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Influence of Fertilizer Nitrogen and Sulfur on Production of Malting Barley

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CONTENTS

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SUMMARY

Studies in north-central Nebraska from 1975 through 1977:

1. Evaluated the malting barley production potential of the irrigated sandy soils of the region.

2. Measured the effect of application of N and S on yield and quality of barley grown for malting purposes.

3. Investigated the ability of N analysis of barley in the vegetative stage to predict protein content of grain at harvest.

Data gathered lead to the following conclusions:

1. The potential for production of malting barley on irrigated sandy soils of north-central Nebraska is limited. Although fertilizer N improves yield, it is detrimental from the malting standpoint in that it increases the protein content of the grain to levels higher than 13.5%.

2. Yields increased with the application of fertilizer N throughout the study although response varied with site and variety. The nature of the yield response could not be predicted from the NO_3^--N analysis of soil samples collected before planting.

3. Application of fertilizer S had no effect on yield throughout the study. Although amounts of S in the soil were relatively low, the S supplied with the irrigation water, together with that released from mineralization of the organic matter, was apparently enough to meet S requirements of the barley crop.

4. Application of N increased the protein content of all grain varieties studied by approximately 2 to 3 percent. Protein content of the grain varied with the variety used. When no fertilizer N was applied, the protein content of Larker and Beacon varieties exceeded the 13.5% value considered to be the upper limit for acceptance as malting barley. The Karl variety produced grain with an acceptable protein level at one site in 1977. Yields from this variety, however, were quite low and would not be economical with the current price structure.

5. Analysis of plant material collected at the boot stage for N provided a reliable indication of the grain protein content. There was a linear relationship between the N content of this tissue and the protein content of grain at all sites in 1976 and 1977.

Influence of Fertilizer Nitrogen and Sulfur on Production of Malting Barley

G. W. Rehm and R. S. Moomaw[1]

The combination of a relatively abundant supply of groundwater and the development of the automated center pivot irrigation system has produced a major change in the agriculture of north-central Nebraska during the past 20 years. As a result, irrigated corn is produced where native range once prevailed. Although corn is grown on a large majority of the acres, a number of cultural and economic factors require that some attention be devoted to consideration of alternate crops. Malting barley has been suggested as one alternative.

In contrast to many crops where yield is the primary consideration, both yield and quality are important in production of barley for malting purposes. Previous research has shown that many factors affect the quality of barley grain. Fertilizer application has had a major effect on protein content of the grain in other regions where malting barley is grown.

Research in Iowa showed that application of both nitrogen (N) and phosphorus (P) influenced both yield and quality of malting barley (Atkins *et al.*, 1955). While the use of both nutrients improved yields, N fertilization reduced and P fertilization improved the grain quality.

Pomeranz *et al.* (1976) emphasized that protein content of the grain is the major quality component to consider in production of malting barley. Consequently, research with barley intended for malting has focused on the prediction of the rate of N fertilizer which will produce high yields while not being detrimental to the protein content of the grain. Barley with a protein content in excess of 13.5% is not considered suitable for malting because the high protein level causes excessive foaming during brewing and a haze in the finished product. Studies by Walker (1975), Soper and Huang (1963), and Geist, Reuss and Johnson (1970) showed that the amount of nitrate-nitrogen (NO_3^--N) in the rooting zone before planting must be considered in making N recommendations for production of malting barley.

Sulfur (S), in addition to N, is a major component of plant proteins. It's logical, therefore, to examine the effect of S fertilizers on the production and quality of malting barley. Reisenauer and Dickson (1961) found that both N and S influenced barley yield but application of S had no effect on the S content of the grain.

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Although malting barley is grown successfully in many parts of the Great Plains, there was no available information to indicate if it would be a suitable alternative to irrigated corn on the sandy soils of north-central Nebraska. If these sandy soils would produce acceptable yields of malting barley, then it would be necessary to determine the fertilizer requirements for this crop. Since N and S are involved in protein formation, it seemed appropriate to first determine the effects of these two nutrients. Therefore, objectives of this study were:

1. To estimate the malting barley production potential on irrigated sandy soils of northeastern and north-central Nebraska.
2. To measure the effect of application of N and S on yield and percentage of protein in barley grown for malting purposes.
3. To determine the ability to predict protein content of the grain at harvest using N analysis of barley in the vegetative stage.

EXPERIMENTAL PROCEDURE

Experiments were conducted in northeast and north-central Nebraska from 1975 through 1977 in growers' fields. Soil properties and varieties changed from year to year. Therefore, procedures used each year are discussed separately.

1975

One site was selected in 1975. The soil was classified as a Thurman loamy fine sand. Soil samples were collected before planting (properties are listed in Table 1). Two varieties (Larker and Beacon) were fertilized with N (0, 38, 56, 84, and 112 kg N/ha) arranged as a complete factorial with five replications.

Nitrogen, supplied as ammonium nitrate (33-0-0), was broadcast and disked in before planting. The barley was seeded on 20 April. Each plot received 9.9 kg P supplied as triple superphosphate (0-46-0) and 11.2 kg S/ha supplied as granular gypsum with the seed at planting. The seeding rate was approximately 78 kg/ha. Each plot consisted of six rows 5 m in length with rows spaced 30 cm apart.

