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Title: EFFECT OF NITROGEN FERTILIZATION OF WHEAT (*Triticum* spp.) ON CHEMICAL AND BIOCHEMICAL COMPOSITION AND PERFORMANCE OF SEEDS

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High protein wheat seeds frequently perform better than low protein seeds of the same variety. Protein content of seeds can be increased by management practices, the most important of which is rate and timing of N applications. The purpose of this study was to determine the chemical, biochemical and physiological changes that occur in seeds as a result of nitrogen fertilization, and to relate these changes to seed performance.

Seeds of Yamhill, Paha and Hyslop soft white winter wheat were produced with N applications of 0 to 450 kg/ha. Applications were made at planting, flower initiation, and anthesis. Supplemental irrigation was supplied.

Applications of 150 and 300 kg N/ha increased the grain yield and protein yield per hectare, seed size, and percent and amount of

protein per seed of Yamhill wheat.

N applications caused several biochemical changes in the food reserve of the seeds. These included increases in the amounts of gluten, each amino acid studied and free amino acids. The amount of soluble sugars decreased slightly and starch remained constant with high rates of N.

N also caused several biochemical changes in embryos. These included increases in: free amino acids and soluble sugars; protein concentrations and amount per embryo; ADP, ATP and energy charge. Regardless of protein concentration, the quantities of solubles and adenylate phosphates were higher in larger embryos.

Biochemical changes in seedlings associated with N applications and higher protein content included: more sugars and free amino acids; higher amounts of ATP, ADP and total AP; and faster rate and higher net translocation of food reserves.

Small seeds contained a higher concentration of ash, some mineral elements, soluble sugars and free amino acids. The total amount of these compounds per seed, however, was related to protein content and seed size.

The large seeds with high protein concentration produced seedlings with the highest ADP, ATP and total AP content, energy charge and growth potential.

Smaller seeds absorbed water and germinated faster than larger seeds. Seedlings from small seeds produced longer roots and shoots during the early stages of growth, but their growth rate was slower at later stages.

High protein seeds of Hyslop, Paha and Yamhill outyielded low protein seeds by 12 to 17%. Yield differences were obtained when N was added to the crop, but not in the absence of added N.

These and other studies indicate the potential for improving wheat seed and quality by applying specialized management practices for seed production rather than managing for grain production.

Effect of Nitrogen Fertilization of Wheat (*Triticum* spp.) on Chemical and Biochemical Composition and Performance of Seeds

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DEDICACION

Todas las horas de sacrificio
son dedicadas a mi familia
como invitación a seguir este
pequeño ejemplo de superación

TABLE OF CONTENTS

LIST OF FIGURES

Figure		Page

LIST OF TABLES

Appendix Table		Page

EFFECT OF NITROGEN FERTILIZATION OF WHEAT (*Triticum* spp.) ON CHEMICAL AND BIOCHEMICAL COMPOSITION AND PERFORMANCE OF SEEDS

INTRODUCTION

Wheat (*Triticum* spp.) is the most widely cultivated of all cereals and higher yields are of great importance in the continuing battle against world hunger. Increase in yields will be achieved through a combination of improved varieties and production practices. In the development of programs for producing more grain per hectare, all aspects of management need to be considered. Seed quality is one of these aspects.

The quality and quantity of food reserves is an important component of seed quality that contributes to plant vigor. Researchers at Michigan State University and Oregon State University have demonstrated that within a genotype, high protein seeds will produce more vigorous seedlings and sometimes higher yields.

The management practices that result in the highest quality seed may not necessarily be the same as those commonly used for grain production. When growing wheat for grain, the optimum N application is that which produces the maximum yield economically. Optimum N rates for seed production should be those that produce seeds with the highest quality substrates, good enzymatic and organellar machinery, and a high level of biosynthetic ability during germination.

The protein content of wheat can be increased with application of N in excess of that needed to satisfy yield requirements, and especially with late applications. Unfortunately, increases in protein are usually associated with lower yields and smaller seed size. This poses a problem as large seed size is also thought to be an important component of seed quality.

A better understanding of the effects of seed food reserves on subsequent plant growth is needed to determine the practices required to produce seed of the highest possible quality. The objectives of this study were to:

1. Determine the chemical, biochemical and physiological changes that occur in seeds and seedlings as a result of N fertilization of the mother plant, and
2. Relate these changes to the improved seed performance.

LITERATURE REVIEW

Effect of Fertilization and Other Cultural Practices on Seed Quality

Among the inorganic nutrients, nitrogen is considered to be the most important macronutrient in the nutrition of plants. Wheat is very sensitive to insufficient nitrogen and is very responsive to nitrogen fertilization according to Terman et al. (1969), Staicu and Bratu (1961), Sexsmith and Russell (1963), Barker and Stivers (1963), Hatfield (1961), Roberts et al. (1972), Rohle (1963), and others.

Nitrogen is taken up by roots, passes rapidly through the stem and is then incorporated into the grain proteins. Neals, Anderson and Wardlaw (1963) reported that increases in grain N after heading exceeded losses by leaves and stems during grain development, indicating the balance of grain N came from reduction of soil nitrogen absorbed by roots after anthesis. Leaf removal at anthesis reduced the N content of the culm and grain at maturity. Removing flag leaves decreased grain N at harvest in excess of that contained in the flag leaves at anthesis. From this, he considered three roles of the leaves in transfer of N to the grain: (a) While the leaves actively transpire and photosynthesize, uptake of N by the culm is promoted, (b) N taken up is reducted in the leaves via nitrate or nitrite reductase, and (c) leaves directly supply grain with N by mass transfer from the vegetative parts after heading.

Role of Translocation and Nitrate Reductase Activity on Protein Content

Mikessell and Paulsen (1971) studied the translocation of C^{14} labelled amino acids from culms to grain of high and low protein wheat lines during grain development. The accumulation was low initially after anthesis, increased at midmaturity, and decreased slightly at full maturity. They reported that total N content was similar in flag leaves and greater in lower leaves removed at anthesis from high protein wheat lines. Grain N content at maturity was greater in high protein wheat lines when no leaves were removed at anthesis. Removing flag leaf blades at anthesis had little effect on grain N content of low-protein wheat lines, but greatly decreased N content of high protein wheat lines. This indicated the importance of flag leaves in mobilizing and translocating vegetative N to the developing grain. Also flag leaf blades have been shown to maintain higher nitrate reductase activity than other leaf blades after anthesis (Harper and Paulsen, 1967). Mikessel and Paulsen concluded that grain protein in low-protein lines depended on translocation of N already present in lower leaves at anthesis. In contrast, high protein lines required continued assimilation of N by flag leaves after anthesis. However both continued assimilation by flag leaves and high translocation efficiency from lower leaves was necessary for maximum grain N content. Seth, Hebert and Middleton (1960) also found no difference in total N content of the vegetative parts of high and low protein wheat varieties prior to heading; but thereafter N increased more rapidly in the heads of high protein varieties, which now can be explained by Mikessel's results of efficient translocation. Recently Edwards, Frohberg and Deckard (1973) reported that in spring wheat, the ears contained 68 to 82% of the total plant N at harvest. Translocation efficacy was correlated significantly with grain protein yield but not with percent protein.

Efficient translocation alone cannot account for high protein content of seeds. Croy and Hageman (1970), studied the correlation of nitrate reductase activity (NRA) with water soluble leaf protein, grain and grain protein (percent and total) production arriving at the following major conclusions: a) Nitrate content of the tissue was a major factor in controlling the level of enzyme activity, b) nitrate reductase activity was related, though not numerically, to leaf protein content, c) induction of nitrate reductase on a field scale was achieved by supplemental N, d) increased enzyme activity from supplemental N treatments was associated with increase in grain protein (percent and total), e) a significant correlation was found between the spring seasonal total of NRA (units of N reduced per hectare) and grain protein (kg/ha), f) this correlation is valid only for a specified genotype as Ponca required a higher level of enzyme activity to accumulate a unit of grain protein than Monon, g) this observation suggested that Monon is more efficient in transporting reduced N from the vegetation to the grain than Ponca.

Edwards _et al._ (1973), working with spring wheat varieties and Samphantharak (1973), working with barley varieties, concluded that cultivars with high NRA also had a higher total protein (kg/ha). Samphantharak indicated that this was true in greenhouse and field experiments. Under field conditions, however, both high and low protein cultivars maintained similar percentages of N in leaf tissue at the booting stage. This led him to conclude that nitrate nitrogen levels in the leaf tissue had little effect on the amount of nitrate reductase activity.

Effect of Nitrogen Fertilization on Yield and Protein

Researchers recognized increases in yield as the main effect of N fertilization. Terman _et al._ (1969), in an irrigation - N rate experiement on hard red winter wheat over a 3-year period in Nebraska, found that the chief effect of applied N (one application of N) with adequate water supply was to increase yield; however when water deficits were present the entire effect was to increase protein content. Rohde (1963) found that N fertilization caused increases in the grain yield, number of culms per plot, plant height, and straw weight of winter wheat. None of the variables included in his study showed an effect on the calculated number of kernels per head. The effect on 100-kernel weight, heading date, test weight, and straw-grain ratio were variable. When Barber and Stivers (1963), applied N in the row in addition to P and K, they obtained large yield increases of wheat over those with P and K alone. Staicu and Bratu (1961) obtained superior yield in winter wheat with high quantities of ammonium nitrate and especially when applied in combination with P and K.

Other researchers have found an increase of both yield and protein as an effect of N fertilization (Subda, 1971; McGregor, 1961; Hunter, 1958; Schlehuber, 1959; and Williams, 1954). Hunter et al., working with pastry-type wheats, found that protein content was not raised to objectionably high values until more N was applied than that needed to produce maximum yield. He noticed that when applied N increased the yields significantly, protein increased at a lower rate; however for greater applications of N, protein content increased more rapidly than yield. In general, increased N increased test weights on farms where it also increased yields. Decreases in test weights occurred only on farms where increased N either decreased or had no effects on yield.

Baumeister (1939), working with pot experiments, found that with low N supply little grain was produced, but the grains were of large size and low in protein. More N increased yields, but the grain was lighter, higher in N, crude fiber and ash. Working with corn, McGregor et al. (1961) also found that N fertilization substantially increased yield and crude protein.

Recently Langer and Liew (1973), working with wheat grown in nutrient solutions applied 150 and 15 ppm N at three stages of development: between double ridge and floret initiation; at ear emergence; and after ear emergence. They found that spikelet numbers were increased only by raising N supply at the double ridge stage. Number of grains per spikelet also responded to treatment during the same period, but was greatest when high N was applied until ear emergence. Basal and terminal spikelets contributed least when N supply was low. Individual grain weight responded less to treatment than grain numbers. At low N, the basal spikelet contained no grain, the next two spikelets showed improved grain setting leading to three grains per spikelet in the middle of the ear, only to decline again near the apex. Raising N supply between floret initiation and ear emergence brought about a dramatic increase in basal spikelet positions, some improvement in the middle of the ear, but had little effect on upper spikelets; however, high N given still earlier, between double ridges and floret initiation, affected grain setting throughout the entire length of the ear, so that the first seven spikelets from the base contained at least four fertile florets each. They also observed that early N application increased area and longevity of leaves and late applications increased only longevity.

Contrasting with the former results, several workers reported no increase in yield or a negative relationship between yield and protein, when N was applied (Hojjati and Maleki, 1972; Hough et al., 1962, 1963; Lopez, 1972; and Solen, 1973). Hojjati and Maleki (1972) indicated that yield of grain was not affected by applications of 50 or 100 kg N/ha, but yield decreased at the 200 level. In their experiments, N stimulated vegetative growth much more than seed production. Under this condition, protein content of the grain was consistently increased by each additional increment of N at the rate of 1% for each addition of 50 kg N/ha. Solen (1973), working with four varieties of wheat, found a significant negative correlation between protein content and grain yield including some components of yield in Pendleton, Oregon. At the Pendleton site, where moisture became a limiting factor, the negative association resulted largely as the indirect effect of kernel weight on protein content. With the spring application of N, a delay in maturity for Hyslop and Yamhill was noted, which with the subsequent loss of moisture, resulted in shriveled grains. This resulted in Hyslop and Yamhill (low protein cultivars), having higher protein content than Atlas 66 and NB 68513 (high protein cultivars). These results are in agreement with data presented by Eck, Tucker and Schlehuber (1963) where N fertilizer delayed maturity.

