# Effects of Nitrogen and Phosphorus Fertilizer on Yield and Malting Quality of Barley

R. E. ATKINS, GEORGE STANFORD, and LLOYD DUMENIL
Iowa State College, Ames, Iowa

**Varying rates of nitrogen and phosphorus fertilizer were applied to spring barley plots in northwest Iowa during the 1948 to 1950 seasons. Increases in grain yield through combined nitrogen and phosphorus fertilization were unusually high. The highest yields for the three seasons were 90, 150, and 120% greater than the check or no-treatment plots. Lower rates of application, and nitrogen and phosphorus applied separately, generally gave significant increases, but of lesser magnitude. Malting quality characteristics of the barley produced under conditions of high response to fertilization generally were not significantly altered, but those affected sufficiently to be of practical consequence in the malting and brewing process were improved rather than diminished. Nitrogen fertilizer, applied in excess of that required for maximum yield per acre, resulted in an undesirable increase in protein content and a reduction in malt extract. Phosphorus fertilizer improved malting quality by increasing weight per 1000 kernels and malt extract, and had no injurious effect on other criteria of malting quality.**

In the corn belt and upper Mississippi valley areas, barley often follows corn in the rotation. Readily available supplies of nitrogen frequently are low with this cropping system and fertilizer must be applied to produce a satisfactory barley crop. On many soils, available phosphorus content also may be low. The grower primarily is interested in increasing the grain yield of the crop through the use of fertilizer and in maintaining standing ability suitable for harvesting. Processors of malting barley, however, are more concerned with effects of the fertilizer upon malting quality of the grain. This paper presents the results of fertilizer experiments with barley conducted in northwestern Iowa for yield of grain, several criteria of malting quality, and certain interrelationships among quality factors.

### Literature Review

The results of numerous fertilizer experiments with barley have been reviewed by Olson and others (*15*). Most of the experiments have shown an appreciable yield response from nitrogen and phosphorus fertilizers alone and in combination. The magnitude of response and the significance of variety-fertilizer interactions, however, have varied considerably. Gregory and Crowther (*8*), in England, reported no differential response in grain yield for five varieties of barley produced at eleven different levels of nitrogen, phosphorus, and potassium application. Significant fertilizer-variety interactions for yield were obtained by Frey and others (*7*) in Michigan experiments with fertilizers varying in nitrogen, phosphorus, and potassium content. Pendleton and others (*16*) in Illinois found significant varietal response to varying combinations of nitrogen, phosphorus, and potassium fertilizer. Nitrogen was observed to be the primary nutrient element limiting grain yields in their experiments, even on highly productive land and in a rotation containing legumes; the response to phosphorus was next in magnitude. The time and rate of application and two sources of nitrogen were varied in studies by Foote and Batchelder (*5*) in Oregon; all methods gave some yield increase in two of the three years tested. Lack of response in the other season was attributed to below average rainfall and very low yield levels.

Studies relating fertilizer applications with malting characteristics of the barley generally have shown variable effects on malting quality. In experiments reported by Ahr and Mayr (*1*) in Bavaria, calcium and phosphorus applications improved the malting quality of the grain, but nitrogen affected quality adversely, while potassium lowered the protein content of the grain. They noted striking tendencies of climatic and growth conditions to mask varietal differences. Frey and Robertson (*6*) refer to experiments in Wisconsin which have shown significant effects of fertilizers upon malting quality. The quantity of extract from barley malt was increased from 1 to 2%, protein content and diastatic power were increased with heavy applications of nitrogen fertilizer, and kernel size—i.e., weight per 1000 kernels—was increased with the application of fertilizer.

Meredith and others (*12*) in Manitoba, Canada, found a somewhat greater effect of fertilizer on malting quality with early sown barley than from later plantings. They concluded, however, that the application of fertilizers generally did not affect the malting quality to any great extent. The application of commercial fertilizers of varying composition to five varieties of malting barley by Frey and Robertson (*6*) in Michigan resulted in an average increase of 0.9 and 0.4% in malt extract in two different years. Protein content of the barley grain was not appreciably altered by the fertilizer applications in either season, while diastatic activity was decreased by each fertilizer used in one year but not affected in the other.

Certain associations among quality measures and of grain yield with quality factors have been reported. Neatby and McCalla (*14*) in Alberta, Canada, observed that high yielding barley varieties have a marked tendency to be low in protein content. Correlation coefficients from a number of their experiments were all negative for the comparison of yield and protein content and ranged in magnitude from $-0.21$ to $-0.88$. Meredith and Anderson (*11*) in Canada obtained a positive intervarietal correlation between 1000-kernel weight and malt extract, but obtained negative correlations for 1000-kernel weight with both nitrogen content and diastatic activity. Nitrogen content also was negatively correlated with malt extract and diastatic activity, although the coefficients were small in magnitude.