Yields were measured on July 21. Composite grain samples for each treatment were sent to the Barley and Malting Laboratory for quality analysis.

Table 1. Soil properties for experimental site used in 1975.

Soil class	loamy fine sand
pH	5.7
pH, Woodruff	6.4
NO_3-N, 0-20 cm	1.8 ppm
NO_3-N, 20-60 cm	9.0 ppm
NO_3-N, 60-90 cm	9.0 ppm
NO_3-N, kg/ha to 90 cm	100 kg/ha
P (Bray + Kurtz)	38 ppm
Exchangeable K	203 ppm
Organic matter content	1.04%

Table 2. Properties of the soils at the experimental sites in 1976.

Property	Depth cm	County		
		Antelope	Stanton	Holt
Soil class	0-30	loamy fine sand	loamy fine sand	fine sandy loam
Organic matter content, %	0-30	.8	1.6	2.0
P (Bray + Kurtz), ppm	0-30	17.7	7.7	8.0
Exchangeable K, ppm	0-30	114.3	120.7	148.0
Extractable S, ppm	0-30	9.9	7.0	10.8
NO_3^--N, ppm	0-30	1.6	1.0	4.3
NO_3^--N, ppm	30-60	3.2	3.5	.9
NO_3^--N, ppm	60-90	3.0	1.7	1.9
NO_3^--N, kg/ha to 90 cm	——	32.3	27.8	31.8

1976

Three sites were selected in 1976. Soil at the Antelope and Stanton County sites was classified as a Thurman loamy fine sand. Soil at the Holt County site was classified as a Meadin fine sandy loam. Soil samples to a depth of 90 cm were collected before planting. Soil properties are listed in Table 2.

Two varieties (Larker and Beacon) were fertilized with N (0, 28, 56, 84, and 112 kg N/ha) and S (0, 8, 16, 24, 32 kg S/ha). Fertilizer treatments were selected from a 5^2 complete factorial to form a central composite factorial design. Three replications were used. Plot size was the same as used in 1975.

Nitrogen, supplied as ammonium nitrate (33-0-0), and S, supplied as granular gypsum, were broadcast in early April. Each plot received a broadcast application of 39 kg P/ha as triple superphosphate (0-46-0). All fertilizer materials were incorporated with a light disking before planting. Barley was seeded in early April at a rate of approximately 78 kg/ha.

Whole plant samples were collected at the boot stage. These samples were dried, ground to pass a 2 mm screen, and analyzed for N by the Kjeldahl procedure. Samples of irrigation water were collected in early June and analyzed for nutrient content.

Grain yields were measured in early July. Grain samples from individual plots were sent to the Barley and Malting Laboratory. These samples were analyzed for protein and percentage of plump kernels.

Regression equations for yield, N content of whole plants at the boot stage, and protein content of the grain were used to compute predicted values for the complete factorial. Equation 1 was used as the model.

$$(1) \quad Y = b_0 + b_1 N + b_2 S + b_3 N^2 + b_4 S^2 + b_5 NS$$

In this equation, Y is the predicted value; N and S refer to coded

Table 3. Coded values which were used in Equation 1 to compute predicted values.

Nutrient	Coded Value −2	−1	0	+1	+2
	kg/ha				
Nitrogen	0	28	56	84	112
Sulfur	0	8	16	24	32

amounts of applied N and S (Table 3). The b values are the regression coefficients computed from the observed data indicating linear, quadratic, or interaction effects of the nutrients used.

1977

Three sites were selected for study in 1977. Since a poor stand prevented the collection of meaningful data at one site, results from the two remaining sites are reported here. The soil at both sites was classified as a Thurman loamy fine sand.

Soil samples to a depth of 90 cm were collected before planting (properties are listed in Table 4).

Two varieties (Karl and Klages) were fertilized with N (0, 28, 56, 84, and 112 kg N/ha) and S (0, 8, 16, 24, and 32 kg S/ha).

Design, plot size, method of fertilizer application, seeding dates and rates, collection of plant samples, and harvest methods were the same as used in 1976.

RESULTS

1975

Rate of applied N and variety affected yield in 1975 with no interaction between N rate and variety. When averaged over all rates of applied N, the Larker variety produced 3699 kg/ha while the Beacon

Table 4. Properties of the soil at the experimental sites used in 1977.

Property	Depth cm	County Pierce	Holt
Soil class	0-15	loamy fine sand	loamy fine sand
Organic matter content, %	0-15	1.17	.94
P (Bray + Kurtz), ppm	0-15	38	10
Exchangeable K, ppm	0-15	194	74
pH	0-15	6.4	5.9
Extractable S, ppm	0-15	7.2	4.3
Cation exchange capacity, meq/100 gm	0-15	5.9	4.3
NO_3-N, ppm	0-15	2.4	2.0
NO_3-N, ppm	15-30	3.7	1.8
NO_3-N, ppm	30-60	6.3	2.3
NO_3-N, ppm	60-90	7.3	3.2
NO_3-N, kg/ha to 90 cm		46.4	29.8