Great number of researchers showed that N fertilization increases the protein content of wheat grain (Ewald and Wenzel, 1967; Coic *et al.*, 1963; Fernandez and Laird, 1959; Fitzgerald *et al.*, 1958; Guidy *et al.*, 1957; Lopez, 1972; Gunthardt and McGinnis, 1957; Lal and Prashad, 1952; Littler, 1961; McNeal *et al.*, 1971; Norden *et al.*, 1952; Ries, 1971; Thompson *et al.*, 1962; Wells and Keogh, 1963; Williams and Smith, 1954; Chang and Robertson, 1968; Eck *et al.*, 1963; Warder *et al.*, 1963; Roberts *et al.*, 1972) and others. Chang and Robertson (1968) found that seeds fertilized with 90 kg N/ha, contained 1.1-1.3 times as much Kjeldahl-N as did those from parents receiving no N. Williams (1954) found increased protein content as a result of N fertilizer alone or in combination with P and/or K. In other studies this tendency was most pronounced for the heavier applications of N fertilizer (Williams and Smith, 1954; Lopez, 1972; Littler, 1967; Fernandez and Laird, 1959).

Some researchers showed a decrease in protein content after a low N fertilization. Fernandez and Laird (1959), working with soil moisture and N fertilization, found a decrease of protein content of whole grain with small applications of N, but protein increased by large applications. The lower protein content of the grain from wheat fertilized with 50 kg N/ha than from unfertilized wheat was attributed to a greatly increased vegetative growth in the fertilized wheat. Protein content was lowest in the wettest treatment and highest in the driest treatment.

Roberts *et al.* (1972), in the Columbia Basin, found that added increments of fertilizer N in most cases produced increases in grain protein, although the initial small increments of applied N which resulted in marked yield increases caused a slight depression in the percentage of grain protein.

Effect of Type and Time of Nitrogen Fertilization on Seed Yield and Quality

Although a progressive increase in protein content is obtained by increased application of N, timing of N fertilization according to the developmental stage of the plant seems to be more important in increasing the protein content. Olsen and Rhoades (1953), in winter wheat in Nebraska, indicated that spring applications generally were slightly superior to fall applications from the standpoint of yield as well as protein content of the grain. The nitrate form of N generally was more effective than the ammonium form for spring broadcast. Hamid (1972) working with N^{15} labelled ammonium sulfate and sodium nitrate indicated that N was most effectively used when applied at tillering. In agreement with these results, Michael (1963), Williams and Smith (1954), and Spratt (1974) reported increased protein when N was applied at flowering stage; Spillane (1967), when fertilized at ear emergence; Gomez and De Datta (1973), at heading stage. Langer and Liew (1973), also showed that lateness of N applications increases percentage grain protein.

Several researchers applied N by the calendar. Davidson (1922), in Virginia, applied N on April 11, April 24, and May 14. The highest grain yields were obtained from the first date of application, with yields declining as time of application approached the heading stage. In his study, the later application gave greater increase in protein content of the grain. Long and Sherbakoff (1951) indicated increased protein content of wheat when fertilized on May 4, but yield was lowered by this practice. Hucklesby et al. (1971) reported that applications of 56 and 112 kg N/ha as KNO_3 on April 2, 23 and May 9; and 224 kg N/ha on April 23 to Arthur and Blueboy (soft red winter wheat) and Parker (hard red winter wheat) increased yield, grain protein and grain protein percent.

Researchers have also increased yield and protein by split applications of N. Long and Ewing (1949) found that a split application, with half of the N applied in the fall and the other half top dressed in the spring, produced the highest yield. Patrick (1971) obtained higher protein yield when all the N was applied at sowing or 50% at sowing and the remainder at the 2 mm panicle stage. In his study, grain yield was inversely related to protein percent.

Other researchers have successfully increased protein content of seeds by foliar sprays of N. Nerson and Karchi (1972), from a pot experiment, reported that foliar and soil top-dressing of liquid ammonium nitrate, applied 5-7 days prior to heading of the main culms, had an immediate effect but of short duration. It increased yields mainly by increasing the grain weight in the main spike; however soil applied was more effective in increasing yield and all yield components. Sadaphol and Das (1966) found that spraying the crop with urea (1-6%) solution increased yields, crude protein, and pure protein of the grain. They indicated that three sprays given at heading, blooming and after blooming were apparently much better for obtaining a very high increase in the protein content. Phosphorus content of the grain also increased from spraying urea. This is in agreement with Thorne's (1963) finding that application of N spray during the growth period was accompanied by a greater uptake of P by the roots.

Foliar application of N after heading results in a greater increase in protein content of grain than spraying before heading (Seth, 1963; Smith, 1964; and Finney *et al.*, 1957). Smith (1964) indicated that foliar sprays applied at flowering time gave the maximum benefits in terms of increased protein content. Foliar sprays 7 weeks before flowering increased protein only slightly but raised yields substantially. His results agree with Finney's *et al.* (1957) findings who reported significant increases in yield when urea was used as a foliar spray before flowering; however, one spraying of urea at flowering increased the protein content of the grain by 4.4%. They increased protein from 10.8% with no N, to 21% with 15 sprays of

56 kg/ha of N each applied between flowering and 32 days after flowering.

Foliar spray at bloom stage of sorghum resulted in 10-30% increase in percent protein of seeds (Krieg and Stevens, 1974). The yield decreased 10-30% mainly due to smaller seeds.

Pesticides, Herbicides and Growth Regulators

Nontoxic levels of some herbicides have been found to affect the protein content of seeds (Freeney, 1965; Ries *et al.*, 1970; Saghir and Bhatti, 1970; Tweedy *et al.*, 1971; Vergara *et al.*, 1970; Hill, 1964; Huffaker *et al.*, 1967; Michalczyk, 1972; and others). Ries *et al.* (1970) reported that subherbicidal applications of simazine and terbacil increased the protein content in all tests in Michigan and Mexico and also the yield in two tests. Increase in protein content of grain with addition of simazine may have occurred due to the reduction in yield caused by injury. Huffaker (1967), applying the isooctyl ester of 2, 4-D combined with Fe-DTPA (Fe-diethylene triamine pentaacetic acid) greatly increased the protein content of wheat. From the three formulations, isopropyl ester, isooctyl ester and the dimethylamine salt of 2, 4-D, the isooctyl ester had the greatest effect on the concentration of protein. Presence of Fe-DTPA with the isooctyl ester increased the concentration of protein even higher.

When sorghum plants were under N stress, Tweedy *et al.* (1971) found that simazine increased the grain yield and crude protein content. In rice, Vergara *et al.* (1971) reported that although simazine application to flooded soil at flowering time increased the percent protein, it was accompanied by a decrease in grain yield which was attributed to increased sterility. This resulted in a lower total grain protein production.

Hill (1964) reported that spraying cereals with 2, 4-D for weed control did not affect the protein percentage. Michalczyk (1972) decreased the protein content of spring barley by applications of 4 kg of atrazine or 2 kg of 2, 4-D/ha.

Working with soybeans, Saghir and Bhatti (1970) reported that pre-emergence application of diphenamid at 6 kg/ha resulted in a significant increase in the protein percentage of seeds produced and a reduction in the oil content and amount of unsaturation of the seeds. Linuron and propachlor reduced the protein values significantly. Post emergence application of chloroxuron, diphenamid, linuron and propachlor caused a reduction in the protein percentage, whereas the oil percentage remained unaffected. No effect was observed on the percentages of Ca and P as a result of herbicide treatments. Effect on yield was not reported.

Very recently fungicides have also been shown to affect the protein content. Benchat *et al.* (1974) treated peanut *Arachis* *hypogaea* L. with benomyl, chlorothalonil, copper-sulfur dust, and fungi-sperse. Significant differences were observed in the percent protein and oil content of the peanut kernels treated with benomyl and chlorothalonil as compared with the control. They reported that chlorothalonil-treated nuts matured slower.

Other Cultural Practices and Climatic Factors

The effect of planting density on protein content and seed quality has not been researched as extensively as the effect of fertilization. Siemans (1963) found that protein content of 'Selkirk' spring wheat increased from 15 to 18% as distance between rows was increased from 15 to 76 cm. He speculated that protein content in wheat grain may be expected to increase with wider row spacings regardless of variety. Demirlicakmak *et al.* (1963) found that rate of seeding had a significant influence on 1000-seed weight, the lowest rate producing the heaviest seeds.

A distinct climatic effect on the protein content and size of seeds has long been recognized. McNeal and Berg (1960) indicated that 'Thatcher' spring wheat seed lots from different sources had different protein contents and different bushel weights. Hough *et al.* (1963), working with N fertilization in Wyoming, found that protein content varied with location, and Woodman *et al.* (1972) indicated that variation between sites was more important than the effect of increase in applied N. Patrick (1974) indicated that protein content of rice varies widely from year to year.

Sites associated with low moisture as a yield limiting factor during seed development and maturity are associated with high protein seeds (Alsberg and Griffing, 1934; Day and Barmore, 1971; Botkin, 1935; and others). Alsberg and Griffing (1934) indicated that hot, dry weather, which retards starch deposition more severely than it does gluten formation, results in kernels high in gluten. Day and Barmore (1971) also indicated that moisture stress at the jointing, flowering and dough stages resulted in an increase in flour protein. Sosulski _et al._ (1963) increased protein content of 'Thatcher' wheat from 10 to 23% by controlling soil moisture and fertility levels.

Sites associated with enough moisture for seed development, on the other hand, are associated with high yields and low proteins. Ramig (1964) indicated that in a climate with considerable rainfall the protein content will be low and the yield high. Bayfield (1936) found rainfall to influence the amount of protein in wheat when it occurred during 10 to 15-day intervals during and just preceding the heading period. He observed that heavy soil texture was associated with increased percentages of wheat protein, and that darker and more fertile soils gave increased amounts of protein.

Generally the protein content tends to be high when wheat is grown in hot, dry climates. Waldron _et al._ (1942) indicated that in

North Dakota, high day temperatures from ten days before heading until about July 15 were conducive to high protein content in hard red spring wheat. The protein content was above 13% when the average July temperature was above 20 C, while it was above 12% when the July temperature averaged slightly above 18 C (preceded by a low June temperature). Schlehuber and Tucker (1959) rationalized that when moisture is limited there is not much vegetative growth, therefore more nitrogen is left for the production of grain. When yields are lowered by drought, the N is distributed among fewer bushels, resulting in the negative correlations of yield and protein. They also indicated that in hot, dry regions the N content of the soil and the rate of nitrification are in general higher than in humid areas, and there is less leaching, hence the supply of available N in the soil at seeding time is greater.

Variation in Protein Between and Within Spikes

Variations in protein content have been found between plants of the same cultivar (Stuber *et al.*, 1967) as well as within portions of individual spikes (Stuber *et al.*, 1962; Khadr, 1970; Altaf *et al.*, 1969; Staikov, 1964; and McNeal and Davis, 1966) and between central and lateral florets (McNeal and Davis, 1954).

Altaf *et al.* (1969) and Khadr (1970) found that grain from the bottom third of the spike had the highest protein content; on the other hand, Staikov (1964) found that grain in the middle part had a higher percentage of proteins. Altaf et al. and McNeal and Davis (1966) reported that grain from the top third of the spike had the lowest protein content. Earlier, McNeal and Davis (1954) reported that kernels from central florets of spring wheat were higher in protein than lateral florets.

Variation of Protein Content During Maturation

Ingle and Hageman (1965) illustrated elegantly the biochemical changes during corn seed maturation. They recognized two phases. First phase was characterized by accumulation of soluble constituents (soluble sugars, soluble N and amino acids and nucleotides) and by synthesis of proteins. During the second phase, there was a utilization of the soluble constituents with further increases in protein.

A short postfloral period favors a high protein percentage in wheat (Alsberg and Griffing, 1934; Johnson et al., 1967); in sorghum (Haikerwal and Mathieson, 1971); in legumes (Gassi et al., 1973); and in corn (Thornton et al., 1969).