Correlations among a large number of barley and malt properties have been presented by Anderson and others (*2*) in

**Table I. Analyses of Variance for Grain Yield**

(In bushels per acre for barley varieties grown on soil receiving different levels of nitrogen and phosphorus fertilizer application, O'Brien and Lyon Counties, Iowa, 1948–50)

| Source of Variation | 1948 D.F. | 1948 Mean square | 1949 D.F. | 1949 Mean square | 1950 D.F. | 1950 Mean square |
|---|---|---|---|---|---|---|
| Treatments | 8 | 760.5[a] | 8 | 792.0[a] | 8 | 175.3[a] |
| N | 2 | 102.6[a] | 2 | 3072.0[a] | 2 | 500.7[a] |
| P | 2 | 2797.5[a] | 2 | 76.8[a] | 2 | 186.6[a] |
| NP | 4 | 70.9[b] | 4 | 9.6 | 4 | 6.9 |
| Error a | 16 | 16.4 | 16 | 7.4 | 16 | 11.6 |
| Varieties | 3 | 197.4[a] | 2 | 75.5[a] | .. | ... |
| Var × treat. | 24 | 20.8[a] | 16 | 4.6 | .. | ... |
| N × var. | 6 | 44.2[a] | 4 | 5.9 | .. | ... |
| P × var. | 6 | 24.6[b] | 4 | 8.0 | .. | ... |
| NP × var. | 12 | 7.3 | 8 | 2.2 | .. | ... |
| Error b | 53 | 8.2 | 36 | 7.1 | .. | ... |

[a] Exceeds 1% level of probability.
[b] Exceeds 5% level of probability.

Canada. From intravarietal correlations a close association of protein content, diastatic activity, and malt extract was apparent. A positive correlation between diastatic activity and protein was obtained, while both diastatic activity and protein were negatively correlated with extract. Diastatic activity of the malt and of the barley were observed by Meredith and others (*13*) in Canada to be positively correlated, with a coefficient of 0.902 obtained from 807 samples. A high correlation ($r$ = 0.824 from 304 samples) between barley extract and malt extract was obtained by Meredith (*10*).

Den Hartog and Lambert (*4*) in Minnesota found the three malting-quality characters—protein, diastatic activity, and extract—to be rather closely interrelated on the basis of both simple and partial correlations. Protein content was positively correlated with diastatic activity and negatively correlated with malt extract. The simple coefficient between diastatic activity and extract was significant, but the partial coefficient, when protein content was held constant, was not. They concluded that the simple correlation between diastatic activity and extract was due to the association of each with protein. Comparisons of agronomic with quality characters showed grain yield to be positively correlated with extract and negatively correlated with both protein and diastatic activity. Both average kernel weight and bushel weight were found to be positively associated with malt extract.

### Experimental Procedure

The experiments reported herein were conducted in 1948 in O'Brien County and in 1949 and 1950 in Lyon County, Iowa. Soil type for the 1948 and 1949 experiments was a Primghar silt loam, while the 1950 experiment was on Galva silt loam. For all three experiments, corn, oats, and corn, respectively, had been grown during the three preceding crop seasons on the experimental area. Soil tests of the experimental areas indicated supplies of available phosphorus to be low.

The experimental design used was a 3 × 3 nitrogen-phosphorus (NP) factorial in 1948 and 1949 for the fertilizer treatments, with the barley varieties superimposed as subplots within each treatment. Mars, Moore, Kindred, and Wisconsin 38 varieties were grown in 1948, and all four varieties were used in both the yield and quality analyses. Wisconsin 38 variety was dropped from the field experiments in 1949 and only the Moore variety was analyzed for malting characteristics. In 1950 only the Moore variety was used in both field and quality studies and the factorial arrangement of fertilizer treatments again was used.

Nitrogen was applied at rates of 20 and 40 pounds per acre as 60 and 120 pounds of ammonium nitrate in 1948 and 1950, and as 100 and 200 pounds of ammonium sulfate in 1949. Phosphorus applications of 40 and 80 pounds per acre, supplied as 200 and 400 pounds of 0–20–0, were made in all three seasons. Fertilizers were broadcast and disked in prior to seeding for all experiments. All plots were seeded at a rate of 2$^1/_2$ bushels per acre with a small drill and from 52 to 100 square feet of each plot was harvested for yield in the different seasons.

One-pound grain samples from each of three replicates were submitted each year to the Malting Barley Improvement Association, Milwaukee, Wis., for evaluation of malting quality. Quality determinations were made in the laboratories of three members of this association.

### Experimental Results

The experimental results are presented in three sections: effects of fertilizers on grain yield, effects on malting quality of the grain, and interrelationships among certain of the quality factors.

**Grain Yield**

The variance analyses for grain yield given in Table I show a highly significant yield response to both nitrogen and phosphorus in all three seasons. Superphosphate applications were particularly effective in increasing yields in the 1948 experiment, greatest response in 1949 was from nitrogen, while a more nearly equal response to the two elements was obtained in 1950. The nitrogen-phosphorus interaction was significant only in the 1948 test and then only at the 5% level of probability. A significant interaction between varieties and fertilizer treatments was apparent in the 1948 experiment, but all varieties responded in essentially the same manner to the different fertilizer applications in 1949.

