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Title: Influence of different nitrogen and moisture levels on the expression of grain yield and protein content in selected wheat (*Triticum aestivum*, L. em Thell) and barley (*Hordeum vulgare*, L em Lam.) cultivars.

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Warren E. Kronstad

This investigation was conducted to provide information regarding 1) the relationship between the nitrogen percentage in the vegetative tissue of wheat and barley at various growth stages with grain protein and 2) to evaluate the possible association between grain yield and grain protein as influenced by different cultivars, nitrogen levels and available moisture.

Five wheat and four barley cultivars were selected based on their diverse genetic backgrounds and potential differences for the 12 attributes measured. These experimental materials were grown at low and high rainfall sites and under two different nitrogen levels.

In wheat a decrease in the percentage of nitrogen in the flag leaves was found as the plants developed. The highest values were observed at the boot stage. In contrast, the highest percentage of nitrogen in the flag leaves of barley was observed at anthesis. Wheat cultivars which had the greatest genetic potential for grain protein usually had the highest percentage of nitrogen in the flag

leaves at the boot stage and the lowest percentage in the vegetative tissue at harvest. This was especially true under high rainfall conditions. A similar relationship was found for the barley cultivars.

At both experimental sites higher grain yields were accompanied by negative associations with grain protein for wheat. However, for barley no association was found between these two traits at either site or fertility level. Higher grain protein values were found for both wheat and barley at the high rainfall site.

Influence of Different Nitrogen and Moisture Levels on the Expression of Grain Yield and Protein Content in Selected Wheat (*Triticum aestivum*, L. em Thell) and barley (*Hordeum vulgare*, L. em Lam.) cultivars

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Professor of Agronomy in charge of major

Redacted for Privacy

Head of Crop Science Department

Redacted for Privacy

Dean of Graduate School

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Typed by Kathie Klahn for Luz Gomez-Pando

In Dedication To

Antonio and Maximiliana, my parents

My sister and brothers

My colleagues of the Cereal Department
at the Universidad Nacional Agrària,
La Molina, Lima, PERU

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INTRODUCTION

Cereal grains are the predominant source of calories and proteins for human nutrition, thus cereal breeders have directed their efforts to developing cultivars which combine maximum grain yield with improved protein levels.

Unfortunately, as high grain yielding cultivars are developed, a decrease in grain protein is frequently observed. This fact has led to the general conclusion that grain yield and grain protein are inversely related. A further factor to consider is that when protein content is increased in wheat and barley it is frequently at the expense of the nutritional quality of the protein. Therefore, a compromise must be reached between grain yield and the desired level and quality of protein. If grain yield and grain protein both are to be increased, it is important to develop cultivars which are more efficient in their uptake of nitrogen and subsequent translocation of the nitrogen to the grain.

High grain yield and protein in wheat and barley cannot be achieved by breeding alone. Environmental factors especially moisture and soil nitrogen supply are thought to have a major effect on grain yield and protein percentage of the grain harvested. Genetic and environmental factors may interact and their relative roles vary between locations. Therefore, it is important to examine soil moisture and fertility levels in order to properly manage the cereal crop for optimal yield and protein content. To gain an understanding of these factors, the following objectives were identified: (1) to determine the relationship between the nitrogen percentage at various stages of plant growth and subsequent grain protein and (2) to evaluate the possible association between grain yield and grain protein as influenced by different cultivars, fertilizer and moisture levels.

LITERATURE REVIEW

This literature review covers research findings involving: (1) the effect of nitrogen supply on plant development, grain yield and grain protein and (2) the influence of soil moisture on grain yield and protein content.

Effect of Nitrogen Supply on Plant Development and Grain Yield

Nitrogen Uptake

Nitrogen is taken up by the wheat plant from the time the roots begin to function until all uptake of nutrients ceases with physiological maturity (Miller, 1939). Three distinctive stages of nitrogen absorption have been identified: (1) between germination and tillering, (2) at heading time and (3) between heading and harvest. Eighty percent of the total nitrogen is taken up during the first two stages of growth and the remaining between heading and harvest (Laopirojana, 1970; Sinha, 1971; Eilrich and Hageman, 1973; Waldren and Flowered, 1979).

Many environmental factors affect nitrogen uptake. High soil temperatures prior to the period of maturation have been shown to increase nitrogen uptake and result in higher protein levels in the grain (Smika and Greb, 1973; Miflin, 1980).

Interaction of fertilizer and available soil moisture have been reported (Pushman and Bighman, 1976). At low moisture levels the nitrogen uptake decreases with increasing rates of nitrogen (Humbert and McVickar, 1963). Ambler (1977) reported that at sites with excellent moisture only 44 to 66% of the nitrogen from the first fertilizer application was taken up by the wheat plants. With additional fertilizer increments, nitrogen uptake values were near 100%. At low rainfall sites under fallow cropping the recovery values were 38 to 56% and decreased with above optimum fertilizer rates.

Ramig (1960), working with winter wheat in Nebraska, observed that increasing the soil moisture at seeding time increased nitrogen uptake from 33.61 to 67.21 kilograms of nitrogen per hectare at the 87.50 kilograms of nitrogen per hectare fertilization rate. Robins and Domingo (1962) reported that in spring wheat low water supply several weeks prior to heading greatly decreased nitrogen uptake. In this study, with good moisture supply after the stress period, the nitrogen uptake eventually reached the same level as the control plots. Low water supply from boot to milk stage also decreased nitrogen uptake.

With increasing amounts of applied nitrogen, both the uptake and percentage of nitrogen increased in all plant parts. The increase in nitrogen uptake and percent was pronounced when nitrogen was applied through the soil and declined when supplied through the foliage (Singh and Seth, 1978). Altman (1980) in a greenhouse study, reported that foliar applications with 15 N labelled urea resulted in a potential uptake of 29.2 to 61.4 percent of 15 N.

Alessi and Power (1973) found that the nitrogen content of the wheat plant was usually increased at all stages of growth using different sources of fertilizer. The ammonium and nitrate forms at the 68 kg rate resulted in the highest increases. Breteler and Smith (1974), working with one-month old wheat plants grown in a mixed nutrition medium (nitrate and ammonium), found that uptake of ammonium exceeded nitrate even at the lowest ammonium level.

The nitrogen uptake of three wheat varieties differing in their pattern of tillering, but having similar growth rates for the main tillers was measured by Asana et al (1966). They reported that nitrogen uptake was approximately proportional to tiller production. The variety with the highest tiller number also had the greatest nitrogen uptake.

Using nutrient solutions, Mugwira et al (1980) investigated the nitrate uptake efficiency of different cultivars of triticale, wheat and rye when grown in a growth chamber. They found that increasing nitrate concentrations from 0.1 to 2.5 mm increased plant dry matter and nitrogen uptake suggesting that triticale, wheat and rye were similar in their uptake effectiveness.

Photosynthetic Efficiency

The synthesis of carbohydrates and proteins is a highly competitive process. Wheat plants fix carbon dioxide, forming carbohydrates. Also, some wheat genotypes are capable of reducing more nitrate and nitrite and thus produce more protein and less grain yield. To obtain high yielding, high protein wheats, the plant must have the photosynthetic capacity to furnish sufficient energy to reduce carbon dioxide to sugar and also reduce and assimilate nitrate into protein (Keppler, 1974).

A rich supply of nitrogen gives the crop a lush, dark green color. The increased leaf area and the greater number of leaves provided additional opportunities for assimilation and growth (Nilsson, 1972). The positive relationship between nitrogen fertilization and chlorophyll content (Ibragimov, 1965) also promotes photosynthesis. Obolenskaya and Zhadkova (1963) demonstrated an increase in the chlorophyll content of leaves of young barley, sunflowers and maize plants when fertilized with nitrogen. These results could be registered 36 hours after the nitrogen was applied.

The photosynthetic activity of the plant is increasingly centered in the upper layers of the canopy as the plant matures (Patterson and Moss, 1979). Flag leaf and plant structures above it constitute the main source of assimilates for the developing grain (Wardlaw, 1968). Under water stress there is a greater utilization of both stored carbohydrate and photosynthate from lower leaves (Wardlaw, 1967). Neales et al (1963) reported that the increases in dry matter in the cereal inflorescence are the net result of the import of assimilates and organic salts plus the photosynthetic activity of the spike itself minus the losses due to spike respiration.

Nitrogen Translocation to the Grain

Nitrogen and dry matter accumulation in the cereal plant may give an indication of the yield potential. However, mobilization towards the reproductive sink is more important for higher economic yield (Pyare et al., 1978).

A rapid increase in nitrogen accumulation in the kernels accompanied by decreases in the culm leaf, flag leaf and spike chaff nitrogen has been observed suggesting that nitrogen was transported to the kernels (Knowles and Walkings, 1931; Boatwright and Haas, 1961, Pyare et al, 1978). Leaves and glumes became direct suppliers of grain nitrogen by the mass transfer of nitrogen that takes place during leaf senescence (Neales et al, 1963). At maturity more than 60 to 85% of the nitrogen in the above ground plant parts was located in the grain (Miller, 1939; McNeal et al, 1966; Campbell et al, 1977; Campbell and Davidson, 1979b).

No differences were found in total nitrogen content of vegetative parts of high and low protein wheat varieties prior to heading. After heading nitrogen increased more rapidly in the spikes of high protein varieties (Seth et al, 1960). Mikesell and Paulsen (1971) found that removing leaves caused a much greater decrease in grain protein of the high protein than the low protein varieties. Johnson et al (1973) suggested that the high protein content of the Atlas 66 derived lines resulted from more efficient and complete translocation of nitrogen from the plant to its grain.

It appears that for good translocation of plant nitrogen to the grain there must be adequate late moisture. Storrier (1965) found that when nitrogen fertilization increased plant growth enough to deplete soil water before grain maturation, both grain yield and nitrogen yield were decreased, even though the total plant nitrogen was the same.

In winter wheat plants Daigger and Sander (1976) noted that while nitrogen was translocated rapidly from other plant parts to the grain after anthesis, total plant nitrogen losses ranged from 25 to 80 kilograms per hectare in different experiments. Dry matter and nitrogen losses were primarily from the stems where 73 to 75% of the nitrogen losses occurred. Dry matter and nitrogen losses from leaves and roots were relatively small.

Effects of Nitrogen on Grain Yield and the Yield Components

The magnitude of grain yield can be said to be a function of the following three variables: (1) number of spike-bearing tillers, (2) number of kernels per spike and (3) kernel weight (McNeal and Davis, 1954).

The growth of tillers is favored by several environmental conditions such as good supply of nutrients. Sievers and Holtz (1922) found that the number of tillers per plant before stem elongation is dependent on the soil nitrogen supply. Tiller survival may be increased by nitrogen fertilization when moisture is good (Thorne and Blacklock, 1971).

McNeal and Davis (1954) using nine varieties of spring wheat and three levels of nitrogen fertilizer with irrigation found that the variety x fertilizer interaction for yield and tiller number was not significant.

Nitrogen supply at or close to the double ridge stage of spike differentiation may increase the number of spikelets per head as was noted by Single (1964). He also found that raising the nitrogen supply prior to the appearance of the flag leaf increased the proportion of fertile florets. Langer (1973) grew wheat in solution culture with high (150 ppm) or low (15 ppm) nitrogen supply at three stages of development and observed that the spikelet numbers were increased only by raising nitrogen supply at the double ridge stage. The number of kernels per spikelet also responded to the treatment during the same period but a greater response was noted when nitrogen was available until spike emergence. Individual grain weight responded less to the treatment than grain number. Divay (1961) stated that the plant requires an increasing concentration of nitrogen at the time of flower formation and embryo development. If sufficient nitrogen is not available at this time, the number of fertile florets per spike,and hence yield, will be reduced. However, after flowering soil fertility has little or no influence on the kernels per square meter (Laude and Pauli, 1956; CIMMYT, 1974).

In barley grain yield components like tillers per plant, final spikes per square meter, spike length and number of kernels per spike and grain and straw yield were found to be significantly increased by banding nitrogen at the time of sowing. However, 1000 kernel weight was adversely affected (Singh et al, 1979a).

Campbell and Davidson (1979) working with Manitou wheat found that the number of spikelets per spike, seed set of primary and secondary florets and kernel weight were inversely related to and mainly a function of temperature. At high temperature and low nitrate-nitrogen and moisture stress were detrimental to several yield components where those conditions existed during a period critical to the development of the component.

