AN ABSTRACT OF THE THESIS OF

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Wheat production in the Pacific Northwest consists mainly of the soft white wheat market class. Over 80% of this wheat is exported. In recent years there has been an increase in soft white wheat production (due in a large part to improvements in the yielding capabilities of the genotypes grown in the Pacific Northwest). To expand into different commodity markets, it would be desirable to diversify and produce wheat cultivars representing more market classes and product uses. One opportunity would be to develop cultivars representing the Hard Red Winter market class. An effort to breed high yielding, high protein Hard Red Winter wheats is now underway at Oregon State University.

This research was conducted to gain a better understanding of the components (genetic and/or environmental) that determine yield and grain protein content of hard red wheat genotypes. There were two general objectives of the research. One was to study the differences in nitrogen assimilation and remobilization in a diverse group of winter wheat genotypes grown in the different agricultural environments of Oregon. The second objective was to determine the efficacy of using "hill

plots" (micro-plots) as a planting method to screen for agronomic and nitrogen assimilation traits in geneticly distinct genotypes which may be used as parents in breeding efforts.

Results of this study indicate that genetic differences for nitrogen assimilation and remobilization do exist, and improvements in Pacific Northwest hard red wheat genotypes can be made with appropriate selection techniques. Data also indicate that the traditional high protein wheat genotypes (from the U.S. Great Plains) do not show an advantage from a grain protein concentration standpoint when produced in the Pacific Northwest. Additionally, the environment played a critical role in determining expression of harvest index, grain protein concentration, and nitrogen harvest index. Genotype by environment interactions were high, suggesting that zone-specific varieties may need to be developed in order to attain both high grain yields and high grain protein yields.

# MULTIPLE LOCATION EVALUATION OF WINTER WHEAT (*Triticum aestivum* L.) LINES FOR GENOTYPIC AND ENVIRONMENTAL INFLUENCES ON NITROGEN ASSIMILATION AND REMOBILIZATION

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Judith C. Holmer

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Professor of Crop and Soil Science in charge of major

Redacted for Privacy

Head of the Department of Crop and Soil Science

Redacted for Privacy

Dean of the Graduate School

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## INTRODUCTION

Soft white winter wheat is the predominant class of wheat produced in the Pacific Northwest. In fact, this area and Australia are the major exporters of this market class of wheat. With the Pacific Northwest's close proximity to Pacific shipping ports, almost 80% of wheat produced is exported, primarily to Pacific Rim countries.

Most of the Hard Red Winter wheat production in the U.S. occurs in the Great Plains states. This area can produce top quality bread-type wheat. High grain protein concentration is the primary quality measurement. However, the high grain protein yield is offset by low production of grain yield.

Soft white wheat genotypes developed and grown in the Pacific Northwest produce high yields and low grain protein; two characteristics of this wheat class and this production area. Even though there is a desire to diversify into other market classes, reduced yields in favor of high grain protein content would not be economically acceptable to Pacific Northwest wheat producers. In an effort to respond to the call for Hard Red Wheat genotypes for the Pacific Northwest, the wheat breeding program at Oregon State University will research the possibility of developing a high protein, high yielding, Hard Red Winter Wheat genotype.

Prior to developing a Hard Red Winter Wheat genotype for the Pacific Northwest, an understanding of the genetic and environmental factors affecting grain yield and protein content is required. Once this is accomplished, parental material can be screened, and crosses and selections made. This research was conducted to obtain an understanding of the factors influencing nitrogen assimilation (uptake) and

nitrogen remobilization (translocation), and how these factors influence grain protein concentration.

Nitrogen assimilation from the soil into vegetative tissues and subsequent remobilization of nitrogen from the vegetative to reproductive tissues results in both grain protein and grain carbohydrate formation. One objective of this research was to understand the basis for differences in nitrogen assimilation and remobilization. For this part of the research, harvest index (often used as an indicator of grain yield), grain protein content, and nitrogen harvest index (a ratio of total plant nitrogen assimilation and subsequent remobilization to the grain) were used. A second objective was to determine the influence the environment and the genotype have on nitrogen assimilation and remobilization. The third objective was to determine if micro-plots can be used as a screening and selection tool for the three traits of primary interest (harvest index, grain protein concentration, and nitrogen harvest index).

# LITERATURE REVIEW

## Nitrogen Assimilation and Remobilization

In order to identify parents for crosses designed to produce progeny with high grain yield and high grain protein content, two parameters: total nitrogen assimilation and remobilization (or translocation) must be examined.

Nitrogen assimilation is important to both grain yield (amount of grain/area) and grain protein yield (amount of grain protein/area). While genetic differences in nitrogen assimilation have been reported in many crop species (Cregan and Van Berkum, 1984), concentration on limited arrays of genotypes for breeding purposes may have led to limited genetic variation for this character. Selection for both agronomic performance and improved nitrogen metabolism (specifically, high nitrogen assimilation and remobilization) should be effective, provided ample genetic variation is available and suitable selection criteria can be identified.

The relative importance of genotype and environment for nitrogen assimilation and remobilization is not known. Cox et al., (1985a) conducted a study on a cross between two wheat genotypes (both short-stature, but differing in protein yield) and 96 of their F4 and F5 progeny lines. Their results indicated that there are genetic differences in nitrogen assimilation and subsequent nitrogen remobilization to the grain. Significant differences in nitrogen assimilation and allocation among the F4 and F5 lines and between the parents occurred.

The movement of nitrogen from vegetative to reproductive tissues (grain) has been termed "Nitrogen Remobilization Efficiency" (Cregan and Van Berkum, 1984). Lal et al., (1978) reported varietal differences in wheat for nitrogen remobilization efficiency from culm, flag leaf, lower leaves, and spike chaff. In a study of five varieties of winter wheat, the maximum nitrogen remobilization

efficiency for leaves and spike chaff to the grain was 82.7% of total nitrogen initially assimilated in the leaves, and 49.5% of total nitrogen initially assimilated in the chaff (Cregan and Van Berkum, 1984).

Johnson, Mattern, and Schmidt (1967) conducted experiments on the relationship of plant nitrogen assimilation and grain protein content in wheat and found that nitrogen assimilation and subsequent remobilization are separate and independent physiological functions. Most of the nitrogen assimilated in the above-ground plant material occurs prior to anthesis, as was found by Rattunde and Frey (1986) in their study of 20 oat genotypes. Subsequent remobilization or translocation of nitrogen from vegetative to reproductive tissues accounts for more than 75% of the nitrogen found in the grain. Loffler et al. (1985) studied 30 wheat genotypes for grain protein differences and found that 93% of total plant nitrogen assimilated at physiological maturity occurred by anthesis. Cregan and Van Berkum (1984) reported that 85% of total plant nitrogen at physiological maturity is taken up by anthesis. Short stature genotypes can assimilate as much nitrogen as the tall cultivars (Cregan and Van Berkum, 1984).

The physiology of nitrogen assimilation and remobilization was studied by Simpson et al., (1983) in a series of greenhouse and growth chamber experiments. This study was conducted to determine the primary source of vegetative plant nitrogen for remobilization to the grain. They discovered that the largest amount of grain nitrogen is translocated from the leaves (40%) followed by the glumes (23%), stem (23%), and the roots (16%). It was also discovered that the lower leaves initially remobilize nitrogen to the roots, and this root nitrogen is later translocated to the grain. The glumes were found to be one of the last actively transpiring plant parts, and they may

act as a temporary sink for nitrogen prior to translocation to grain.

Total nitrogen assimilation differences (significant at .05) at maturity among different wheat genotypes were reported by McNeal et al. (1968) and Paccaud et al. (1985) in a study of 10 winter wheat cultivars. Bhatia (1975) has stated that those plants giving the highest total nitrogen content at maturity are considered the most efficient in nitrogen uptake. In Paccaud's et al. study, one line, cultivar 'Bernina', had the highest biological yield, grain yield, total plant nitrogen, total grain nitrogen, and the highest harvest index. This variety also had the highest post-anthesis nitrogen uptake. However, Bernina had one of the lowest grain protein concentrations. It was found that the high grain yielding cultivars had a high harvest index, high nitrogen uptake, but low grain protein concentration. The correlation coefficient between total plant nitrogen content and grain yield was 0.68.

Grain protein concentration is strongly influenced by total nitrogen assimilation. Cregan and Van Berkum (1984) found this to be true, as did Desai and Bhatia (1978) in their study of 15 durum wheat genotypes. They found that the genotypes assimilating the most total plant nitrogen (measured in grams/meter$^2$) produced the highest grain protein concentration and near maximal grain yield. However, Loffler et al. (1985) in a study of 30 hard red spring wheat genotypes found that the correlation between total plant nitrogen at maturity and grain protein concentration was not significant.

The environment strongly influences nitrogen assimilation and remobilization. Differences in nitrogen remobilization are found in dryland vs. irrigated conditions for hard red spring wheat production. McNeal et al. (1968) sampled seven varieties produced under irrigated and dryland conditions for nitrogen content in the leaves, stems, head

chaff, and grain on five dates. Under dryland conditions, nitrogen remobilization from top vegetative growth to grain averaged 66.2% of total vegetative plant nitrogen, while under irrigated conditions 74.8% of the nitrogen was remobilized from vegetative parts to grain parts. Grain yields, grain nitrogen yields, and total nitrogen in top growth was lower for all genotypes produced under dryland conditions. It was also found that grain protein concentration decreased as the grain to straw ratio (or harvest index) increased.

Prior research indicates both genetic and environmental factors strongly influence nitrogen assimilation and remobilization. This research thesis also proposes genetic differences do exist for these traits. Careful selection criteria may identify genotypes (within a designated environment) with high nitrogen assimilation and remobilization potential.

Nitrogen Harvest Index

Nitrogen Harvest Index (hereinafter referred to as NHI), according to Canvin (1976) and Austin et al. (1977) is the proportion of the total plant nitrogen that is contained in the grain at physiological maturity. It is an important indicator of grain yield and grain protein concentration potential of a variety (Fawcett and Frey 1983), and it is associated with efficient nitrogen utilization. However, this trait typically has a negative association with grain protein concentration (Loffler et al., 1985).

Genetic variability for NHI was reported by Rattunde and Frey (1986) in their study of 20 oat genotypes. Hill plots were used. Genotypes were grown in plots with either a low or a high nitrogen fertilizer application. NHI differed significantly among the 20 cultivars at both nitrogen levels, and the genotypic differences in NHI were moderately consistent in the three years of the study. High NHI was positively associated with high grain yields.