Yields obtained in 1948 for the four varieties grown at varying levels of fertilizer application are given in Table II. Increases from phosphate application were outstanding, but nitrogen responses

**Table II. Yield of Barley Grown on Primghar Silt Loam Receiving Different Levels of Nitrogen and Phosphorus Fertilizer Application**

(O'Brien County, Iowa, 1948)

| Variety | $N_0P_0$ | $N_0P_1$ | $N_0P_2$ | $N_1P_0$ | $N_2P_0$ | $N_1P_1$ | $N_1P_2$ | $N_2P_1$ | $N_2P_2$ |
|---|---|---|---|---|---|---|---|---|---|
| | Fertilizer Level[a]: Yield, Bushels per acre | | | | | | | | |
| Wisconsin 38 | 29.2 | 36.1 | 40.6 | 27.6 | 30.8 | 44.3 | 43.7 | 40.8 | 50.5 |
| Mars | 30.6 | 38.9 | 45.7 | 26.4 | 25.7 | 39.5 | 42.5 | 39.6 | 45.8 |
| Moore | 30.2 | 38.4 | 47.9 | 28.6 | 32.6 | 46.7 | 50.7 | 49.6 | 58.3 |
| Kindred | 33.9 | 42.5 | 45.9 | 33.3 | 35.0 | 47.4 | 48.6 | 41.1 | 50.8 |
| Mean | 31.0 | 39.0 | 45.0 | 29.0 | 31.0 | 44.5 | 46.4 | 42.8 | 51.3 |

[a] $N_1$, 20 lb. N/acre. $N_2$, 40 lb. N/acre. $P_1$, 40 lb. $P_2O_5$ acre. $P_2$, 80 lb. $P_2O_5$/acre.

**Table III. Yield of Moore Barley Grown on Soil Receiving Different Levels of Nitrogen and Phosphorus Fertilizer Applications**

(Lyon County, Iowa, 1949 and 1950)

| Year | Soil Type | Fertilizer Level[a] | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | $N_0P_0$ | $N_0P_1$ | $N_0P_2$ | $N_1P_0$ | $N_2P_0$ | $N_1P_1$ | $N_1P_2$ | $N_2P_1$ | $N_2P_2$ |
| | | Yield, Bushels per acre | | | | | | | | |
| 1949 | Primghar silt loam | 16.6 | 17.8 | 19.4 | 29.4 | 35.5 | 29.9 | 34.1 | 38.6 | 42.7 |
| 1950 | Galva silt loam | 18.5 | 23.2 | 26.0 | 26.6 | 30.4 | 31.8 | 34.0 | 40.3 | 41.7 |

[a] $N_1$. 20 lb. N/acre. $N_2$. 40 lb. N acre. $P_1$. 40 lb. $P_2O_5$/acre. $P_2$. 80 lb. $P_2O_5$/acre.

**Table IV. Significant Effects Exerted by Fertilizer Treatments on Malting Quality Criteria in Iowa Tests, 1948, 1949, and 1950**

| Quality Factor | Significant Effects and Interactions | | |
|---|---|---|---|
| | 1948 | 1949 | 1950 |
| Bushel weight | Var.[a], P[a] | N[a], P[a] | N[a], P[a] |
| Weight/1000 kernels | Var.[a], P[b], P × Var.[a] | N[b], P[a] | nd |
| Phosphorus in grain, % | Var.[a], P[a] | nd | P[a] |
| Barley protein | Var.[b], N[b], NP × Var.[b] | (−)N[b] | nd |
| Malt extract | Var.[a] | P[a] | P[a] |
| Total malt protein | Var.[a], N[a] | ns | N[b] |
| Malt diastase | Var.[a] | ns | nd |
| α-Amylase | Var.[a] | (−)N[b] | nd |
| Papain diastase | nd | nd | N[a] |
| Formol N in wort, % | Var.[a] | nd | nd |
| Soluble protein in wort | Var.[a], N[a], P[a] | nd | nd |
| Soluble malt protein as % total malt protein | Var.[a], P[b] | ns | nd |

[a] Exceeds 1% level of probability.
[b] Exceeds 5% level of probability.
ns. None of varieties exceeded 5% level of probability.
nd. Quality factor not determined.
(−). Negative effect.

were lower than normally obtained, probably a result of the unusually warm days in April and a dry May which favored nitrification in the soil. The largest increase in yield resulted from the heavier application of both nitrogen and phosphate. In general, Kindred was comparatively higher in yield at the lower rates of application, while Moore variety was superior at the higher rates. The Mars variety was second to Kindred at the lower application rates, but generally was poorest where the heavy rate of nitrogen and the nitrogen-phosphorus combinations were applied. Yields of Wisconsin 38 were poorest at the low rates of application and when phosphorus alone was added, but improved when both nitrogen and phosphorus were applied.

The response of Moore barley to the different fertilizer applications in 1949 and 1950 is presented in Table III. Mars and Kindred varieties also were included in the test in 1949, but as all three varieties responded in like manner to the fertilizer treatments and only the Moore variety was submitted for malting tests, means for the other two varieties are not given. Increases in yield from nitrogen were outstandingly greater than from phosphorus applications in 1949 and were slightly greater in 1950.