The relationship of protein content in the wheat grain to various agronomic characteristics, notably grain yield, were reported by Clark, 1926; Grant and McCalla, 1949; and Schlehuber and Tucker, 1959. Some investigators (Grant and McCalla, 1949 and Schlehuber and Tucker, 1959) have found a significant inverse relationship between grain yield and the grain protein. Terman (1979) studied yield-protein relationships in three soft red winter wheats (Atlass 66, Knox 62 and Blueboy) and three hard red winter wheats (Norin 16, Toscosa and Omaha) in a pot experiment with six nitrogen levels. The ranking for grain yield was: Toscosa > Blueboy = Knox 62 > Omaha > Norin 16 > Atlas. The ranking for crude protein concentrations was in the reverse order. These trends indicated pronounced genetic differences among cultivars.

Johnson et al (1973) reported responses of Lancer and CI 14016 (Atlas 66 x Comanche) hard red winter wheat cultivars to applied nitrogen in six field tests in Nebraska. Grain protein concentration trends show 1.7 percent more protein in CI 14016 than in Lancer with no applied nitrogen and almost 2 percent with various rates of nitrogen. The yield of both cultivars leveled off or decreased with more than 45 kilograms of nitrogen presumably because of lack of moisture, but protein continued to increase with increased rates of applied nitrogen. Yield-protein relationships became confused as other growth limiting factors became dominant.

Terman (1979) found that nitrogen, moisture supply, light, temperature and other growth factors greatly affect yield-protein relationships among wheat cultivars. Differences among cultivars tended to be greatest under optimum growing conditions.

Effect of Nitrogen on Grain Protein Content

Protein formation in the wheat grain is a function of genetic factors interacting with soil and climate factors (Gericke, 1930; Schlehuber and Tucker, 1959; and Haunold et al, 1962).

Middleton et al (1954) compared several varieties of soft red winter wheat over a three-year period in the southeastern United States. They found one of the varieties, Atlas 66, to be 3.2% higher in grain protein content and higher yielding than the check variety, Hardired. They found that Atlas 66 had the genetic potential for high grain protein. Haunold et al (1962) studied two hard red winter wheats, Wichita and Comanche, and the soft winter wheats, Atlas 66 and Atlas 50, in the greenhouse and under field conditions. They found that Atlas 66 had the highest and Wichita had the lowest grain protein among the varieties observed.

Hutcheon and Paul (1966) reported that the protein content of spring wheat, growing in growth chambers, could be effectively controlled by nitrogen supply and soil moisture stress. Protein content above 16% was obtained only where yields were below the maximum attainable. Partridge and Shaykewich (1972) found that protein concentrations in the grain of wheat grown in a growth chamber decreased greatly at 25 and 50 ppm of nitrogen, but then increased to the highest levels with 200 ppm. Dubetz and Wells (1965) reported increases of protein content of Betzes barley with each succeeding level of nitrogen up to 70 kilograms per hectare.

In summer fallow wheat crops in Saskatchewan, fertilization with nitrogen and phosphate at recommended field rates did not alter the protein content of the grain even through increases in yield of up to 100% were measured. The data obtained indicated that much of the variation in protein values of wheat within fields can be attributed to changes in the type of soil profile and the associated microclimate (McKercher, 1964).

Effect of Soil Moisture on Grain Yield and Protein Content

Cultivars differ in their reaction to soil water. Irvine et al. (1980) growing semidwarf and normal heihgt barley genotypes under different levels of available soil moisture, reported that barley differed significantly in grain yield due to environment and genotype. Keim and Kronstad (1973), working with nine winter wheat cultivars on a wide range of moisture-limited environments found that Hyslop and McDermid were the most widely adapted cultivars having better than average yield under the severe moisture stress and high yield under more favorable environments.

The response of wheat to a given application of nitrogen depends upon the availability of soil nitrogen and water. Singh et al. (1979a) reported that no response was observed beyond a nitrogen application of 80 kilograms per hectare without irrigation, whereas the response was linear up to 120 kilograms of nitrogen per hectare in all the irrigation treatments. Sharma and Singh (1971), working with the barley cultivar, NP 21, found that the crop responded well to postsowing irrigation and nitrogen fertilization.

The effect of soil moisture on the yield components has been studied. Domingo and Robins (1960) noted that tillering is supressed when there is moisture stress but when plants are rewatered there is a great stimulation of tillering. Water stress developed at the early boot stage in three cultivars of spring wheat did not affect tillering but reduced yield by severely decreasing the number of kernels per spike (Dubetz and Bole, 1973). Storrier (1965) showed that irrigation which increased water supply several weeks before anthesis caused marked improvement in the number of kernels per spike.

When a wheat crop receives inadequate moisture during grain filling, many kernels may be shriveled or unfilled (Evans, 1972). Ramusson et al (1975) reported that in eastern Oregon grain yields can be reduced when there is excessive vegetative growth with moisture stress during grain filling period.

Aspinall (1965) working with barley, found that grain number per spike was seriously affected by stresses in soil moisture occurring prior to anthesis. Soil moisture stress during the period between anthesis and flowering in barley can result in a considerable reduction in kernel grain size at harvest.

Terman et al (1969), working in an irrigation-nitrogen rate experiment on hard red winter wheat over a three year period in North Platte, Nebraska, reported that the chief effect of applied nitrogen with adequate water was to increase yields, while the chief effect with several water deficit levels was to increase protein content. In intermediate situations, nitrogen increased both yield and protein. To obtain maximum grain yield for wheat with at least 12 percent protein at several locations in the Central Great Plains, 28 cm of available soil water and at least 106 kilograms of nitrate-nitrogen at seeding were needed (Smika and Greb, 1973).

Wells and Dubetz (1966) demonstrated varietal differences in reaction to soil water stress of 8 bars under greenhouse conditions. The effects of stress on grain yield and protein content were greater at the early boot stage than at the soft dough stage and were larger at the soft dough stage than at the onset of tillering or ripening stage.

MATERIALS AND METHODS

Treatments and Experimental Sites

Five wheat and four barley cultivars served as the experimental materials for this investigation. To determine how these cultivars responded to nitrogen fertilization when grown under diverse environmental conditions two experimental sites were selected. The amount of nitrogen applied, the source of nitrogen and the method and application dates were based on previous experimental results.

Wheat cultivars used included three low protein types (Stephens, Yamhill and Faro) and two potentially high protein lines (Lancota and NB 6853). The four barley entries (Robur, Hudson, Hesk and Lakeland/Kamiak) are adapted to the growing conditions observed for winter grains in Oregon. A more detailed description of the cultivars can be found in Appendix Table 1.

In Appendix Table 2, climatic data are provided for the two experimental sites. The Kaseberg location is in Sherman County, Oregon near the town of Wasco. This area is typical of the dryland summer-fallow region of eastern Oregon where one crop every two years is obtained from a given field. The management practices employed were similar to the common cultural practices for wheat and barley production. Prior to planting 60 kg/ha of nitrogen was applied as anhydrous ammonium, subsequently 40 kg/ha of nitrogen was broadcast to establish the high nitrogen plots at the end of February (the elongation stage of growth). The source of fertilizer was ammonium nitrate. A deep furrow drill was used to plant the

the experimental material on September 28, 1979. Sixty kg/ha was the seeding rate. Precipitation of 405 mm in the form of rain or snow was recorded during the growing season. A mixture of Sincor, Banvel and 2,4-D low volatile ester was used for weed control. The soil is classified as a Walla Walla silt loam.

The second location (East Farm) is located one mile east of Corvallis, Oregon in the Willamette Valley. During the growing season, 996 mm of moisture was received in the form of rain. Prior to planting, 30 kg/ha of nitrogen and 60 kg/ha of P_2O_5 were worked into the soil during the seedbed preparation. At the elongation stage an additional 30 kg/ha of nitrogen was applied to the low nitrogen plots and 70 kg/ha of nitrogen to the high nitrogen treatments. The seeding rate was 100 kg/ha and a disc opener drill was used for planting the material on October 22, 1979. Diuron (1.6 kg/ha effective material) was applied as a post-emergence spray in the fall for weed control. Subsequent weeding was done by hand. The soil is classified as a Chehalis silt loam.

In the experimental results section the sites will be referred to as the dryland (Kaseberg location) and high rainfall (East Farm) sites.

The seeding rate for individual cultivars was adjusted according to the 1000 kernel weight obtained for each cultivar to insure that an equal number of seeds was planted per row. Four row plots, five meters long with .30 m between rows was used at the Kaseberg site. For

East Farm, each plot consisted of six rows, 5 m long with .20 m between the rows.

Measurements

Plant samples (flag leaves) were collected at boot and anthesis stage for each plot. They were dried in an oven at 70°C for 48 hours. The dried smaples were ground in a Wiley Mill (20 mesh per inch screen) and nitrogen content was determined by Oregon State University Soil Science Department Laboratory. This procedure was also used to determine nitrogen content in straw (stem, leaves and chaff) at harvest.

At the two experimental sites, plant height was measured and spikes in a square meter at the center of each plot were counted before harvesting. This section was cut by hand at the surface of the ground. The bundles were weighed with a Mettler electronic balance and then threshed.

The total grain yield for each plot was obtained from the remaining plot plus the grain from the square meter. Using an automatic seed counter, 1000 kernels were counted and weighed. These samples were then ground using a Udy Cyclone Sample Mill and analyzed for total percent protein. Grain protein was analyzed with a Technicon InfraAlyzer 400. Table 1 lists the variables measured.

Table 1.

Variables measured for individual plots of wheat and barley cultivars growing under two nitrogen levels at the dryland and high rainfall sites in 1979-80.

Experimental Sites	Growth Stage	Variable
Dryland and high rainfall	Boot	Percent nitrogen in flag leaves
High rainfall	Anthesis	Percent nitrogen in flag leaves
Dryland and High rainfall	Maturity	Average plant height
		Number of spikes per square meter
		Number of kernels per spike
		Grain yield
		Straw yield
		Harvest index
		1000 kernel weight
		Grain percent nitrogen and percent protein
		Straw percent nitrogen

Calculations

For each plot the following calculations were made:

a) The number of kernels per spike (x) was determined indirectly from the following data.

(A) Grain yield per square meter

(B) 1000 kernel weight

(C) number of tillers bearing spikes

$$x = \frac{1000(A/B)}{C}$$

b) Harvest index from a sample of one square meter.

$$\text{H.I.} = \frac{\text{grain weight}}{\text{straw + grain weight}}$$

c) Percent nitrogen in grain.

$$\text{Wheat \%N} = \frac{\text{\% protein}}{5.7}$$

$$\text{Barley \%N} = \frac{\text{\% protein}}{6.25}$$

Statistical Analysis

Data were collected from all plots and punched onto IBM computer cards. The CDC CYBER 720 System of the Milne Computer Center at Oregon State University was used for the analysis.

A factorial arrangement of treatments in a randomized block design was used. Cultivars and nitrogen were considered as treatments. An analysis of variance was done on the variables measured (Table 1). Each location was analyzed separately and then the two locations were combined and analyzed for grain yield and grain protein content. The F test was used to determine significant differences.

The mean values for each cultivar were compared using Duncan's Multiple Range Test for each trait measured.

RESULTS

The experimental results will be presented for the dryland and high rainfall sites for wheat and barley cultivars separately.

Observed mean square values from the analysis of variance for each study are provided in the Appendix. Data for the precent nitrogen for flag leaves, straw and grain will be presented first along with the results for grain protein. Plant height, straw yield and harvest index will be covered. These will be followed by information concerning the components of grain yield and grain yield per se. Relationships between the traits measured will also be given. Finally, a comparison of grain protein percentage and grain yield will be analyzed when the data are combined over the two locations.

Dryland Location

Wheat

Mean square values for nitrogen in the flag leaves at the boot stage, the the straw and grain along with the percentage of protein in the grain are provided in Appendix Table 3. Statistical differences were observed between nitrogen treatments for all four measurements. Differences between cultivars were observed for nitrogen percentage in the flag leaves and in the grain and for grain protein.

Information regarding how these factors responded to different nitrogen levels for each of the five wheats can be found in Table 2. It was observed that, without exception, every measurement increased at

Table 2.

Mean values for percentage of nitrogen in the flag leaves, straw and grain and grain protein percent of five wheat cultivars grown under two nitrogen levels at the dryland site in 1979-80.