However, genotypes showed no association between soil nitrogen applications and NHI. Cox et al. (1985a) also found little association between soil nitrogen applications and plant nitrogen uptake. In their complete study (Cox et al. 1985a, 1985b, and 1986) the environment (years) played a larger role in plant nitrogen assimilation differences. In their last study, mean NHI values were lower at high soil nitrogen applications for both the parents and F5 progeny.

Rattunde and Frey (1986) also found that high soil nitrogen applications gave lower mean NHI values than did low soil nitrogen applications, but selection for high NHI was more effective under high soil nitrogen conditions. High NHI lines responded better in terms of grain yields to a productive environment, and they were more stable from a grain yield standpoint than the low NHI lines - possibly more widely adapted.

Paccaud et al. (1985) theorized that our present-day high yielding wheat genotypes are morphologically and physiologically dissimilar to the older genotypes. The new genotypes generally have higher harvest indices, are short-stature, have lower stem weights, longer leaf growth duration (which increases the duration and rate of grain growth), but decreased photosynthetic activity per unit leaf area. They felt that breeding for a higher NHI will foster concurrent increases in grain yield and grain quality.

Nitrogen assimilation was found to be independent of nitrogen remobilization (Desai and Bhatia 1978; McNeal et al. 1966; Johnson et al. 1967). Cregan and Van Berkum (1984) have suggested concurrent selection of genotypes with high nitrogen uptake and high (or non-reduced) NHI in order to increase grain protein concentration without reducing yields.

As with nitrogen assimilation and remobilization, genetic differences exist for NHI, and the environment is a strong influence. Selection for NHI alone may not produce

high protein/high yielding cultivars. Concurrent selection for NHI and nitrogen assimilation appears necessary.

Carbohydrate and Nitrogen Partitioning

The importance of carbohydrate and nitrogen partitioning as it relates to NHI, grain yields, and grain protein concentration has been studied extensively. Penning de Vires et al. (1974) found that for every gram of glucose produced from photosynthesis, .83 gram of carbohydrate **or** .40 gram of protein could be produced.

Positive correlations between nitrogen harvest index and harvest index may be an indicator of carbohydrate and nitrogen translocation in a genotype (Desai and Bhatia 1978). High grain protein concentration was consistently associated with high efficiency of nitrogen translocation in the study of Cox et al. (1986). The environment and genotype may together or singly influence nitrogen and carbohydrate partitioning.

Grain Protein

Fourteen of the 21 wheat chromosomes are believed to carry genes important to grain protein yield (Sampson and Flynn, 1983). An additional three chromosomes may be involved as indicated by monosomic analysis (Tarkowski and Otlowska-Miazaga, 1976). Sampson and Flynn (1983) studied the inheritance of grain protein using crosses of four spring wheat lines ranging from low to high grain protein concentrations. Grain protein concentration in progeny varied more than the parents, and followed a normal distribution, indicating that progeny grain protein variation was largely due to quantitative and/or environmental effects. Sampson and Flynn (1983) theorized that grain protein concentration is due mainly to minor genes (additive effects). Over a three-year period they observed that low protein progenies were descendants from low protein parents, and high protein progeny were from high protein parents. F4 and F5 progenies showed continuous

segregation, but there was partial dominance for low grain protein. Halloran (1981) in a study of grain yield and grain protein relationships in soft white spring wheat also found continuous segregation in early generation progeny for grain protein.

Kramer (1979), however, believes that the genetic variation observed for grain protein concentration in wheat varieties is not due to "protein genes" but is the result of the gene(s) involved in dry matter distribution between grain and straw. It is generally accepted that grain protein concentration is negatively correlated with grain yield (Loffler et al. 1985, Paccaud et al. 1985, Cox et al. 1985a). McNeal et al. (1968) found a close relationship between the amount of above ground biomass and grain protein. He felt that narrowing the grain to straw ratio close to 1:1 (increasing harvest index) would decrease grain protein concentration. Cox et al (1985a) found that any significant negative correlations between grain protein concentration and grain yield were low to moderate. Therefore, improvements in grain protein concentration may be attained without reducing yields. Paccaud et al. (1985) also found correlation coefficients between grain protein concentration, biological yield, and harvest index to be negative and significant. Loffler et al. (1985) studied 30 Hard Red Spring Wheat varieties in four locations. Stepwise regression analyses indicated maximization of grain protein percentages may necessitate a reduction in harvest index. However, a few genotypes were able to maintain mean grain protein concentrations and exceed the mean for grain yield.

The physiological determinants of a wheat variety for nitrogen assimilation, nitrogen translocation, and photosynthetic duration may also be important in attaining high grain protein concentrations. Bhatia (1975) concluded that in order to attain higher grain protein concentrations without increasing nitrogen inputs, genotypes must be

developed that have larger root systems (for greater soil nitrogen uptake) and greater nitrogen remobilization capabilities. Cox et al. (1985a) concurs with this, and adds that a longer post-anthesis photosynthetic period is necessary. They also showed high nitrogen remobilization and photosynthetic duration to be heritable traits. Paccaud et al. (1985) however, postulated that a longer photosynthetic period should result in an increased production of carbohydrates, thus diluting protein in the grain.

Grain protein concentrations are dependent on, and sensitive to, environmental factors (Baenziger et al. 1985). One of the most important factors is available soil nitrogen (Sampson and Flynn, 1983; Porter et al. 1982; Cox et al. 1985a; Smika and Greb, 1973). Bhatia (1975) calculated that for a 1% increase in grain protein concentration, 6% additional nitrogen must be supplied to the plant. This nitrogen can come from the soil or be remobilized from plant parts. Cox et al. (1986) found that an increase of 6% nitrogen resulted in a grain protein concentration increase of .41% to .97%.

Johnson et al. (1969) found that soil nitrogen uptake was no different in high compared to low grain protein concentration lines. Loffler et al. (1985) also found that total plant nitrogen at maturity and nitrogen harvest index are not correlated with grain protein concentration. They theorized that varieties capable of remobilizing nitrogen from vegetative to reproductive tissues may also be efficient in moving carbohydrates, thereby attaining the "protein dilution" effect suspected by Paccaud et al. (1985). They felt it more important to select genotypes with high nitrogen harvest indices to attain high grain protein concentrations.

Other environmental factors strongly influencing grain protein concentration include soil nutrients other than

nitrogen, the form of fertilizer used and its location in the soil profile, available soil water, and air temperature (Smika and Greb, 1973). Porter et al. (1982) in a study of 30 winter wheat cultivars in 16 environments over three years, found that phosphorus, potassium, nitrogen, and organic matter in the 15-46 cm section of the soil profile significantly effect grain protein concentration. Climatic variables did not significantly influence grain protein content, but the most important variable was mean daily high temperature from late May to early June (early grain filling). Also, the soil factors most important in determining high grain protein concentration were found deep in the profile (50 cm or deeper). Overall, grain protein concentration was found to be a function of location, cultivar, soil, and climatic factors.

Baezinger et al. (1985) also found highly significant differences among cultivars and environments for expression of protein content. In order to determine protein percentages among cultivars, multiple environment testing was suggested for advanced lines. Cox et al. (1985b) also found that while grain protein concentration and grain yield usually give a negative correlation, this may not always occur, and the correlation is strongly dependent on environmental conditions of a particular location.

In the foregoing four sections, the cited researchers present an array of concepts, many dissimilar, on the factors that influence grain protein concentration. Grain protein concentration and grain yield interactions are usually negative and significant, but certain genotypes or environments may give less significant interactions. It is also apparent that an understanding of a particular genotype's nitrogen assimilation and remobilization (as indicated by nitrogen harvest index) potential, and harvest index, are essential to increasing grain protein concentration while maintaining grain yields. The target

environment for production must also be taken into consideration when measuring these traits. A study aimed at determining the influence that the environment and genotype have on wheat grain protein concentration in the Pacific Northwest production areas could be useful for identifying parents and progeny for hard red winter wheat breeding programs directed at increasing protein while maintaining high yields.

Utility of Hill Plots

Hard red winter wheat varieties adapted to the Pacific Northwest may aid wheat growers by diversifying their product market base. To develop such cultivars, potential parents need to be identified. This identification process involves screening many non-adapted varieties over a range of environments. Such screening may be more efficiently conducted using hill plots. A small grain hill plot typically consists of 25-34 seeds planted in a "hill" with one foot spacings between hills (Frey, 1965). Jellum et al. (1962) noted that hill plots are most useful when a large number of lines are to be screened. In a study of 100 oat lines planted in hills and meter rows, overall performance was similar in both hills and meter rows.

One of the problems of early generation selection is that seed quantity may be limited (McKenzie and Lambert, 1961) and multi-environment testing or quality testing requiring large amounts of seed (500 grams or more) is usually impossible. Hill plots could circumvent both problems. Baker and Leslie (1970) used hill plots for early generation selection of 10 durum cultivars, and found this method to be satisfactory for both quality and yield criteria. One way to improve the efficiency of early generation selections is to reduce the environmental variation in growing conditions (Bos and Kleikamp, 1985), which may be accomplished using smaller plot sizes, thus reducing edaphic variation.

Numerous studies have been conducted to determine the overall effectiveness of hill plots compared to conventional meter row plots in small grain breeding programs. O'Brien et al. (1979) investigated the effectiveness of hill vs. meter row plots for early generation yield testing of wheat lines. Hill plots were grown in nine replications, while meter rows were grown in three replications. The yield range and coefficients of variation were greater in hill plots than meter rows. Selection in a single hill plot was not as efficient as selection within a single meter row plot. However, selection among replicated hill plots was expected to be better than selection from a single meter-row plot.

Frey (1965) found that two or less replications of hill plots are needed per meter row plot replication. Jensen and Robson (1969) found 2.37 hill plots were needed compared to a meter row plot to achieve comparable coefficients of variation for varietal mean yields. O'Brien et al. (1979) felt that 2-4 times as many hill plots are needed per meter row plot to give equal or greater selection efficiency in hills compared to rows.

Some plant characteristics will differ in hill plots vs. meter row plots. Briggle, Cox, and Hayes (1967) noted that at high plant densities (as in hill plots) higher yields (grams of grain per unit area) were attained. Chapman et al. (1969) suggested using hill plots to measure intergenotypic interactions to predict yield in mixed populations. Jellum et al. (1962) found hill plots to be satisfactory for recording height and maturity data, but not lodging. Khadr et al. (1970) found hill plots to have favorable coefficients of variation (compared to meter rows) for plant height, 100 seed weight, and heading date. However, the coefficient of variation for yield was greater in hill plots. Frey (1965) found hill plots to have higher coefficients of variation for yield than meter rows.