Except for the poor response to nitrogen alone in 1948 and to phosphorus alone in 1949, the yield increases from nitrogen and phosphorus applications were very striking, the highest yield in all three years resulting from the heavier application of both elements. To be of greatest value to the grower, however, such increases in yield must not be accompanied by corresponding increases in severity of lodging. No lodging was observed in either the 1949 or 1950 experiments at any fertilizer level. In 1948 some lodging occurred with the Wisconsin 38 and Kindred varieties, particularly when phosphorus alone was applied at the higher rate, but would not have been sufficient to cause harvesting difficulties.

**Malting Quality Factors**

The interpretation and relative importance of the various determinations made for evaluating malting quality in barley are not universally agreed upon by malsters and brewers. Whether the malt is to be used by brewers, distillers, or for other purposes affects the evaluation for some criteria, and perferences of individual brewers as to color, taste, and other properties of the brew also are reflected in variable emphasis on quality determinations. Ranges of values for the different factors generally considered satisfactory by most commercial maltsters and chemists have been discussed by Burkhart and Dickson (*3*). Values of 11 to 13% malt protein are cited as satisfactory for the production of brewer's malts, and 13 to 15.5% protein for distiller's malts. Malt extract values to 72 to 76% are suggested as satisfactory in most cases, but are somewhat dependent on the variety, season, and location. These two criteria, together with bushel weight and 1000-kernel weight, are likely to be of particular concern in a study of effects of fertilizer on malting quality.

The significant effects and interactions obtained from the analyses of variance for the various quality factors measured in 1948, and 1949, and 1950 are presented in Table IV. The application of nitrogen had a significant effect in increasing barley protein, malt protein, and soluble protein in the wort in the 1948 test. Phosphorus additions to the 1948 experiment resulted in significant increases in bushel weight, 1000-kernel weight, phosphorus content of the grain, soluble protein in the wort, and per cent soluble of total malt protein. The nitrogen-phosphorus interaction was not significant for any of the eleven determinations made on the 1948 samples. Varieties differed significantly in 1948 for all quality criteria, but the interaction of varieties with treatments was not significant for any character measured.

Samples for quality analyses in 1948 were submitted from only the $N_0P_0$, $N_2P_0$, $N_0P_2$, and $N_2P_2$ treatments. Means for the eleven criteria measured on the four fertilizer treatments are given in Table V. Means of the four varieties tested are shown, as the analysis

**Table V. Means for Barley and Malting Quality Criteria**

(Four barley varieties grown at different levels of nitrogen and phosphorus fertilization in northwest Iowa in 1948)

| Character | Fertilizer Level[a] | | | |
|---|---|---|---|---|
| | $N_0P_0$ | $N_0P_2$ | $N_2P_0$ | $N_2P_2$ |
| Bushel weight, lb. | 43.3 | 44.8 | 43.5 | 44.7 |
| 1000-kernel weight, grams | 32.6 | 34.2 | 32.1 | 33.9 |
| Phosphorus content of grain, % | 0.315 | 0.398 | 0.325 | 0.404 |
| Barley protein, % | 14.6 | 14.8 | 16.0 | 15.8 |
| Malt extract, % | 72.9 | 74.0 | 72.5 | 73.0 |
| Total malt protein, % | 14.2 | 14.4 | 15.9 | 15.7 |
| Formol N in wort, % | 0.288 | 0.311 | 0.272 | 0.301 |
| Sol. protein in wort, % | 4.85 | 5.26 | 5.27 | 5.63 |
| Sol. protein–total malt protein, % | 34.2 | 36.6 | 33.2 | 35.9 |
| Malt diastase, ° Lintner | 141.6 | 171.4 | 158.9 | 181.7 |
| α-Amylase, units | 73.3 | 84.7 | 78.1 | 85.3 |

[a] $N_2$. 40 lb. N/acre. $P_2$. 80 lb. $P_2O_5$/acre.

of variance indicated no differential response of varieties to the fertilizer treatments. All significant effects of nitrogen and phosphorus application were to increase the numerical values of quality factors measured.

Increases in protein of the magnitude obtained in the 1948 experiment resulting from the application of the fertilizers containing nitrogen could be objectionable from the standpoint of malting quality. Whether the increases would be detrimental or not would be predicated upon the protein content normally obtained without nitrogen fertilizer in a given area. The value of 14.6% protein, for example, obtained for the no-treatment plots in the 1948 experiment, already was beyond the level generally considered acceptable for brewer's malt and the application of nitrogen fertilizer resulted in protein values approaching or exceeding the upper limits desired in distiller's malts. The increases in bushel weight, 1000-kernel weight, and malt extract are particularly desirable in malting barley. The increases obtained for two of these criteria might well be attributed to phosphorus, as nitrogen alone (Table V) reduced kernel weight and malt extract.