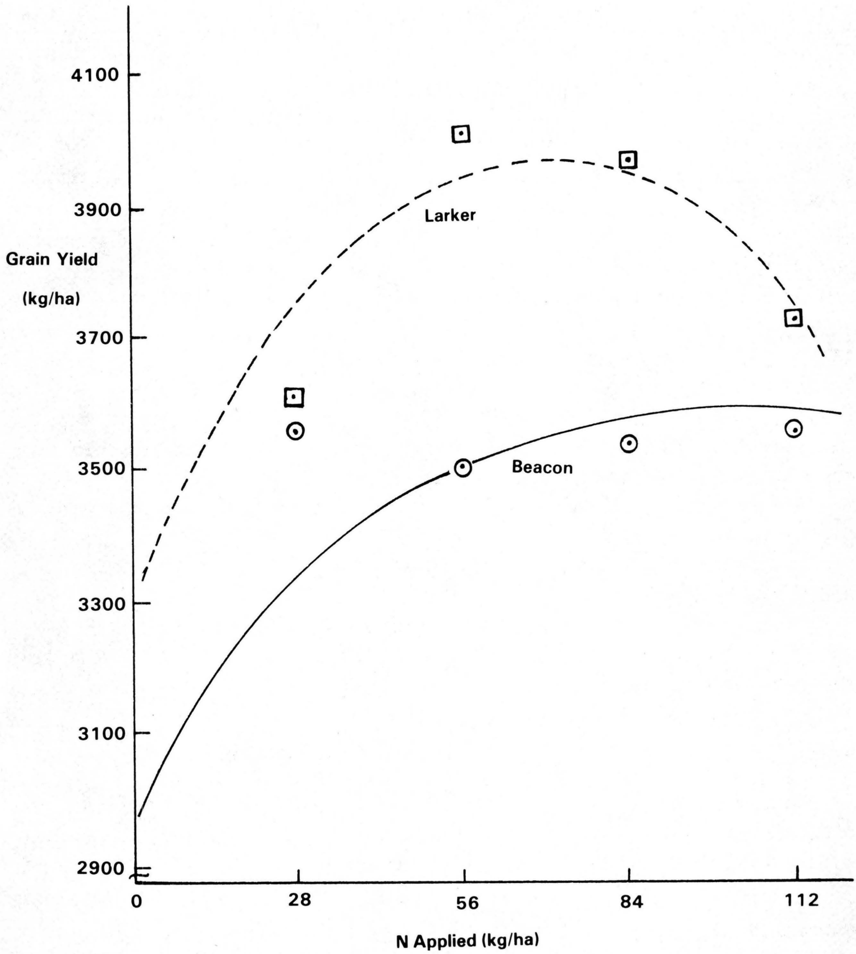

Figure 1. Response of Beacon and Larker barley to the application of N. 1975.

variety produced 3419 kg/ha. This yield difference was significant at the .05 confidence level.

For both varieties, the relationship of yield to rate of applied N was curvilinear (Figure 1). Combining the data from both varieties, the regression equation relating yield (Y) in kg/ha to N in kg/ha is $Y = 3135.3 + 19.66N - .151N^2$. The application of 56 kg N/ha was sufficient to produce maximum yields of both varieties at this site. The combination of 56 kg/ha fertilizer N with 100 kg N/ha in the soil before planting (Table 1) was apparently sufficient to produce maximum yields at this site. The irrigation water contained enough NO_3^--N to supply about 9.5 kg N/ha for each 30 cm water applied (Table 5). Actual irrigation water applied at this site was approxi-

Table 5. Nutrient content of the irrigation water at the 1975 experimental site.

Nutrient	County: Antelope
	ppm
Nitrogen	3.1
Phosphorus	.05
Potassium	7.3
Sulfur	.6
Magnesium	9.1

mately 10 cm. Therefore, a relatively small amount of N was supplied in the irrigation water.

1976

The study was continued at three sites in 1976 with the research expanded to include a study of the effect of S on yield, the N content of plants at the boot stage, and protein content of grain. The regression equations listed in Table 6 show that application of N increased the yield of both varieties at the Antelope and Stanton County locations. The application of fertilizer N increased yield of only the Larker variety at the Holt County site. The addition of fertilzier S had no effect on yields at all sites.

Relationship of yield to amounts of applied N was curvilinear for the Larker variety at both the Antelope and Holt County sites (Figure 2). This curvilinear response can be attributed to lodging observed when N in excess of 84 kg/ha was applied at these sites.

Yields of the Larker variety at the Stanton County site and the Beacon variety at Antelope and Stanton County sites were linearly related to the application of fertilizer N (Figure 2). The data provide an explanation neither for the failure of the Beacon variety to respond to N at the Holt County site nor for the difference in the nature of response to N among sites. The NO_3-N content of the soil was

Table 6. Regression coefficients, their significance, and the R^2 values for the effect of N and S on the yield (kg/ha) of Larker and Beacon barley in 1976.