However, Baker and Leslie (1970) have suggested that yield selection is easiest among genotypes that greatly differ in their yielding capabilities, and the planting method which produces the highest coefficients of variation would be the most efficient for yield selections.

In multi-location evaluations, Jellum et al. (1962) found that genotypes in hill plots did not show significant genotype by environment interactions, whereas genotype by environment interaction in row plots was significant. Selection among hills and meter row plots was equally effective. Baker (1970) determined heritability estimates from hill and meter row plots for yield, seed weight, and number of seeds per head. While the range of performance was greater in hill plots than meter rows, the genetic correlation was almost perfect (.99) between the two planting methods in all tests. Frey has been conducting oat trials using hill plots since the late 1950's. His results indicate that hill plots are satisfactory for early generation testing of small grains for yield components, plant height, heading date, and weight per volume, but not yield (1965). However, the coefficient of variation can be reduced for grain yield by increasing the number of hill plot replications.

The research proposed for this thesis is directed at evaluating an array of genotypes in a multiple-location trial for differences in nitrogen assimilation and remobilization. Concentration is on the measurements harvest index, grain protein concentration, and nitrogen harvest index. Similar research has been conducted, but not in the Pacific Northwest. Questions that may be answered include: 1. Do the Great Plains hard red wheat genotypes have intrinsicly higher levels of protein? 2. Can Pacific Northwest hard red wheat genotypes also have high protein levels? 3. Is the environment the key factor for production of high protein genotypes?

Identification of parents for crosses resulting in high protein, high yielding Pacific Northwest red wheat lines requires screening a large number of genotypes. The diverse environments in the Pacific Northwest necessitate a minimum of three locations for evaluation purposes. Testing 25 genotypes in three environments, with replications, is costly in terms of land expense and labor input. Hill plots were therefore used as the planting method. The thesis research is two-fold - 1) evaluation of an array of genotypes in multiple locations to determine differences in nitrogen assimilation and remobilization, and to determine the relative contribution both genotype and environment make to these factors in the Pacific Northwest, and 2) determination of the efficacy of hill plots as a screening method for nitrogen assimilation and remobilization.

# MATERIALS AND METHODS

## Plot Design

Twenty-five winter wheat genotypes of diverse geographic and genetic origin were evaluated at Corvallis, Moro, and Pendleton, Oregon. At all locations, a six-replicate split plot design consisting of randomized complete blocks was used for hill plot evaluations. Hill plots were chosen in an effort to reduce experimental error, and experimental area (a cost factor).

The 25 entries were arranged in 1.52 meter x 1.52 meter square blocks, with six replications per location. At each location, the hill plot experiment totaled 5.48 meters x 3.96 meters, which included the six replicates of the 25 entries, a hill plot border row, and a solid planted border row. The split plot design used locations as main plots and genotypes as sub-plots.

For comparative purposes, a meter row experiment using the 25 entries was planted at the Corvallis site. The meter row plots consisted of three rows, 4.26 meters long, with an inter-row spacing of 20.32 cm, and were arranged in a three replicate randomized complete block design. The entire experimental area was bordered by a three-row planting of "Stephens" wheat.

When comparing meter rows to hill plots, mean values, ranges, standard deviations, coefficients of variation, and phenotypic correlations are used.

## Genotypes

Twenty-five winter wheat genotypes were selected that had agronomic characteristics suitable for the three environments. The selections included U.S. (Pacific Northwest and Mid-West) and foreign genotypes of club wheat, soft white, soft red, red, and hard red wheats. The kernel classification, and area of origin of the twenty-five genotypes is given in Appendix Tables 1 and 2. Seed for the hill plots was obtained from the OSU wheat breeding project

nurseries at Hyslop Farm, Corvallis, Oregon.

The selected wheat genotypes were expected to show differences in harvest index, grain protein concentration, and nitrogen harvest index. These three parameters were used as indicators of nitrogen assimilation and remobilization. The wheat genotypes were planted in replicated hill plots in three locations differing markedly in mean yearly rainfall and temperature (see Appendix Table 3), with the intention of assessing the importance of genotype and genotype x environment interaction. This is important to determine if widely adapted high protein cultivars are possible in the Pacific Northwest, or whether area-specific cultivars are required.

The twenty-five wheat genotypes were assigned to four groups based on geographic origin and market class, Pacific Northwest White, European Red, Great Plains Hard Red, and Pacific Northwest Hard Red (all winter habit). Group means, standard deviations, and within-group ranges were computed for each plot type and location for the primary variables of interest. Another goal of this experiment was to determine if one or multiple wheat groups appeared to have an advantage from a protein standpoint such that the group could be used as a source of germplasm for enhancement of protein content in the breeding of hard red winter wheat varieties for the Pacific Northwest. The group abbreviations in Appendix 2 will be used in this section.

Location

Three diverse locations were selected for this experiment. The locations were Corvallis (Hyslop Experimental Farm), Moro (Sherman County Experiment Station), and Pendleton (Rugg Farm), Oregon. These three locations have mean climatological differences for temperature and precipitation, but similar day-lengths (see Appendix Table 3). All three sites are non-irrigated cereal production areas.

The soil type at Corvallis is a fine silty mixed mesic Aquultic Agrixeroll. Moro's soil type (Sherman Station) is a coarse silty, mixed mesic Typic Haploxeroll. The soil type at the Pendleton location (Rugg farm) is a coarse silty, mixed mesic Typic Haploxeroll.

At all locations, a pre-plant soil sample was taken. Soil cores from 0-30 cm, 30-60 cm, and 60-90 cm were extracted, twenty cores per location, spaced equidistant from each other while walking diagonally across the experimental area. A representative sample was removed from each core depth at each location and analyzed by the OSU Soil Testing Laboratory. Nitrogen was determined for all three core depths, while phosphorus, potassium, and sulfur was determined in the 0-30 cm depth only. Fertilizer applications were made in accordance to the soil test results. Fertilizer was applied to optimize yield, but not protein content. The higher nitrogen fertilizer rates required for grain protein optimization may cause lodging with the taller genotypes, and was therefore not used. Seeding rates and planting dates for the three locations were determined using local agricultural practices.

**Pendleton**

The hill plot experiment was planted at the Rugg Farm site on October 3, 1985, using a hand-held corn planter. A pre-plant fertilizer application of 85 kgs/ha nitrogen and 17 kgs/ha sulfur was applied by farm management prior to planting. For weed control, a pre-plant application of 0.35 kg a.i./ha Bromoxynil and .08 kg a.i./ha Dicamba was used. Seeds were planted to a soil depth where there was 30% soil moisture depletion (70% available soil water) to ensure adequate moisture for germination prior to rain. Additional manual weed control was performed. Plots were harvested at maturity (July 10, 1986). Each hill plot was cut at ground level with a sickle. The harvested material was placed in 76.2 cm tall brown paper bags and closed with staples. At

this location, rain began and persisted throughout harvest. To help prevent growth of fungus or bacteria on plant material during transport, plot material was dried for three hours at 40°C. After transport to Hyslop Farm, bags were stored in a dry, pest-free environment.

**Moro**

The hill plot experiment was planted on September 23, 1985, using a hand-held corn planter. The experimental area received a pre-plant fertilizer treatment in June of 56 kg/ha Nitrogen. A preplant application of Diclofopmethyl (1 kg a.i./ha) and Bromoxynil (0.5 kg a.i./ha) was used to control weeds. Seeds were planted to a soil depth where there was approximately 30% soil moisture depletion (70% available soil water), to ensure adequate moisture for germination prior to rain. Plots were harvested at maturity (July 11, 1986) using the same harvest method described for the hill plot harvest at Pendleton. The plot bags were transported to Hyslop Farm, Corvallis, and stored in a dry, pest-free environment.

**Corvallis**

The hill plot experiment and the meter row experiment were planted on October 15, 1985. The area received a preplant fertilizer application of 56 kg/ha of nitrogen and 7 kg/ha sulfur. A hand-held corn planter was used for hill plot planting. The meter row experiment was planted with an H&N Equipment Company custom drill planter. Both meter row and hill plots were planted to a depth of approximately 5 cm.

Weeds were controlled with a post-emergence application of Chlorsulfuron (24.5 grams a.i./ha) plus Alachalor (1.16 liters a.i./ha) in early December. Additional weed control was performed manually. To control septoria species (Septoria tritici and/or nodorum) three foliar applications of the fungicide Tilt (292 ml/ha) were made in late February and March using a hand-pump pressurized back-pack sprayer.

An additional 22.4 kg/ha of nitrogen was applied in early March based on soil test results, OSU Extension Service Fertilizer Guides, and a personal communication with Dr. John Hart, Extension Soil Specialist, Oregon State University.

As needed, entries from hill and meter row plots were staked up to prevent lodging.

Both hill and meter row plots were harvested at maturity (July 29, 1986). A meter length of row was cut at ground level with a sickle from the center of the central row of the meter row plots. The hill plots were harvested as described previously.

Data

The following traits were recorded/calculated for each plot and plot type at each location:

a. Height (cm - ground to tallest tiller, not including awns)
b. Number of tillers per plot
c. Number of spikelets per spike per plot, using three spikes chosen randomly from the harvest bags.
d. Total above ground biomass (grams)
e. Weight of grain (grams - dry weight adjusted for grain moisture concentration)
f. Harvest Index (grain weight/total above ground biomass weight)
g. Nitrogen in grain (converted to % protein)
h. Nitrogen in straw, chaff, and leaf material (This is referred to as "**CHAFF** nitrogen")

i. Nitrogen Harvest Index:

((Grain wt x %N in grain)/
((Grain wt x %N in grain)+(total plant biomass - grain wt) x %N in plant))

For grain weight, the plot bundles were threshed using a plant thresher. Spikes were removed from the stems to avoid loss of stem or leaf material during threshing. Threshing was performed using a plant thresher fitted with a screen attachment over the chaff blower outlet area to catch spike chaff for use in plant nitrogen analyses. Each bag of spikes was run through the thresher two to three times to remove all grain from the head chaff.

After grain weights were recorded, grain was ground in a UDY Cyclone Mill fitted with a .25 mm brass screen. A random sample of spike chaff, stem, and leaf material was used for the plant tissue analysis ("**CHAFF**" nitrogen). Plant tissue was ground using a Wiley Mill, Model 4, fitted with a 20 mesh screen. Grain and plant tissue samples were analyzed by the OSU Tissue Analysis Laboratory (Soil Science Department) for nitrogen using the Micro-Kjeldahl technique.