Significant effects and interactions from the variance analyses for the 1949 and 1950 quality determinations with Moore barley are presented in Table IV. Nitrogen applications had a significant effect upon bushel weight in both seasons, and 1000-kernel weight, malt protein, and papain diastase in the one season in which they were determined. Increased values for these criteria with the application of nitrogen are shown in Table VI. Quality determinations were made for all nine fertilizer treatments with both the 1949 and 1950 samples of Moore barley, and the means for the various quality criteria are presented in this table. Barley protein content and α-amylase activity were decreased slightly with nitrogen application in 1949, but the decreases were significant only at the 5% level. Phosphorus applications resulted in significant increases in bushel weight and malt extract in both seasons, while they increased weight per 1000 kernels in the 1949 test and phosphorus content of the grain in 1950. Kernel weights were not taken on the 1950 samples and phosphorus content of the grain was not determined for the 1949 test. The nitrogen-phosphorus interaction was not significant for any of the quality measures in either season.

In 1949 the general effect of the application of fertilizer, particularly the lower rate of nitrogen with phosphorus, was to improve malting quality. The low rate of nitrogen when combined with the heavier rate of phosphorus resulted in a decrease in barley protein and the greatest increase in 1000-kernel weight and malt extract for any of the fertilizer treatments.

In 1950, the application of nitrogen fertilizer alone or at the heavier rate with phosphorus resulted in a slight although statistically significant increase in total malt protein, but none of the treatments resulted in protein content beyond the range generally considered acceptable in the malting and brewing industries. The greatest increase in malt extract resulted from the lower nitrogen rate combined with the higher phosphorus rate. All other fertilizer treatments had a beneficial effect on the malt quality factors studied.

### Interrelationships among Quality Factors

Numerous correlations among quality factors have been presented above. The data obtained from the present study would lend themselves to the calculation of many similar associations. In view of the effects exerted by nitrogen and phosphorus fertilizers on the content of these nutrients in the grain, the relationships between protein and phosphorus content of the grain and other malting quality criteria seem to be of particular interest. Applications of nitrogen and phosphorus fertilizer in the 1948 and 1950 seasons resulted in significant increases in the protein and phosphorus content of the barley grain, respectively. Phosphorus content of the grain was not determined for the 1949 experiment, but protein content of the grain was slightly decreased with the application of 20 pounds of nitrogen plus phosphorus in 1949. Correlation coefficients for the association of barley protein and phosphorus content of the grain with eight different quality criteria for the 1948 experiment are given in Table VII.

The number of significant associations between quality characters was observed to vary considerably among varieties. Only one correlation, between determinations of barley protein and soluble protein in the wort, was significant for the comparisons with the Mars variety, while several significant associations of quality measures were observed for the other varieties. As the degrees of freedom for testing the significance of individual variety comparisons are small, the correlations based on the within-variety averages probably are a more reliable comparison of the interrelationships among the various quality criteria. Observation of these coefficients associating phosphorus content of the grain with the eight quality measures shows a significant positive correlation for each association, although all coefficients were of only moderate magnitude. Thus, in these studies the application of phosphorus fertilizer to barley plants resulted in increased phosphorus content of the grain, which in turn was positively associated with kernel weight, extract per cent, diastatic activity, and other malting quality criteria.

The associations of barley or malt protein with the various quality measures were much less consistent than the similar associations of phosphorus content with other quality criteria. Considering

**Table VI. Means for Barley and Malting Quality Criteria of Moore Barley Grown at Different Levels of Nitrogen and Phosphorus Fertilization in Northwest Iowa, 1949 and 1950**

| | | Fertilizer Level[a] | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| *Year* | *Character* | $N_0P_0$ | $N_0P_1$ | $N_0P_2$ | $N_1P_0$ | $N_2P_0$ | $N_1P_1$ | $N_1P_2$ | $N_2P_1$ | $N_2P_2$ |
| 1949 | Bushel weight, lb. | 42.1 | 42.6 | 43.0 | 42.5 | 43.0 | 44.2 | 44.2 | 44.0 | 44.3 |
| | 1000-kernel weight, grams | 29.5 | 30.6 | 30.8 | 30.2 | 30.3 | 31.2 | 31.6 | 31.3 | 31.5 |
| | Barley protein, % | 12.4 | 12.5 | 12.4 | 12.3 | 12.4 | 11.9 | 11.6 | 12.4 | 12.6 |
| | Malt extract, % | 75.4 | 75.6 | 75.7 | 75.2 | 75.4 | 76.0 | 76.3 | 75.7 | 75.8 |
| | Total malt protein, % | 11.9 | 12.2 | 12.1 | 11.9 | 12.3 | 11.0 | 11.3 | 12.0 | 12.3 |
| | Sol. nitrogen/malt N, % | 46.4 | 46.2 | 49.3 | 46.8 | 46.8 | 47.0 | 47.0 | 45.3 | 45.8 |
| | Malt diastase, °Lintner | 106 | 110 | 113 | 113 | 116 | 112 | 105 | 109 | 114 |
| | α-Amylase, units | 41.2 | 40.0 | 40.5 | 37.7 | 34.8 | 37.6 | 33.5 | 34.6 | 37.1 |
| 1950 | Bushel weight, lb. | 39.7 | 41.6 | 42.1 | 41.0 | 40.7 | 42.6 | 43.7 | 42.8 | 43.2 |
| | Phosphorus content of grain, % | 0.397 | 0.436 | 0.412 | 0.351 | 0.356 | 0.419 | 0.420 | 0.426 | 0.482 |
| | Papain diastase, °Lintner | 127 | 119 | 129 | 142 | 136 | 133 | 127 | 151 | 148 |
| | Malt extract, % | 74.6 | 75.7 | 76.1 | 74.4 | 74.7 | 75.5 | 76.3 | 75.5 | 75.5 |
| | Total malt protein, % | 9.5 | 9.3 | 9.4 | 10.4 | 10.0 | 9.8 | 9.5 | 10.3 | 9.9 |
| | Soluble–total protein, % | 38.9 | 39.9 | 40.0 | 35.4 | 39.2 | 38.6 | 40.2 | 38.6 | 39.7 |