	Percent nitrogen in flag leaves at boot stage		Percent nitrogen in straw at harvest		Percent nitrogen in grain at harvest		Protein Percent in grain	
Cultivar	Low N	High N	Low N	High N	Low N	High N	Low N	High N
Faro	3.65 b*	4.08 a	.26	.30	1.22 b	1.38 b	6.82 b	7.89 b
Stephens	3.28 c	3.72 b	.26	.36	1.24 b	1.52 b	7.12 b	8.69 b
Yamhill	3.14 c	3.48 c	.19	.30	1.17 b	1.51 b	6.68 b	8.61 b
NB 6853	3.94 a	4.16 a	.30	.36	1.69 a	2.07 a	9.68 a	11.90 a
Lancota	3.51 b	3.69 b	.27	.36	1.72 a	2.14 a	9.81 a	12.20 a
Nitrogen Means	3.50	3.82	.26	.34	1.41	1.72	8.02	9.86

*Duncan's Multiple Range Test. Cultivar means with the same letter are not significantly different at the five percent probability level.

the higher nitrogen fertility level for all cultivars. When the cultivars are compared NB 6853, a potentially high protein selection, had the highest percentage of nitrogen in the flag leaves at the boot stage. This was also true for the percentage of nitrogen remaining in the straw at harvest even though the differences between cultivars were not significantly different. However, the percentage of nitrogen in the kernels was less than that of Lancota. The latter cultivar had the highest protein percentage at both the low and high nitrogen fertilizer levels (9.81 and 12.20, repspectively). The soft white winter cultivars, Faro, Stephens and Yamhill, which were developed to have a low protein content, retained this property under the conditions of this experiment. It is interesting to note that Faro was similar to Lancota in percent nitrogen in the flag leaves at both fertility levels. At harvest time they were not the same for nitrogen percent in grain, however.

The observed mean squares for height, straw yield and harvest index in Appendix Table 4 showed differences between nitrogen rates for straw yield and differences among cultivars for height, straw yield and harvest index.

It can be noted that Yamhill had the highest straw yield per hectare for the high nitrogen level and Lancota for the low nitrogen level. The mean values for this characteristic also increased with the higher nitrogen rate.

In Table 3 the mean values for plant height, straw yield and harvest index are presented. For plant height, the cultivar Lancota was the tallest and Stephens had the shortest stature when compared to

Table 3.

Mean values for plant height, straw yield and harvest index of five wheat cultivars grown under two nitrogen levels at the dryland site in 1979-80.

	Plant Height (cm)		Straw Yield (T/ha)		Harvest Index	
Cultivar	Low N	High N	Low N	High N	Low N	High N
Faro	95.80 b*	98.80 c	5.57 b	6.20 b	.436 a	.443 a
Stephens	88.0 c	88.60 d	6.16 b	6.50 b	.432 a	.436 a
Yamhill	102.20 b	105.40 b	8.28 a	9.83 a	.365 b	.370 b
NB 6853	101.60 b	100.00 bc	5.18 b	6.18 b	.386 b	.378 b
Lancota	113.60 a	115.60 a	8.54 a	9.44 a	.268 c	.283 c
Nitrogen means	100.24	101.68	6.74	7.63	.377	.383

*Duncan's Multiple Range Test. Cultivar means with the same letter are not significant different at the five percent probability level.

the other cultivars. Faro and Stephens, which exhibited the lower plant height, had a higher harvest index at both nitrogen levels. The lowest harvest index value was observed for Lancota.

In general, a greater expression of these traits was observed at the higher nitrogen fertility level. The exception was NB 6853 for plant height and harvest index, where there was very little difference. It is interesting to compare the cultivars in terms of how much total nitrogen was produced in the straw on a per hectare basis. This information is provided in Table 4. It can be observed that an increase in total nitrogen in the straw was realized which increased soil nitrogen fertility. When the individual cultivars are compared, Lancoat produced the largest amount of nitrogen per hectare followed by Yamhill. This was true at both nitrogen fertility levels. Faro gave a consistently lower level of nitrogen per hectare.

Appendix Table 5 shows the mean square values for the components of grain yield and grain yield as influenced by nitrogen levels and cultivars. Differences were found between rates of nitrogen application in spikes per square meter and grain yield. Among cultivars, spikes per square meter, kernels per spike, 1000 kernel weight and grain yield were also found to be statistically different. There was a significant nitrogen x cultivar interaction for spikes per square meter and grain yield as well.

The cultivar means of spikes per square meter, kernels per spike, 1000 kernel weight and grain yield are presented in Table 5.

The soft white winter wheat cultivar, Stephens, at the highest nitrogen fertility level had the greatest yield of grain per unit area,

Table 4.

Total amount of straw nitrogen per hectare for five wheat cultivars grown under two nitrogen levels at the dryland site in 1979-80.

Cultivar	Straw Nitrogen (T/ha)	
	Low N	High N
Faro	.0145	.0186
Stephens	.0160	.0234
Yamhill	.0157	.0295
NB 6853	.0155	.0222
Lancota	.0231	.0340

Table 5.

Mean values for number of spikes per meter squared, number of kernels per spike, 1000 kernel weight and grain yield of five wheat cultivars grown under two nitrogen levels at the dryland site in 1979-80.

	Number of spikes per meter squared		Number of kernels per spike		1000 kernel weight (gm)		Grain Yield (T/ha)	
Cultivar	Low N	High N	Low N	High N	Low N	High N	Low N	High N
Faro	349.0 c*	420.0 b	44.09 a	42.96 a	37.28 d	37.34 d	4.54 a	4.93 ab
Stephens	392.0 ab	462.4 a	24.24 b	30.32 b	56.73 a	56.50 a	4.19 b	5.46 a
Yamhill	344.4 c	342.6 c	27.85 b	31.36 b	50.10 b	52.54 b	4.00 b	4.84 b
NB 6853	362.0 bc	366.0 c	25.15 b	25.79 b	47.98 c	48.19 c	3.08 c	3.02 c
Lancota	398.0 a	402.6 b	22.81 b	26.68 b	36.22 d	35.44 e	2.48 d	2.64 c
Nitrogen Means	369.0	398.7	28.83	31.42	45.68	46.00	3.66	4.18

*Duncan's Multiple Range Test. Cultivar means with the same letter are not significantly different at the five percent probability level.

the highest number of spikes per square meter and the highest 1000 kernel weight at both nitrogen levels. It was surpassed for number of kernels per spike at both nitrogen treatments by the club variety, Faro.

Faro had a slightly higher yield than Stephens at the low nitrogen level. Yamhill yielded slightly less total grain per unit area than Stephens and Faro and, except for Stephens, had heavier kernels than the other cultivars.

Correlation coefficients for various agronomic traits and grain protein percent are given in Table 6. Only those values which are statistically significant will be mentioned.

Grain yield showed positive correlations with plant height, harvest index, 1000 kernel weight and kernels per spike. A negative correlation was observed between grain yield and grain protein percent.

Grain protein percent had positive correlation with plant height and straw nitrogen percent. A significant negative correlation with harvest index, flag leaf nitrogen percent and kernels per spike was detected.

Kernels per spike was negatively correlated with nitrogen percent in grains and 1000 kernel weight. It was positively correlated with harvest index.

Kernel weight showed a positive correlation with harvest index and a large negative correlation with plant height.

Other negative correlations were noted between straw yield and harvest index (-.649) and plant height and harvest index (-.729). Height and straw yield were also positively correlated.

Table 6

Correlation coefficients for ten agronomic characteristics and grain protein of five wheat cultivars grown under two nitrogen levels at the dryland site in 1979-80.

Characteristics	Plant Height	Straw Yield	Harvest Index	Percent Nitrogen in flag leaves at boot stage	Percent Nitrogen in straw at harvest	Percent Nitrogen in grain at harvest	Number of spikes per square meter	1000 kernel Weight	Kernels per Spike	% Grain Protein
Grain Yield	.537**	-.144	.667**	-.064	-.022	-.578**	.191	.399**	.496**	-.576**
Grain Protein	.516**	.250	-.545**	-.486**	.534**	.998**	.169	-.256	-.361*	1.000
Kernels per Spike	-.191	-.222	.499**	.271	-.007	-.346*	-.103	-.302*	1.000	
1000 Kernel Weight	-.579**	-.112	.396*	-.287	-.028	-.266	.018	1.000		
Straw Yield	.586**	1.000	-.649**	-.421*	-.004	.248				
Plant Height	1.000	.586**	-.729**							

*Significant at the five percent level of probability.
**Significant at the one percent level of probability.
N = 50

Barley

Appendix Table 6 and Table 7 show the means and the observed mean squares from the analyses of variance respectively for percent nitrogen in the flag leaves, straw and grain and percentage of protein in the grain for the four barley cultivars are presented.

Statistical differences were found between nitrogen rates for nitrogen percent in flag leaves and grain and protein grain percent. Percent nitrogen in the grain and grain protein percent differed among the cultivars.

Nitrogen percent in flag leaves and grain and grain protein percent increased at the higher nitrogen level for all cultivars.

Among the four barley cultivars studied, Lakeland/Kamiak had the highest value for nitrogen percent in flag leaves at the high nitrogen treatment, followed by Hudson, which also had the highest value at the low nitrogen level. Robur and Hesk tended to have similar nitrogen percentages for this measurement.

Hudson had the highest grain nitrogen percent and grain protein percent at both nitrogen levels.

Mean square values from the analyses of variance for plant height, straw yield and harvest index are given in Appendix Table 7. Significant differences between nitrogen levels and cultivars were obtained for most of these traits. The one exception being straw yield between cultivars.

The mean values for these characteristics, which are presented in Table 8, reveal an increase in all the traits with the increase in nitrogen applied, except for the plant height and harvest index

Table 7.

Mean values for percentage of nitrogen in the flag leaves, straw and grain and grain protein percent of four barley cultivars grown under two nitrogen levels at the dryland site in 1979-80.

Cultivar	Percent nitrogen in flag leaves at boot stage		Percent nitrogen in straw at harvest		Percent nitrogen in grain at harvest		Protein percent in grain	
	Low N	High N	Low N	High N	Low N	High N	Low N	High N
Robur	3.60	3.62	.32	.35	1.04 b*	1.21 b	6.52 b	7.59 b
Hesk	3.62	3.78	.28	.29	.93 b	1.11 b	5.88 b	6.95 b
Hudson	3.76	3.80	.25	.32	1.33 a	1.48 a	8.33 a	9.30 a
Lakeland/ Kamiak	3.58	4.04	.28	.27	1.07 b	1.25 b	6.68 b	7.83 b
Nitrogen Means	3.64	3.81	.28	.31	1.09	1.26	6.86	7.92

*Duncan's Multiple Range Test. Cultivar means with the same letter are not significantly different at the five percent probability level.

Table 8.

Mean values for plant height, straw yield and harvest index of four barley cultivars grown under two nitrogen levels at the dryland site in 1979-80.

	Plant Height (cm)		Straw Yield (T/ha)		Harvest Index	
Cultivar	Low N	High N	Low N	High N	Low N	High N
Robur	82.0 c*	86.0 c	5.90	6.10	.364 a	.395 a
Hesk	90.0 b	99.0 b	7.22	7.37	.361 a	.398 a
Hudson	106.0 a	108.0 a	9.40	9.69	.313 b	.335 c
Lakeland/ Kamiak	100.0 a	100.0 b	7.73	9.10	.364 a	.360 b
Nitrogen Means	94.50	98.25	7.56	8.07	.350	.372

*Duncan's Multiple Range Test. Cultivar means with the same letter are not significantly different at the five percent probability level.

of Lakeland/Kamiak.

Hudson had the highest value for plant height and straw yield among the four barley cultivars. Similar to the wheat cultivars the short barley cultivars also showed the highest harvest index ratio. When the total nitrogen produced per hectare is considered, Hudson had the highest values (.0235 and .0310) under low and high nitrogen levels respectively. Robur was the lowest in total nitrogen produced at the low nitrogen level on a similar basis (Table 9).

The observed mean square values for the components of grain yield and grain yield of the four barley cultivars are given in Appendix Table 8. Significant differences between nitrogen rates were found for number of kernels per spike, 1000 kernel weight and grain yield. Significant differences among cultivars were obtained for all traits measured.

Table 10 gives the means for spikes per square meter, kernels per spike, 1000 kernel weight and grain yield for each cultivar at two levels of nitrogen. The cultivar Hesk was the highest in grain yield per unit area at both nitrogen levels. It also had the greatest number of spikes per square meter at the high nitrogen level.

Lakeland/Kamiak yielded less grain per unit area than Hesk despite having the highest number of kernels per spike. The highest value for 1000 kernel weight was achieved with Robur. Robur also had more spikes per square meter under low nitrogen rate.

Hudson was the lowest in grain yield, spikes per square meter and 1000 kernel weight when compared to the other cultivars. For total number of kernels per spike, it was higher than Robur, however.