# RESULTS AND DISCUSSION

The three primary objectives of this research were 1) to characterize differences in nitrogen assimilation and remobilization in an array of winter wheat genotypes using harvest index, grain protein concentration and nitrogen harvest index as measurement indicators, 2) to determine the effect of environment on harvest index, grain protein concentration, and nitrogen harvest index, and 3) to examine the efficacy of hill plots as a screening tool for selection of these traits in wheat lines.

Analyses of variance were computed for hill plots at each location, for hill plots combined across locations (using a split plot design), and for the one meter row plots location. Mean separation using the least significant difference (LSD, Fisher's protected) was computed at the 5% probability level for the primary variables of interest - harvest index (**HI**), grain protein concentration (**GPC**) and nitrogen harvest index (**NHI**) (these abbreviations will be used throughout the remainder of the text). Phenotypic correlations (on a mean plot basis) were calculated for each plot type and location.

## Combined Hill Plot Experiments Results

For the combined hill plot experiment, a split plot analysis was used. In accordance with McIntosh (1983), random location/fixed treatments were used for F-tests.

Analysis of variance mean square results for the combined hill plot experiment are listed on Tables 1 and 2. Highly significant mean square values (as indicated by tests) were detected for all of the variables of primary interest for the location, genotype, and location by genotype variation sources. CV's ranged from 4.93 (height) to 29.54 (percent nitrogen in straw and chaff). Moderate CV's were obtained for HI (17.98), GPC (13.80), and NHI (22.32).

Because of the highly significant genotype x location

effects found for all traits in the combined analysis of hill plot data (except spikelets/spike - see Table 2), data are presented separately for each location. The following sections will concentrate on the three variables of primary interest - HI, GPC, and NHI.

Pendleton

In the analysis of variance highly significant differences ($P<0.01$) among genotypes were found for all 10 variables measured (Tables 3 and 4). Coefficients of variation ranged from a low of 5.32 for plant height to a high of 30.22 for nitrogen in the chaff, leaves, and stem material (CHAFF).

The primary variables of interest - HI, GPC, and NHI - had relatively high coefficients of variation (CV's) of 20.69, 13.28, and 22.39, respectively.

Mean values for HI (Table 5) ranged from 14.89 (Batum) to 32.42 (Chisolm). GPC mean values (Table 6) ranged from 12.29 (Centura) to 16.27 (Maris Marksman). Table 7 lists the mean value ranking for NHI. Values ranged from 0.21 (Batum) to 0.65 (Centura). The mean separation obtained from the LSD tests, and the mean values themselves, were not what might normally be expected from these genotypes. For example, Batum is a PNWSW variety that would be expected to have a high HI but a low GPC. Tables 5 and 6 indicate the opposite. This particular variety may not respond the same in a hill plot as a meter row. The least amount of mean separation in this research was produced with GPC.

One of the objectives of this experiment was to determine the differences between classes of wheat genotypes based on their area of origin and kernel classification, and to determine if these differences are influenced more strongly by genetics or the cropping environment. Appendix 2 lists the wheat varieties according to origin and kernel classification (soft white, hard red, etc.). As shown in Table 8, Pendleton class means for HI ranged from 23.68

(PNWSW) to 27.85 (GPHR). PNWSW lines have a relatively high HI, yet the opposite was found in this experiment. Wheat class GPC means ranged from 13.08 (GPHR) to 14.48 (ESR). The PNWSW ranked second (13.988) in this category. These results indicate that the environment may strongly influence GPC, as GPHR varieties will yield a high GPC when produced in the Great Plains, but they had the lowest mean GPC in Pacific Northwest production conditions. It may also indicate that these cultivars react differently when produced in a hill plot. For NHI, the lowest value was 0.428 (PNWSW) and the highest value was 0.574 (GPHR). It is interesting to observe that while the GPHR class had the lowest mean GPC, it had the highest value for NHI and HI. This was also found by Loffler et al. (1985) and Fawcett and Frey (1983). SD's and mean ranges are also given on Table 5.

Phenotypic correlations are shown in Table 27. HI was negatively associated with chaff protein percentage and NHI. The negative association between HI and NHI could be indicative of the "carbohydrate dilution effect" proposed by Desai & Bhatia (1978), in that greater HI is an indication of both the carbohydrate and nitrogen remobilization capabilities of a cultivar. The negative association between HI and NHI index was high (-.91) and highly significant, which may provide further evidence for the "dilution effect" theory. GPC was negatively associated with NHI (-.62), which was also found by Loffler et al. (1985). However, Cregan and Van Berkum (1984) have suggested selection for high or constant NHI to increase GPC without reducing yields. These data indicate that selection for reduced NHI would give gains in GPC and it may also reduce grain yield, as the correlation between grain weight and NHI was positive and significant (0.73).

Positive phenotypic correlations were highest (>0.80) for HI and grain weight (as expected since grain weight is a

part of the HI calculation), and grain weight and above ground biomass. Correlations were negative and highest (>-.80) for HI and chaff nitrogen percentage and NHI, and chaff nitrogen percentage vs. NHI.

Moro

Genotypes reached physiological maturity earlier than at Pendleton, but were harvested on the same day as the Pendleton location.

The ANOVA mean squares for Moro data is presented in Tables 9 and 10. There were highly significant differences among genotypes for HI, and significant differences were detected in GPC and NHI. All other variables indicate highly significant differences. CV's ranged from 4.99 (height) to 36.93 (total nitrogen in plant). The Moro location is the driest of the three locations, with an average yearly rainfall of 25.4 cm. The high CV's for HI (25.34), GPC (16.99), NHI (22.41), and total nitrogen in plant (36.93) suggest that the high planting densities in a hill plot may be deleterious in this type of environment (or with this planting method) and may cause competition both within and between individual plots in an experiment, thereby masking true differences of a variety.

Harvest indices (Table 11) means ranged from 17.20 (Batum) to 31.75 (Wanser). The HI range was not too dissimilar from Pendleton, but the change in rank of genotypes is pronounced. Wanser ranked towards the middle of the entries in Pendleton, but at Moro it was the highest in HI. Batum remained at the bottom of the values for both locations, but other entries changed considerably. The LSD ranking gave few distinct groups for HI at this location. A similar situation was observed with GPC (Table 12). The mean value range changed slightly (11.76 (Chisolm) to 16.06 (Yamhill)), but the entry rankings and their mean values changed. NHI mean values (Table 13) were higher for Moro, (0.38 for Batum to 0.65 for TAM 105), but the LSD mean

separation was not as distinct as at the Pendleton site.

Considering classes of genotypes (Table 14) there was a narrower range for HI (23.15 for ER to 25.22 to PNWHR) than at other locations. The greatest SD (standard deviation) was with the PNWHR for HI. GPC class mean values ranged between 13.37 (GPHR) and 14.47 (ER). The PNWSW class had the greatest SD (1.75) for GPC, and ER had the lowest (0.77). NHI means were lowest for PNWSW (0.53) and greatest for GPHR (0.57). SD's ranged from 0.07 (ER) to 0.11 (PNWHR). At this location, as with Pendleton, the PNWHR class had some of the highest SD values. The overall observation is that as with the individual varieties, the wheat class results also changed with the cropping environment, suggesting a strong environmental influence for these variables.

Phenotypic correlations (Table 27) gave high (>.80) and significant positive associations for HI vs. NIH, and aboveground biomass vs. total plant nitrogen. In fact, this location gave the highest correlation for aboveground biomass vs. total plant nitrogen, but the greatest (and negative) correlation for NHI vs. total plant nitrogen. While nitrogen assimilation was very efficient at this location, remobilization was not. Highly significant negative correlations were observed (> - 0.80) for chaff nitrogen percentage vs. NHI. It is interesting to observe that some of the correlations at Moro are almost the complete opposite of what was indicated for Pendleton. This difference in correlations indicates a strong genotype x environment interaction, and suggests that area-specific varieties may be required due to the distinct climatic zones of the Pacific Northwest. McNeal et al. (1968) also made the observation that nitrogen assimilation and remobilization are strongly influenced by the environment.

Corvallis - Hill Plots

The ANOVA results (mean squares) for hill plots

evaluated at Corvallis are presented in Tables 15 & 16. There were highly significant differences among genotypes for all variables. CV's at this location were lowest for height (5.19) and greatest for chaff protein percentage (31.36). HI and NHI CV's were much lower than at Pendleton or Moro.

Mean values for traits of interest are presented in Tables 17, 18, and 19. The Corvallis location has the greatest rainfall (averaging 100 cm annually) of the three experimental sites, so the higher mean values for HI (26.59 for Aurora to 40.89 for Jugoslavia), lower mean values for GPC (9.92 for Wanser to 15.90 for Arkan) and higher mean values for NHI (0.46 for Batum to 0.78 for Jugoslavia) are not surprising. Varietal rankings changed again, further indicating the strong influence of both the genotype and environment for these factors.

Wheat class values are presented in Table 20. The GPHR had the lowest mean value for HI (32.83), while the PNWSW class had the highest mean value for HI (35.01). SD for this variable was again greatest for PNWHR. Class mean GPC was lowest for PNWHR lines (11.19) and highest for ER lines (12.30). The PNWSW gave a surprisingly high mean of 12.29 for GPC. As with individual entry means, wheat group rankings have rotated at this location, but again the PNWHR group produced some of the highest SD values. This wheat class may be very sensitive to the hill plot design, as it gave low SD's in the meter row experiment.

Phenotypic correlations (Table 27) were positive (>0.80) and highly significant for grain weight vs. above ground biomass. Negative but highly significant correlations (< -0.80) were found for chaff nitrogen percentage vs. nitrogen harvest index. Again there were correlation changes for this location, although this location and Pendleton appear to be most similar.

Corvallis - Meter Rows

The analysis of variance (mean squares) is presented in Tables 21 and 22. Highly significant differences were found for all traits, except aboveground biomass and total plant nitrogen. The Corvallis hill plot experiment, however, resulted in highly significant treatment differences in all variables measured. Considering the significant treatment differences for height, tillers/plot, spikelets/spike, and grain weight and HI, it is interesting to see that this array of genotypes, when grown in a more conventional evaluation system (meter rows) produced fairly uniform amounts of biomass. Perhaps when interplant competition is reduced by using more uniform plant spacing, genetically distinct cultivars will nonetheless produce similar biomass and assimilate similar volumes of nitrogen (on a percent by weight basis) under high rainfall conditions.