[a] $N_1$, 20 lb. N/acre. $N_2$, 40 lb. N/acre. $P_1$, 40 lb. $P_2O_5$/acre. $P_2$, 80 lb. $P_2O_5$/acre.

**Table VII. Coefficients of Correlation for Protein and Phosphorus Content of Grain with Eight Malting Quality Criteria from Barley-Fertilizer Experiment**

(O'Brien County, Iowa, 1948)[a]

| *Characters Correlated* | *Variety* Wis. 38 | Mars | Moore | Kindred | *Within Variety Average* |
|---|---|---|---|---|---|
| Barley protein | | | | | |
| Bushel weight | 0.034 | −0.173 | −0.043 | −0.428 | −0.197 |
| 1000-kernel weight | −0.016 | 0.266 | −0.070 | −0.259 | −0.057 |
| Diastatic activity | 0.493 | 0.461 | −0.247 | −0.140 | 0.239 |
| α-Amylase | 0.279 | 0.158 | −0.279 | −0.522 | −0.138 |
| Malt extract | −0.606[b] | −0.451 | −0.558 | −0.652[b] | −0.576[c] |
| Sol. protein in wort | 0.685[b] | 0.617[b] | 0.313 | 0.591[b] | 0.522[c] |
| % formol N in wort | −0.569 | 0.531 | −0.097 | 0.247 | −0.110 |
| Sol. wort protein / Malt protein | −0.201 | −0.098 | −0.777[c] | 0.415 | −0.377[c] |
| Phosphorus content | | | | | |
| Bushel weight | 0.800[c] | 0.466 | 0.789[c] | 0.560 | 0.624[c] |
| 1000-kernel weight | 0.601[b] | 0.331 | 0.899[c] | 0.175 | 0.547[c] |
| Diastatic activity | 0.774[c] | 0.188 | 0.798[c] | 0.658[b] | 0.639[c] |
| α-Amylase | 0.532 | 0.093 | 0.517 | 0.414 | 0.402[c] |
| Malt Extract | 0.473 | 0.442 | 0.738[c] | 0.180 | 0.444[c] |
| Sol. protein in wort | 0.625[c] | 0.366 | 0.528 | 0.413 | 0.430[c] |
| % formol N in wort | 0.097 | 0.416 | 0.209 | 0.682 | 0.312[b] |
| Sol. wort protein / Malt protein | 0.470 | 0.321 | 0.436 | 0.410 | 0.394[c] |
| Barley protein | 0.184 | 0.172 | −0.313 | 0.163 | 0.031 |

[a] Degrees of freedom, variety comparisons = 10, within variety averages = 44.
[b] Exceeds 5% level of probability.
[c] Exceeds 1% level of probability.

the calculations based on within-variety averages in the 1948 experiment, only three of the eight correlations of barley protein with the various quality factors were significant and these were of medium size. The correlations of barley and malt protein content with several quality criteria for the 1949 and 1950 experiments are given in Tables VIII and IX, respectively. While the frequency of significant correlations with quality criteria from these two seasons for protein relationships was somewhat greater than for the 1948 experiment, the magnitude of most of the coefficients again was relatively small. The negative correlation between protein content of the grain and malt extract per cent was one of the most consistent associations, being negative in all three seasons and significantly so in two of the experiments. The association was of only moderate magnitude but was consistently negative, as has been reported by several other workers (*2, 4, 11*). In view of this it seems that the use of nitrogen fertilizer on barley, when it results in marked increases in protein content of the grain, may have an adverse effect on quality by resulting in a lower per cent malt extract. Several of the other characters correlated with protein content indicated a small positive association in one season and a slight negative relationship in others, which would not indicate definite detrimental effects of nitrogen in these instances upon malting criteria.

The associations of phosphorus content of the grain with several quality criteria in 1950 are shown in Table IX. As was the case with the 1948 phosphorus comparisons, all correlations were positive and of only moderate magnitude. The correlations with bushel weight and malt extract were statistically significant.