When the protein is deposited in the kernel at a rapid rate relative to the starch early in the postfloral period, a high protein percentage is favored (Alsberg and Griffing, 1934). Johnson et al. (1967), working with different varieties of wheat found that N content of the grain first decreased from an initially high level, then increased during the last 3 weeks of grain maturation. In the high protein varieties the decrease was less pronounced and the subsequent increase more rapid than in the low protein varieties. In Nebraska, Kiesselback and Lyness (1954) harvested wheat in the early dough, late dough and mature stages with yields of 21. 7, 27. 6 and 30. 7 bushels/acre, respectively, with protein contents of 19. 4, 12. 8 and 13. 1 percent.

In sorghum, Haikerwal and Mathieson (1971) showed that earlier maturing varieties had higher protein contents. Thornton et al. (1969), working with corn demonstrated that as seeds matured, the concentration of crude protein, crude fiber and ash decreased, but the starch increased. The concentration of most minerals in the dry matter decreased as maturity advanced. Exceptions were sodium, iron, and molybdenum. All minerals were not simultaneously deposited in the kernel, and furthermore, when minerals were expressed as percent of ash they found that Ca and K were more completely deposited at the early milk and mid-dent stages.

Gassi et al. (1973), working with Pisum sativum, Lens culinaris, Cajanus cajan, and Cicer arietinum, found a high protein content in the early stages of maturity but there was gradual reduction in protein percentage as the seeds matured. He acknowledged that the synthesis and deposition of protein in the seed, which are important metabolic steps during the early phases of seed development, are very rapid and are probably completed much earlier than the deposition of carbohydrates and fats in the maturing seeds of legumes.

Effect of Lodging on Yield and Protein Content

Lodging results in great decreases in yield, test weight and kernel weight although seeds are of high protein percentage. The harmful effects of lodging are more severe when lodging is imposed at the heading stage than later (Weibel and Pendleton, 1964). These authors reported that lodging at heading, milk, soft-dough and hard-dough stages cut yields below the unlodged check by 31, 24, 20 and 12% respectively; however, the lodged plants gave grain with higher protein. Laude and Pauli (1956) indicated that the influence of lodging on the protein content of the grain suggested a restricted capacity to translocate nutrients or a restricted capacity to synthesize carbohydrates. This may be the reason why shriveled kernels were higher in protein content in studies by Haunold et al., 1962. Applications of high rates of N reduced yields of grain in dry weather, where earlier wilting on the high N plots led to production of shriveled seeds, or where heavy rains during ripening were followed by lodging on the high N plots (Barley, 1960-1961).

Effect of Fertilization on Test Weight, Seed Size, and Seed Color

Test weight is defined as the weight of grain that fills a given volume. It is the product of density and volume of grain occupying the container. The latter component when expressed as percentage of the volume of the container is referred to as packing efficiency and is a cultivar characteristic. Of the two components, packing efficiency has a greater effect on test weight when comparing soft winter wheats (Ghaderi et al., 1971). They also pointed out that kernel widths were correlated more than length with kernel volume. Hayfield (1936) indicated that test weight may increase with either increasing or decreasing protein content. The former occurs when normal well-filled kernels have increasing amounts of protein materials stored between the starch granules and the latter when carbohydrate synthesis is interfered with and the percentage crude protein becomes progressively greater as the kernels become more and more shrunken. Hunter et al. (1961) observed that the effects of N on test weights tended to parallel effects on yields. Generally on sites where yields were increased by N, test weights were also increased. Largest decreases in test weights occurred on sites where increased N reduced yields. On these sites, reduced yields were often accompanied by burning of foliage and shriveling of grain resulting from the early exhaustion of soil moisture supply. Similar results have been found by Klages and Watson (1958).

Several researchers have increased seed size by N applications (Ries, 1971; Zali et al., 1973; and Chang and Robertson, 1968), however only Zali et al. have reported an increase of both 100-seed weight and protein percentages with N applications. On the other hand, Lopez (1972), and Volke and Inostroza (1967) reported a decrease in seed size especially at increased N fertilization levels.

Variation in seed size between and within spikelets has also been reported by Staikov (1964), Tandon and Gulati (1966) and Walpole and Morgan (1973). Tandon and Gulati (1966) and Staikov (1964), reported that in barley the larger seeds arose from the central flowers.

Walpole and Morgan (1973) studied the effect of floret sterilization on grain weight of wheat ears. Sterilization of all florets in spikelets 2, 4, 6 and 8 (numbered from the base of the ear upwards) led to more grain setting and greater grain growth in the untreated spikelets. These compensatory increases were insufficient to prevent a depression in the yield of grain per ear. Sterilization of more than one of the basal florets of spikelet 8 led to a more frequent setting of the grain in the distal florets on that spikelet and to the centrally positioned grain becoming heavier. From this, they concluded that development of grain in some florets in wheat ears is inhibited by development of grain in other florets in the same or in other spikelets. As a consequence, the order in which florets are fertilized would be a critical factor in determining which florets of the ear are to be larger and heavier.

Physical appearance of durum and red wheats is a fair indication of their relative protein content; kernels having a distinctly horny or glutenous appearance being higher in protein than those of a more or less dull or starchy appearance. Baez (1971) reported that protein content was linearly related to the degree of yellow pigmentation of the kernel and with kernel calorific value. Grain yield was non-linearly correlated with grain protein content, but was linearly related to the degree of yellow pigmentation. Sadaphal and Das (1966) observed that mottling in wheat seeds was related to protein content of the grain. The percentage of mottled grains was very markedly reduced by spraying 1% urea, and was eliminated with 3% urea. Lipsett (1963), working with pot experiments with P, S, N and water as variables, reported that these treatments affected incidence of mottling in all varieties, and that vitreous grains generally had a higher N percentage than mottled grains. Feather and Ruckman (1971), working with samples from plots with various supplemental N rates up to 448 kg/ha showed that the frequency of yellow berry (amylaceous) was reduced to 10% in the early maturing cultivars INIA 66 and Sonora 64 through an application of 112 kg/ha N, and to less than 5% at higher N application rates. The later maturing

'Siete Cerros 66', and 'DG 301' contained more yellow berry at all fertility levels studied.

Phosphorus Fertilization and Seed Quality

The effect of P fertilizer on the composition of grain crops has not been researched to the same extent as the effect of N. Roberts et al. (1972) found a sharp increase in yield with each increment of soil-test P in the range below 20 ppm. They indicated very low probability of obtaining a response to P when the soil test value exceeded 20 ppm P. By contrast, when the soil test was 5 ppm or less there was a high probability of obtaining a response to P fertilization. Fertilization with P resulted in a marked increase in the concentration of P in the plants, particularly at the P-responsive sites. Even at the non-responsive sites, plant P at tillering was increased to some extent by the application of P fertilization.

Rennie (1956) found a reduced percentage of P in the wheat seed as N applications were increased. Grain grown on stubble land contained consistently higher percentages of P than that on fallow due conceivably to a deficiency of available N in the stubble land. In general, the effect of soil type or climate caused greater variations in percentage P in the grain than did fertilizer treatments. Boatwright and Viets (1966), working with spring wheat, reported that a supply of P for the first 5 weeks (up to heading) was adequate to produce a maximum grain production. Although P uptake occurred after wheat headed, this P was not utilized for dry matter or grain production. Khera et al. (1972), studying the effect of P on Indian soils, found an inferior quality of protein when available soil P levels were below 12.5 ppm; other researchers, including Schlehuber et al. (1963), found that quality of grain was depressed by P. On the other hand, Bennet et al. (1953) reported that quality was unaffected by P fertilization. Chang and Robertson (1968) reported that P fertilizers had little influence on seed size; but caused a significant reduction in percent Kjeldahl-N at two locations, a small increase at one location and no effect at two other locations.

Working with peas, Birecka et al. (1962) obtained seeds with different P content from mother plants which were given different doses of labelled P at the beginning of pod formation.

Potassium Fertilization and Seed Quality

The general effect of K is well summarized in the following statement made by Lamb (1967): Adequate K results in superior quality in the whole plant because of improved efficiency of photosynthesis, increased resistance to certain diseases, and greater efficiency in water use. It helps maintain a normal balance between carbohydrates and proteins, to some degree it balances excess N and results in stiffer straw and well filled grain in wheat. The increase in K levels during photosynthesis was highly significant in all cases (alfalfa and wheat) particularly in the presence of very high soil K levels, even though the phenomenon was not observed in the grain (Miller and Bauer, 1944). Working in the Columbia Basin of Oregon, Roberts et al. (1972) indicated that the critical soil test level below which K response is anticipated in wheat is 100 ppm.

Baumeister (1939), in a pot experiment with spring wheat, observed that grains from pots with little K were small, poor in starch but high in N and crude fiber; more K increased yields, weight of single grains and starch content. Berecks (1939) indicated that in barley and oats, deficiency in K halved the weight of single grains and reduced starch to one-third normal.

Finlayson et al. (1970), working with rape seeds found that additions of potassium sulfate to the soil increased the amount of protein deposited in mature seed and caused changes in the relative proportions of the N containing seed components. Poskura et al. (1970), working with fodder lupine seeds, also observed that K increased the protein content and decreased the alkaloid content in the seeds.

Effect of Other Inorganic Nutrients on Seed Quality

Saggar and Dev (1973) reported that S application to sorghum increased the contents of total N, protein N, total S, and soluble S of seeds. On the other hand, Mortenson and Baker (1973) found that an application of 70 or 140 kg/ha of S furnished by an ammonium phosphate-sulfate fertilizer caused a kernel color abnormality termed 'black kernel' in Jubilee sweet corn. The abnormality appeared associated with percent increase in nonprotein N of seeds.

Vander (1951), in several cereal crops, did not find any effect of P and N on the 100-seed weight except in extreme cases; however, both the 100-seed weight and the specific weight depended on the lime and potash levels of the soil. Kashirad (1970) studied the effect of N, zinc, copper and manganese fertilization on irrigated winter wheat on a calcareous silty clay soil with pH 8.2. The Cu, Zn and Mn content of the grain and the straw increased significantly after the application of these elements, especially when N was applied. Fuehring (1969) also worked with irrigated wheat on calcareous soil and found that K had a significant negative effect on Cu concentration, and that N had a significantly positive effect on Ca concentration. Beyer (1973) found that concentrations of Ca, Mg, K and P were not associated with seed size in sorghum.

Hewitt et al. (1954) reported that seed reserves of Mo were usually sufficient for a complete generation, but reserves of copper and zinc were not adequate. Suzalski (1969) increased Mo content of seeds of field beans, red clover, oats and flax by Mo fertilization. The high Mo content in field bean seeds improved plant development.

Field bean seeds containing 10 ppm Mo satisfied the Mo requirements of plants grown from them throughout their vegetative period; in addition, soaking red clover seeds for 2 hours in 2% ammonium molybdate solution raised their Mo content to 3940 ppm and increased plant yield.

Association of Protein Content and Seed Size with Physiological and Biochemical Quality Components of Seeds

The reserve materials of cereal grains can be divided into two categories (MacLeod, 1969): those which are present in the embryo and are immediately available for use by the growing seedling, and those which are stored in an insoluble form in the endosperm and must be hydrolyzed and translocated through the scutellum before they can be utilized.

Effect of N Fertilization on the Relative Changes of Storage Protein

In wheat, enhanced protein content following increased N fertilizer application is mainly accounted for by an increase in gluten content (Abrol, 1971). Within the storage protein (gluten), the prolamin and glutelin components are increased by N fertilization (Abrol, 1971; Ewald and Wenzel, 1967; Michael, 1963). Ewald and Wenzel reported that protein fractionation studies in wheat showed that most of the increase was in the prolamin and glutelin fractions, which rose by 27 and 15% respectively. Abrol (1971) reported an increase in the relative proportion of prolamin and glutelin while cytoplasmic proteins, albumin and globulin, were not changed appreciably by increasing fertilizer levels. Michael (1963) reported that N fertilization near blossoming time will increase the protein content of the grain. The proteins that increased were mainly the prolamin and the glutelin of the flour, and only to a lesser degree, the globulin and albumin of the alourone layer. Through N fertilization, the composition of these proteins remain constant, only the total quantity of protein and the relative proportion of the individual proteins will be changed.