CV's ranged from 4.52 for plant height to 24.97 for chaff protein percentage. Overall, the coefficients of variation for the meter rows were reduced when compared to the hill plots. However, GPC and NHI CV's were not greatly reduced compared to the hill plots. Due to the fairly consistent CV's, hill plots may be considered comparable to meter rows and may have utility as an early generation selection tool for GPC and NHI in a high rainfall evaluation location.

Mean HI values for the 24 genotypes are shown in Table 23. The lowest mean value was obtained with Arkan (13.86) while the greatest mean value was obtained by Adam (41.00). Overall, HI mean values did not change considerably between hill and meter row plots, but as with location differences, changes in entry rank occurred. The meter rows also allowed for greater mean separation than the hill plots, and may therefore be a better tool for distinguishing genotypes differing in HI. This is not unexpected, as HI is an indicator of grain yield, and grain yield selections are

reputed to be unreliable in a hill plot evaluations (O'Brien et al. 1979; Khadr et al. 1970; Frey 1965). The lowest GPC was for Hill 81 (8.82) and highest mean value for Arkan (17.67 - see Table 24). The mean values were on the lower side for meter rows compared to hill plots, and the meter rows gave less mean separation than hill plots. The two varieties with the highest GPC were the same for the meter rows and hill plots, but again the majority of genotypes performed differentially in the two plot types. Table 25 indicates Jugoslavia had the highest NHI in both plot types, but other genotypes responded differentially.

Considering wheat classes of genotypes (Table 26) HI mean values were comparable, but there were differences in range of expression. PNWSW had the lowest GPC mean value (9.76) while the GPHR class had the highest GPC mean value (12.686). This is the reverse of the hill plot data, and is more in line with expectations of wheat class performances. The range of expression was different for GPC, with the GPHRW group showing the greatest variance. NHI was lowest in the GPHRW class (0.65) and highest in the PNWSW class (0.72). SD's ranged from 0.04 for PNWSW class to 0.115 for GPHR class.

In general, expression of HI on a wheat class basis was comparable in hill and row plots. Expression of other characteristics was not comparable. Hill plots performance may not be indicative of a genotype's performance in row plots (meter rows) for GPC and NHI. Also, due to the greater CV's with hill plots, a higher number of hill plots may need to be used. This would reduce the cost advantage of using hill plots.

Phenotypic correlations for the Corvallis meter row experiment (Table 28) indicate highly significant positive interactions (>0.80) between HI vs. grain weight. There were no correlations that were highly significant and (<-0.80). However, HI vs. GPC was greater in the meter rows

than hill plots. According to McNeal et al. (1968) this indicates the meter row plot type as a better planting method when selecting for increased grain protein concentration.

# CONCLUSIONS

One objective of this experiment was to study the interrelationships of the factors that are indicative of nitrogen assimilation and remobilization - namely harvest index, grain protein concentration, and nitrogen harvest index. Coupled with this objective, it was hoped to determine if these factors are influenced more by the environment or the genetic constitution of a variety.

The results showed that harvest index is negatively and significantly associated with grain protein concentration, but positively associated with nitrogen harvest index. These results are not unexpected, as they have been found by other researchers. However, there are significant differences between genotypes for these traits. This is positive as it indicates genetic differences which can be capitalized on in a breeding program. The meter row experiment indicated significant genotype differences for almost all measured variables. Data suggest that selection for higher harvest index, or higher yields, will only be accomplished with the loss or reduction of grain protein concentration. However, careful selection for increased grain yield without increasing harvest index may produce higher grain and protein yielding cultivars. Additionally, the high genotype by environment interactions may necessitate development of zone-specific cultivars, rather than widely adapted ones, for increasing grain protein in the Pacific Northwest.

The third objective of this experiment was to determine if hill plots could be used as a selection method for the primary traits of interest. For hill plots to be efficient, hill plot data should be comparable to data from plots more closely resembling commercial production practices (meter rows). This was not the result in this experiment. For example, the meter row analysis showed that the GPHR lines

averaged 1.5% higher in grain protein concentration, but yielded less than the PNWSW, and had a considerably lower harvest index. But in the Corvallis hill plot experiment, the ER lines had the highest GPC, and the second highest HI. Also, the high coefficients of variation for almost all hill plot traits (the only exceptions being height and spikelets per spike), coupled with the high interactions between genotypes and plot types (as indicated by a switching of mean rankings on a per genotype and wheat class basis) suggests that hill plots cannot be used for early generation screening of wheat lines for the primary traits of interest. Variation among replications of the same genotype was also quite high, which indicates that a greater number of hill plot replications would be required. The cost and labor reduction feature of hill plots would therefore be eliminated, and use of conventional meter rows becomes more attractive.

# TABLES

**Table 1**
Mean square values for variables of primary interest, and Nitrogen variables, for the combined location analysis of hill plots (Pendleton, Moro, Corvallis - 1986).

| Source of Variation | df | Harvest Index | Grain Protein Concentration | Nitrogen Harvest Index | Chaff, Leaf & Stem Nitrogen | Total Nitrogen in Plant |
|---|---|---|---|---|---|---|
| Location | 2 | 3896.25 ** | 156.16 ** | 1.44 ** | 185.48 ** | 58.96 ** |
| Replications /Location | 15 | 72.77 | 20.02 | 0.03 | 7.33 | 0.69 |
| Genotypes | 24 | 212.18 ** | 20.07 ** | 0.12 ** | 26.55 ** | 1.72 ** |
| Location x Genotype | 48 | 64.58 ** | 7.03 ** | 0.02 ** | 3.84 ** | 0.56 ** |
| Error | 360 | 25.46 | 3.30 | 0.01 | 1.63 | 0.26 |
| CV | | 17.98 | 13.80 | 17.32 | 29.54 | 27.03 |

*, ** indicate significance at $P \leq 0.05$ and $P \leq 0.01$, respectively

**Table 2**
Mean Squares for agronomic traits for the combined location analysis of hill plots (Pendleton, Moro, Corvallis - 1986).

| Source of Variation | df | Height | Tillers /Plot | Spikelets /Spike | Aboveground Biomass | Grain Weight (gm/plot) |
|---|---|---|---|---|---|---|
| Location | 2 | 54388.53 ** | 530.78 | 411.34 ** | 439238.35 ** | 79652.29 ** |
| Replications /Location | 15 | 125.04 | 513.19 | 6.41 | 1117.11 | 177.02 |
| Genotypes | 24 | 4782.24 ** | 1103.13 ** | 66.67 ** | 19924.83 ** | 2659.11 ** |
| Location x Genotype | 48 | 356.57 ** | 282.30 ** | 8.02 | 4511.65 ** | 742.41 ** |
| Error | 360 | 28.27 | 142.28 | 8.15 | 1356.03 | 201.98 |
| CV | | 4.93 | 23.13 | 15.98 | 22.24 | 29.38 |

*, ** indicate significance at $P \leq 0.05$ and $P \leq 0.01$, respectively

**Table 3**
Mean squares for variables of primary interest, and Nitrogen variables, at Pendleton in 1986.

| Source of Variation | df | Harvest Index | Grain Protein Concentration | Nitrogen Harvest Index | Chaff, Leaf, and Stem Nitrogen | Total Nitrogen in Plant |
|---|---|---|---|---|---|---|
| Genotypes | 24 | 142.92 ** | 7.09 ** | 0.08 ** | 17.33 ** | 1.05 ** |
| Error | 125 | 28.75 | 3.37 | 0.01 | 2.74 | 0.23 |
| CV (%) | | 20.69 | 13.28 | 22.39 | 30.22 | 20.69 |

*, ** indicate significance at $P \leq 0.05$ and $P \leq 0.01$, respectively

**Table 4**
Mean squares for agronomic traits at Pendleton in 1986.

| Source of Variation | df | Height | Tillers /Plot | Spikelets /Spike | Aboveground Biomass | Grain Weight (gm/plot) |
|---|---|---|---|---|---|---|
| Genotypes | 24 | 1517.25 ** | 487.01* * | 20.96 ** | 8268.95 ** | 1413.99 ** |
| Error | 125 | 39.88 | 119.92 | 2.30 | 1148.89 | 216.66 |
| CV (%) | | 5.32 | 20.43 | 7.98 | 18.31 | 29.72 |

*, ** indicate significance at $P \leq 0.05$ and $P \leq 0.01$, respectively

**Table 5**
Harvest indices for twenty-five winter wheat genotypes evaluated at Pendleton in 1986.

| Genotype | Harvest index (%) | |
|---|---|---|
| Chisolm | 32.42 | A |
| Centura | 31.29 | AB |
| Clement | 30.91 | ABC |
| Aurora | 30.58 | ABC |
| Jugoslavia | 30.50 | ABC |
| OR 8313 | 30.43 | ABC |
| Newton | 30.36 | ABC |
| Bezostaja | 29.67 | ABC |
| Hill 81 | 28.85 | ABC |
| Stephens | 27.74 | ABCD |
| Adam | 27.28 | ABCD |
| TAM 105 | 26.94 | ABCDE |
| Arkan | 26.91 | ABCDE |
| Wanser | 26.35 | ABCDE |
| Kharkov | 26.08 | BCDEF |
| Kavkaz | 26.08 | BCDEF |
| Hatton | 25.59 | BCDEF |
| Atlas 66 | 24.85 | CDEF |
| Bounty 1705 | 22.31 | DEF |
| Cheyenne | 20.97 | EFG |
| Daws | 20.93 | EFG |
| Jacmar | 20.89 | EFG |
| Yamhill | 20.01 | FG |
| Maris Marksman | 15.09 | G |
| Batum | 14.89 | G |

Means followed by the same letter are not significantly different at $P \leq 0.05$ by F-protected LSD tests.

**Table 6**
Grain protein concentration for twenty-five winter wheat genotypes evaluated at Pendleton in 1986.

| Genotype | Grain protein concentration | |
|---|---|---|
| Maris Marksman | 16.27 | A |
| Batum | 15.74 | AB |
| Yamhill | 15.50 | ABC |
| Adam | 15.27 | ABC |
| Bounty 1705 | 14.60 | ABCD |
| Jugoslavia | 14.47 | ABCD |
| Arkan | 14.29 | ABCD |
| Daws | 14.10 | ABCD |
| OR 8313 | 13.99 | ABCD |
| TAM 105 | 13.83 | BCD |
| Jacmar | 13.64 | BCD |
| Stephens | 13.60 | BCD |
| Aurora | 13.52 | BCD |
| Cheyenne | 13.44 | BCD |
| Bezostaja | 13.42 | BCD |
| Hatton | 13.25 | CD |
| Kavkaz | 13.14 | CD |
| Hill 81 | 13.10 | CD |
| Kharkov | 12.82 | D |
| Clement | 12.77 | D |
| Wanser | 12.71 | D |
| Atlas 66 | 12.71 | D |
| Newton | 12.56 | D |
| Chisolm | 12.32 | D |
| Centura | 12.29 | D |

Means followed by the same letter are not significantly different at $P \leq 0.05$ by F-protected LSD tests.