Table 9.

Total amount of straw nitrogen per hectare for four barley cultivars grown under two nitrogen levels at the dryland site in 1979-80.

Cultivar	Straw Nitrogen (T/ha)	
	Low N	High N
Robur	.0189	.0214
Hesk	.0202	.0214
Hudson	.0235	.0310
Lakeland/Kamiak	.0216	.0246

Table 10

Mean values for number of spikes per meter squared, number of kernels per spike, 1000 kernel weight and grain yield of four barley cultivars grown under two nitrogen levels at the dryland site in 1979-80.

	Number of spikes per meter squared		Number of kernels per spike		1000 kernel weight (gm)		Grain Yield (T/ha)	
Cultivar	Low N	High N	Low N	High N	Low N	High N	Low N	High N
Robur	422.2 a*	375.2 b	22.48 c	30.06 c	48.05 a	50.80 a	3.68 b	4.58 b
Hesk	415.4 ab	417.8 a	33.09 b	42.06 ab	42.55 b	43.02 b	4.58 a	5.43 a
Hudson	356.4 c	368.6 b	34.13 b	40.02 b	38.36 c	39.30 c	3.42 b	4.08 b
Lakeland/ Kamiak	388.0 bc	381.4 ab	40.71 a	43.29 a	38.78 c	39.53 c	4.38 a	4.77 ab

*Duncan's Multiple Range Test. Cultivar means with the same letter are not significantly different at the five percent probability level.

Correlation coefficients for agronomic characteristics and percent grain protein are shown in Table 11. Only associations which are statistically significant will be mentioned for specific measurements.

A positive correlation with harvest index and kernels per spike with grain yield can be noted.

Grain protein percent showed positive correlations with plant height, straw yield, flag leaf nitrogen percent and nitrogen percent in the grain. A negative correlation was observed between grain protein and harvest index.

It is interesting to note that a large negative correlation was found between the yield components kernel number and 1000 kernel weight. Kernel weight was also negatively associated with plant height, straw yield and percent nitrogen in the flag leaves. Other negative associations were noted between straw yield and harvest index and between plant height and harvest index. High positive associations were found between plant height and straw yield, straw yield with flag leaf nitrogen and straw nitrogen at harvest, 1000 kernel weight with harvest index and nitrogen percent in straw and grain.

High Rainfall Location

Wheat

The observed mean square values presented in Appendix Table 9 indicate that significant differences existed between nitrogen rates for nitrogen percent in flag leaves at boot stage, straw and grain nitrogen at harvest and protein percent in grain. Significant

Table 11.

Correlation coefficients for ten agronomic characteristics and grain protein of four barley cultivars grown under two nitrogen levels at the dryland site in 1979-80.

Characteristics	Plant Height	Straw Yield	Harvest Index	Percent Nitrogen in flag leaves at harvest	Percent Nitrogen in straw at harvest	Percent Nitrogen in grain at harvest	Number of spikes per square meter	1000 kernel weight	Kernels per Spike	% Grain Protein
Grain Yield	.031	-.058	.420**	.310	.030	-.072	.274	.062	.428**	-.070
Grain Protein	.439*	.542**	-.316*	.328*	.250	.999**	-.310	-.261	.234	
Kernels Per Spike	.664**	.614**	-.034	.406*	-.158	.233	-.232	-.686**	1.000	
1000 Kernel Weight	-.769**	-.804**	.502**	-.319*	.354*	.354	.268	1.000		
Straw Yield	.830**	1.000	-.640**	.448*	-.216	.542**				
Plant Height	1.000	.830**	-.577**							

*Significant at the five percent probability level.
**Significant at the one percent probability level.
N = 40

differences were also detected among cultivars for all the traits mentioned and for nitrogen percent in flag leaves at anthesis (a measurement made only at the high rainfall site). There was also a significant interaction between nitrogen and cultivar.

The mean values for these measurements noted in Table pointed out the reduction in percentage of nitrogen in flag leaves from boot stage to anthesis stage for all the cultivars studied. Lancota, a potentially high protein cultivar, showed the highest decrease from 3.79 to 2.38 at the high nitrogen level. The other potentially high protein selection, NB 6853, had the lowest decrease between these growth stages (4.09 and 3.74, respectively). Faro, Stephens and Yamhill had a lower percent nitrogen in the flag leaves at these sampling dates. NB 6853 had the highest value for this trait in both sampling dates. In general, there was an increase in nitrogen percent in flag leaves with high nitrogen application. Yamhill was an exception where a decrease at boot stage and no difference between nitrogen rates at anthesis were noted, while Lancota did not respond to the increased nitrogen rate at anthesis for this measurement.

Yamhill, Faro and Stephens had higher and similar mean values for the percentage nitrogen remaining in the straw at harvest. Lancota had a lower percent of straw nitrogen and showed no response to increased nitrogen fertilizer for this trait.

Lancota had the highest percent protein in the grain followed by NB 6853. They had about three percentage points higher grain protein than the other cultivars. Yamhill, Faro and

Table 12.

Mean values for percentage of nitrogen in the flag leaves, straw and grain and grain protein percent of five wheat cultivars grown under two nitrogen levels at the high rainfall site in 1979-80.

Cultivar	Percent Nitrogen in flag leaves at boot stage		Percent Nitrogen in flag leaves at anthesis		Percent Nitrogen in straw at harvest		Percent Nitrogen in grain at harvest		Protein Percent in Grain	
	Low N	High N	Low N	High N	Low N	High N	Low N	High N	Low N	High N
Faro	3.44 a	3.72 ab*	3.05 a	3.38 a	.52 a	.64 ab	1.48 b	1.54 b	8.30 b	8.82 b
Stephens	3.28 a	3.55 b	2.63 a	3.32 ab	.42 a	.55 ab	1.34 c	1.55 b	7.63 c	8.84 b
Yamhill	3.16 a	2.94 c	2.23 b	2.23 b	.50 a	.66 a	1.42 bc	1.60 b	8.11 bc	9.10 b
NB 6853	3.58 a	4.09 a	3.54 a	3.74 a	.38 a	.50 bc	2.20 a	2.46 a	12.54 a	14.04 a
Lancota	3.54 a	3.79 ab	3.16 a	2.38 b	.39 a	.39 c	2.25 a	2.63 a	12.85 a	14.99 a
Nitrogen Means	3.40	3.62	2.92	3.01	.44	.55	1.74	1.96	9.89	11.16

*Duncan's Multiple Range Test. Cultivar menas with the same letter are not significantly different at the five percent probability level.

Stephens had similar means in grain percent. The mean values for the percentage of protein in the grain increased with the higher level of nitrogen with all five cultivars.

The observed mean squares from the analysis of variance in Appendix Table 10 illustrates that significant differences between nitrogen levels for plant height existed. Such differences were also found among cultivars for plant height, straw yield and harvest index. The mean values for these traits are given in Table 13. Lancota was the tallest cultivar and had the most straw; however, it did not show a response to the additional nitrogen for either trait. Stephens was the shortest and had the highest harvest index ratio. Little or no increase in harvest index was noted for any of the cultivars at the higher nitrogen levels. Of interest is that, with the exception of Lancota, the higher nitrogen fertility level increased the amount of nitrogen when computed on a per hectare basis (Table 14). Furthermore, the potentially low grain protein cultivars Faro and Yamhill were the highest in the production of straw nitrogen per hectare when compared to NB 6853 and Lancota.

Appendix Table 11 gives the observed mean square values for the yield components and grain yield. Significant differences between nitrogen rates were found for spikes per square meter, 1000 kernel weight and grain yield. Significant differences were observed among cultivars for all traits. There was a nitrogen x cultivar interaction involving spikes per square meter and grain yield.

In Table 15 the means of the yield components studied and the means of grain yield per unit area for each cultivar in the experi-

Table 13.

Mean values for plant height, straw yield and harvest index of five wheat cultivars under two nitrogen levels at the high rainfall site in 1979-80.

	Plant Height (cm)		Straw Yield (T/ha)		Harvest Index	
Cultivar	Low N	High N	Low N	High N	Low N	High N
Faro	108.0 c*	115.0 bc	11.3 bc	12.66 ab	.370 b	.362 b
Stephens	103.0 c	104.0 d	12.33 b	12.89 ab	.402 a	.394 a
Yamhill	118.0 b	120.0 b	11.94 b	12.04 bc	.360 b	.360 b
NB 6853	108.2 c	112.0 c	10.19 c	10.97 c	.365 b	.374 b
Lancota	143.0 a	143.0 a	13.74 a	13.62 a	.249 c	.260 c
Nitrogen Means	116.0	118.8	11.92	12.44	.348	.350

*Duncan's Multiple Range Test. Cultivar means with the same letter are not significantly different at the five percent probability level.

Table 14.

Total amount of straw nitrogen per hectare for five wheat cultivars grown under two nitrogen levels at the high rainfall site in 1979-80.

	Straw Nitrogen (T/ha)	
Cultivar	Low N	High N
Faro	.0588	.0810
Stephens	.0518	.0709
Yamhill	.0597	.0795
BN 6853	.0387	.0549
Lancota	.0536	.0531

Table 15.

Mean values for number of spikes per meter squared, number of kernels per spike, 1000 kernel weight and grain yield of five wheat cultivars grown under two nitrogen levels at the high rainfall site in 1979-80.

	Number of spikes per meter squared		Number of kernels per spike		1000 kernel weight (gm)		Grain Yield (T/ha)	
Cultivar	Low N	High N	Low N	High N	Low N	High N	Low N	High N
Faro	408.4 c*	460.4 ab	55.78 a	57.52 a	34.48 e	31.28 d	3.10 cd	3.14 d
Stephens	488.6 a	489.8 a	37.42 c	39.47 c	54.30 a	50.88 a	7.27 a	6.90 a
Yamhill	402.8 c	410.6 c	42.70 b	43.26 b	43.78 c	42.96 b	5.70 b	6.05 b
NB 6853	388.0 c	442.2 bc	35.18 cd	33.48 d	51.53 b	49.62 a	3.32 c	4.44 c
Lancota	451.0 b	447.4 b	32.30 d	32.28 d	40.84 d	40.62 c	2.43 d	3.17 d
Nitrogen Means	427.8	450.08	40.68	41.20	44.98	43.07	4.36	4.94

*Duncan's Multiple Range Test. Cultivar means with the same letter are not significantly different at the five percent probability level.

are provided.

Across both nitrogen levels, Stephens had the highest number of spikes per square meter, 1000 kernel weight and grain yield. However, it showed lower number of kernels per spike than either Yamhill or Faro. Yamhill was the next highest in grain yield but it was lower in the yield components. Faro had the highest number of kernels per spike and had similar yield to NB 6853.

The correlation coefficients for the wheat cultivars grown under the high rainfall site for all measurements made are found in Table 16. Only statistically significant values for specific traits or measurements will be identified.

Grain yield was positively correlated with harvest index, spikes per square meter and 1000 kernel weight. Large negative correlations were noted with plant height, nitrogen percent in grain at harvest and grain protein percent with grain yield. For grain protein percent, positive correlations were observed with plant height, flag leaf nitrogen percent at boot stage. Negative correlations with harvest index, straw nitrogen percent and kernels per spike were noted with grain protein percentage.

A negative relationship was noted between the components of yield, kernels per spike and 1000 kernel weight. When plant height and harvest index are considered, a high negative relationship was found. This was also true when straw yield and harvest index were considered.

Barley

The observed mean squares for the five measurements are given in Appendix Table 12. Significant differences between nitrogen rates

Table 16.

Correlation coefficients for eleven various agronomic characteristics and grain protein of five wheat cultivars grown under two nitrogen levels at the high rainfall site in 1979-80.

Characteristics	Plant Height	Straw Yield	Harvest Index	Percent Nitrogen in flag leaves at boot stage	Percent Nitrogen in flag leaves at anthesis	Percent Nitrogen in straw at harvest	Percent Nitrogen in grain at harvest	Number of spikes per square meter	1000 kernel Weight	Kernels per Spike	% Grain Protein
Grain Yield	-.511**	.014	.628**	-.276	-.155	.233	-.598**	.334*	.490**	.016	-.595**
Grain Protein	.575	.020	-.606**	.470**	.158	-.304*	.999**	-.112	.078	-.632	
Kernels per Spike	-.361*	-.053	.374*	-.163	-.056	.460	-.628**	-.150	-.662**	1.000	
1000 Kernel Weight	-.384*	-.301*	.390*	-.026	.102	-.311	.072	.104	1.000		
Straw Yield	.506**	1.000	-.512**	.001	-.244	.144	.020				
Plant Height	1.000	.506**	.918**								

*Significant at the five percent probability level.
**Significant at the one percent probability level.
N = 50

were found for nitrogen percent in flag leaves at boot stage, nitrogen percent in grain and grain protein percent. Significant differences among cultivars were noted for nitrogen percent in flag leaves at boot stage and at anthesis, nitrogen percent in grain and grain protein percent. Mean values for these observations are given in Table 17. Robur had the highest percentage of nitrogen in flag leaves at boot stage for both nitrogen levels, however, this decreased slightly by anthesis. For the other cultivars an increase in the percent nitrogen in the flag leaves from boot to anthesis was found.