Morton and Raison (1964) found that the storage and soluble proteins of wheat endosperm are synthesized by independent systems. Localization of enzymes and RNA associated with the initial stages of protein synthesis in protein body and supernatant preparations of wheat endosperm implicated independent synthesis of storage and cytoplasmic proteins (Morton et al., 1964). Smith (1973), working with peas, reported that RNA synthesis increases several days after the increase in DNA has begun and at the same time accumulation of reserve protein and starch begins. RNA and starch synthesis apparently cease sometime before maturation but protein synthesis continues until the seeds are ripe.

Effect of N Fertilization on the Embryonic Protein

Changes in the protein content of the embryo have not been researched to the same extent as changes in endosperm protein. Lowe and Ries (1973) reported that there was no difference in the weight or protein content of embryos from low and high protein seeds. Lopez (1972) reported that neither the protein content of the embryo, nor embryo size were affected significantly by the rate of N application. Although the difference in protein content in the embryo was not considerable, there was a trend towards higher concentration of protein in the embryo as the N fertilization increased both in 'Nugains' winter wheat and 'Casbon' winter barley

Alterations in the Amino Acid Content

Alterations in the amino acid content are attributable to changes in the proportion of different types of protein within the total protein complex (McDermott and Pace, 1960; Abrol, 1971; and Michael, 1963). Michael (1963) reported that N fertilization changes the relative proportion of individual proteins. This causes reduction in the biological value of the grain protein in barley and wheat as the increased reserve proteins (mainly prolamin) are poor in lysine. Abrol (1971) reported that the protein increase from N fertilization is due mostly to increase in the endosperm proteins prolamin and glutelin which are rich in glutamic acid, proline, leucine, and phenylalanine, and deficient in lysine, threonine, valine, isoleucine and tyrosine. Coic et al. (1963), Hepburn and Bradley (1965), Larsen and Nielsen (1966), Patrick et al. (1974), Pessi et al. (1971), Schiller (1971), Sosulski et al. (1966), and Waggle et al. (1967) also reported an increase in glutamic acid and proline as protein content of seed increased. In addition to these amino acids, Coic et al., Hepburn and Bradley (1965) and Waggle et al. (1967) reported an increase in phenylalanine. Patrick et al. (1974) also reported an increase in aspartic acid, valine and tyrosine and Waggle et al. (1967) reported an increase in alanine, leucine and isoleucine.

Other amino acids change inversely as the protein content of the seed increases: Several researchers reported a decrease in lysine as the protein content of the seed increased (Coic et al., 1963; Sosulski et al., 1966; Waggle et al., 1967; Parson and Nielsen, 1966; Pessi et al., 1971; Schiller, 1971; Chemeleva et al., 1972; Sawhney and Naik, 1969; Hojjati and Maleki, 1972; Subda, 1971; Gunthardt and McGinnis, 1957; Woodham et al., 1972; and Patrick et al., 1974; and others). Increases in alanine, asparagine, cysteine and glycine with N application have been shown by Schiller (1971) and Sosulski et al. (1966); arginine by Sosulski et al. (1966) and Larsen and Nielsen (1966), and Waggle et al. (1967). In addition, Waggle et al. (1967) reported a decrease in threonine, and Patrick et al. (1974) reported a decrease in histidine and leucine.

In contrast to these results, Hucklesby *et al.* (1971), McGregor *et al.* (1961), and Pleshkov and Savitskalte (1966) reported no change in amino acid composition with increasing protein content of seeds. Only Hojjati and Maleki (1972) in wheat, and Keeney (1969) in corn, reported an increase of lysine percentage in the protein due to K fertilization, especially at the lowest or zero level of N fertilization. Sims and Jackson (1973) reported that early applications of N had little effect or decreased the amount of lysine, methionine, arginine and histidine in the grain of winter wheat. When N was applied at booting and flowering stages, however, the amounts of these amino acids were increased.

Haikerwal and Mathieson (1971), working with sorghum, reported that the embryo contained the highest proportion of protein followed in order by the whole kernel, endosperm and pericarp. They also reported that the embryo had more lysine, histidine, arginine, glycine, aspartic acid, threonine and valine than the whole kernel.

Maturity and Amino Acid Changes

Thornton *et al.* (1969) reported that the concentration of each amino acid expressed as percent of corn dry matter, decreased as corn increased in maturity. When expressed as a percent of the crude protein, histidine, serine, glutamic acid, proline, leucine, and phenylalanine increased; lysine, aspartic acid, alanine, and tyrosine decreased; and arginine, threonine, glycine, cystine, valine, methionine, and isoleucine did not show consistent changes as the corn matured. The total weight of each amino acid per seed increased at each succeeding stage of maturity. Their data illustrated that no amino acid was completely deposited in the kernel before maturity was reached. Gassi et al. (1973) reported that total methionine content remained almost at the same level during maturation.

Alterations in Free Amino Acids

Free amino acids are readily used for metabolism (MacLeod, 1969) and are more plentifully distributed in the embryo than in the remainder of the grain.

In wheat, few or no differences were found in the concentration of free amino acids between varieties or crop years (Hoseney and Finney, 1967); however the number and concentration of free amino acids decreased strikingly during wheat maturation. The amount of free amino acids per kernel of wheat rose to a maximum at about physiological maturity and then declined to a minimum when combine ripe. Several nonprotein amino acids were found at the earliest stages of maturity. In barley, application of 4 kg of atrazine or 2 kg of 2, 4-D/ha increased the contents of free amino acids (Michalczyk, 1972).

Cruz _et al._ (1970), working with rice, reported that the maximal level of free amino-nitrogen and the capacity of the developing grain to incorporate amino acids were consistently higher in the samples with high protein content in the mature grain.

Finlayson _et al._ (1970) found a low free amino acid content of unfertilized rape seeds; but the addition of ammonium nitrate or phosphate to the soil caused an increase in the amounts of free amino acids. When all N, P, K and S were present, free amino acids were reduced.

Alterations in Starch and Soluble Sugars

Nitrogen fertilization has been reported to lower the starch content of seeds. Scheck and Fetzer (1950) found that N fertilization decreased the starch content of barley from 76.86% to 61.3% and in wheat from 69.34 to 64.55% by N fertilization. Pots with little K were small and poor in starch but high in protein and crude fiber; more K increased yields and weight of single grains and starch content.

Parental N fertilization increased the percent free sugars and decreased the percent residual available carbohydrates and total available carbohydrates of barley seeds (Chang and Robertson, 1968). The same researchers showed that large seeds contained 1.6-2.3 times as much total available carbohydrates in seeds from unfertilized or N and P fertilized parents. Beyer (1973) also found that starch concentration was directly related to seed size of both yellow and red endosperm type sorghum.

Content of Adenosine Phosphates and Adenylate Energy Charge

Atkinson (1968) has pointed out that the energy status of the cell is best expressed in terms of the extent to which the adenosine triphosphate (ATP), adenosine diphosphate (ADP), adenosine monophosphate (AMP) system is "filled" with high-energy phosphate bonds. If all the adenine nucleotide in the cell is ATP, the system is completely filled and is considered to have an energy charge of 1.0. At the other extreme, if all the adenine nucleotide is present as AMP, the system is empty of high-energy bonds and has an energy charge of 0.0. Working with *Escherichia coli*, Chapman, Fall and Atkinson (1971) reported that growth can occur only at energy charge values greater than about 0.8, and that viability is maintained at values between 0.8 and 0.5.

Recently Ching and Ching (1972) in ponderosa pine (*Pinus ponderosa* Laws) seeds and Ching and Kronstad (1972) in wheat reported that the content of adenosine phosphates of germinating seeds reflects growth, organogenesis and morphogenesis. In ponderosa pine, oscillating increases of adenosine phosphates occurred before the emergence of radicle and cotyledons during which the highest mitotic index prevailed in all tissues. In wheat, the dynamic synthesis and utilization of adenosine triphosphate in embryos and seedlings of a fast growing wheat cultivar 'Yamhill,' resulted in a higher overall energy level and energy charge than that of slower growing 'Hyslop' seedlings. Synthesis and utilization of adenosine phosphates (AP) were more dynamic in 'Yamhill' embryos and seedlings than those of 'Hyslop' during a 48-hr experimental growth period under optimum conditions. In dry seeds the embryo of both varieties contained about 150 picomoles of ADP, and about 20 picomoles each of ATP and AMP.

Adenosine phosphate content and energy charge has been found associated with seed weight (Ching, 1973; Ching and Danielson, 1972; and Abernethy et al., 1973). Ching (1973) reported good correlation of ATP content and seed weight or seedling size in crimson clover seeds (proteinaceous), rape seeds (fatty), and ryegrass seeds (starchy). Ching and Danielson (1972), working with 28 lots of nine cultivars of lettuce, reported a highly significant correlation between adenosine triphosphate (ATP) content in 4-hour-imbibed seeds and seed weight and seedling height. In blue panicgrass (Panicum antidotale Retz), Abernethy et al. (1973) reported that heavy seed weight selections exhibited 26% greater mean energy charge than the light weight-seeded selections.

The high energy status of larger seeds is indicative of more competent mitochondria. Mitochondria have been observed in electron micrographs of dry seeds of many species by Ching (1972), and they become active instantly upon hydration. McDaniel (1969), working with barley, reported that seedling fresh weight, seedling mitochondrial protein and mitochondrial biochemical activity are positively correlated with seed weight. The increased quantity of mitochondrial protein of seedlings produced from heavy seeds is indicative of a higher respiratory rate and greater amount of energy (ATP) production. Thus these seedlings have a greater growth potential than seedlings produced from lighter seeds of the same pure line (McDaniel, 1969).

Effect of Seed Size and Protein Content on Seed Performance

Moisture Uptake

Rates of water absorption differ with different strains, seed lots, and age and size of the seed as indicated by Keller and Bleak (1970) in crested wheatgrass (*Agropyron desertorum*) and fairway wheatgrass (*A. cristatum*). Their results indicated that the largest seed imbibed water at a slow rate between 0 and 90 hours of soaking, whereas the smallest seed had the fastest absorption during the first 40 hrs. In wheat, Lopez (1972) reported that rates of water absorption of germinating barley and wheat seed increased as a result of the high protein content (his high protein seeds were of smaller size, howeveer). In corn, Dungan (1924) found that the low protein corn (6.10%) absorbed water faster than high protein seeds (15.29%). He concluded that high protein levels in the endosperm gave it a hard vitreous texture, which could contribute to its low absorptive rate.

Speed of Germination, Germination and Emergence

Effect of Fertilization

Scheck and Fetzer (1950) reported that seed which has ripened in dry, hot climates showed greater germination ability than seeds of the same variety grown under moist conditions. He increased the germination of 'Taca' winter wheat from 35 to 60-72% by increasing protein content from 13.19 to 13.44-14.10%. Kamal (1953) reported that high protein wheat seed had highest germination, medium protein had intermediate, and low protein seed had the lowest germination in the germinator, in the flats and in the field. They did not identify whether the difference was due to deterioration or dormancy. The difference was less pronounced in the field. Alten and Schulte (1942) reported that speed of germination of cereals was dependent on the fertilizer treatment of the mother plant but showed no apparent connection between their contents of N, P and K and their speed of germination. They reported that in wheat and rye, plots receiving N and P produced seed which germinated more slowly than N, P and K fertilized seed with greater speed of germination than those receiving N alone. Semeniuk (1964) reported that low levels of N produced seed which gave a germination of 88%, but when N, P and K were at higher levels, the seed had a germination of 67%.

Effect of Seed Size

Speed of emergence has been reported to be affected by seed size. Scott et al. (1957) reported that immature wheat seed germinated rapidly. Chang and Robertson (1968), reported that time to emergence was virtually the same for large and small seeds of barley. Kneebone and Cremer (1955) reported that seedlings from larger seeds of several grass species emerged faster.

Kittock and Law (1968) reported that, in wheat, germination and emergence were positively correlated with seed weight for five seed size classes. Chambers (1963), however, reported no significant difference between the germination of pinched (99%), small (91%), and large grain (95%) in wheat 9 months after harvest. Emergence, on the other hand, was considerably less for pinched (73%) and small seeds (72%) than for large seeds (86%).