	County and Variety					
Regression	Antelope		Stanton		Holt	
coefficient	Larker	Beacon	Larker	Beacon	Larker	Beacon
b_0	2157.4	1845.3	3249.5	3002.0	4825.9	4637.6
b_1 (N)	231.3***	317.4***	318.5***	164.6***	178.1***	−38.2
b_2 (S)	−20.4	−4.8	−8.1	42.5	−88.8	1.1
b_3 (N^2)	−349.7***	−55.4	−57.6	−175.9	−358.9***	−106.0
b_4 (S^2)	161.4	1.6	−127.5	−60.3	171.1	36.6
b_5 (NS)	−6.5	−3.2	5.9	−16.7	−15.1	37.7
R^2:	.946	.863	.792	.909	.726	.494
CV, (%):	7.9	13.1	12.0	7.2	6.5	4.6

***—significant at the .01 confidence level.

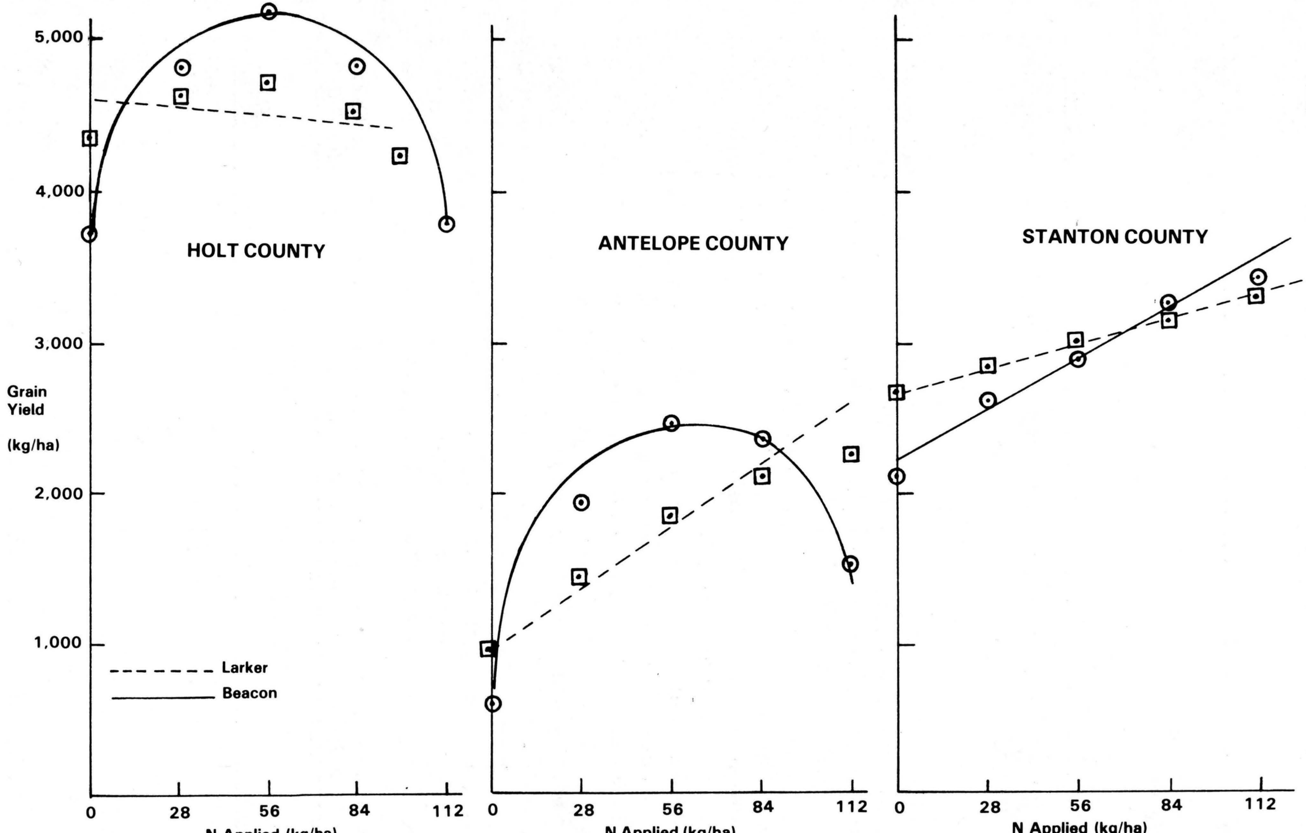

Figure 2. Response of Beacon and Larker barley to the application of fertilizer N. 1976.

Table 7. Nutrient content of the irrigation water at experimental sites used in 1976 and 1977.

1976: Nutrient	County: Antelope	Stanton	Holt
		---------ppm---------	
Nitrogen	4.4	2.5	1.1
Phosphorus	.04	.73	.02
Potassium	5.7	15.0	4.1
Sulfur	2.8	14.0	0
Magnesium	9.3	11.0	4.2

1977: Nutrient	County: Pierce	Holt
	------ppm------	
Nitrogen	5.5	.7
Phosphorus	.24	.03
Potassium	6.0	4.0
Sulfur	4.5	2.9
Magnesium	14.0	2.0

nearly the same (Table 2). In addition, there were no major differences in the N content of irrigation water used at each site (Table 7).

Yields from the Antelope County site were quite low. These low yields can be attributed to an unexpected delay in installation of the irrigation system. As a result of the delay, barley at this site received about 15 cm of moisture in rainfall and irrigation water. Rainfall and irrigation water supplied a total of 28 and 33 cm of water at the Stanton and Holt County sites, respectively, where grain yields were substantially higher.

When averaged over all rates of applied N and S, the Larker variety yielded 1780, 2876, and 4446 kg/ha at the Antelope, Stanton and Holt County sites, respectively. Observed yields from the Beacon variety were 1737, 2532, and 4494 kg/ha from the respective sites. Analysis of yield data by the standard "t test" showed that there was no difference in yield when the two varieties were compared at each site. The computed "t" values were .434, 1.568 and .105 for the Antelope, Stanton, and Holt County sites, respectively.