The percentage of protein in the grain increased at the higher nitrogen level. The highest values for these measurements were associated with Hudson. Significant differences were found between nitrogen rates for plant height and straw yield. Significant differences among cultivars for plant height, straw yield and harvest index were also found (Appendix Table 13).

As seen in Table 18, the harvest indices increased as the height of the plant decreased. Hesk had the highest harvest index ratio (.410) which was found at the low nitrogen level. The straw yield means consistently increased with the higher amount of nitrogen fertilizer. This was also true for plant height with Hudson being the tallest at both nitrogen levels. Lakeland/Kamiak provided the highest values for both nitrogen fertility levels when tons of of nitrogen per hectare are considered. The greatest response to increased soil nitrogen was noted for Robur with an increase from .0284 to .0425 when comparing low and high fertility levels, respectively (Table 19).

Appendix Table 14 shows the mean square values for the components of grain yield and grain yield. Significant differences were found

Table 17.

Mean values for percentage of nitrogen in the flag leaf, straw and grain and grain protein percent of four barley cultivars grown under two nitrogen levels at the high rainfall site in 1979-80.

Cultivar	Percent Nitrogen in flag leaves at boot stage		Percent Nitrogen in flag leaves at anthesis		Percent Nitrogen in straw at harvest		Percent Nitrogen in grain at harvest		Protein Percent in Grain	
	Low N	High N	Low N	High N	Low N	High N	Low N	High N	Low N	High N
Robur	3.63 a*	3.94 a	3.56 b	3.88 a	.40	.59	1.30 a	1.48 b	7.94 a	9.30 b
Hesk	3.62 a	3.63 b	4.12 a	3.98 a	.47	.48	1.26 a	1.50 b	7.87 a	9.41 b
Hudson	3.00 b	3.18 c	3.30 b	3.64 ab	.35	.46	1.38 a	1.81 a	8.63 a	11.25 a
Lakeland/Kamiak	2.95 b	3.35 c	3.36 b	3.40 b	.58	.51	1.35 a	1.54 b	8.45 a	9.64 b
Nitrogen Means	3.30	3.53	3.58	3.72	.45	.51	1.32	1.58	8.22	9.90

*Duncan's Multiple Range Test. Cultivar means with the same letter are not significantly different at the five percent probability level.

Table 18.

Mean values for plant height, straw yield and harvest index of four barley cultivars grown under two nitrogen levels at the high rainfall site in 1979-80.

	Plant Height (cm)		Straw Yield (T/ha)		Harvest Index	
Cultivar	Low N	High N	Low N	High N	Low N	High N
Robur	85.0 c*	98.0 c	7.10 c	7.20 c	.380 a	.404 a
Hesk	110.0 b	123.0 b	7.48 c	9.42 b	.410 a	.372 a
Hudson	131.0 a	134.0 a	12.09 a	13.54 a	.288 b	.312 b
Lakeland/ Kamiak	110.0 b	124.0 b	10.60 b	12.48 a	.313 b	.310 b
Nitrogen Means	109.0	119.8	9.32	10.66	.347	.350

*Duncan's Multiple Range Test. Cultivar means with the same letter are not significantly different at the five percent probability level.

Table 19.

Total amount of straw nitrogen per hectare for four barley cultivars grown under two nitrogen levels at the high rainfall site in 1979-80.

Cultivar	Straw Nitrogen (T/ha)	
	Low N	High N
Robur	.0284	.0425
Hesk	.0352	.0452
Hudson	.0423	.0623
Lakeland/Kamiak	.0615	.0636

between nitrogen rates and cultivars for all traits with the exception of spikes per square meter. There was also a significant interaction between nitrogen and cultivar for spikes per square meter and grain yield.

Hesk had the highest grain yield per hectare at the high nitrogen level (Table 20). It also had the highest value for the number of kernels per spike. Robur had the highest 1000 kernel weight and, along with Lakeland/Kamiak, had the most spikes per square meter at the highest nitrogen fertility level. Hesk yielded slightly less than Robur at the low nitrogen level. The response to increased nitrogen fertilizer depended on the trait and the cultivar with a general decrease being noted for 1000 kernel weight with the higher level.

Correlation coefficients for all measurements and percent grain protein are presented in Table 21. Only those associations found to be significant for specific traits will be reported. Grain yield was found to be positively correlated with harvest index, nitrogen percent in flag leaves at boot and anthesis stage. A negative correlation with straw yield was also observed between grain and straw yield.

Grain protein percent showed positive correlations with plant height, straw yield and a significant negative correlation was presented with 1000 kernel weight.

Negative associations were also detected between kernels per spike and the other yield components, spikes per square meter and 1000 kernel weight. Plant height and straw yield were also negatively associated with 1000 kernel weight. Negative associations were also found for straw yield with harvest index and the percentage of nitro-

Table 20.

Mean values for number of spikes per meter squared, number of kernels per spike, 1000 kernel weight and grain yield of four barley cultivars grown under two levels of nitrogen at the high rainfall site in 1979-80.

	Number of spikes per meter squared		Number of kernels per spike		1000 kernel weight (gm)		Grain Yield (T/ha)	
Cultivar	Low N	High N	Low N	High N	Low N	High N	Low N	High N
Robur	416.8	409.0	29.02 c*	33.38 c	40.90 a	39.58 a	6.03 a	6.82 ab
Hesk	385.0	388.8	40.68 a	51.37 a	36.06 b	34.70 b	5.72 ab	6.96 a
Hudson	388.6	371.4	33.01 bc	42.60 b	36.61 b	35.49 b	5.16 b	4.96 c
Lakeland/ Kamiak	360.8	438.6	37.36 ab	39.06 bc	36.06 b	34.70 b	5.17 b	6.25 b
Nitrogen Means	387.8	402.0	35.02	41.60	37.40	36.12	5.52	6.25

*Duncan's Multiple Range Test. Cultivar means with the same letter are not significantly different at the five percent probability level.

Table 21.

Correlation coefficients for eleven agronomic characteristics and grain protein of four barley cultivars grown under two nitrogen levels at the high rainfall site in 1979-80.

Characteristics	Plant Height	Straw Yield	Harvest Index	Percent Nitrogen in flag leaves at boot stage	Percent Nitrogen in flag leaves at anthesis	Percent Nitrogen in straw at harvest	Percent Nitrogen in grain at harvest	Number of spikes per square meter	1000 kernel Weight	Kernels per Spike	% Grain Protein
Grain Yield	-.256	-.412*	.504**	.613**	.418*	.188	.064	.170	.094	.215	.070
Grain Protein	.546*	.567**	-.287	-.063	.037	.192	.993**	-.082	-.322*	.278	
Kernels per Spike	.442	.220	.219	-.036	.362	.066	.240	-.357*	-.640**	1.000	
1000 Kernel Weight	-.730**	-.588**	.235	.353*	-.059	.002	-.270	.008	1.000		
Straw Yield	.834**	1.000	-.663**	-.658**	-.364*	-.140	.549**				
Plant Height	1.000	.834**	-.537**								

*Significant at the five percent probability level.
**Significant at the one percent probability level.
N = 40

gen in flag leaves at boot and anthesis stages; however, a positive association was noted between straw yield and nitrogen percentages in the grain at harvest. Plant height was negatively associated with harvest index and positively correlated with straw yield.

Combined Analysis of Variance for Grain Yield and Grain Protein Percent for Both Locations

Wheat

The observed mean square values for the combined analysis involving wheat are presented in Appendix Table 15. Significant differences for nitrogen, cultivar and location were found for both grain protein and grain yield. Also, significant interactions of nitrogen x cultivar, nitrogen x location and cultivar x location were found for protein grain percent. Significant differences for nitrogen, cultivar, location and the interactions cultivar x location and nitrogen x cultivar x location were observed in the analysis for grain yield.

The mean values for the grain yield and grain protein percent for different nitrogen levels at the dryland and high rainfall sites are given in Tables 22 and 23. In general, there were increases in yield with increased nitrogen fertilizer with the exception of NB 6853 at the dryland location and Stephens at the high rainfall location. Stephens, among the cultivars studied, showed the highest yield over both locations with the exception of the low nitrogen level at the dryland site.

Grain protein percent (Table 23) reflected a positive response to nitrogen fertilizer at both locations with the exception of Faro at the high rainfall site. Lancota and NB 6853 had the higher protein values. When the mean values for protein percentage across fertility

Table 22

Mean values for grain yield (T/ha) of five wheat cultivars grown under two levels of nitrogen at the dryland and high rainfall sites in 1979-80.

	Dryland Site		High Rainfall Site	
Cultivar	Low N	High N	Low N	High N
Faro	4.54 a*	4.93 a	3.10 c	3.14 d
Stephens	4.19 ab	5.46 a	7.27 a	6.90 a
Yamhill	4.00 b	4.84 a	5.70 b	6.05 b
NB 6853	3.07 c	3.02 b	3.32 c	4.44 c
Lancota	2.48 c	2.64 b	2.43 d	3.17 d
Nitrogen Means	3.66	4.18	4.36	4.74

*Duncan's Multiple Range Test. Cultivar means with the same letter are not significantly different at the five percent probability level.

Table 23

Mean values for protein grain percent of five wheat cultivars grown under two levels of nitrogen at the dryland and high rainfall site in 1979-80.

	Dryland Site		High Rainfall Site	
Cultivar	Low N	High N	Low N	High N
Faro	6.82 b*	7.89 b	8.30 b	8.22 b
Stephens	7.12 b	8.69 b	7.63 b	8.84 b
Yamhill	6.68 b	8.61 b	8.11 b	9.10 b
NB 6853	9.68 a	11.90 a	12.54 a	14.04 a
Lancota	9.81 a	12.20 a	12.85 a	14.99 a
Nitrogen Means	8.02	9.86	9.89	11.16

*Duncan's Multiple Range Test. Cultivar means with the same letter are not significantly different at the five percent probability level.

levels and locations are noted for all five cultivars, it can be noted that consistently higher values were obtained at the high rainfall site. In Table 24 the amount of protein per hectare for each cultivar for both sites and nitrogen fertility levels are found. With all cultivars a consistent increase can be noted with the higher soil nitrogen levels. At the dryland site, the largest response to increase soil nitrogen was with Stephens and Yamhill. For the high rainfall site, Stephens produced the highest amount of protein per hectare a the low fertility levels (.555) and was second only to NB 6853 at the high soil nitrogen levels (.610 vs .623, respectively). Stephens' high grain yield is responsible for its high protein production on a per hectare basis. It is also apparent that more protein per hectare was produced under the high rainfall site.

Barley

Appendix Table 16 gives the observed mean square values from the combined analysis of variance for both locations for barley. For grain protein percent significant differences were found for nitrogen, cultivar and location. The observed means for grain yield showed significant differences for nitrogen, cultivar, location and the interaction cultivar x location.

The mean values for grain yield and grain protein percentages are presented in Tables 25 and 26, respectively.

There was an increase in grain yield with increased nitrogen levels for most cultivars with the exception of Hudson, where a

Table 24.

Amount of protein per hectare for five wheat cultivars grown at the low and high rainfall sites in 1979-80.

	Dryland Site (T/ha)		High Rainfall Site (T/ha)	
Cultivar	Low N	High N	Low N	High N
Faro	.310	.389	.257	.258
Stephens	.298	.474	.555	.610
Yamhill	.267	.417	.462	.551
NB 6853	.297	.359	.416	.623
Lancota	.243	.322	.312	.475

Table 25

Mean values for grain yield (T/ha) of four barley cultivars grown under two levels of nitrogen at the dryland and high rainfall sites in 1979-80.