## Discussion

The increases in grain yield resulting from the use of combined nitrogen and phosphorus fertilizer for the three years of this study were outstandingly great. Increases of from 70 to 90% for the high yielding treatments in comparison with the check or no-treatment plots were obtained in the 1948 experiment. In the 1949 experiment yield increases of as much as 150% were observed for the combined high levels of nitrogen and phosphorus fertilization, while an increase of 120% over the check plot was obtained for this treatment in the 1950 test. Yield increases from the lower rates of application and for nitrogen or

**Table VIII. Coefficients of Correlation for Protein Content of Grain of Moore Barley with Six Malting Quality Criteria from Barley-Fertilizer Experiment**

(Lyon County, Iowa, 1949, 25 degrees of freedom)

| *Characters Correlated* | *r* |
|---|---|
| Barley protein and bushel weight | −0.173 |
| Barley protein and 1000-kernel weight | −0.409[a] |
| Barley protein and diastatic activity | 0.423[a] |
| Barley protein and α-amylase | 0.269 |
| Barley protein and malt extract | −0.457 |
| Barley protein and sol. N as % malt N | −0.381[a] |

[a] Exceeds 5% level of probability.

**Table IX. Coefficients of Correlation for Malt Protein and Phosphorus Content of Grain of Moore Barley with Four Malting Quality Criteria from Barley-Fertilizer Experiment**

(Lyon County, Iowa, 1950, 25 degrees of freedom)

| *Characters Correlated* | *r* |
|---|---|
| Malt protein and bushel weight | 0.036 |
| Malt protein and papain diastase | 0.733[a] |
| Malt protein and malt extract | −0.136 |
| Malt protein and % sol.-total protein | −0.769[a] |
| Phosphorus content and bushel weight | 0.528[a] |
| Phosphorus content and papain diastase | 0.056 |
| Phosphorus content and malt extract | 0.406[b] |
| Phosphorus content and % sol.-total protein | 0.296 |

[a] Exceeds 1% level of probability.
[b] Exceeds 5% level of probability.

**Table X. Relation of Level of Nitrogen Deficiency and Increase in Malt Protein Content of Barley Grown in Northwest Iowa 1948–50**[a]

| Year | Treatment | Yield Increase from Nitrogen, Bushels | Lb. Nitrogen for 1 Bushel Increase | Malt Protein Content, % Total | Malt Protein Content, % Increase |
|---|---|---|---|---|---|
| 1948 | $N_1$ without P | −2.0 | ... | ... | ... |
| | $N_2$ without P | 0 | ... | 15.9 | +1.7 |
| | $N_1$ with $P_1$ | 5.5 | 3.6 | ... | ... |
| | $N_1$ with $P_2$ | 1.4 | 14.3 | ... | ... |
| | $N_2$ with $P_1$ | 3.8 | 10.5 | ... | ... |
| | $N_2$ with $P_2$ | 6.3 | 6.3 | 15.7 | +1.5 |
| | No treatment | ... | ... | 14.2 | ... |
| 1949 | $N_1$ without P | 12.8 | 1.6 | 11.9 | 0.0 |
| | $N_2$ without P | 18.9 | 2.1 | 12.3 | 0.4 |
| | $N_1$ with $P_1$ | 12.1 | 1.6 | 11.0 | −0.9 |
| | $N_1$ with $P_2$ | 14.7 | 1.4 | 11.3 | −0.6 |
| | $N_2$ with $P_1$ | 20.8 | 1.9 | 12.0 | 0.1 |
| | $N_2$ with $P_2$ | 23.3 | 1.7 | 12.3 | 0.4 |
| | No treatment | ... | ... | 11.9 | ... |
| 1950 | $N_1$ without P | 8.1 | 2.4 | 10.4 | 0.9 |
| | $N_2$ without P | 11.9 | 3.4 | 10.0 | 0.5 |
| | $N_1$ with $P_1$ | 8.6 | 2.3 | 9.8 | 0.3 |
| | $N_1$ with $P_2$ | 8.0 | 2.5 | 9.5 | 0.0 |
| | $N_2$ with $P_1$ | 17.1 | 2.3 | 10.3 | 0.8 |
| | $N_2$ with $P_2$ | 15.7 | 2.5 | 9.9 | 0.4 |
| | No treatment | ... | ... | 9.5 | ... |

[a] Average values for all varieties in 1948, and for Moore only in 1949 and 1950.

phosphorus applied separately were of a lesser magnitude, but in all but a few instances a good level of response was obtained. The average response to fertilizer applications was equal to the response that generally would be obtained by growers of malting barley and probably was greater.

If any malting quality criteria have a tendency to be adversely affected by the application of nitrogen or phosphorus fertilizer, the wide range of response obtained from these experiments over the 3-year period would seem to be adequate to detect these effects. The general effect of applying phosphorus fertilizer to the barley was to improve malting quality, as measured in the tests reported. A number of the improvements in quality were statistically significant and the increases in malt extract were commercially valuable. The effects of phosphorus fertilization which were large enough to influence malting qualities were favorable rather than unfavorable. Two of the quality factors significantly increased in two of the three seasons through phosphorus fertilization were 1000-kernel weight and malt extract. These are of considerable importance to malsters and brewers in quality evaluation of barley. Phosphorus application did not result in significant adverse effect on any of the quality measures in any of the three seasons.