Edward and Hartwig (1971) worked with three nearly isogenic lines of soybean seed weighing 9.5, 13.6 and 22.6 grs/100 seeds. When planted in soil with moisture contents of 20, 22.5, 25, 27.5, and 30%, the small and medium seed size gave more rapid emergence and greater root development than the large seed at each soil moisture level where germination occurred. All size classes showed excellent emergence at 30% moisture, with the small-seeded line showing the greatest hypocotyl development. Radwan *et al.* (1972), working with four seed sizes in 32 commercial lots of 'Fahl' berseem clover (*Trifolium alexandrinum* L.), reported that both laboratory germination and seedling emergence from soil in the greenhouse were significantly influenced by seed source and seed size. Hanumaiah and Andrews (1973) reported that small turnip seeds were significantly lower in standard germination. Also both small and small-medium seeds were significantly lower in final stand establishment as compared to large seeds. In cabbage, however, all seed sizes performed equally in final stand.

Germination Under Moisture Stress

Parmar and Moore (1968) used Carbowax 6000, manitol and sodium chloride for simulating drought in corn of strong and weak vigor. Increasing the osmotic pressure had a greater effect on germination of seed lots with low vigor than on seed lots with high vigor, and more effect on shoot elongation than on primary root elongation. Wiggans and Gardner (1959) reported that progressively increasing concentrations of glucose, sucrose and D-manitol solutions decreased the germination percentage and radicle elongation of radish and sorghum seed. Increasing concentrations progressively delayed germination, but total germination percentage was not appreciably reduced. In safflower, Sionet et al. (1973) reported that cultivars differed in the rate of germination due to osmotic effects of the media.

Working with wheat, Lindstrom and Koehler (1973) reported that soil water potential variation exerted only a slight influence on emergence rate until the potential dropped below -4 bars, but markedly reduced emergence rate occurred as the potential decreased below this value. Kaufman and Ross (1970), working with lettuce and wheat in soil and solute systems, reported that germination was reduced by a decrease in water potential.

Hadas (1970) studied soil moisture potential, soil moisture diffusivity, water diffusivity of the seed, and the seed-soil interface characteristics. He found that even at low moisture content, the soil can supply water to the germinating seed at a rate equal to or higher than the capacity of the seed to absorb it. The amount of water absorbed by the seed and the rate of germination depended on the internal potential adaptability of the seed and on the actual moisture potential at the seed-soil interphase. Harper and Benton (1966) studied the behavior of seeds on the surface of a water supplying substrate and reported that seeds with smooth testas showed a graded response to tension, small seeds being less and large seeds more sensitive. Results of their experiments were interpreted in terms of the area of contact made between seed and substrate, and degree of exposure of the seed to the atmosphere.

Rate of Endosperm Utilization

Bremmer et al. (1963) reported that the rate at which wheat endosperm was used depended on the amount present and the seedling growth rate which tended to be increased from the larger endosperm. After endosperm exhaustion, all relative growth rates were similar. Cooper and McDonald (1970) studied the rate of endosperm utilization of corn in light and dark conditions. They reported that endosperm utilization and growth rates were similar in light and dark until the two-leaf stage (10 days after germination). Therefore, most of the energy was supplied by the endosperm until the 10th day, even under light conditions.

Coleoptile Length and Strength

Many of the short-statured wheat varieties tend to emerge slower than tall varieties and many often lack the necessary seedling vigor to survive if planted too deep, since the coleoptile may cease to grow while still beneath the soil surface. Feather et al. (1968) determined the relative emergence of short-statured wheat varieties at various planting depths in the greenhouse. Although all varieties emerged well at the 1-inch depth, all were affected by a 3-inch depth. A highly significant correlation between coleoptile length and plant length for 24 varieties was reported.

Inouye et al. (1970), working with naked barley, reported that an effect of increased seed size on coleoptile strength was observed at all temperature conditions (10-30 C). In intermediate wheatgrass (*Agropyron intermedium*), seed size, coleoptile length, emergence and seedling height varied widely, but all were positively correlated.

Effect of Protein Content of Seeds on Seedling Vigor and Yield

Lopez (1972) reported that high protein seeds of wheat and barley developed into larger seedlings with a higher dry matter content when grown in N deficient soil. Lowe and Ries (1972) showed a significant positive correlation between seed protein content and dry matter after 3 weeks of growth. They also reported that seedlings grown from high protein seeds were more advanced in morphological development than seedlings grown from low protein seeds. Lowe and Ries (1973) reported that seedling dry weight was positively related to the protein content of the aleurone layer and endosperm, but not to the embryo. This conclusion was reached because 35-mg high protein seeds (4. 7 mg protein/seed) produced larger seedlings than large 45-mg low protein seeds (4. 3 mg protein/seed). The same researchers transferred embryos from high protein seeds to low protein seeds and vice versa. They reported that high protein endosperm produced more vigorous seedlings regardless of the embryo type grown on it. This indicated that the factor(s) responsible for the greater growth of high protein seeds is in the endosperm. Lowe et al. (1972) reported that the mole percent of glutamic acid was positively related to seedling growth, but several other amino acids were found to be negatively correlated. Amino acid analysis did not prove to give a better estimate of seedling vigor or yield than N analysis.

Ries et al. (1970) reported that increases in seed protein due to both herbicide and N applications were reflected in higher yields the next generation. Yield was directly correlated with seed protein content, but not with seed size. In one test in Mexico, the effect of protein on the next generation was eliminated by 120 kg N/ha applied at time of planting. On an average, seed from the high N plots yielded 12% more than that from the low N plots. Schweizer and Ries (1969) also reported that seedling growth of wheat and both seedling growth and yield of oats were highly correlated with protein content of the seed planted. Ries and Everson (1973) reported that both environment and genotype affected the protein content of wheat seed, but regardless of genotype or environment, seedling vigor (dry weight of shoots) was consistently related to seed protein content. In this study seedling vigor was also related to seed size, but when seed size was eliminated as a factor by using uniformly sized seed, the seed protein content and vigor relationships were significant. They also reported that vigor was more closely associated with protein content per seed when Hoagland solution contained 3 mM nitrate than none.

Ries (1971) reported that seedling size, yield and number of fruit were more highly correlated with protein per seed than with seed size in beans.

Effect of Phosphorus Content of Seeds on Seedling Vigor and Yield

Seeds with high P content have been shown to perform better than low P content seeds, especially under P deficient substrate (Austin, 1966a; Austin, 1966b; Birecka *et al.*, 1962; Iwata and Eguchi, 1958; and Szukalski, 1962).

Austin (1966a) grew watercress (*Rorippa nasturtium aquaticum*) seeds of 0.47, 0.84 and 0.95% P, under conditions of P deficiency. Seven to 9 week old plants from .95%-seed were larger than those from 0.84%, which in turn were larger than those from 0.47% seed, but such differences were not measurable when plants were mature at 16 to 20 weeks. No difference was present when cultures were adequately supplied with P. Szukalski (1962) reported an advantageous effect of a large P content in oat seeds upon development and yield when P fertilization was delayed and on soil poor in P.

Birecka et al. (1962) reported that growth of pea plants derived from seeds of higher P content (2.5 mg P_2O_5/seed) was greater than that of plants from seeds of lower P (1.8 mg P_2O_5/seed). He also reported higher P content in the vegetative parts of plants grown from P-rich seeds and attributed this to the greater amount of P transported from the cotyledons. In greenhouse experiments with peas, Austin (1966b) reported lower haulm weights and pea yields from sowings of low P seeds as compared with high-P seed when the plants were grown in cultures deficient in P. In cultures not deficient in P, there were no such differences. In field experiments carried out on a fertile soil, low-P seeds gave 20 to 25% lower yields of both haulms and peas. Working with Chinese cabbage, Iwata and Eguchi (1958) reported that seeds from cabbage plants deficient in P were smaller and that their radicle growth was slower than that of seed from plants not deficient in P.

Effect of Seed Size on Seedling Vigor and Yield

Seedling Vigor. Several researchers have demonstrated that larger seeds in wheat produced more vigorous seedlings. Kittock and Law (1968) reported that emergence, shoot weight and seed weight were positively correlated for five seed size classes. Bremmer et al. (1963) reported that plant weight was reduced in plants from seeds with small endosperm but not from those with small embryos. During the first 6 days of growth, small embryos had a higher relative growth rate than large ones, thereafter until the exhaustion of reserves growth was related to the amount of reserve material present. Christian and Gray (1935) showed that plants grown from large seed had an advantage when grown in competition with those grown from small seed of the same variety. Voronin et al. (1969) showed that large, medium and small seeds of spring wheat produced 6, 5 and 4 seminal roots, respectively.

Similar results have been reported in barley. Kaufmann (1958) reported that seedlings were more vigorous when grown from large than from small or medium-sized kernels of the same variety. Chang and Robertson (1968) reported that large seeds produced taller plants with broader leaves. Kaufmann and Guitard (1967) reported that in greenhouse tests with two varieties, large seeds were superior to those grown from small in rate of seedling growth, plant height and size of the first two leaves. Differences in rate of growth were more pronounced when plants were grown on vermiculite than when grown in soil, but even less difference was observed when grown in vermiculite with a complete nutrient solution. From this they concluded that increasing nutrient content of the substrate reduces dependence of the seedling on the nutrients available from the seed.

Parallel results have been demonstrated for other gramineae species such as corn, sorghum and small seeded grasses. Cooper and McDonald (1970) reported that partial removal of the corn endosperm at seeding resulted in decreased growth of roots and shoots and decreased leaf area per seedling. Beyer (1973) reported that no effect of seed size was evident in germination or emergence of sorghum, but small seeds had a greatly reduced growth rate up to 17 days post emergence. In blue panicgrass (Panicum antidotale) Abernethy et al. (1973) reported that heavy seed weight selections exhibited greater dry matter production. In other grasses, Kneebone and Cremer (1955) showed that the larger the seed within a lot, the more vigorous were the seedlings produced.

Seedling growth is also affected by seed size in legumes. Black (1956, 1957 and 1958), working with Trifolium subterraneum, showed that the area of the cotyledons produced by seeds of different sizes decreased with increasing depth of sowing and with decreasing seed size. Cotyledon weight after emergence essentially paralleled the size of the seed sown. In berseem clover (T. alexandrinum), Radwan et al. (1972) showed that early seedling growth was significantly affected by seed size. They attributed the difference to an initial advantage in photosynthetic area maintained for 55 days from planting. At 55 days, seedlings from large seed had about 30% more leaf area than those from small seed.

Seed sizes also affects seedling vigor in horticultural crops, Ching and Danielson (1972) found a direct correlation between seed size and seedling vigor in lettuce. Scaife and Jones (1970), working with the same species under uniform conditions and in the absence of inter-plant competition, found a linear relationship between the fresh weight of the plant top at harvest and the weight of the seed sown. Hanumaiah and Andrews (1973) reported that growth and vigor of seedlings of both cabbage and turnips increased as seed size increased. In cabbage, yield was not significantly increased as seed size increased, but large turnip seeds always produced superior plants, particularly through the first 80-103 days after planting.

Seed size effects have also been recognized in oily seeds. Harper and Obeid (1967) working with flax, and Edward and Hartwig (1971) working with soybeans, demonstrated that in early seedling development, both the leaf area and dry weight were closely related to seed size. Taller plants were obtained from the larger seeds.

Yield. Seed size has been shown to influence yield of wheat. Pinthus and Osher (1966) worked with large and small seeds taken in equal numbers from individual spikes of three common wheat, three durum wheat and three 6-rowed barley cultivars at a constant planting density. The plants grown from large seed produced 24% more grain which was due, almost equally, to a greater number of spikes per plant and a greater number of kernels per spike. Geiszler and Hoag (1967) separated a certified lot of 'Selkirk' into large and small seeds; the fractions were further separated into light and heavy seeds using a gravity table. Seeds which were large and well filled produced highest yields in the field. Morrison et al. (1973) reported that in 'Nugains' wheat, large seeds yielded 74 bushels compared to 70 bushels for medium and 63 bushels for small seeds.