	Dryland Site		High Rainfall Site	
Cultivar	Low N	High N	Low N	High N
Robur	3.68 ab*	4.58 ab	6.03 a	6.82 a
Hesk	4.58 a	5.43 a	5.72 a	6.96 a
Hudson	3.42 b	4.08 b	5.16 a	4.96 b
Lakeland/Kamiak	4.38 ab	4.76 ab	5.17 a	6.25 a
Nitrogen Means	4.02	4.71	5.52	6.24

*Duncan's Multiple Range Test. Cultivar means with the same letter are not significantly different at the five percent probability level.

slight decrease in yield was observed at the high rainfall site. Higher grain yields were observed at the high rainfall site for all cultivars evaluated. Hesk showed the highest grain yield at the two locations under the higher nitrogen level of fertilizer.

For protein percentage of the grain (Table 26), it was observed that a consistent increase in the mean values was obtained with the high nitrogen level in all four barley cultivars studied. Hudson had the highest value for the two levels of nitrogen and for both locations. As with wheat, the higher protein percentage values were observed at the high rainfall site.

The tons of protein for each of the barley cultivars at the two sites and for the two soil nitrogen levels are presented in Table 27. Increases were noted for all the cultivars with higher soil nitrogen and at the high rainfall site. No consistent cultivar responses were measured at the dryland site, however, Robur produced the most protein per hectare at both fertility levels in the high rainfall location.

Table 26

Mean values for protein grain percent of four barley cultivars grown under two levels of nitrogen at the dryland and high rainfall sites in 1979-80.

	Dryland Site		High Rainfall Site	
Cultivar	Low N	High N	Low N	High N
Robur	6.52 b*	7.59 b	7.94 a	9.30 b
Hesk	5.88 b	6.95 b	7.87 a	9.41 b
Hudson	8.33 a	9.30 a	8.63 a	11.25 a
Lakeland/Kamiak	6.68 b	7.83 b	8.45 a	9.64 b
Nitrogen Means	6.85	7.92	8.22	9.90

*Duncan's Multiple Range Test. Cultivar means with the same letter are not significant different at the five percent probability level.

Table 27.

Amount of protein per hectare for four barley cultivars grown at the low and high rainfall site in 1979-80.

	Dryland site (T/ha)		High Rainfall Site (T/ha)	
Cultivar	Low N	High N	Low N	High N
Robur	.240	.348	.479	.634
Hesk	.269	.377	.450	.655
Hudson	.285	.379	.445	.558
Lakeland/ Kamiak	.293	.373	.437	.602

DISCUSSION

Forty-one percent of the protein and energy in the human diet comes from the direct consumption of cereals. If the grain fed to animals, and that used in brewing and other industrial purposes is also included, then cereals actually contribute 75 percent of the energy and protein (Loomis, 1976). Therefore, it is important to understand how both yields and protein can be improved to better meet this ever-increasing need.

A major question frequently asked is whether both grain yield and protein percentage can be simultaneously increased in wheat and barley. It is generally believed that if grain yields are increased, the percentage of protein in the grain will be decreased. An additional question is, "How does the environment influence this relationship between grain protein and yield?" Also, "What is the relationship between the percentage of nitrogen in the vegetative parts of the plant and grain protein and grain yield?"

In an effort to answer these questions, genetically diverse cultivars of both wheat and barley were grown at different nitrogen levels under two moisture conditions. For wheat, two cultivars with the genetic potential to attain high protein were included along with two low protein, high yielding types. A fif cultivar was a club wheat which represented a type adapted to dryland areas and with low protein. Four cultivars of barley were selected from diverse pedigrees but all were regarded as being intermediate for grain protein content.

The reported results of this study will be discussed in three main sections: (1) the fate of the nitrogen in plants at different stages of development, (2) how the diverse wheat and barley cultivars responded to different nitrogen levels and (3) the role of the environment in influencing cultivar response to nitrogen fertilizer with regard to grain yield, grain protein percent and especially in the environment x genotype interaction between grain yield and grain protein. Also, the results for wheat and barley will be discussed separately.

Wheat

Movement of nitrogen to the grain

Since the leaves play an important role in the accumulation and subsequent translocation of nitrogen to the cereal grain, the nitrogen content of flag leaves was determined. It is interesting to note that in general terms the mean values for nitrogen percent in flag leaves at boot stage for each cultivar was higher for the high nitrogen level at the dryland location. Cultivar differences for this measurement were found at both the dryland and high rainfall locations.

At anthesis there were decreases in nitrogen percent in the flag leaves. The losses were attributed to nitrogen being translocated from the leaves to the kernels. These findings are similar to those reported by Daigger and Sander (1976) and Waldren and Flowered (1979). The amount of the decrease varied depending upon the cultivar. The sampling at anthesis was done only in the high rainfall location.

The lowest nitrogen content in the vegetative portion of the plant was observed at the harvest time. The decreases in nitrogen percent could be attributed to the translocation to the grain and to the losses from the plant by leaching, by slight defoliation or by translocation to the root.

The higher mean values of nitrogen percent in straw found at the high rainfall location indicated an increase in the uptake of nitrogen. These increases would be in line with the results reported by Ramig (1960) and Alessi and Power (1973). By sampline at the anthesis stage as well as two other growth stages at the high rainfall site, a more precise picture of the uptake and translocation of nitrogen was given.

When the nitrogen remaining in the straw at harvest and grain protein are considered, it is difficult to make a general statement regarding the relative rate of translocation of nitrogen between cultivars. Johnson and Mattern (1972) have suggested that there are cultivar differences in translocation of nitrogen and subsequent grain protein between cultivars. If the amount of nitrogen in the straw on a per hectare basis is considered, Lancota had the greatest production at the dryland site at both soil nitrogen levels. At the high rainfall site, Yamhill produced the highest amount of nitrogen per hectare at the lower fertility level with Faro resulting in more nitrogen per hectare at the higher nitrogen level. Therefore, it can be concluded that there were cultivar differences in either uptake or translocation or both which resulted in more tons of straw nitrogen when the percentage of nitrogen in the straw in considered in relation to the total amount of straw.

Response to Nitrogen Fertilizer

For nitrogen percent in flag leaves at boot stage, there was a general increase of the mean values with the high nitrogen application at both locations. The same response was found for nitrogen straw at the high rainfall location.

Plant height at the dryland location and straw yield at the high rainfall site were increased with increased nitrogen fertility. There was a negative relationship between plant height and harvest index. Harvest indices were in the order: Stephens - Faro - NB 6853 - Yamhill - Lancota at the dryland location and Stephens - NB 6853 - Faro - Yamhill - Lancota at the high rainfall site. The order is essentially the reverse for plant height. Similar results were found by McNeal et al. (1972). Straw yields were also reflected in the harvest indices. Increase in straw yield meant decrease in harvest index. Therefore, under the high rainfall conditions, where plant height was greater and the straw yield nearly twice that of the dryland site, the harvest indices were lower. A contributing factor to the low harvest indices was the fact that at the dryland site many tillers were formed which did not produce grain. This was not true to the same degree at the high rainfall site. However, due to more favorable growing conditions at the higher rainfall site, the plants were much larger in terms of their overall vegetative growth which resulted in a lower harvest index.

Among the yield components studied, spikes per square meter showed an increase with higher amounts of nitrogen fertilizer at the dryland location. At the high rainfall site there was a good linear relationship between spikes per square meter and grain yield but only a slight increase in spikes per square meter was found with increased nitrogen supply. This suggests that the increased nitrogen supply may have caused additional formation of new tillers which did not form fertile spikes and thus did not contribute to grain yield. The straw yields were almost twice that of the dryland area.

Kernels per spike was consistently lower at the dryland site. The mean values of kernels per spike increased slightly with higher amounts of nitrogen with only a few exceptions when the cultivars are compared. This is an important yield component since it is a measure of the storage capacity of both carbohydrate and protein. If it is decreased, the grain yield will be reduced. A major difference between the two sites was in kernel number where there were substantially more kernels per spike at the high rainfall site.

The kernel weight is determined by the supply of photosyntate available to fill the grain and by the number of kernels to be filled. Under high rainfall, the kernel weight decreased at the higher nitrogen rate. There could be two explanations for this: (1) competition between kernels per spike and kernel weight or (2) the smaller kernels found on the extra spikes formed. The data suggest that when photosyntate for grain development is limited, increasing the kernels per spike is simply balanced by decreasing kernel weight. This conclusion is further substantiated when the association between kernel weight and kernel number was significant and negative, particularly at the high rainfall site or higher grain yielding site.

When the cultivars are compared for their grain yield over locations, it was observed that Stephens was the highest yielding at both sites at the highest nitrogen level. Of special interest is that at the dryland site a significant response to increased nitrogen fertilizer was noted for both Stephens and Yamhill. These cultivars are regarded as having the greatest genetic yield potential of the cultivars listed. For the high rainfall site, the opposite was true. NB 6853 and Lancota had a significant increase for grain yield at the higher nitrogen levels. It would appear that Stephens and Yamhill reached their optimum grain production even at the lower nitrogen level.

Grain protein percent was in the following order: Lancota - NB 6853 - Stephens - Yamhill - Faro at the dryland area and Lancota - NB 6853 - Faro - Yamhill - Stephens at the high rainfall area. The differing protein levels pointed out the genetic differences among cultivars, which were also affected by the growing conditions (nitrogen and experimental sites). Lancota and NB 6853 under high nitrogen treatments increased in protein by more than 2% at both locations contrasting with the increases of less than 1% protein in the other cultivars. At the high rainfall site NB 6853 was the highest yielder of protein on a per hectare basis at the high nitrogen followed by Stephens. For the low nitrogen level, Stephens produced the most protein per hectare. When the same comparison is made for the dryland site, Faro produced more protein at the lower nitrogen fertilizer level and Stephens produced more at the high nitrogen rate. The existence of genotypic differences for nitrogen utilization gives the potential for future improvement.

It should be remembered that when considering the amount of protein produced on a hectare basis, both the percentage of grain protein and grain yield must be considered. Even the Stephens wheat had relatively low grain protein at both sites, its greater yield contributing to more total protein being produced.

The goal of plant breeders, therefore, must be to increase both grain protein and grain yield on a per plant basis and thereby increase total protein per hectare. It is important to realize that in one's diet only a certain quantity of food can be consumed at any one time. Therefore, both the quantity and quality of the protein are important on a per plant basis. Even though both grain yield and protein content responded to increased nitrogen fertilizer in this study, a significant negative association between both were found when selected cultivars were compared. For example, Lancota and Stephens (high protein, low grain yield vs low protein and high grain yield), it may be necessary for the plant breeder to reach a compromise between protein percentage in the grain and grain yield on a per plant basis.

Responses to the Environment

The traits studied were greatly affected by differences in soil moisture between experimental locations.

The nitrogen concentrations in straw and grain at harvest were higher in the high rainfall area. This suggests a greater uptake and translocation of nitrogen from vegetative plant parts to the grain. The high moisture in the soil may be lengthened by the growing cycle and therefore leaf senescence did not limit the uptake and translocation of nitrogen as it did in the dryland site.

Plany height and stray yield increased significantly in the high rainfall area. The reduction of vegetative growth in the dryland area was due to the low moisture and shorter growing season. The harvest indices were postively correlated with grain yield at the two locations. The mean values of the harvest indices were greater at the dryland site since moisture limitations restricted the total vegetative development of the cultivars.

The most significant responses to the different environments were in grain yield and yield components.

In every comparison the expression of these traits was always higher at the high rainfall site. This again reflects the long growing season found in the Willamette Valley. Not only does the wheat plant have an opportunity to develop vegetatively, but also the long cool period between anthesis and physiological maturity allows for the expression of the components of grain yield. The one exception was the cultivar Faro which is a club wheat and developed under dryland conditions. It actually yielded less under the high rainfall conditions. This yield reduction appears to have been the result of the lighter kernel weight observed at this site. When the overall associations between grain yield and the components of yield are considered, spikes per square meter and kernels per spike had a greater influence on grain yield than did kernel weight. This was true for both locations. A larger negative correlation was found between kernel weight and kernel number at the high rainfall site, where the grain yields were the highest. Such a negative association at the higher yielding site may reflect a greater biological competition between these components.

Surprisingly in this investigation there was consistently higher grain protein percentage observed at the high rainfall site. It is generally thought that to obtain high protein grain, cultivars must be grown under relatively low moisture conditions. The average percent protein of the grain at the dryland site for low and high nitrogen levels was 8.02 and 9.86, respectively. In contrast, at the high rainfall location, the same comparisons were 9.89 and 11.16

percent. More nitrogen may have been available in the soil at the high rainfall site. With the exception of Faro, the cultivars did respond with greater grain yield as well. It is assumed that the more favorable growing conditions at this site did favor greater translocation of the nitrogen from the vegetative parts to the grain. However, when the amount of nitrogen in the straw was evaluated, there appeared to be a much greater concentration at the high rainfall site. It might also reflect that at this site more nitrogen was actually taken up by the plant. This may have been true, but when the percentages of nitrogen in the flag leaves is considered, a higher percentage was found at the dryland site. It is possible that after this measurement was made nitrogen from other parts of the plant moved up and eventually was translocated to the grain.