The N content of both Larker and Beacon varieties at the boot stage of plant development was influenced by application of fertilizer N at all sites (Table 8). N content of the Larker variety was also increased by application of S at the Antelope and Holt County sites at high rates of S. Although the use of S increased N content of the Larker variety in the boot stage at two locations, the importance of this effect, in general, can be questioned because of the lack of a consistent effect of fertilizer S on yield.

These data do not provide a readily apparent explanation for differences in the nature of response of N content of plants to rate of fertilizer N at different locations. The difference in nature of re-

Table 8. Regression coefficients, their significance, and the R^2 values for the effect of N and S on the N content (%) of whole plants at the early boot stage 1976.

Regression coefficient	County and Variety					
	Antelope		Stanton		Holt	
	Larker	Beacon	Larker	Beacon	Larker	Beacon
b_0	2.090	2.085	2.515	2.443	3.151	3.162
b_1 (N)	.110***	.078**	.231**	.181***	.250***	.118**
b_2 (S)	−.006	.016	−.035	−.045	−.027	−.078
b_3 (N^2)	−.111**	.147**	.187	−.025	−.245**	−.108
b_4 (S^2)	.104**	−.133	−.163	.050	.259**	.191
b_5 (NS)	−.008	.023	−.003	−.006	.001	.037
R^2:	.879	.720	.865	.717	.898	.695
CV (%):	3.8	5.7	6.8	8.5	5.2	6.9

***; **;—significant at the .01 and .05 confidence level, respectively.

sponse with location can best be attributed to the complex interaction of weather, plant, and soil variables that affect either the rate of growth or rate of N uptake.

N content of the Larker variety at boot stage when averaged over all treatments was 2.07, 2.56, and 3.18% for Antelope, Stanton, and Holt County sites. For the Beacon variety, N content of tissue from these respective sites was 2.11, 2.49, and 3.33%. Analysis of these data by the standard "t test" showed that there was no difference between the varieties ("t" = .498, .531, and .914 for Antelope, Stanton and Holt County sites, respectively).

Protein content is a major consideration when grain is used for malting. In 1976, application of N increased the protein content of grain of both varieties at all sites (Table 9) while application of fertilizer S had no effect. The increase in protein content with applied N was linear in all cases.

The effect of N rate on protein content of grain is shown in Table 10. For the most part, protein contents were higher than the 13.5%

Table 9. Regression coefficients, their significance, and the R^2 values for the effect of N and S on the protein content (%) of grain 1976.

Regression coefficient	County and Variety					
	Antelope		Stanton		Holt	
	Larker	Beacon	Larker	Beacon	Larker	Beacon
b_0	14.81	15.38	13.23	14.23	14.05	14.70
b_1 (N)	.99***	.59***	.45***	.68***	.30***	.21***
b_2 (S)	.01	−.02	.10	−.02	.01	−.01
b_3 (N^2)	−.19	.05	.12	.38	−.04	−.22
b_4 (S^2)	.19	.01	−.01	−.31	.15	.25
b_5 (NS)	.03	.07	−.06	.01	−.04	−.01
R^2:	.953	.820	.800	.843	.782	.536
CV (%):	2.6	3.3	3.3	3.7	2.3	2.7

***—significant at the .01 confidence level.

Table 10. Influence of rate of applied N on the protein content of barley grain 1976.

Applied N	County and Variety					
	Antelope		Stanton		Holt	
	Larker	Beacon	Larker	Beacon	Larker	Beacon
kg/ha	------------% protein------------					
0	12.44	14.36	12.78	13.78	13.61	13.94
28	13.99	14.80	12.89	13.33	14.03	14.76
56	15.16	15.34	13.23	13.61	14.35	15.20
84	15.96	15.99	13.80	14.66	14.63	15.20
112	16.38	16.73	14.61	15.96	14.83	14.76

value which has been established as the upper limit for barley suitable for malting purposes. These data indicate that the unfertilized Larker barley at Antelope and Stanton County sites and Larker receiving 28 kg N/ha at the Stanton County site may have been acceptable for malting. However, grain yields from these treatments were low and it is difficult to justify production of low grain yields to maintian low protein values.

Comparing data from all treatments, there was no significant difference in protein content between the Larker and Beacon varieties at the Antelope County site ("t" = .814). However, protein content of the Beacon variety was higher at both Stanton ("t" = 2.505*) and Holt ("t" = 2.189*) County sites.

1977

Data collected in both 1975 and 1976 indicated that Larker and Beacon barley produced in northeast Nebraska would not be suitable for malting because of high protein content of the grain. Therefore, Karl and Klages were the two varieties selected for the 1977 trials. Grain of these two varieties was known to have a low protein percent-

Table 11. Regression coefficients, their significance, and the R^2 values for effect of N and S on the yield (kg/ha) of Karl and Klages barley in 1977.