In barley, higher yields have been reported for larger seeds. Tandon and Gulati (1966) reported that larger seeds which arose from the central flowers produced taller, earlier maturing plants giving higher yields, more tillers and a higher 1000-seed weight than did the smaller seeds. Demirlicakmak et al. (1963), working with three seed sizes and three seeding rates of each of three barley varieties, reported that culm counts and yields were highest for large seed and lowest for small seed over all rates, varieties, and tests. The differences between yields of large and small seed decreased slightly as the seeding rate increased. On the average, large seed yielded 3.9% more than medium seed and 12.6% more than small seed. Higher yields from large seeds have also been reported by Kaufman and McFadden (1963), in barley; Vlach (1964), in winter wheat and spring barley; and Voronin et al. (1969), in spring wheat, barley and sorghum.

Das Gupta and Christensen (1971), working with seed lots of hard red 'Manitou' spring wheat obtained from farmer's fields in Saskatchewan, reported that grain yields obtained from the different seed lots varied significantly. Yield was correlated positively with bushel weight, percent germination under cool temperature, and stand. Positive correlations were also obtained with 1000-seed weight and seedling dry weight.

Other researchers have reported no yield response or negative responses to seed size, especially when the same weight of seeds was planted per unit area. McNeal and Berg (1966), working with 'Thatcher' spring wheat from different sources of different protein contents and bushel weights, reported no difference in yielding ability. Rothman and Bowman (1967), working with winter oat seed lots that ranged in test weight from 28.3 to 46.3 kg/hl, reported that no significant differences in yield were obtained when three rates of seeding were used. Srivastava and Nigam (1973) reported that seed size did not have a significant effect on yield of spring wheat when uniform seeding rate of 100 kg/ha was used.

MATERIALS AND METHODS

Experiments were conducted to determine the effect of N fertilization on quality components of wheat seeds; the association of seed chemical and biochemical components with protein content and seed size; and the effect of protein content and seed size on germination, and plant performance in the greenhouse and field.

Description of Soil and Cultivars

Soil Conditions

Field studies were conducted at the Hyslop Crop Science Field Laboratory on a Woodburn silt loam with good drainage. The field had been in green fallow the year prior to planting. A soil analysis showed pH, 5.2; P, 98 ppm; K, 250 ppm and N, 1185 ppm.

Cultivars

Yamhill (*Triticum aestivum*) is a mid-tall, stiff-strawed, awnleted, high yielding soft white common winter wheat. It is resistant to stripe rust and mildew. The kernels are white, midlong, soft, and ovate to oval. The embryo is small to midsize, crease midwide to wide and middeep, cheeks rounded and the brush large and midlong. It has an average protein content of about 8.7%. Developed by Dr. W. Kronstad at Oregon State University.

Hyslop (*T. aestivum*) is a semidwarf, stiff strawed, high yielding soft white common winter wheat. It is resistant to stripe rust, leaf rust, mildew, smut and Septoria. The kernels are white, midlong, soft and eliptical. The germ is midsize with narrow and shallow crease, with rounded cheeks. A large, midlong brush is present. It has an average protein content of about 8.2%. Developed by Dr. W. Kronstad at Oregon State University.

Paha (*T. compactum*) is a midtall, soft white winter club wheat. It is resistant to stripe rust, smut and *Cercosporella* foot rot. Susceptible to flag smut. The kernels are white, short, soft and ovate. The germ is small, crease midwide and shallow, cheeks rounded and bursh midsize. It has an average protein content of about 7.7%. Developed by Dr. R. E. Allan, USDA, Washington State University.

Seed Production

Seed Production of 'Yamhill' under N, P and K Fertilization

The effect of N, P and K fertilization rates on seed quality of 'Yamhill' was studied. Nitrogen rates consisted of 0, 150, 300 and 450 kg/ha. Phosphorus of 0, 45 and 90 kg/ha; and K of 0, 80, 160 kg/ha. The combination of these N, P and K rates gave 36 treatments, which were arranged as a factorial experiment in a randomized block design with three replications.

N fertilization consisted of split applications according to the developmental stages of plants as follows:

Fall, 1972 at planting October, 2nd week	Winter, 1973 at flower initiation March, 2nd week	Spring, 1973 at anthesis May, 3rd week	Total
	kg/ha		
0	0	0	0
25	62.5	62.5	150
25	137.5	137.5	300
25	212.5	212.5	450

Fall applied N (as urea, 46% N), all P (as superphosphate, 20% P_2O_5) and all K (as muriate of potash, 52% K_2O), were uniformly hand broadcast in each 7.5 m^2 plot (2.5 m x 3 m) and disc-incorporated in the top 8-10 cm of soil before planting. Then foundation seeds were planted at a depth of 2.5-3.0 cm at the rate of 85 kg/ha with a commercial grain drill at a 17.5 cm row spacing. After planting, a 2-inch irrigation was provided by sprinkler irrigation.

For weed control, diuron (Karmex, 80%) was applied post emergence at the rate of 725 g/ha (active ingredient), in 120 liters of water with a ground sprayer. Winter and spring applications of N (as ammonium nitrate, 34% N) were uniformly hand broadcast.

After the spring application of N, a 1-inch irrigation was provided to incorporate it in the root zone. An additional 2-inch irrigation was applied in early June 1973 to provide good soil moisture during seed development.

Seeds were hand harvested in late July 1973. Only the middle 2.0 m^2 (1.0 m x 2.0 m) were harvested from each plot. After the bundles were threshed, the seeds were cleaned and weighed, and seeds from the three replications of each fertilizer treatment were bulked. These seeds were identified as Yamhill Lot A and were used for most of the seed quality studies.

Seed Production of 'Yamhill,' 'Hyslop' and 'Paha' under N Fertilization

This study was done to obtain seeds with different protein content in other high yielding cultivars.

Foundation seed of 'Yamhill,' 'Hyslop' and 'Paha' were planted on the third week of November. Duplicate 7.5 m^2 plots were planted to harvest the middle 2.0 m^2. N fertilization treatments consisted of 0, 150 and 450 kg/ha in split applications. No P and K was applied. Rate of planting, weed control, irrigation and harvesting were followed like in 'Yamhill' under N, P and K fertilization.

The effect of these treatments on yield was not evaluated. These seeds were used to study seed size, protein content, chemical composition and yielding ability. Yamhill from this experiment was identified as Yamhill Lot B.

Effect of Fertilization on Yield and Agronomic Quality Components of Seeds

Physical Characteristics of Seeds

Seed Size. Seed size was estimated by determining the 100-seed weight on four samples of 100 air-dried seeds. Results from the 36 NPK combinations were analyzed as a factorial arrangement of treatments.

Seed Size and Weight Distribution. Seeds from each of the 36 NPK combinations were sized into different width categories with a laboratory tester screen shaken by an electric vibrator. Round holes were used since more sizes could be obtained than with available slotted holes (seed thickness) and indented disc or cylinder (seed length). The percentages of seeds held between the following screen sizes were recorded: over 11 (largest seeds), 10 1/2-11, 10-10 1/2, 9 1/2-10, 9-9 1/2, 8 1/2-9, 8-8 1/2, and 6 1/2-8/64 of an inch (smallest seeds). The separation was repeated three times. Four samples of 100 seeds from each width category were also weighed.

Shriveled Seeds. Percent shriveled seeds (by number) were also determined for each seed size within each N fertilization level.

Shriveled seeds were recognized because they do not have the normal well-rounded cheeks and plump shape of typical 'Yamhill.'

Seed Color. The percentage (by number) of amylaceous and dark vitreous seeds were determined within each of the four N fertilization levels. Some seeds showed a mottled surface and these were included in the white amylaceous group. The percentage of these seeds was also determined in each of the seed size classes from the non-N fertilized plots.

Protein Content of Seeds

Protein determinations were done for the highest and lowest level of P and K within each N fertilization level, seeds of different sizes from plots fertilized with 0 and 450 kg N/ha, and white amylaceous and dark vitreous seeds from the non-N fertilized plots. Whole seeds were ground to pass a 40 mesh screen and analyzed for total nitrogen by the Micro-Kjeldahl method. The percent crude protein was determined by multiplying the % N by 6.25.

Ash and Mineral Content of Seeds

Whole seeds were ground to pass a 40 mesh screen, weighed into porcelain crucibles and ashed at 450 C for 6 hours. Five ml of an internal standard buffer solution (0.2% cobalt and 0.5% lithium in HCl) were added to the remaining ash. The resulting solution was analyzed by the Horticultural Plant Analysis Laboratory, OSU, where it was subjected to a 30-second burning on the spectrometer, and each element analyzed by emission spectroscopy (Chaplin, 1974).

Association of Protein Content and Seed Size with Physiological and Biochemical Quality Components of Seeds

Protein Content of Embryos

Seeds from each of the four N rates were placed in tap water at room temperature. After 2 hours, the water was discarded and 0.5 g of embryos were dissected. Embryos were dried at 100 C for 24 hours, ground and total N analyzed by the Micro-Kjeldahl method. The percent crude protein was determined by multiplying % N by 6.25.

Embryo size was determined by weighing four samples of 100 oven-dry embryos from each of the four N fertilization levels.

Amino Acid Composition of Seeds

Whole wheat seeds were pulverized. A 100-mg sample of oven-dried meal was hydrolyzed in 100 ml of 6 N HCl, with 20 hour refluxing. The hydrolysate was centrifuged at 10,000 g for 10 minutes and the supernatant was sent to the Department of Biochemistry, OSU, where amino acids were analyzed using a Beckman Analyzer (Moore *et al*, 1958).

Free Amino Acid, Soluble Sugar and Starch Content of Seeds

Sample Preparation. Determinations were made on large (10 1/2-11), medium (9-9 1/2), small (6 1/2-8/64 inch width) and unsized seeds within high (16. 75%) and low (8. 62%) protein seeds. Two samples of 500 mg of oven-dried wheat meal were homogenized in 85% ethanol for 10 minutes. The homogenate was filtrated with the aid of vaccum through a double layer of Whatman No. 1 filter paper. Extraction was repeated twice. The residue was dried at 80 C for 24 hours and weighed.

Starch Determination. Two samples of 200 mg of ethanol extracted dry residue were digested with 20 ml . 2 N sulfuric acid and refluxed for 60 minutes. The hot mixture was filtrated through Whatman No. 42 filter paper and the residue was washed with 20 ml hot distilled water. Filtrate and wash were combined and volume brought to 100 ml. The quantity of hydrolyzed product, sugar, was determined colorimetrically by the Anthrone method (Ching, 1974).

Soluble Sugars. The filtrate from alcohol extraction was evaporated to dryness in a rotary vacuum evaporator at 70 C, then 10 ml distilled water added. The aqueous extract was filtrated with the aid of vacuum through a thin mat of celite to remove soluble proteins and lipids. The filtrate was purified through a column containing 10 g of washed Dowex 50 W-X4 (cation exchanger). The charged column was washed with 20 ml distilled water. The effluent and wash were combined and their anions were removed by a column containing 5 g of washed Dowex 1-X4 (anion exchanger). An aliquot from the neutral effluent was used for soluble sugar determination by the Anthrone method (Ching, 1974).

Free Amino Acids. Free amino acids retained in the first column (Dowex 50W-X4) were eluted with 50 ml 2N ammonium hydroxide. The eluate was evaporated to dryness to remove ammonia and the evaporation was repeated after adding 2 ml distilled water. Then 5 ml distilled water was added to dissolve the residue. An aliquot was used for free amino acid determination by the Modified Moore-Stein method (Ching, 1974).

Adenylate Energy Status and Energy Charge

Determinations were made on the largest (10 1/2-11) and smallest (6 1/2-8/64 inch) seeds within high (16.75%) and low (8.62%) protein seeds. Seeds were disinfected in 1.0% sodium hypoclorite for 5 minutes and rinsed in distilled water, then planted between germination blotters in 24 x 16.5 x 3.8 cm plastic boxes. The seeds were then incubated in a dark germination chamber at 20 C. Embryos or seedlings were removed every 24 hours from planting. Embryos for the zero time were removed from dry seeds. Two samples of ten embryos each were used for zero time and four seedlings were used from germinating seeds 1, 2, 3, 4 and 5 days after planting. Dissection was carried out in a moist chamber.