The finding that a greater response to increased nitrogen fertility resulted in increases in both grain protein and grain yield may provide a better insight to the plant breeders in developing cultivars which combine higher yields with desired levels of protein. Selection for such cultivars would be more effective under medium nitrogen levels and under high rainfall or irrigated conditions where a greater response to both grain yield and protein content can be achieved.

Barley

Translocation of nitrogen to the grain

When the flag leaves were sampled at the boot stage, the nitrogen percentage found was much greater than on the straw at harvest. This was true for all cultivars, both locations and nitrogen fertilizer levels. At the high rainfall site where the percentage of nitrogen in the flag leaves was sampled at anthesis as well, an increase in the percentage was found at the latter stage.

A general increase in nitrogen in the flag leaves for Hesk, Hudson and Lakeland/Kamiak was observed from boot to anthesis stage. Robur, which is the earliest in maturity, had a decline in percent of nitrogen as the season progressed. With the exception of this cultivar, it appears that uptake of nitrogen continued even after anthesis. This suggests that the translocation of nitrogen from the aerial barley tissues to the grain is limited by leaf senscence. A further indication of this is the lower amounts of nitrogen in the barley grain compared with wheat at similar flag leaf and straw concentrations of nitrogen. It may also indicate that the barley plant is not as efficient as wheat in translocating nitrogen to the grain.

The four barley cultivars studied showed an increase in nitrogen percent in the straw at the high rainfall site indicating a higher uptake of nitrogen, which was also manifested by the higher amount of nitrogen in the grain. When the cultivars are compared for straw nitrogen on a per hectare basis over both nitrogen levels, Hudson had the highest values for tons of nitrogen/ha across the nitrogen levels followed by Lakeland/Kamiak at the dryland location. The cultivars were reversed at the high rainfall location with Lakeland/Kamiak being the highest. Therefore, there appears to be a cultivar difference for uptake and subsequent nitrogen translocation, especially when total nitrogen produced is considered on a per hectare basis.

Responses to Nitrogen Fertilizer

In general all four barley cultivars had a significantly higher nitrogen concentration in their flag leaves and grain due to increased nitrogen fertility. Grain samples contained about three times as much nitrogen percentage as found in straw (leaves + stem + chaff) at harvest.

The nitrogen supply had a marked positive influence on the height of the plants with the greatest response observed at the high rainfall site. This is reflected in the significant increase in stray yield under high nitrogen fertilization. The increases were more noticeable for Robur, Hesk and Lakeland/Kamiak. This further illustrates that under more favorable growing conditions there is a greater expression of plant height and hence straw yield.

Harvest indices for Robur, Hesk and Hudson were increased significantly with the increase in nitrogen, but only at the dryland location. Lakeland/Kamiak showed a slight decrease, which may have resulted from the production of more tillers without fertile spikes. In a similar manner to wheat, there was a negative relationship between plant height and harvest index of barley.

Among the yield components studied, the kernels per spike was found to be significantly increased due to application of the higher rate of nitrogen at both locations. In the same way, nitrogen fertilization increased the 1000 kernel weight at the dryland location. In the high rainfall area, 1000 kernel weight tended to decrease at the high nitrogen rate. This decrease, as with wheat, could be due to the competition between kernels per spike and kernel weight. At both locations kernels per spike had a significant negative correlation with 1000 kernel weight, which further substantiates the conclusion. This was particularly true as the grain yields increased.

Grain yield significantly increased as nitrogen application was increased from 60 to 100 kg/ha. The one exception was Hudson, which showed a slight decrease in yield at the high rainfall site when more nitrogen was applied. It appeared that the nitrogen applied was used to produce more vegetative growth as noted with the higher straw yield per hectare for this cultivar.

The protein in the grain was found to increase with the application of nitrogen. A similar response was found for the production of protein per unit area. Even though Hudson had the lowest grain yield per hectare it did have the highest grain protein percentage resulting in the largest amount of protein per hectare when compared to the other cultivars. Therefore, again from a plant breeding point of view, it is desirable to increase both grain yield and percentage of protein to give the highest total amount of protein on a per plant and per hectare basis. Of particular interest was that when the behavior or the cultivars are analyzed, unlike wheat where a large negative correlation was found between grain yield and protein, in barley little or no association was found at either site. This may be due to the fact that none of the barley cultivars had the genetic potential for high protein or grain yield.

Responses to the Environment

A comparision between the dryland and the high rainfall areas revealed that nitrogen uptake and nitrogen translocation were considerably higher in the high rainfall environment. In the high rainfall area the leaves of the cultivar remained green and intact longer thereby contributing to an enhanced nitrogen uptake and translocation.

Plant height, straw yield and harvest index were affected by both genotype and environmental factors (nitrogen and experimental site).

All yield components and grain yield differed significantly due to genotype and environment. When the four cultivars were grown at the high rainfall site they yielded much higher than they did under dryland conditions.

The correlation coefficients between grain yield and yield components were low and often nonsignificant within each environment. This, again, may be due to the fact that a sufficient grain yield was not achieved thereby avoiding possible biological limitations between the component kernel number and kernel weight. This might also explain why at the lower grain yield level found with barley that a negative relationship was not observed between grain yield and grain protein.

Perhaps the most interesting finding of this investigation when considering the wheat and barley data was the greater grain protein percentages found under the higher rainfall conditions. This result may require the plant breeders to re-evaluate their programs for the screening and development of high protein wheat and barley cultivars. Certainly in addition to more moisture, the high rainfall site (Willamette Valley) does also provide more favorable growing conditions for the expression of grain yield. The entire growing season for the vegetative development is long, extending from October through mid-April. This is followed by a long, cool maturation period after anthesis. As a result, there is very little leaf senescence piero to physiological maturity. A good balance between the sink and source is achieved which, in this study, resulted in increased grain yield and protein.

An additional factor was also observed which could be very significant in the development of winter malting barley cultivars. A major problem in the production of spring type malting barley, particularly in the Klamath Basin, had been the high percentage of protein found in the grain. It would appear that under dryland conditions, as found in the northcentral area of the state, the use of nitrogen fertilizer for increased grain yield would not cause an unacceptable amount of grain protein.

SUMMARY AND CONCLUSIONS

The objectives of this investigation were: (1) to determine the relationship between the nitrogen percentage at various stages of plant growth and subsequent grain protein and (2) to evaluate the possible association between grain yield and grain protein as influenced by different cultivars, fertilizer and moisture levels.

Experimental materials for this study included five winter wheat and four winter barley cultivars selected for their genetic diversity either for grain protein or grain yield potential. The experimental sites represented two very different growing conditions in terms of available moisture and cultural practices employed. Two nitrogen fertilizer levels were established at each location. The amount of nitrogen, its form, mode and time of application were based on the current practices for each area.

Analyses of variance were conducted for 11 and 12 measurements taken at the dryland and high rainfall sites, respectively. Duncan's Multiple Range Test was used to determine the differences among cultivars and attributes measured for each location.

The following conclusions are based on the results of this experiment and as such must be considered in terms of the cultivars used and the experimental sites employed.

Wheat

1. There were cultivar differences for uptake and subsequent nitrogen translocation to the grain, especially when considered on a per hectare basis where percent nitrogen in the straw and grain protein were considered in terms of straw and grain yield.
2. It was observed that the percentage of nitrogen continued to decrease with the development of the plant from the boot stage to anthesis and finally to harvest.
3. NB 6853 and Lancota had the highest percentage of nitrogen in the flag leaves at boot stage and the lowest percentage of nitrogen in the straw at harvest when they were grown under high rainfall conditions. This resulted in approximately five percent more protein in these cultivars when contrasted with Yamhill, Faro and Stephens.
4. Among the traits studied increases due to higher nitrogen fertilization were observed for nitrogen percent in the flag leaves, straw and grain, straw yield and spikes per square meter at the dryland site. At the high rainfall site, positive responses were found to nitrogen fertilization for nitrogen percent in the flag leaves, straw and grain, plant height, spikes per square meter and a decrease for 1000 kernel weight was recorded.

5. Grain yield and grain protein were increased by the higher amount of nitrogen at both locations. Grain yield and grain protein were consistently higher at the high rainfall site for all cultivars.
6. Protein content of the wheat cultivars studied was strongly affected by nitrogen and moisture availability. With high fertility levels there was an increase in average percent protein in the grain from 8.02 to 9.86 at the dryland site. At the high rainfall site, where moisture availability was also a factor, the increase was higher being 9.89 to 11.16 percent for the low and high nitrogen fertility levels, respectively.
7. A significant negative relationship between grain yield and grain protein was found at both locations when the effect of cultivar was considered. Stephens, the highest yielding cultivar, showed a lower amount of protein percentage in the grain than Lancota. The cultivar Lancota with the highest protein percentage in the grain had the lowest grain yield of the cultivars in this experiment. However, an increase in grain protein percent and grain yield was observed for Lancota and NB 6853 at the high rainfall site. Furthermore, it should be noted that since both grain protein and grain yield increased with additional nitrogen fertilization at both sites, a positive response in terms of total protein per hectare and grain yield was realized across cultivars.

8. Results suggest that plant breeders interested in achieving an optimum balance between grain protein and grain yield should select potential new cultivars under high rainfall and moderate nitrogen fertility levels.

Barley

1. Among the four barley cultivars studied, differences in uptake and translocation of nitrogen were detected.
2. A difference between wheat and barley was noted in the fate of the nitrogen during plant development. With barley, the percentage of nitrogen in the flag leaves continued to increase up to anthesis, however, like wheat a large decrease in percent nitrogen was found in the vegetative parts at harvest. This might also reflect the earlier plant development associated with barley.
3. At the dyrland site, there was a general increase in nitrogen percent in flag leaves and grain, plant height, straw yield, harvest index, kernels per spike and 1000 kernel weight due to the higher level of nitrogen fertilization. At the high rainfall site the following traits showed an increase with increased nitrogen levels: nitrogen percent in flag leaves and grain, plant height, straw yield and kernels per spike. A decrease in 1000 kernel weight was found.
4. Grain yield and grain protein showed increases with higher nitrogen levels at both locations. Higher values for both traits were recorded at the high rainfall site.

5. Unlike wheat, no significant negative relationship between grain yield and protein percent was found at either location for barley, when the effect of cultivar was studied. Since both grain protein and grain yield responded to increased soil nitrogen in a positive manner across cultivars, more protein per hectare was obtained with the high nitrogen level at both locations.

6. It would appear that where low protein barley grain is desired, dryland sites should be evaluated. High protein lines should be developed under higher rainfall conditions with moderately high nitrogen fertility levels.

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APPENDICES

Appendix Table 1.

Pedigree and description of cultivars.

Wheat

FARO

Suwon 92/3* Omar//Moro. A soft white club winter wheat cultivar released by Oregon State University in 1976. Faro is beardless, brown-chaffed, medium early maturity, short white straw (50 - 100 cm), and well adapted to the lower rainfall areas of eastern Oregon. It has good milling and baking qualities.

STEPHENS

Nord Desprez/Pullman Selection 101. An awned, soft white common winter wheat released by Oregon State University in 1977. Early maturity, standard height (90 - 100 cm) and high yielding for Pacific Northwest conditions. It has good quality.

YAMHILL

Heines VII/Redmond (Alba). A soft white common winter wheat cultivar released by Oregon State University in 1969. Late maturity, medium height, high yielding and awnless. It has good milling and baking qualities.

LANCOTA

Atlas 66/Comanche//Lancer. An awned, hard red common winter wheat cultivar released by Nebraska AES and ARS. Medium maturity, tall and yields better than Lancer. It has excellent milling and baking quality.

Appendix Table 1. (continued)

NB 6853

Warrior/3/Atlas 66/2/Comanche/4/Comanche/Orfed. An awned, medium hard red winter wheat selection made at Nebraska for inclusion in the protein improvement germ plasm.

Barley

ROBUR

Ager x (Hatif de Gignon x Ares). A six-row feed barley released by Institute Nationale du Recherche Agronomique in France in 1973. Very early maturity, semi-dwarf height, high yielding under intermediate rainfall conditions.