**Table 7**
Nitrogen harvest index for twenty-five winter wheat genotypes evaluated at Pendleton in 1986.

| Genotype | Nitrogen harvest index | |
|---|---|---|
| Centura | 0.65 | A |
| Chisolm | 0.62 | AB |
| Clement | 0.61 | ABC |
| Newton | 0.61 | ABCD |
| TAM 105 | 0.61 | ABCD |
| Jugoslavia | 0.60 | ABCD |
| Arkan | 0.60 | ABCD |
| OR 8313 | 0.58 | ABCD |
| Aurora | 0.58 | ABCDE |
| Hill 81 | 0.57 | ABCDE |
| Bezostaja | 0.56 | ABCDE |
| Kavkaz | 0.52 | ABCDEF |
| Adam | 0.52 | ABCDEF |
| Kharkov | 0.50 | BCDEF |
| Wanser | 0.49 | CDEFG |
| Atlas 66 | 0.49 | CDEFG |
| Stephens | 0.48 | DEFGH |
| Hatton | 0.45 | EFGHI |
| Cheyenne | 0.43 | FGHI |
| Bounty 1705 | 0.41 | FGHI |
| Jacmar | 0.38 | GHIJ |
| Yamhill | 0.36 | HIJ |
| Daws | 0.35 | IJ |
| Maris Marksman | 0.26 | JK |
| Batum | 0.21 | K |

Means followed by the same letter are not significantly different at $P \leq 0.05$ by F-protected LSD tests.

**Table 8**
Means, standard deviations and ranges for nitrogen related traits in wheat genotypes assigned to four classes. Pendleton location, 1986.

| Class | Harvest Index | Grain Protein Concentration | Nitrogen Harvest Index |
|---|---|---|---|
| Pacific Northwest Soft White | 23.68 ± 4.24<br>20.01 to 28.85 | 13.99 ± 0.92<br>13.10 to 15.50 | 0.43 ± 0.09<br>0.35 to 0.57 |
| European Red | 25.29 ± 5.49<br>15.09 to 30.91 | 14.48 ± 1.21<br>12.77 to 16.27 | 0.49 ± 0.12<br>0.26 to 0.61 |
| Great Plains Hard Red | 27.85 ± 3.90<br>20.97 to 32.42 | 13.08 ± 0.71<br>12.29 to 14.29 | 0.57 ± 0.08<br>0.43 to 0.65 |
| Pacific Northwest Hard Red | 24.32 ± 6.63<br>14.89 to 30.43 | 13.29 ± 1.32<br>12.71 to 15.74 | 0.43 ± 0.16<br>0.21 to 0.58 |

**Table 9**
Mean squares for variables of primary interest, and Nitrogen variables, at Moro in 1986.

| Source of Variation | df | Harvest Index | Grain Protein Concentration | Nitrogen Harvest Index | Chaff, Leaf, and Stem Nitrogen | Total Nitrogen in Plant |
|---|---|---|---|---|---|---|
| Genotypes | 24 | 93.85 ** | 8.83 * | 0.03 * | 4.31 ** | 0.39 ** |
| Error | 125 | 38.18 | 5.48 | 0.01 | 1.79 | 0.18 |
| CV (%) | | 25.34 | 16.99 | 22.41 | 31.63 | 36.93 |

*, ** indicate significance at $P \leq 0.05$ and $P \leq 0.01$, respectively

**Table 10**
Mean squares for agronomic traits at Moro in 1986.

| Source of Variation | df | Height | Tillers /Plot | Spikelets /Spike | Aboveground Biomass | Grain Weight (gm/plot) |
|---|---|---|---|---|---|---|
| Genotypes | 24 | 625.03 ** | 812.17 ** | 16.79 ** | 2782.21 ** | 279.50 ** |
| Error | 125 | 18.40 | 261.22 | 2.00 | 995.22 | 59.51 |
| CV (%) | | 4.99 | 32.39 | 8.85 | 30.22 | 31.15 |

*, ** indicate significance at $P \leq 0.05$ and $P \leq 0.01$, respectively

**Table 11**
Harvest indices for twenty-five winter wheat genotypes evaluated at Moro in 1986.

| Genotype | Harvest Index (%) | |
|---|---|---|
| Wanser | 31.75 | A |
| Chisolm | 30.22 | AB |
| Hill 81 | 29.20 | ABC |
| Daws | 29.08 | ABC |
| Hatton | 28.43 | ABCD |
| Maris Marksman | 27.19 | ABCDE |
| Centura | 27.12 | ABCDE |
| TAM 105 | 27.09 | ABCDE |
| Adam | 26.29 | ABCDEF |
| Bezostaja | 25.55 | ABCDEFG |
| Jugoslavia | 25.37 | ABCDEFG |
| Arkan | 25.21 | ABCDEFG |
| Clement | 24.99 | ABCDEFG |
| Aurora | 23.55 | BCDEFGH |
| OR 8313 | 23.50 | BCDEFGH |
| Stephens | 23.14 | CDEFGH |
| Cheyenne | 22.91 | CDEFGH |
| Yamhill | 22.79 | CDEFGH |
| Newton | 21.83 | DEFGH |
| Kavkaz | 21.07 | EFGH |
| Jacmar | 19.88 | FGH |
| Bounty 1705 | 19.56 | FGH |
| Kharkov | 19.02 | GH |
| Atlas 66 | 17.56 | H |
| Batum | 17.20 | H |

Means followed by the same letter are not significantly different at $P \leq 0.05$ by F-protected LSD tests.

**Table 12**
Grain protein concentration for twenty-five winter wheat genotypes evaluated at Moro in 1986.

| Genotype | Grain protein concentration | |
|---|---|---|
| Yamhill | 16.06 | A |
| Clement | 15.91 | AB |
| Batum | 15.29 | ABC |
| Adam | 14.97 | ABCD |
| Jacmar | 14.73 | ABCD |
| Kharkov | 14.56 | ABCDE |
| Stephens | 14.48 | ABCDEF |
| Aurora | 14.47 | ABCDEF |
| Bounty 1705 | 14.39 | ABCDEFG |
| Atlas 66 | 14.33 | ABCDEFG |
| Cheyenne | 14.25 | ABCDEFG |
| Maris Marksman | 14.24 | ABCDEFG |
| Kavkaz | 13.91 | ABCDEFG |
| Arkan | 13.87 | ABCDEFG |
| Jugoslavia | 13.55 | ABCDEFG |
| Newton | 13.41 | ABCDEFG |
| TAM 105 | 13.33 | BCDEFG |
| Hatton | 12.91 | CDEFG |
| OR 8313 | 12.87 | CDEFG |
| Wanser | 12.54 | DEFG |
| Centura | 12.41 | DEFG |
| Daws | 12.39 | DEFG |
| Bezostaja | 12.05 | EFG |
| Hill 81 | 11.82 | FG |
| Chisolm | 11.76 | G |

Means followed by the same letter are not significantly different at $P \leq 0.05$ by F-protected LSD tests.

**Table 13**
Nitrogen harvest index for twenty-five winter wheat genotypes evaluated at Moro in 1986.

| Genotype | Nitrogen Harvest Index | |
|---|---|---|
| TAM 105 | 0.65 | A |
| Chisolm | 0.64 | AB |
| Centura | 0.63 | AB |
| Hatton | 0.62 | AB |
| Hill 81 | 0.62 | AB |
| Yamhill | 0.60 | ABC |
| Wanser | 0.59 | ABC |
| Kavkaz | 0.58 | ABCD |
| Adam | 0.56 | ABCDE |
| Daws | 0.56 | ABCDE |
| Clement | 0.56 | ABCDE |
| Jugoslavia | 0.56 | ABCDE |
| Arkan | 0.55 | ABCDE |
| Bezostaja | 0.53 | ABCDEF |
| Aurora | 0.53 | ABCDEF |
| OR 8313 | 0.53 | ABCDEF |
| Cheyenne | 0.53 | ABCDEF |
| Newton | 0.52 | ABCDEF |
| Maris Marksman | 0.51 | BCDEFG |
| Stephens | 0.47 | CDEFG |
| Jacmar | 0.44 | DEFG |
| Kharkov | 0.44 | DEFG |
| Atlas 66 | 0.43 | EFG |
| Bounty 1705 | 0.40 | FG |
| Batum | 0.38 | G |

Means followed by the same letter are not significantly different at $P \leq 0.05$ by F-protected LSD tests.

**Table 14**
Means, standard deviations and ranges for nitrogen related traits in wheat genotypes assigned to four classes. Moro location, 1986.

| Class | Harvest Index | Grain Protein Concentration | Nitrogen Harvest Index |
|---|---|---|---|
| Pacific Northwest Soft White | 24.28 ± 4.52<br>19.88 to 29.20 | 13.90 ± 1.75<br>11.82 to 16.06 | 0.54 ± 0.08<br>0.44 to 0.62 |
| European Red | 23.15 ± 3.72<br>17.56 to 27.19 | 14.47 ± 0.77<br>13.55 to 15.91 | 0.54 ± 0.07<br>0.40 to 0.58 |
| Great Plains Hard Red | 24.77 ± 3.68<br>19.02 to 30.22 | 13.37 ± 1.32<br>11.76 to 14.56 | 0.57 ± 0.07<br>0.44 to 0.65 |
| Pacific Northwest Hard Red | 25.22 ± 6.33<br>17.20 to 31.75 | 13.40 ± 1.27<br>12.54 to 15.29 | 0.53 ± 0.11<br>0.38 to 0.62 |

**Table 15**
Mean squares for variables of primary interest, and Nitrogen variables, at Corvallis (hill plots) in 1986.

| Source of Variation | df | Harvest Index | Grain Protein Concentration | Nitrogen Harvest Index | Chaff, Leaf, and Stem Nitrogen | Total Nitrogen in Plant |
|---|---|---|---|---|---|---|
| Genotypes | 24 | 104.58 ** | 18.22 ** | 0.05 ** | 12.58 ** | 1.40 ** |
| Error | 125 | 15.11 | 1.95 | 0.00 | 1.05 | 0.41 |
| CV (%) | | 11.48 | 11.66 | 9.86 | 31.36 | 29.81 |