Adenosine phosphates from each replicate were extracted in 10 ml distilled boiling water for 10 minutes. The extract was cooled in an ice bath and a .5 ml aliquot of extract was diluted with 4.5 ml buffer containing 0.025 M HEPES-Mg Acetate, pH. 7.5. Adenosine monophosphate (AMP) and adenosine diphosphate (ADP) were converted to ATP first, and then adenosine triphosphate (ATP) and resulting ATPs from AMP and ADP were determined by the luciferin-luciferase method (Ching and Ching, 1972).

Energy charge (EC) was calculated by Atkinson's formula:

$$EC = \frac{[ATP] + \frac{1}{2}[ADP]}{[AMP] + [ADP] + [ATP]}$$

Free Amino Acid and Soluble Sugars of Seedlings

An aliquot of the boiling water extract used for ATP determination was also used to determine soluble sugars and free amino acids. Sugars were determined by the Anthrone method and free amino acids by the modified Moore-Stein method.

Effect of Protein Content and Seed Size on Seed Performance

Water Uptake

Moisture Imbibition. Determinations were made on the largest (10 1/2-11) and smallest (6 1/2-8/64 inch) seeds within high (16.75%) and low (8.62%) protein levels. Forty samples of about 1 g of seeds from each type of seed were prepared. Each sample was weighed before placing between germination blotters. Two samples from each treatment were weighed every two hours for 40 hours. Moisture uptake as percent of initial weight was calculated as follows:

$$\text{Percent moisture uptake} = \frac{\text{Weight after imbibition}}{\text{Weight before imbibition}} \times 100$$

Moisture Equilibration. The effect of seed protein content on equilibrium moisture content at 15, 45 and 75% relative humidity (R. H.) was studied. Unsized seeds of high (16.75%) and low (8.62%) protein were placed in porous wire baskets over a layer of cheesecloth. Seeds were placed in layers about 1 cm thick. The baskets were suspended inside sealed humidity chambers containing saturated concentration of different salts to produce desired relative humidities (Winston and Bates, 1960). Salts used were LiCl, KNO_2, and $NaClO_3$ to give 15, 45 and 75% R. H., respectively. The equilibrium chambers were placed at 20 C during the study. Seeds were sampled after 2, 3, 4 and 8 weeks to determine the percent moisture content. Moisture was determined on a wet weight basis after drying at 100 C for 24 hours.

Germination

Speed of Germination in Laboratory Germination Media. Seeds of seven size classes plus unsized seeds within high (16.75%) and low (8.62%) protein were used. Three samples of 50 seeds each were planted between wet blotters and placed at 20 C. Percent radicle protrusion was determined 45, 47, 50, 53, 56, 60, 68 and 75 hours after planting.

Speed of Germination under Moisture Stress. Large (10 1/2-11), small (6 1/2-8/64 inch width) and unsized seeds within high (16.75%) and low (8.62%) protein were placed to germinate at several osmotic concentrations. The osmotic pressures in germination media were obtained by using different concentrations of polyethylene glycol-1000[1] (Jackson, 1962) as follows:

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[1]Polyethylene glycol-1000, obtained from J. T. Baker Chemical Co.

Polyethylene Glycol-1000 Percent	Osmotic Pressure Atmospheres
16.6	10
18.3	12
19.9	14
21.2	16
23.5	20

Three samples of 50 seeds each were planted between blotters and placed at 20 C. Percent radicle protrusion was evaluated daily for 11 days.

Food Reserve Translocation from Endosperm to Developing Seedling

The effect of seven seed sizes and high (16.75%) and low (8.62%) protein on reserve food translocation was studied. Disinfected seeds were planted between germination blotters in 24 x 16.5 x 3.8 cm plastic boxes and placed at 20 C in complete darkness. Two samples of 10 germinating seedlings from each treatment were removed every day, then seedlings were separated into cayopses and root-shoot axes, and each fraction was dried at 100 C for 24 hours. Each fraction was weighed and the percent of weight distribution was calculated according to the following formula.

$$\text{Reserve translocated, } \% = \frac{\text{Dry weight of root-shoot axes}}{\text{Dry weight of axes + caryopses}} \times 100$$

Emergence and Coleoptile Length

Seeds of seven sizes within four protein levels were planted in the greenhouse for emergence studies. Three samples of 50 seeds each were planted at 2, 6 and 12 cm depths in gallon cans. Day temperature of the greenhouse ranged from 20-25 C. Cans were irrigated every day. Seedling emergence was counted daily. Results were analyzed as a factorial arrangement of treatments.

Coleoptile lengths of ten seedlings from each replication from the 12 cm planting depth were measured. Seedlings were recovered by screening the soil and washing in tap water.

Seedling Growth in Germination Towels

The effect of protein content and seed size on root and shoot growth rate was studied. Disinfected seeds were planted in laboratory germination towels at 20 C. Two samples of 20 seeds were placed in line in the upper part of germination towels to provide enough room for root growth. Towels were covered with plastic sheets to avoid moisture loss. Initial root and shoot length was measured 3 days after planting and final measurement was made after 10 days for roots and 16 days for shoots.

Seedling Growth in the Greenhouse

Effect of Protein Content. Greenhouse experiments were conducted to study the effect of four seed protein levels on plant growth. Four samples of 25 seeds were planted 2 cm deep in sand in gallon cans. Immediately after emergence the seedlings were thinned to 20. Plants were irrigated with complete Hoagland's nutrient solution (Appendix Table 14) every other day. The sand was flushed with tap water the days when nutrient solution was not used. Temperature of the greenhouse room ranged between 20-25 C, and daylength was 12 hours. Treatments were set up in a randomized block design and results were analyzed as a factorial arrangement of treatments.

Growth measurements were made 2 and 3 weeks after planting. Length and width of first leaf, plant height (measured to the top of the majority of leaves), and fresh and dry weight of shoots were evaluated. Roots from each treatment were recovered by screening out the sand and washing in tap water. Shoots and roots were dried at 100 C for 24 hours and weighed.

Effect of Proteins and Sizes. The effect of seed sizes within high (16. 75%) and low (8. 62%) protein seeds was studied under complete Hoagland and Hoagland-N. Planting, thinning, watering, and room temperature and daylength were similar to the former experiment.

Growth measurements were made 2 and 3 weeks after planting. Length and width of first leaf, plant height, fresh and dry weight of shoots, and dry weight of roots were measured. Results were analyzed as a factorial arrangement of treatments. Only plant height, and fresh and dry weight of shoots were evaluated for plants irrigated with Hoagland-N. These results were not analyzed statistically.

Yield

The effect of seed protein content on yielding ability at two N fertilization rates was studied at the Hyslop Agronomic Crop Science Field Laboratory during the 1973-74 crop year. Nitrogen rates consisted of 0 and 120 kg N/ha. N was split with 20 kg N/ha at planting and 100 kg N/ha at the time of flower initiation. Within each N level, the experiment was arranted in a split-plot with cultivars in main plot and seed protein content in the sub-plot. Seeds of Yamhill Lot A and B, Hyslop and Paha were planted on the second week of October at a rate of 22 seeds per square foot (about 85 kg/ha), with a belt type hand planter. The plots were 4. 5 m long, each with four rows 30. 5 cm apart, with border rows for each main plot.

In late July 1974, the middle 3 m of all four rows were harvested with a plot combine. Seeds were cleaned and weighed. Seeds averaged 9% moisture at weighing time.

The effect of seed protein on yield was analyzed separately within each N rate and averages were compared by Tukey's Test (Honestly Significant Difference).

RESULTS AND DISCUSSION

Effect of Fertilization on Yield and Agronomic Quality Components of Seeds

Rates and combinations of N, P and K differentially affected yield, physical characteristics, protein content, ash content and mineral composition of the seeds.

Yield

When averaged over P and K, seed yield was increased significantly with an application of 150 kg/ha of N (Fig. 1 and Table 1) and still further with an application of 300 kg N/ha. Application of 450 kg N/ha reduced the yield from that obtained with 300 kg N/ha, but the difference was nonsignificant. When averaged over N and K, a significant increase in yield was also obtained with 45 and 90 kg/ha of P. No yield difference was observed among different rates of K.

There was a significant interaction between N and P, indicating that the relative response to P changed from one rate of N to another and vice versa. The highest yielding combinations were 300-90-80 with 8333: 300-0-0, 7650; 150-90-80, 7526; 300-45-0, 7433 and 450-90-80 with 7310 kg/ha.

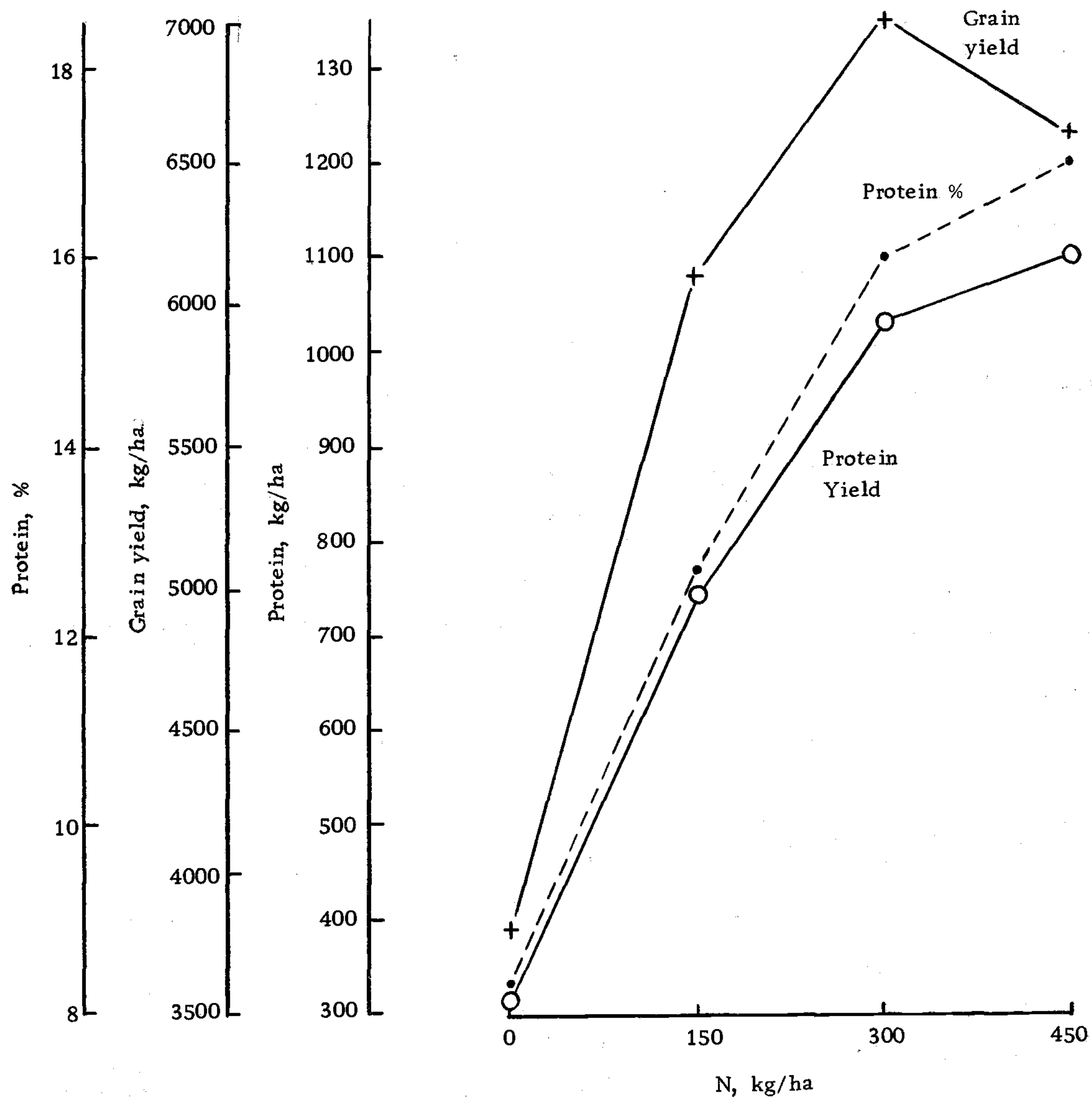

Figure 1. Effect of N on yield, percent protein and protein yield of Yamhill wheat Lot A. Average over P and K.

Table 1. Effect of N, P and K on yield of Yamhill wheat Lot A.