The applications of nitrogen fertilizer produced less consistent effects on the quality measures than the phosphorus applications. In the 1948 test, when the application of nitrogen fertilizer alone resulted in no increase in yield, barley protein was very high even in the no-treatment plots and the application of nitrogen significantly increased barley protein. In the 1949 experiment, the application of nitrogen alone resulted in large significant increases in yield but no significant increase in protein content. Phosphorus alone in 1949 produced little or no increase in yield. In the 1950 test, nitrogen alone resulted in larger increases in yield than phosphorus alone, but phosphorus alone significantly increased yield of grain. In 1950, the application of nitrogen fertilizer resulted in significant increases in malt protein, but not in values beyond the acceptable range for malting barley. It may be concluded that applications of nitrogen fertilizer to barley, when in excess of the amount needed for maximum yield of grain, are likely to result in higher protein content than desired for malting and brewing.

The relationships between increases in grain yield and in protein values are shown in Table X. In general, wherever good increases in grain yield were obtained from added increments of nitrogen fertilizer, as in the 1949 and 1950 experiments, the increases in protein content were too small to affect malting quality adversely. The additional nitrogen apparently is largely used for increased growth and grain production rather than for producing higher protein content of the grain. In the 1948 experiment, however, where yield increases from nitrogen fertilizer were relatively small and protein content was already high, the application of nitrogen resulted in increases in protein content of the grain of sufficient magnitude to affect malting quality.

The results presented in Table X and preceding tables point up the fact that considerable care must be exercised in the use of nitrogen fertilizer in the production of high quality malting barley. Barley growers most certainly should be interested in yield increases comparable to those obtained in these experiments, and the use of nitrogen and phosphorus fertilizers should be encouraged on soil types and in areas where such gains are possible. In regions or on soil types where the protein content of the grain normally approaches the upper limits suitable for malting barley without the application of nitrogen fertilizer, considerable caution should be exercised in applying additional increments of nitrogen to barley to be sold for malting purposes. Previous experience, knowledge of current and past cropping systems on the land and of inherent soil fertility, and climatological data for the area should be of value for roughly estimating the protein content of the grain produced in a specific area. With the development of suitable tests for appraising the relative nitrogen-supplying abilities of soils (*17*), an additional guide is available for more exacting and efficient utilization of nitrogen fertilizer. Considerable success has been achieved in predicting rate of nitrogen fertilization for corn, based on measurements of relative nitrate production rates in soils (*9*).

The trend of the interrelationships

among phosphorus content of the grain and the various quality measures was toward improved malting quality. All correlations of phosphorus content of the grain with the other criteria were positive, and although most of the coefficients were not sufficiently great to indicate a pronounced increase in the quality criteria from applying phosphorus fertilizer, they were in the desired direction. The associations of protein content of the grain and malt with other quality factors were more variable than the similar associations between phosphorus content and the same factors. Both negative and positive correlations were observed for the relationships with protein content, but again the coefficients did not appear to be sufficiently high for most comparisons to constitute a serious deterrent to good quality. The negative correlations between protein content and malt extract percent and between protein content and 1000-kernel weight were the most undesirable from a quality standpoint.

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# Colorimetric Determination of Biuret

**G. C. ELLIS and R. L. FORMAINI**
**Nitrogen Division, Allied Chemical and Dye Corp., Hopewell, Va.**

**Previous methods for biuret determination—i.e., complexing with copper ion in alkaline media—necessitate removal of hydrated oxide precipitates prior to measurement of the color development. These methods were found to be unreliable and the inaccuracies were attributed to such factors as sorption of the colored complex by the oxides formed and variance in reagent concentration. The procedures were modified and specifically developed for urea pyrolyzate products containing biuret in a wide concentration range. This new method is based on an advantageous equilibrium existing between copper-tartrate and copper-biuret complexes in Fehling's solution. The equilibrium favors the more highly colored copper-biuret complex, oxide precipitation is prevented, and biuret can be directly determined by standard colorimetric methods.**

Biuret finds potential use in agriculture as a combined herbicide-fertilizer and in the resin industry as an intermediate. It may be conveniently prepared by pyrolysis of urea at moderate temperatures. The solid pyrolyzates contain varying proportions of concomitant materials such as urea, cyanuric acid, ammonia, and triuret.

The development of direct analytical methods for biuret was based on procedures applicable to materials containing the polypeptide linkage or giving the "biuret test" (*2–4, 6*). These methods entail addition of excess sodium hydroxide to dilute copper sulfate solutions of biuret, which results in the development of a colored copper-biuret complex and precipitation of hydrated copper oxides. Oxide removal, by filtration, provides a solution of the complex suitable for colorimetric analysis by conventional methods. The accuracy and precision of these methods were found to be limited by such factors as the sorption properties of hydrated oxides, peptization phenomena, and effects promoted by variance in reagent concentration (Table I).

Experimentation revealed that reversing the order of reagent addition—i.e., addition of copper sulfate solution to biuret solutions of fixed sodium hydroxide