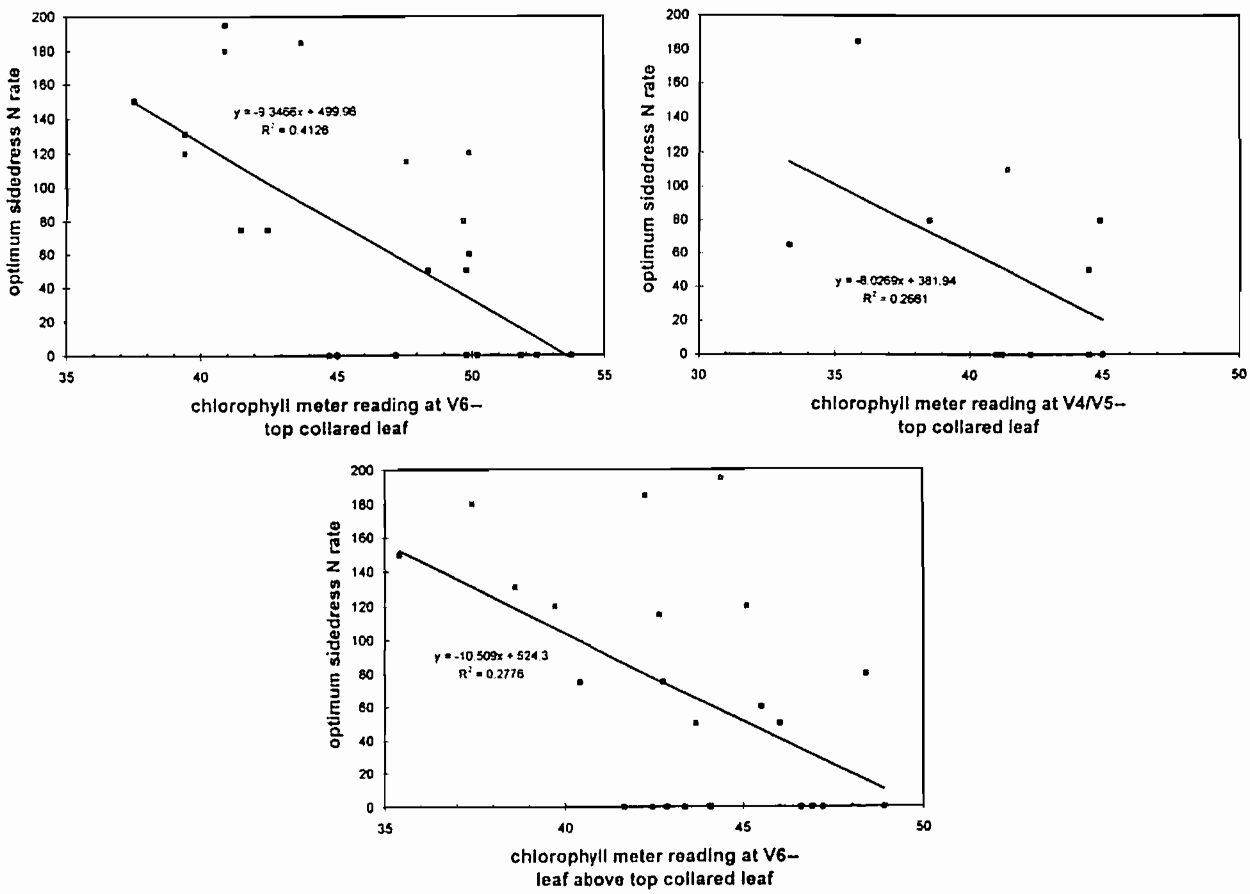

Figure 6. Minolta chlorophyll meter reading on the top collared leaf at growth stage V6 was the second-best predictor of optimum N rate after tissue N. Readings at V4 or on the leaf above the top collared leaf did not work as well.

N rate recommendations and economic performance of tests

The main goal of these experiments was to see whether the soil or plant measurements could be used to predict how much N was needed. For each of the recommendation systems described below, the average amount of N used and the average economic performance was compared to that of the N rates actually used by farmers in these fields (Table 4). For a given system at a given location, the N rate recommendation was translated into a yield using the yield response lines in Figure 1. Cost of N and other production costs was then subtracted from the value of this yield, as described in the procedures section. to give economic return to the recommendation.

The University of Missouri N rate recommendation is based on yield goal (120 bu/acre yield goal was used for 1995 experiments and the Sommer 1996 experiment, all on claypan soils, and 150 bu/acre yield goal was used for all other 1996 experiments, which were on deep loess soils or alluvial soils or irrigated claypan soils), population, and soil organic matter (credit 20 lbs N for each percent organic matter for a silt loam soil). The recommendation used was the one printed on the soil test form, which does not include any N credits. Adding N credits to this system was also tested: 40 lb N/acre for a previous soybean crop, 100 lb N/acre for a previous alfalfa crop, and manure credits calculated from the best estimates that the farmers had available for manure application rate and N content (minus 80% volatilization losses if surface-applied). University of Missouri recommendations with no credits were higher on average than the rates used by farmers, and with credits were lower, but in either case did not significantly improve returns relative to farmer N rates (Table 4).