*, ** indicate significance at $P \leq 0.05$ and $P \leq 0.01$, respectively

**Table 16**
Mean Squares for agronomic traits at Corvallis (hill plots) in 1986.

| Source of Variation | df | Height | Tillers /Plot | Spikelets /Spike | Aboveground Biomass | Grain Weight (gm/plot) |
|---|---|---|---|---|---|---|
| Genotypes | 24 | 3353.10 ** | 386.56 ** | 44.96 ** | 17896.96 ** | 2450.43 ** |
| Error | 125 | 38.13 | 90.20 | 19.93 | 1895.32 | 326.78 |
| CV (%) | | 5.19 | 18.56 | 24.00 | 21.02 | 25.53 |

*, ** indicate significance at $P \leq 0.05$ and $P \leq 0.01$, respectively

**Table 17**
Harvest indices for twenty-five winter wheat genotypes evaluated at Corvallis (hill plots) in 1986.

| Genotype | Harvest index (%) | |
|---|---|---|
| Jugoslavia | 40.89 | A |
| Clement | 40.20 | AB |
| Stephens | 38.91 | ABC |
| Daws | 38.72 | ABCD |
| Hill 81 | 38.47 | ABCD |
| Hatton | 37.33 | ABCDE |
| OR8313 | 37.23 | ABCDE |
| Adam | 36.86 | ABCDE |
| Bezostaja | 36.42 | BCDEF |
| Chisolm | 35.58 | CDEFG |
| Centura | 34.58 | DEFGH |
| Kavkaz | 34.35 | DEFGH |
| Newton | 33.53 | EFGH |
| Cheyenne | 33.24 | EFGH |
| Wanser | 32.28 | FGH |
| Arkan | 32.25 | FGH |
| Kharkov | 32.18 | FGHI |
| Jacmar | 31.51 | GHIJ |
| TAM 105 | 31.48 | GHIJ |
| Bounty 1705 | 31.25 | GHIJ |
| Maris Marksman | 31.03 | HIJK |
| Atlas 66 | 27.80 | IJK |
| Yamhill | 27.42 | JK |
| Batum | 26.78 | K |
| Aurora | 26.59 | K |

Means followed by the same letter are not significantly different at $P \leq 0.05$ by F-protected LSD tests.

**Table 18**
Grain protein concentration for twenty-five winter wheat genotypes evaluated at Corvallis (hill plots) in 1986.

| Genotype | Grain protein concentration | |
|---|---|---|
| Arkan | 15.90 | A |
| Aurora | 15.70 | A |
| Yamhill | 15.06 | AB |
| Bounty 1705 | 13.53 | BC |
| Atlas 66 | 13.52 | BC |
| Jacmar | 12.96 | CD |
| TAM 105 | 12.93 | CDE |
| Maris Marksman | 12.92 | CDE |
| Batum | 12.64 | CDE |
| Kavkaz | 12.24 | CDEF |
| Stephens | 12.15 | CDEFG |
| Bezostaja | 11.81 | DEFGH |
| OR 8313 | 11.73 | DEFGH |
| Centura | 11.35 | EFGHI |
| Hill 81 | 10.80 | FGHI |
| Kharkov | 10.80 | FGHI |
| Adam | 10.73 | FGHI |
| Chisolm | 10.73 | FGHI |
| Jugoslavia | 10.59 | GHI |
| Newton | 10.56 | GHI |
| Daws | 10.48 | HI |
| Hatton | 10.46 | HI |
| Clement | 10.27 | HI |
| Cheyenne | 9.96 | I |
| Wanser | 9.92 | I |

Means followed by the same letter are not significantly different at $P \leq 0.05$ by F-protected LSD tests.

**Table 19**
Nitrogen harvest index for twenty-five winter wheat genotypes evaluated at Corvallis (hill plots) in 1986.

| Genotype | Nitrogen harvest index | |
|---|---|---|
| Jugoslavia | 0.78 | A |
| Clement | 0.77 | AB |
| Bezostaja | 0.76 | ABC |
| Chisolm | 0.75 | ABC |
| OR 8313 | 0.75 | ABC |
| Centura | 0.75 | ABC |
| Kavkaz | 0.74 | ABCD |
| Cheyenne | 0.74 | ABCD |
| Karkov | 0.73 | ABCD |
| Arkan | 0.73 | ABCD |
| Newton | 0.73 | ABCD |
| Hatton | 0.72 | ABCD |
| Aurora | 0.72 | ABCD |
| Adam | 0.72 | ABCD |
| Wanser | 0.70 | BCD |
| TAM 105 | 0.70 | BCD |
| Stephens | 0.69 | CD |
| Daws | 0.68 | CD |
| Hill 81 | 0.68 | CDE |
| Atlas 66 | 0.66 | DE |
| Bounty 1705 | 0.60 | EF |
| Jacmar | 0.55 | FG |
| Yamhill | 0.50 | GH |
| Maris Marksman | 0.50 | GH |
| Batum | 0.46 | H |

Means followed by the same letter are not significantly different at $P \leq 0.05$ by F-protected LSD tests.

**Table 20**
Means, standard deviations and ranges for nitrogen related traits in wheat genotypes assigned to four classes. Corvallis (hill plots) in 1986.

| Class | Harvest Index | Grain Protein Concentration | Nitrogen Harvest Index |
|---|---|---|---|
| Pacific Northwest Soft White | 35.01 ± 5.26<br>27.42 to 38.91 | 12.30 ± 1.84<br>10.48 to 15.06 | 0.61 ± 0.09<br>0.50 to 0.69 |
| European Red | 34.63 ± 3.94<br>27.80 to 40.89 | 12.30 ± 1.31<br>10.27 to 13.53 | 0.68 ± 0.13<br>0.50 to 0.78 |
| Great Plains Hard Red | 32.83 ± 3.52<br>31.48 to 35.58 | 11.75 ± 1.06<br>9.96 to 15.90 | 0.73 ± 0.02<br>0.70 to 0.75 |
| Pacific Northwest Hard Red | 33.41 ± 6.01<br>26.78 to 37.33 | 11.19 ± 1.21<br>9.92 to 12.64 | 0.66 ± 0.13<br>0.46 to 0.75 |

**Table 21**
Mean squares for variables of primary interest, and Nitrogen variables, at Corvallis (meter rows) in 1986.

| Source of Variation | df | Harvest Index | Grain Protein Concentration | Nitrogen Harvest Index | Chaff, Leaf, and Stem Nitrogen | Total Nitrogen in Plant |
|---|---|---|---|---|---|---|
| Genotypes | 24 | 137.50 ** | 11.33 ** | 0.02 ** | 1.19 ** | 0.53 |
| Error | 50 | 8.17 | 1.68 | 0.00 | 0.43 | 0.96 |
| CV (%) | | 8.84 | 11.47 | 8.07 | 24.97 | 21.9 |

*, ** indicate significance at $P \leq 0.05$ and $P \leq 0.01$, respectively

**Table 22**
Mean squares for agronomic traits at Corvallis (meter rows) in 1986.

| Source of Variation | df | Height | Tillers/ Plot | Spikelets /Spike | Aboveground Biomass | Grain Weight (gm/plot) |
|---|---|---|---|---|---|---|
| Genotypes | 24 | 1347.00 ** | 2237.46 ** | 16.66 ** | 4973.50 | 3579.21 ** |
| Error | 50 | 34.33 | 406.33 | 1.93 | 5512.51 | 867.72 |
| CV (%) | | 4.52 | 14.46 | 8.08 | 15.22 | 18.63 |

*, ** indicate significance at $P \leq 0.05$ and $P \leq 0.01$, respectively

**Table 23**
Harvest indices for twenty-five winter wheat genotypes evaluated at Corvallis (meter rows) in 1986.

| Genotype | Harvest index (%) | |
|---|---|---|
| Adam | 41.00 | A |
| Stephens | 40.66 | A |
| Daws | 40.21 | AB |
| Hill 81 | 39.63 | ABC |
| Maris Marksman | 39.40 | ABCD |
| Jugoslavia | 38.40 | ABCD |
| Jacmar | 37.83 | ABCDE |
| OR 8313 | 35.67 | BCDEFG |
| Clement | 35.56 | BCDEFG |
| Batum | 35.28 | CDEFG |
| Bounty 1705 | 34.91 | DEFGH |
| Yamhill | 34.76 | DEFGH |
| Chisolm | 34.68 | EFGH |
| Hatton | 33.68 | FGHI |
| Bezostaja | 31.85 | GHI |
| Kavkaz | 30.50 | HIJ |
| Wanser | 29.96 | IJ |
| Kharkov | 29.25 | IJK |
| Centura | 26.74 | JKL |
| Cheyenne | 26.74 | JKL |
| Newton | 25.94 | JKL |
| TAM 105 | 24.76 | KL |
| Aurora | 24.56 | L |
| Atlas 66 | 22.68 | L |
| Arkan | 13.86 | M |

Means followed by the same letter are not significantly different at $P \leq 0.05$ by F-protected LSD tests.

**Table 24**
Grain protein concentration for twenty-five wheat genotypes evaluated at Corvallis (meter rows) in 1986.

| Genotype | Grain protein concentration | |
|---|---|---|
| Arkan | 17.67 | A |
| Aurora | 14.06 | B |
| Newton | 13.66 | BC |
| Centura | 12.92 | BCD |
| Atlas 66 | 12.88 | BCD |
| TAM 105 | 12.64 | BCDE |
| Kavkaz | 12.48 | BCDE |
| Bezostaja | 11.69 | CDEF |
| Hatton | 11.53 | DEF |
| OR 8313 | 11.36 | DEFG |
| Yamhill | 11.27 | DEFG |
| Chisolm | 11.10 | DEFG |
| Cheyenne | 10.87 | DEFGH |
| Bounty 1705 | 10.68 | EFGH |
| Wanser | 10.55 | EFGH |
| Maris Marksman | 10.30 | FGH |
| Jugoslavia | 10.13 | FGH |
| Kharkov | 9.94 | FGH |
| Clement | 9.88 | FGH |
| Stephens | 9.78 | FGH |
| Adam | 9.67 | FGH |
| Jacmar | 9.63 | FGH |
| Batum | 9.58 | FGH |
| Daws | 9.29 | GH |
| Hill 81 | 8.82 | H |

Means followed by the same letter are not significantly different at $P \leq 0.05$ by F-protected LSD tests.