HESK

Ione/Luther. A six-row feed barley released by Oregon State University in 1980. Medium height, medium to mid-late, shatter resistant. Hesk is well-adapted for growing in the higher yielding areas of eastern Oregon.

HUDSON

Michigan winter X Wong. A six-row feed barley released by Cornell University, New York in 1951. Hudson is a medium tall, early maturing. Gram test weight is heavy. Plants are winter hardy but only moderately resistant to lodging.

FB 741572

Lakeland/Kamiak. A six-row feed barley selection. Medium early, mid-tall and high yielding.

Appendix Table 2.

Summary of climatic data on a per month basis in Corvallis and Wasco, Oregon for the 1979-80 growing season.*

	Hyslop 1979-80			Wasco 1979-80		
Month	Av Max °C	Av Min °C	Precip (mm)	Av Max °C	Av Min °C	Precip (mm)
Aug	26.0	10.4	68	26.1	12.2	27
Sept	24.7	10.0	55	24.8	8.6	13
Oct	19.7	7.7	183	17.2	5.6	66
Nov	10.7	2.3	104	4.4	-2.2	57
Dec	9.9	2.8	159	5.8	-1.4	17
Jan	7.1	-1.2	170	-0.3	-5.9	87
Feb	10.4	1.9	99	3.1	-1.9	47
Mar	12.1	3.1	102	8.3	0.6	24
Apr	16.7	4.5	92	15.0	3.9	23
May	18.3	6.2	37	17.8	6.7	32
June	19.9	9.0	44	20.0	7.8	35
July	27.0	11.4	6	27.2	12.2	4

*No climatic data is available for East Farm. Due to the proximity of Hyslop, its data are used to represent East Farm.

Appendix Table 3.

Observed mean squares for the percentage of nitrogen in the flag leaves, straw and grain and grain protein percent of five wheat cultivars grown under two nitrogen levels at the dryland site in 1979-80.

Source of Variation	df	Percent Nitrogen in flag leaves at boot stage	Percent Nitrogen in straw at harvest	Percent Nitrogen in grain at harvest	Protein Percent in Grain
Residual	36	.022	.0051	.0198	.613
Rep	4	.057	.0222	.0242	.616
Nitrogen	1	1.257**	.0816**	1.2482**	42.264**
Cultivar	4	.869**	.0105	.9659**	32.417**
Nitrogen X Cultivar	4	.035	.0022	.0239	.699
Coefficient of Variation (%)		4.05	23.8	9.0	8.8

*Significant at the five percent probability level.
**Significant at the one percent probability level.

Appendix Table 4.

Observed mean squares for plant height, straw yield and harvest index of five wheat cultivars grown under two nitrogen levels at the dryland site in 1979-80.

Source of Variation	df	Plant Height	Straw Yield	Harvest Index
Residual	36	22.835	.535	.00068
Rep	4	61.58*	.221	.00054
Nitrogen	1	25.92	9.785**	.00032
Cultivar	4	919.53**	28.558**	.04369**
Nitrogen X Cultivar	4	9.87	.519	.00018
Coefficient of Variation (%)		4.7	10.2	6.8

*Significant at the five percent probability level.
**Significant at the one percent probability level.

Appendix Table 5.

Observed mean squares for number of spikes per square meter, number of kernels per spike, 1000 kernel weight and grain yield of five wheat cultivars grown under two levels of nitrogen at the dryland site in 1979-80.

Source of Variation	df	Number of Spikes per square meter	Kernels Per Spike	1000 Kernel Weight	Grain Yield
Residual	36	665.27	21.106	1.497	.210
Rep	4	588.25	14.780	3.594	.236
Nitrogen	1	10981.62**	83.980	1.448	3.343**
Cultivar	4	10430.95**	596.327**	810.241**	10.834**
Nitrogen X Cultivar	4	3528.07**	20.208	3.800	.709*
Coefficient of Variation (%)		6.7	15.2	2.6	11.6

*Significant at the five percent probability level.
**Significant at the one percent probability level.

Appendix Table 6.

Observed mean squares for the percentage of nitrogen in the flag leaves, straw and grain and grain percent protein of four barley cultivars grown under two nitrogen levels at the dryland site in 1979-80.

Source of Variation	df	Percent Nitrogen in flag leaves at boot stage	Percent Nitrogen in straw at harvest	Percent Nitrogen in grain at harvest	Protein Percent in Grain
Residual	28	.0360	.0027	.0193	.751
Rep	4	.0695	.0053	.0431	1.677
Nitrogen	1	.2873**	.0072	.2890**	11.299**
Cultivar	3	.0825	.0060	.2656**	10.381**
Nitrogen X Cultivar	3	.0971	.0037	.0003	.013
Coefficient of Variation (%)		5.1	17.43	7.6	11.2

*Significant at the five percent probability level.
**Significant at the one percent probability level.

Appendix Table 7.

Observed mean squares for plant height, straw yield and harvest index of four barley cultivars grown under two nitrogen levels at the dryland site in 1979-80.

Source of Variation	df	Plant Height	Straw Yield	Harvest Index
Residual	28	27.857	.317	.00039
Rep	4	35.000	.498	.00035
Nitrogen	1	140.625*	2.510**	.00456**
Cultivar	3	942.292**	23.124	.00681**
Nitrogen X Cultivar	3	37.291	.830	.00080
Coefficient of Variation		5.4	5.6	5.4

*Significant at the five percent probability level.
**Significant at the one percent probability level.

Appendix Table 8.

Observed mean squares for the number of spikes per square meter, number of kernels per spike, 1000 kernel weight and grain yield of four barley cultivars grown under two nitrogen levels at the dryland site in 1979-80.

Source of Variation	df	Number of Spikes per square meter	Kernels Per Spike	1000 Kernel Weight	Grain Yield
Residual	28	610.426	3.643	1.021	.266
Rep	4	1250.312	.652	1.663	.201
Nitrogen	1	1210.000	391.125**	14.920**	4.844**
Cultivar	3	4802.800**	446.764**	242.118**	2.934**
Nitrogen X Cultivar	3	1603.466	18.976*	2.683	.138
Coefficient of Variation (%)		6.3	5.3	2.37	11.83

*Significant at the five percent probability level.
**Significant at the one percent probability level.

Appendix Table 9.

Observed mean squares for the percentage of nitrogen in the flag leaves, straw and grain and grain protein percent of five wheat cultivars grown under two nitrogen levels at the high rainfall site in 1979-80.

Source of Variation	df	Percent Nitrogen in flag leaves at boot stage	Percent Nitrogen in flag leaves at anthesis	Percent Nitrogen in straw at harvest	Percent Nitrogen in grain at harvest	Protein Percent in Grain
Residual	36	.137	.672	.011	.0096	.315
Rep	4	.127	.194	.058**	.0131	.359
Nitrogen	1	.594*	.095	.140**	.6050**	19.832**
Cultivar	4	.880**	2.733**	.069**	2.4320**	79.521**
Nitrogen X Cultivar	4	.174	.755	.008	.0320*	.969*
Coefficient of Variation (%)		10.55	27.6	21.06	5.3	5.3

*Significant at the five percent probability level.
**Significant at the one percent probability level.

Appendix Table 10.

Observed mean squares for plant height, straw yield and harvest index of five wheat cultivars grown under two nitrogen levels at the high rainfall site in 1979-80.

Source of Variation	df	Plant Height	Straw Yield	Harvest Index
Residual	36	17.34	.914	.00015
Rep	4	60.07*	3.691**	.00054*
Nitrogen	1	95.22*	3.400	.00001
Cultivar	4	2348.07**	12.641**	.03035**
Nitrogen X Cultivar	4	18.97	.774	.00018
Coefficient of Variation (%)		3.5	7.9	3.5

*Significant at the five percent probability level.
**Significant at the one percent probability level.

Appendix Table 11.

Observed mean squares from the analysis of variance for number of spikes per square meter, number of kernels per spike, 1000 kernel weight and grain yield of five wheat cultivars grown under two levels of nitrogen at the high rainfall site in 1979-80.

Source of Variation	df	Number of Spikes per square meter	Kernels Per Spike	1000 Kernel Weight	Grain Yield
Residual	36	695.68	5.898	3.359	.307
Rep	4	1925.27*	2.489	10.840*	.426
Nitrogen	1	6160.50**	3.490	45.811**	4.222**
Cultivar	4	10664.87**	939.432**	629.354**	31.250**
Nitrogen X Cultivar	4	2035.85*	5.637	4.959	.925*
Coefficient of Variation (%)		6.0	5.9	4.2	11.8

*Significant at the five percent probability level.
**Significant at the one percent probability level.

Appendix Table 12.

Observed mean squares for the percentage of nitrogen in the flag leaves, straw and grain and grain protein percent of four barley cultivars grown under two nitrogen levels at the high rainfall site in 1979-80.

Source of Variation	df	Percent Nitrogen in flag leaves at boot stage	Percent Nitrogen in flag leaves at anthesis	Percent Nitrogen in straw at harvest	Percent Nitrogen in grain at harvest	Protein Percent in Grain
Residual	28	.044	.0807	.015	.009	.343
Rep	4	.071	.0888	.031	.083**	2.910**
Nitrogen	1	.515**	.1863	.038	.699**	28.207**
Cultivar	3	1.204**	.9056**	.033	.098**	3.812**
Nitrogen X Cultivar	3	.071	.1341	.029	.033*	1.039*
Coefficient of Variation (%)		6.1	7.8	25.4	6.5	6.4

*Significant at the five percent probability level.
**Significant at the one percent probability level.

Appendix Table 13.

Observed mean squares for plant height, straw yield and harvest index of four barley cultivars grown under two nitrogen levels at the high rainfall site in 1979-80.

Source of Variation	df	Plant Height	Straw Yield	Harvest Index
Residual	28	24.151	.7112	.00081
Rep	4	23.437	.4017	.00204
Nitrogen	1	1155.625**	18.0096**	.00007
Cultivar	3	2877.291**	69.3697**	.02477**
Nitrogen X Cultivar	3	67.291	1.8382	.00214
Coefficient of Variation (%)		4.3	10.8	8.2

*Significant at the five percent probability level.
**Significant at the one percent probability level.

Appendix Table 14.

Observed mean squares from the analysis of variance for number of spikes per square meter, number of kernels per spike, 1000 kernel weight and grain yield of four barley cultivars grown under two levels of nitrogen at the high rainfall site in 1979-80.

Source of Variation	df	Number of Spikes per square meter	Kernels Per Spike	1000 Kernel Weight	Grain Yield
Residual	28	1493.96	34.50	1.179	.219
Rep	4	4473.25	60.53	5.993**	1.008**
Nitrogen	1	2002.22	433.49**	16.666**	5.358**
Cultivar	3	2110.15	367.77**	54.845**	4.022**
Nitrogen X Cultivar	3	4685.89*	45.48	.033	1.036**
Coefficient of Variation (%)		9.8	15.3	3.0	8.0

*Significant at the five percent probability level.
**Significant at the one percent probability level.

Appendix Table 15.

Observed mean squares from the combined analysis of both locations for protein grain percent and grain yield of five wheat cultivars grown under two nitrogen levels in 1979-80.

Source of Variation	df	Percent Protein in Grain	Grain Yield
Residual	76	.454	.260
Rep	4	.698	.371
Nitrogen	1	60.000**	7.540**
Cultivar	4	106.097**	33.936**
Location	1	62.948**	13.527**
Nitrogen X Cultivar	4	1.575*	.063
Nitrogen X Location	1	2.096*	.025
Cultivar X Location	4	5.842**	8.148**
Nitrogen X Cultivar X Location	4	.093	1.571**
Coefficient of Variation (%)		6.9	12.0

*Significant at the five percent probability level.
**Significant at the one percent probability level.

Appendix Table 16.

Observed mean squares from the combined analysis of both locations for protein grain percent and grain yield of four barley cultivars grown under two nitrogen levels in 1979-80.

Source of Variation	df	Percent Protein in Grain	Grain Yield
Residual	60	.577	.257
Rep	4	3.588**	.747*
Nitrogen	1	37.606**	10.195**
Cultivar	3	13.134**	5.585**
Location	1	56.062**	46.238**
Nitrogen X Cultivar	3	.413	.603
Nitrogen X Location	1	1.900	.006
Cultivar X Location	3	1.059	1.370**
Nitrogen X Cultivar X Location	3	.637	.571
Coefficient of Variation (%)		9.2	9.9

*Significant at the five percent probability level.
**Significant at the one percent probability level.