Regression coefficient	County and Variety			
	Pierce		Holt	
	Karl	Klages	Karl	Klages
b_0	2985.9	3252.5	2462.2	2284.8
b_1 (N)	139.0*	13.2	295.2***	169.3***
b_2 (S)	23.4	−76.7	13.0	41.3
b_3 (N^2)	16.8	55.2	−103.2	17.9
b_4 (S^2)	−104.1	−159.7	−14.5	−148.6
b_5 (NS)	16.5	−17.3	−8.7	−.5
R^2:	.486	.595	.900	.850
CV (%):	11.6	7.5	8.6	8.6

***; * — Significant at the .01 and .10 confidence level respectively.

Table 12. Regression coefficients, their significance, and the R^2 values for the effect of N and S on the N content (%) of whole barley plants at the early boot stage in 1977.

Regression coefficient	County and Variety			
	Pierce		Holt	
	Karl	Klages	Karl	Klages
b_0	2.76	2.80	2.23	2.33
b_1 (N)	.062**	.049	.081***	.188***
b_2 (S)	.013	−.005	−.070**	.009
b_3 (N^2)	.021	−.059	−.073	.045
b_4 (S^2)	.046	.116	.107	.005
b_5 (NS)	−.009	.003	.001	−.030
R^2:	.733	.648	.811	.768
CV (%):	3.9	4.2	4.5	8.3

***; **; — Significant at the .01, and .05 confidence level respectively.

age. Three sites were seeded in the spring of 1977. A poor stand eliminated harvest at one site.

Application of fertilizer S had no influence on yield (Table 11). The Karl variety responded to use of N at both sites while use of N increased yield of the Klages variety at the Holt County site only (Table 11). Yields were linearly related to rate of applied N where responses occurred (Figure 3). When averaged over all fertilizer treatments, yield of Klages barley was higher than that of Karl barley at the Pierce County site ("t" = 1.904*). There was no difference in yields between these varieties at the Holt County site.

Use of fertilizer N influenced the N content of barley at the boot stage in much the same manner that it affected grain yield (Table 12). N content of the young whole plant tissue increased linearly with rate of applied N. In addition, application of S had a small effect on N content of the young barley at the Holt County site. This effect of S was not observed at the Pierce County site and it is not possible to place a great deal of importance on an observation at only one site.

The effect of N rate on N content of the plants is shown in Table 13. When averaged over all fertilizer treatments, there was no signifi-

Table 13. Effect of rate of applied N on the N content of whole barley plants at the early boot stage in 1977.

N Applied	County and Variety			
	Pierce		Holt	
	Karl	Klages	Karl	Klages
kg/ha	% N			
0	2.81	2.70	1.99	2.14
28	2.81	2.93	2.29	2.19
56	2.85	3.03	2.44	2.34
84	2.93	3.03	2.45	2.57
112	3.06	2.90	2.31	2.89

Table 14. Regression coefficients, their significance, and the R^2 values for the effect of N and S on the protein content of barley grain in 1977.

Regression coefficient	Pierce Karl	Pierce Klages	Holt Karl	Holt Klages
	County and Variety			
b_0	12.13	13.75	13.15	15.74
b_1 (N)	.202***	.866***	−.066	.702***
b_2 (S)	−.045	.139	−.103	.191
b_3 (N^2)	.065	−.004	−.159	−.004
b_4 (S^2)	.034	.362	.122	.183
b_5 (NS)	.004	.020	.045	−.037
R^2:	.749	.949	.258	.791
CV (%):	3.7	4.3	2.0	2.7

*** — Significant at the .01 confidence level.

cant difference in N content of the two varieties at either Pierce ("t" = .441) or Holt ("t" = 1.242) sites.

Except for the Karl variety at the Holt County site, the application of fertilizer N produced a linear increase in the protein content of the grain (Table 14).

When all treatments are considered, protein content of the Klages variety was higher in both counties (Table 15) ("t" = 8.622** and 4.761** for Pierce and Holt Counties, respectively).

In general, protein content of the Klages variety was higher than the 13.5% established as the upper limit for barley suitable for malting purposes. In Pierce County, this was the case for non-fertilized plots as well as those plots receiving fertilizer N. In Holt County, application of 56 kg N/ha increased protein content of the grain above the 13.5% level. Protein content of grain of the Karl variety was lower than 13.5%, regardless of rate of N used.

Prediction of N Content of the Grain

Since protein content of grain is a major consideration in the suitability of barley for malting purposes, predicting this characteristic from plant analysis data would be useful. To be useful and practical, the N analysis should be performed on plant tissue collected at

Table 15. Effect of rate of applied N on the protein content of barley grain in 1977.

N Applied	Pierce Karl	Pierce Klages	Holt Karl	Holt Klages
	County and Variety			
kg/ha	% protein			
0	12.88	14.69	12.06	12.03
28	13.30	15.41	12.07	13.43
56	13.40	16.13	12.21	14.49
84	13.18	16.83	12.48	15.21
112	12.63	17.50	12.88	15.60

some standard stage of growth that can be readily recognized in the field. The boot stage in grain development can be recognized in the field and was selected as the time for N analysis in this study.

Regression techniques were used to relate N content of the tissue at the boot stage to both the protein content of the grain and yield. Significant relationships are presented in Tables 16 and 17 for 1976 and 1977, respectively.

N content of Larker barley at the boot stage was related to yield at two of the three locations in 1976. These relationships were both curvilinear. N content of Beacon barley at the boot stage was curvilinearly related to yield at only the Antelope County site.