The pre-plant nitrate test (PPNT) was developed in Wisconsin and is also being used in Minnesota. They measure soil nitrate to two feet at planting, subtract 50 lb that they say would be there normally, then credit any amount in excess of 50 lb (Bundy and Sturgul, 1994). Using this approach to adjust current University of Missouri recommendations cut back on N rates substantially with no effect on return (Table 4). Using this same system but crediting both ammonium and nitrate worked well in the experiments with an organic N source, but not in the inorganic experiments. Using both the PPNT credit and N credits for legumes or manure substantially decreased fertilizer use and increased profitability relative to current farmer practices (Table 4). Schoessow et al. (1996) came to a similar conclusion: that crediting both the PPNT and a soybean N credit worked better than either credit alone for corn following soybean.

The sidedress soil and plant measurements were tested for their ability to predict optimum N rate both for sidedress-only applications and for sidedress applications when 50 or 100 lb N/acre had been applied at planting. Only a small percentage of farmers are willing to sidedress all their corn, but a moderate N application at planting followed by evaluation of which fields needed additional sidedressing might be a more acceptable system. The risk of extremely large yield losses that could occur from not getting on any N at all in wet years is

Table 4. Change in N rate and profit with different recommendation systems, relative to N rates actually used by farmers in these fields.

Recommendation method	Change relative to farmer N rate in: N rate		return	
	lb N/acre		$/acre	
University of Missouri	+22	**	+3	
University of Missouri - N credits	-15	*	+2	
sidedress NO_3^- test (critical value = 25ppm)	+2		0	
sidedress NO_3^- test, rain adjusted + new interp.[§]	-32	*	0	
optimum	-29	*	+18	***
tissue N regression at V6[†]	-33	*	+8	+
chlorophyll meter regression at V6[†]	-32	*	+4	
chlorophyll meter[†] (Piekielik and Fox, 1994)	-50	**	-6	
Univ. of Missouri - preplant NO_3^- test[‡]	-11		+4	
U. of Missouri - preplant NO_3^- test - N credits[‡]	-37	**	+7	*
U. of Missouri - preplant (NO_3^- + NH_4^+)[‡]	-52	***	-10	

Statistical significance levels for differences from zero: +p<0.10, *p<0.05, **p<0.01, ***p<0.001
[§]Iowa's new interpretations use a table instead of a formula for fields with manure or 1 or 2 years after alfalfa
[†]Rothermich 1, 2, & 3, Echelmeier locations missing from these analyses
[‡]Kurtz 1 & 2, Milne 1 & 2 locations missing from these analyses

avoided, and possible losses of N between early pre-plant application and sidedress can be evaluated and compensated for. Although there were only minor differences in yield response between N rates applied at planting and sidedress in these experiments, the N was actually applied right after planting; many production fields are fertilized considerably before planting and therefore have a higher risk of N loss. Two experiments conducted in Missouri have both shown about a 20 bushel yield loss when corn was fertilized March 15 instead of April 15. Alfred Blackmer of Iowa State University thinks that many corn fields suffer substantial N losses that hurt yield but that do not cause striking symptoms and are not noticed by the farmer (personal communication, 1997).

Iowa and a number of other states are now using a soil nitrate test taken to one foot at sidedress time to make sidedress rate recommendations (Blackmer et al., 1997). The potential advantage of this test over preplant soil nitrate tests is that it gives an indication of how much mineralization of organic N is taking place in the field. This could be important in fields with major organic N sources like manure or a previous alfalfa crop. Iowa's interpretation of this test was initially that if the test result is above a critical value of 25 ppm, no N is recommended; if the test result is below 25 ppm, eight lb N/acre is recommended for each 1 ppm below the critical level. They have recently modified this interpretation to drop the critical level to 22 ppm when spring precipitation is above normal, as it was in both of these study years, and to base recommendations for fields with manure or a previous alfalfa crop (1 or 2 years before present corn crop) on a table instead of the formula (Blackmer et al., 1997). Both interpretations of the test gave the same economic return in these experiments as farmer N rates, but using the new interpretations reduced N rates by about 30 lb N/acre with no economic loss (Table 4).

The tissue N test (total Kjeldahl nitrogen) worked the best of the sidedress tests. A similar test has been used successfully with winter wheat (Scharf et al., 1993). This test not only had the strongest relationship to optimum N rate (Figure 5, Table 3), but gave the highest returns (Table 4). The disadvantage of the tissue test is the turnaround time to send it to a lab and get the results back. In a crop that grows as fast as corn. this is a serious obstacle to being able to get the N on without special equipment. However, these results indicate promise for using other more convenient plant measurements for predicting sidedress N need.

One possible plant measurement that is more convenient is the chlorophyll meter. Pennsylvania research indicated a critical chlorophyll meter value of 44 for the top collared leaf at growth stage V6 (Piekielik and Fox, 1992). No sidedress N would be applied when the meter reading is 44 or higher, and a normal full rate would be applied below that reading. We tested this recommendation system in these experiments, and it may have reduced profitability compared to actual farmer N rates (not statistically significant--Table 4); it actually did reasonably well in experiments with an organic N source, but did very poorly in experiments with no organic N source and where some fertilizer N had been applied at planting.

Basing N rate recommendations from the chlorophyll meter on the regression shown in Figure 6 worked better than the Pennsylvania critical value in these experiments, though that is not that surprising since the regression was derived from these experiments. It will be important to evaluate recommendations based on this regression in additional experiments. Compared to farmer N rates, average N rate was reduced substantially, and profitability was either unaffected or improved.

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