**Table 25**
Nitrogen harvest index for twenty-five winter wheat genotypes evaluated at Corvallis (meter rows) in 1986.

| Genotype | Nitrogen harvest index | |
|---|---|---|
| Jugoslavia | 0.78 | A |
| Stephens | 0.77 | AB |
| Adam | 0.76 | ABC |
| OR 8313 | 0.76 | ABCD |
| Chisolm | 0.75 | ABCD |
| Hatton | 0.75 | ABCD |
| Hill 81 | 0.75 | ABCD |
| Daws | 0.73 | ABCDE |
| Kharkov | 0.71 | ABCDEF |
| Bezostaja | 0.70 | ABCDEF |
| Wanser | 0.70 | ABCDEF |
| Jacmar | 0.69 | BCDEF |
| Yamhill | 0.68 | BCDEF |
| Kavkaz | 0.68 | BCDEF |
| Bounty 1705 | 0.68 | BCDEF |
| Centura | 0.68 | BCDEF |
| TAM 105 | 0.68 | CDEF |
| Cheyenne | 0.68 | CDEF |
| Maris Marksman | 0.67 | CDEF |
| Newton | 0.67 | DEF |
| Batum | 0.65 | EF |
| Atlas 66 | 0.63 | F |
| Aurora | 0.63 | F |
| Clement | 0.62 | F |
| Arkan | 0.40 | G |

Means followed by the same letter are not significantly different at $P \leq 0.05$ by F-protected LSD tests.

**Table 26**
Means, standard deviations and ranges for nitrogen related traits in wheat genotypes assigned to four classes. Corvallis location (meter rows), 1986.

| Class | Harvest Index | Grain Protein Concentration | Nitrogen Harvest Index |
|---|---|---|---|
| Pacific Northwest Soft White | 38.62 ± 5.41<br>34.76 to 40.66 | 9.76 ± 0.93<br>8.82 to 11.27 | 0.72 ± 0.04<br>0.68 to 0.77 |
| European Red | 34.64 ± 3.31<br>22.68 to 41.00 | 10.86 ± 1.29<br>9.67 to 12.88 | 0.69 ± 0.06<br>0.62 to 0.78 |
| Great Plains Hard Red | 26.01 ± 3.27<br>13.86 to 34.68 | 12.67 ± 2.56<br>9.94 to 17.67 | 0.65 ± 0.12<br>0.40 to 0.75 |
| Pacific Northwest Hard Red | 34.65 ± 2.36<br>29.96 to 35.67 | 10.75 ± 1.89<br>9.58 to 11.53 | 0.71 ± 0.05<br>0.65 to 0.76 |

**Table 27**
Phenotypic correlations among nitrogen and agronomic variables for twenty-five winter wheat genotypes evaluated in hill plots at Pendleton, Moro, and Corvallis in 1986.

| Variable | Pendleton | Moro | Corvallis |
|---|---|---|---|
| Harvest Index vs. | | | |
| Grain Weight | 0.82** | 0.37** | 0.56** |
| Aboveground Biomass | 0.47** | -0.28** | 0.18** |
| Grain N % | -0.67** | -0.56** | -0.48** |
| Chaff N % | -0.81** | -0.55** | -0.44** |
| NHI | -0.91** | 0.81** | 0.67** |
| Total Plant N | 0.05 | -0.30** | 0.08 |
| Grain Weight vs. | | | |
| Aboveground Biomass | 0.87** | 0.77** | 0.90** |
| Grain N % | -0.56** | -0.05 | -0.29** |
| Chaff N % | -0.67 | -0.08 | -0.43** |
| NHI | 0.73** | 0.25** | 0.54** |
| Total Plant N | 0.48** | 0.66** | 0.70** |
| Aboveground Biomass vs. | | | |
| Grain N % | -0.32** | 0.29** | -0.12 |
| Chaff N % | -0.42** | 0.28** | -0.33** |
| NHI | 0.42** | -0.29** | 0.34** |
| Total Plant N | 0.75** | 0.90** | 0.79** |
| Grain N % vs. | | | |
| Chaff N % | 0.68** | 0.61** | 0.53** |
| NHI | -0.62** | -0.45** | -0.41** |
| Total Plant N | 0.21** | 0.51** | 0.36** |
| Chaff N % vs. | | | |
| NHI | -0.92** | -0.86** | -0.92** |
| Total Plant N | 0.21** | 0.59** | 0.20* |
| NHI vs. | | | |
| Total Plant N | -0.10 | -0.44** | -0.05 |

*, ** indicate significance at $P \leq 0.05$ and $P \leq 0.01$, respectively.
For all correlations, N = 24

**Table 28**
Phenotypic correlations among nitrogen and agronomic variables for twenty-five winter wheat genotypes evaluated in meter rows at Corvallis in 1986.

| Variable | Corvallis |
|---|---|
| Harvest Index vs. | |
| Grain Weight | 0.85** |
| Aboveground Biomass | 0.08 |
| Grain N % | -0.75** |
| Chaff N % | -0.25 |
| NHI | 0.72** |
| Total Plant N | 0.14 |
| Grain Weight vs. | |
| Aboveground Biomass | 0.59** |
| Grain N % | -0.60** |
| Chaff N % | 0.26* |
| NHI | 0.66** |
| Total Plant N | 0.50** |
| Aboveground Biomass vs. | |
| Grain N % | -0.02 |
| Chaff N % | -0.16 |
| NHI | 0.20** |
| Total Plant N | 0.70** |
| Grain N % vs. | |
| Chaff N % | 0.48** |
| NHI | -0.59** |
| Total Plant N | 0.31** |
| Chaff N % vs. | |
| NHI | -0.79** |
| Total Plant N | 0.42 |
| NHI vs. | |
| Total Plant N | -0.06 |

*, ** indicate significance at $P \leq 0.05$ and $P \leq 0.01$, respectively.
For all correlations, N = 24

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# APPENDIX

**Appendix Table 1**

Wheat genotypes and area of origin

| Entry Name | Area of Origin |
|---|---|
| Adam | Europe |
| Arkan | Great Plains |
| Atlas 66 | Great Plains |
| Aurora | Europe |
| Batum | Pacific Northwest |
| Bezostaja | Europe |
| Bounty 1705 | Europe |
| Centura | Great Plains |
| Cheyenne | Great Plains |
| Chisolm | Great Plains |
| Clement | Europe |
| Daws | Pacific Northwest |
| Hatton | Pacific Northwest |
| Hill 81 | Pacific Northwest |
| Jacmar | Pacific Northwest |
| Jugoslavia | Europe |
| Kavkaz | Europe |
| Kharkov | Great Plains |
| Maris Marksman | Europe |
| Newton | Great Plains |
| OR 8313 | Pacific Northwest |
| Stephens | Pacific Northwest |
| TAM 105 | Great Plains |
| Wanser | Pacific Northwest |
| Yamhill | Pacific Northwest |

**Appendix Table 2**

Wheat genotype groupings according to kernel characteristics and area of origin.

| Variety/ Class | Kernel Classification | Wheat |
|---|---|---|
| Yamhill | Soft White | PNWSW |
| Jacmar | Soft White/club | PNWSW |
| Daws | Soft White | PNWSW |
| Stephens | Soft White | PNWSW |
| Hill 81 | Soft White | PNWSW |
| **PNWSW** = Pacific Northwest Soft White | | |
| Maris Marksman | Red | ER |
| Bounty 1705 | Red | ER |
| Kavkaz | Red | ER |
| Adam | Red | ER |
| Jugoslavia | Red | ER |
| Clement | Red | ER |
| Bezostaja | Red | ER |
| Aurora | Red | ER |
| **ESR** = European Red | | |
| Cheyenne | Hard Red | GPHR |
| Atlas 66 | Hard Red | GPHR |
| Kharkov | Hard Red | GPHR |
| Arkan | Hard Red | GPHR |
| TAM 105 | Hard Red | GPHR |
| Newton | Hard Red | GPHR |
| Centura | Hard Red | GPHR |
| Chisolm | Hard Red | GPHR |
| **GPHR** = Great Plains Hard Red | | |
| Batum(WA8616) | Hard Red | PNWHR |
| Hatton | Hard Red | PNWHR |
| Wanser | Hard Red | PNWHR |
| OR 8313 | Hard Red | PNWHR |
| **PNWHR** = Pacific Northwest Hard Red | | |

**Appendix Table 3**

Summary of climatic data at Pendleton, Moro, and Corvallis, Oregon for the 1985-86 crop year.

| Month | Pendleton Temp. (C) MAX | MIN | PPT (mm) | Moro Temp. (C) MAX | MIN | PPT (mm) | Corvallis Temp. (C) MAX | MIN | PPT (mm) |
|---|---|---|---|---|---|---|---|---|---|
| September | 20.8 | 4.3 | 39.1 | 19.0 | 5.2 | 28.2 | 22.0 | 7.6 | 19.8 |
| October | 16.8 | 1.5 | 34.0 | 14.7 | 2.3 | 29.0 | 17.6 | 4.7 | 98.8 |
| November | 1.8 | -8.6 | 67.6 | 0.8 | -7.3 | 30.2 | 7.1 | -0.2 | 119.1 |
| December | -3.6 | -10.7 | 32.3 | -4.3 | -10.7 | 28.4 | 4.5 | -3.6 | 94.5 |
| January | 6.0 | -2.4 | 60.5 | 3.7 | 3.0 | 46.7 | 9.7 | 2.1 | 165.9 |
| February | 7.7 | 0.5 | 77.2 | 5.8 | -1.4 | 60.7 | 10.0 | 3.0 | 251.5 |
| March | 14.7 | 3.2 | 49.3 | 12.7 | 2.6 | 24.9 | 15.6 | 5.3 | 77.2 |
| April | 15.9 | 1.7 | 21.1 | 13.2 | 1.7 | 8.6 | 15.1 | 4.1 | 46.7 |
| May | 20.8 | 6.0 | 47.5 | 19.3 | 7.1 | 8.9 | 18.7 | 6.9 | 63.5 |
| June | 29.7 | 9.9 | 2.3 | 26.4 | 10.9 | 1.5 | 25.2 | 10.6 | 7.9 |
| July | 28.2 | 9.6 | 15.5 | 24.1 | 10.5 | 13.7 | 24.6 | 10.0 | 29.2 |
| August | 33.9 | 11.4 | 4.8 | 30.7 | 13.9 | 1.8 | 30.6 | 11.3 | 0.0 |
| TOTAL (PPT) | | | 451.2 | | | 282.6 | | | 974.1 |