N content of barley tissue at the boot stage proved a better indicator of protein content than of yield of grain at harvest. N content of tissue at the boot stage was linearly related to the protein content of grain for both varieties at all sites in 1976 (Table 16). This relationship was linear in all cases and except for the Beacon variety at the Antelope County site was highly significant. N content of tissue at the boot stage was not related to yield in 1977 (Table 17). N content of young tissue was, however, linearly related to protein content of the grain.

Table 16. Significant relationships between the N content (%) of plants at the boot stage (X) and grain yield (kg/ha) and protein content (%) of the grain harvest (Y) in 1976.

Variety	Dependent variable	Regression equation	Level of significance
Antelope County			
Larker	Yield	$Y = -824.1 + 803.8X - 185.6X^2$	.01
Beacon	Yield	$Y = -34.1 + 54.1X - 33.5X^2$	.05
Larker	Protein	$Y = .53 + 6.86X$	.01
Beacon	Protein	$Y = 9.28 + 2.92X$	.05
Stanton County			
Larker	Yield	$Y = -374.7 + 65.3X - 55.1X^2$	.05
Larker	Protein	$Y = 8.95 + 1.75X$	.01
Beacon	Protein	$Y = 7.34 + 2.82X$	.01
Holt County			
Larker	Protein	$Y = 10.66 + 1.13X$	.01
Beacon	Protein	$Y = 11.35 + 1.03X$	.01

DISCUSSION

There are several criteria that can be utilized to evaluate potential for production of a given crop in any area or region. In this study, grain yield and protein content of the mature grain were the two characteristics chosen to evaluate potential for production of malting

Table 17. Significant relationships between the N content (%) of plants at the boot stage (X) on grain yield (kg/ha) and protein content (%) of the grain at harvest (Y) in 1977.

Variety	Dependent variable	Regression equation	Level of significance
Pierce County			
Karl	Protein	$Y = 17.91 - 1.68X$	.05
Klages	Protein	$Y = .93 + 5.21X$	.01
Holt County			
Karl	Protein	$Y = 8.43 + 1.70X$	.01
Klages	Protein	$Y = 5.61 + 3.52X$	.01

barley on irrigated sandy soils of northeastern and north-central Nebraska.

Except for one variety at the Pierce site in 1977, and the Holt County site in 1976, yields of all varieties were increased by application of fertilizer N at all sites selected for this study. These results are in general agreement with the nature of N responses reported by other researchers (Geist, Reuss, and Johnson, 1970; Atkins, Stanford, and Dumenil, 1955; Soper and Huang, 1963; Reisenauer and Dickson, 1961).

Geist, Reuss, and Johnson (1970) were able to use measurements of soil N to predict response of malting barley to fertilizer N. In Nebraska, measurement of NO_3^--N in the soil has been used to successfully predict fertilizer N requirements for corn (Herron *et al.*, 1968). Response to fertilizer N could not be related to the amount of NO_3^--N in the soil to a depth of 90 cm. Residual soil N, in the form of NO_3^--N, varied from approximately 20 to 100 kg/ha. Even though this wide difference in the NO_3^--N content of the soil existed, yields of both barley varieties were increased by N fertilization.

A relationship between amount of NO_3^--N in the soil before planting and response to fertilizer N may have developed if 1) more sites had been used, or 2) sites with higher levels of residual NO_3^--N had been included. Although Soper and Huang (1963) were able to use a measurement of NO_3^--N to explain the variability in response to fertilizer N, this was not the situation in these studies.

The amounts of soil N at sites used in this study are typical of those found in many irrigated sandy soils in north-central Nebraska. Based on data gathered in this study, it does not appear that a measurement of NO_3^--N in the soil to a depth of 90 cm before planting will provide a reliable guide for making N fertilizer recommendations for production of malting barley.

In addition, N content of the irrigation water appears to have little effect on response of malting barley to fertilizer N. In general, N content of the irrigation water of sites selected for this study was relatively low (Tables 5, 7). Since relatively small amounts of irrigation water are used in the production of malting barley, the amounts of N applied in the irrigation water would be expected to be low.

Some researchers have reported response of malting barley to fertilizer S (Nyborg, 1968; Reisenauer and Dickson, 1961). Although sites having sandy soils were selected in all years for the studies reported here, there was no yield response to fertilizer S throughout the study. Apparently, the $SO_4^=$-S present in the soil when combined with the S in irrigation water and the quantity of S released through mineralization from soil organic matter was sufficient to meet the S requirements of malting barley.

Although fertilizer N had a beneficial effect on yields, it had a reverse effect on the suitability of grain for malting purposes. In general, application of fertilizer N increased protein content of the grain above the 13.5% value considered the maximum allowable protein content. This was especially true for the Larker and Beacon varieties used in 1975 and 1976. It's important to point out that the protein content of the grain from these two varieties was higher than 13.5% even when no N was applied.

Since results of trials of 1975 and 1976 showed that grain of Larker and Beacon varieties would not be suitable for malting purposes, two new varieties, (Karl and Klages) were used in the 1977 trials. Protein content of the Karl variety was increased by N fertilization at one of two sites with the protein content of the Klages variety increased by N fertilization at both sides. Considering the protein content of both varieties, only grain of the Karl variety would have been acceptable for malting purposes.

Effects of N fertilization on quality characteristics measured in this study are consistent with effects of N fertilization reported by Reisenauer and Dickson (1961), Walker (1975), and Pomeranz *et al.* (1976). Throughout the study, S fertilization had no effect on protein content of the grain and results are consistent with those reported by Reisenauer and Dickson (1961).

Although grain from the Karl variety was acceptable for malting purposes from the standpoint of protein content, grain yield must also be considered. In 1977, these yields were quite low. Maximum yields were about 3,000 kg/ha at both the Pierce and Holt County sites (Figure 3). The 1977 growing season was typical of many in north-central Nebraska. So, these relatively low yields cannot be attributed to an abnormal growing season.

The effort to predict both grain yield and grain quality from N analysis of plant tissue at the boot stage met with mixed success. The yield of Larker and Beacon varieties was related to N content of the tissue. There was, however, no relationship between this characteristic and yield of Karl and Klages varieties.

N content of the barley plants at boot stage was related to the protein content of grain of all varieties used. The importance of this

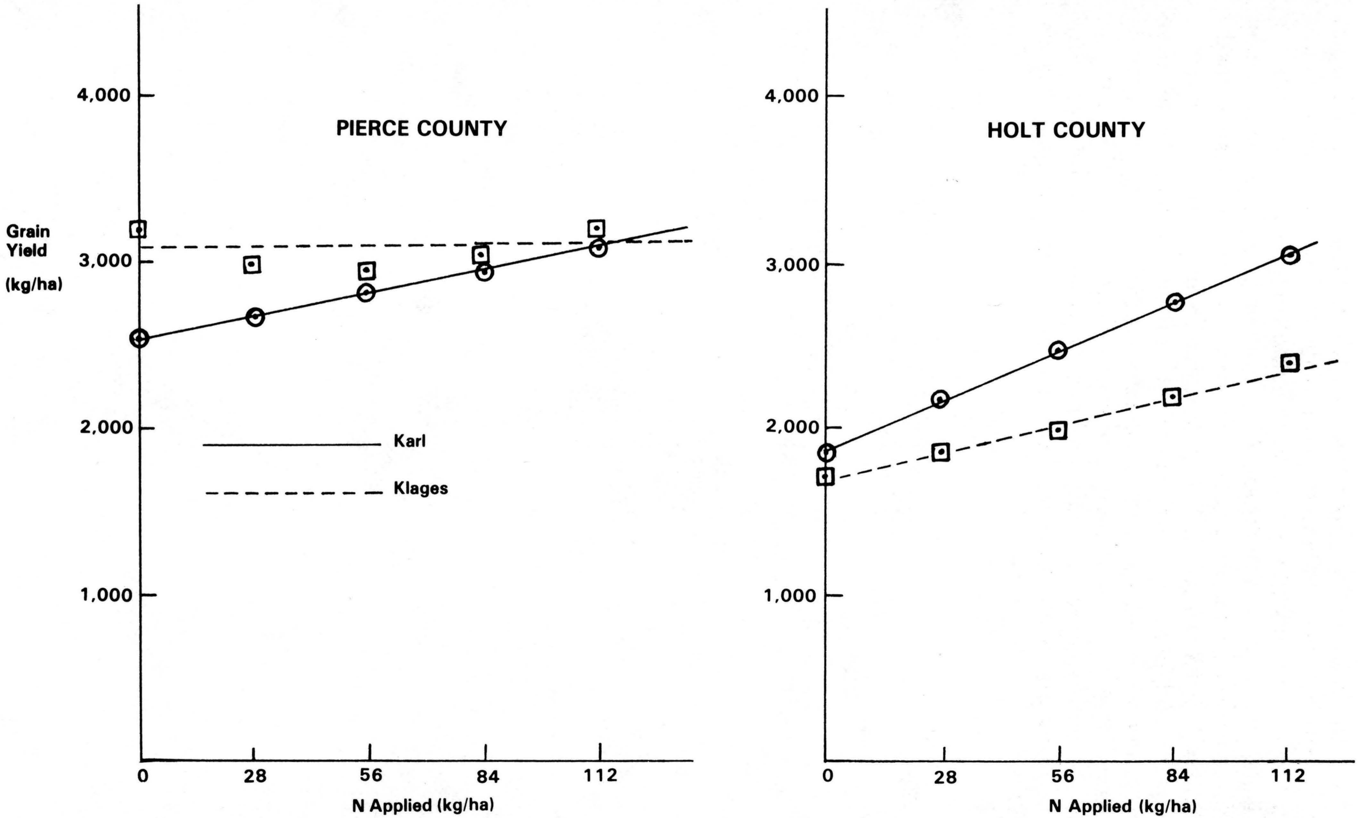

Figure 3. Effect of rate of fertilizer N on yield of Karl and Klages barley. 1977.

relationship, however, is diminished by the fact that protein content of grain produced in high-yielding management situations was higher than the value considered to be acceptable for malting purposes.

Data collected from the three year study indicate that the potential for production of malting barley on irrigated sandy soils of north-central Nebraska is limited. Acceptable yields can be achieved with use of Larker and Beacon varieties. Protein content of grain from these two varieties is in excess of the level needed for malting purposes. If varieties having a low protein content are selected, yields are low. With this information, it appears that crops other than malting barley should be considered as alternatives to corn on these irrigated sandy soils.

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