N (kg/ha)	P (kg/ha)	K, kg/ha 0	K, kg/ha 80	K, kg/ha 160
		kg/ha		
0	0	4133	3956	3700
	45	4076	3983	3833
	90	3516	3983	3580
150	0	6203	5703	4766
	45	5516	6293	6783
	90	6050	7526	6416
300	0	7650	6566	7300
	45	7433	6393	7416
	90	6866	8333	5716
450	0	6166	5676	5866
	45	7100	6766	6350
	90	7200	7310	6983

*H. S. D. 01 = 2, 180 g to compare any two means; c. v. % = 10. 43

Summary of grand means

N, kg/ha	Yield, kg/ha	P, kg/ha	Yield, kg/ha	K, kg/ha	Yield, kg/ha
0	3863	0	5641	0	5993
150	6140	45	5996	80	6041
300	7075	90	6124	160	5726
450	6602				
H. S. D. 01	545		439		439

*H. S. D. = Honestly significant difference (Tukey's Test).

Physical Characteristics of Seeds

Seed Size. The effect of N, P and K on 100-seed weight is presented in Table 2. When averaged over P and K, seed size was increased with 150 kg N/ha, but no further increase in size resulted from higher rates. The 450 kg N/ha, however, reduced seed size. Phosphorus and potassium did not affect seed size, and no NPK interaction was found. The combination that gave the heaviest seeds was 300-90-80 and this was also the highest yielding treatment. Other treatments giving large seeds were 150-90-0, 150-45-160 and 150-90-160.

Seed Size Distribution. The effect of N on the distribution of the seeds among several sizes is presented in Figure 2. N tended to increase the proportion of seeds over 10 1/2/64 inch in width. This is one reason for the higher 100-seed weight obtained from N-fertilized plants (Table 2)

Shriveled Seeds. The amount of shriveled seeds for each N fertilization rate and seed size is presented in Figure 3. Seeds from plants with no added N showed 5. 86% shriveled seeds (in number). Application of 150, 300 and 450 kg N/ha increased the amount of shriveled seeds to 10. 13, 15. 06% and 16. 00% respectively. The shriveled seeds tended to be concentrated in the smaller sizes.

Seed Color. The proportions of white amylaceous and dark

Table 2. Effect of N, P and K on 100-seed weight of Yamhill wheat Lot A.

N	P	K, kg/ha 0	80	160
		----------------	g	----------------
0	0	4.67	4.69	4.67
	45	4.70	4.56	4.70
	90	4.35	4.87	4.61
150	0	4.98	5.00	4.87
	45	4.75	5.16	5.24
	90	5.26	5.17	5.19
300	0	5.07	4.78	5.19
	45	4.91	5.11	5.15
	90	5.14	5.46	4.60
450	0	4.52	4.61	4.64
	45	4.95	4.80	4.85
	90	4.63	5.00	4.73

*H. S. D. 01 = 1.02 g to compare any two means; c. v. % = 7.50

Summary of grand means

N, kg/ha	100-seed wt, g	P, kg/ha	100-seed wt, g	K, kg/ha	100-seed wt, g
0	4.64	0	4.80	0	4.82
150	5.06	45	4.90	80	4.93
300	5.04	90	4.91	160	4.87
450	4.75				
H. S. D. 01	.39				

*H. S. D. = Honestly significant difference (Tukey's Test).

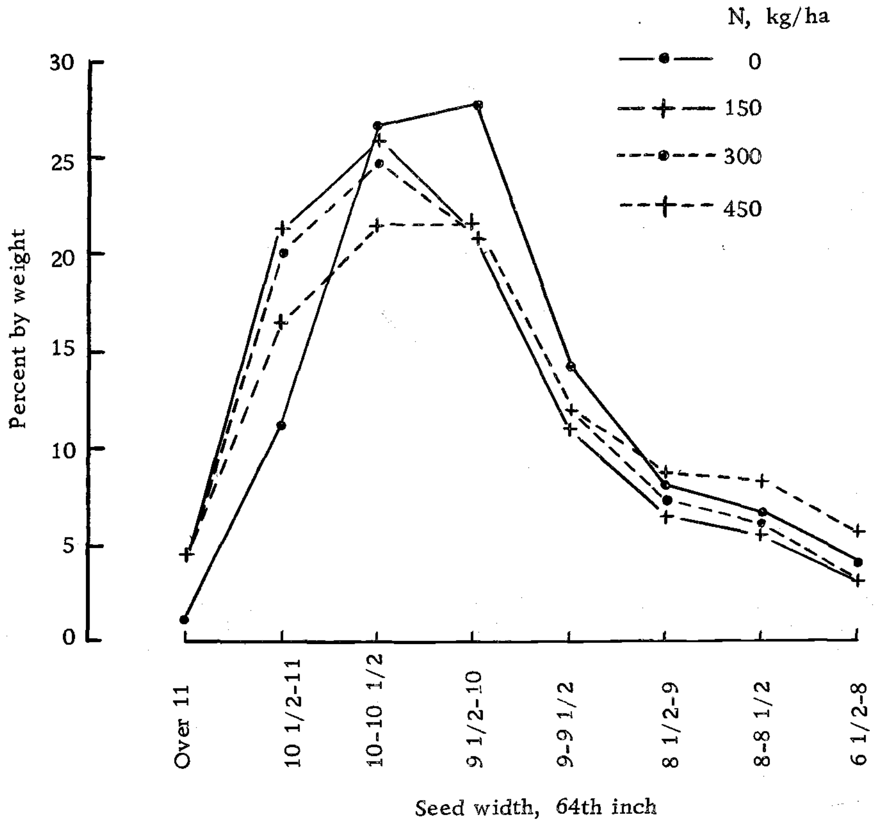

Figure 2. Effect of N on percent seed size distribution (by width) of Yamhill wheat Lot A.

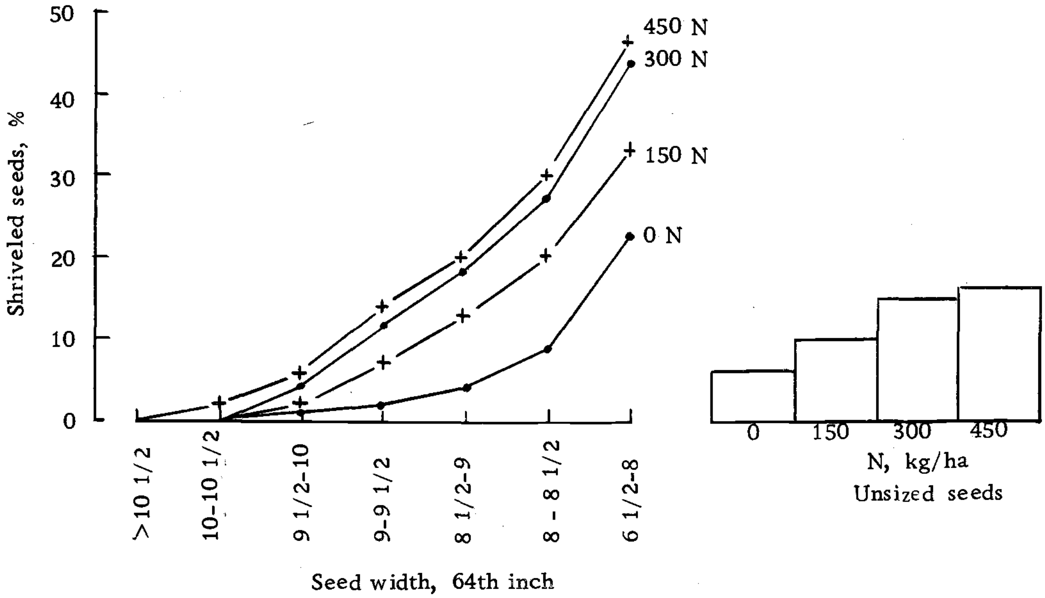

Figure 3. Effect of N on shriveled seeds of Yamhill wheat Lot A.

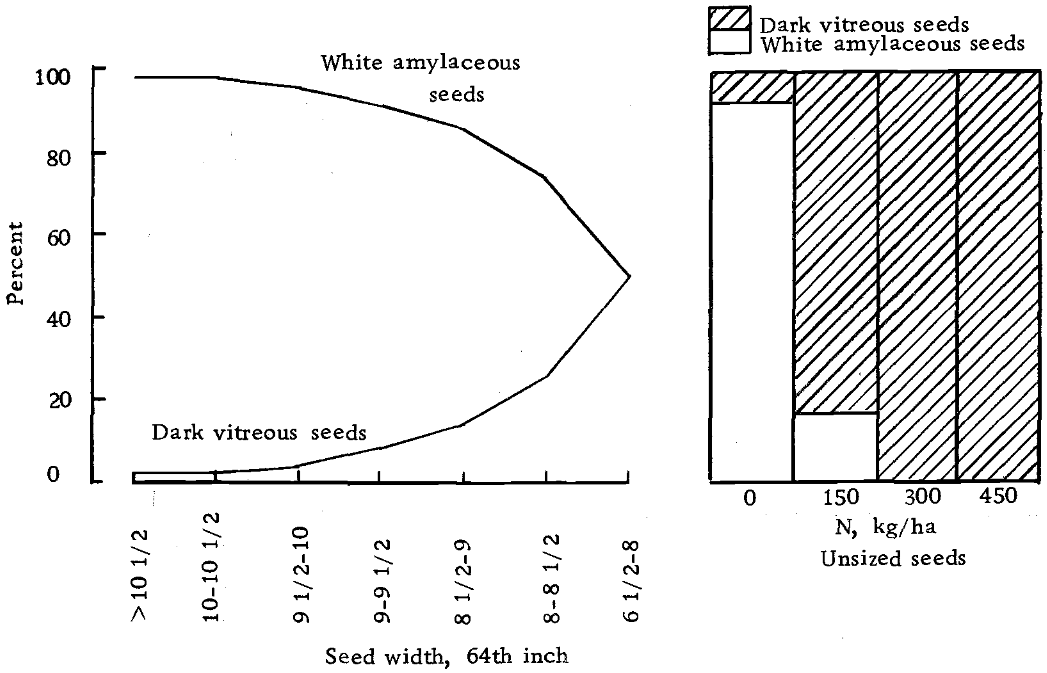

Figure 4. Effect of N on seed color of Yamhill wheat Lot A. Variation of seed color along seed sizes is only for seeds produced with no added N.

vitreous seeds for each N fertilization rate and seed size are presented in Figure 4. White amylaceous seed, averaged 90% (in number) at the 0 N level, 16% with 150 kg N/ha, and disappeared completely with 300 and 450 kg/N ha. Dark vitreous seeds varied inversely with the change in white amylaceous seeds. These results are in agreement with results presented by Feather and Ruckman (1971) and Sadaphal and Das (1966) who showed that the frequency of yellow berry (white amylaceous seeds) was reduced with increased rates of N fertilization.

The frequency of white amylaceous seeds within sizes of the non-fertilized seeds is presented in Figure 4. The percentage of white amylaceous seeds decreased gradually from 98% of the largest seeds to 50% of the smallest size category. The frequency of dark vitreous seeds changed inversely to that of the white seeds. The dark vitreous seeds in the smaller seed sizes were shriveled, indicating that maturity was not fully reached.

Protein Content of Seeds

N Fertilization and Protein Content. Percent protein content was increased from each increment of N applied to Yamhill Lot A (Fig. 1, and Table 3); Yamhill Lot B, Hyslop and Paha (Fig. 5). In every case, the common observation that seed color is an indication of protein content was proven by chemical analyses. Within each

Table 3. Effect of N, P and K on crude seed protein* of Yamhill wheat Lot A.

N, kg/ha	P, 0 kg/ha		P, 90 kg/ha		Average
	K, 0 kg/ha	K, 160 kg/ha	K, 0 kg/ha	K, 160 kg/ha	
			Protein, %		
0	8.62	8.56	7.87	8.25	8.32
150	11.87	13.25	12.75	12.93	12.70
300	14.93	17.00	16.37	16.00	16.07
450	16.75	17.50	16.06	17.50	16.97
			Protein/seed, mg		
0	4.01	3.99	3.41	3.80	3.80
150	5.90	6.46	6.69	6.71	6.44
300	7.53	8.82	8.40	7.34	8.02
450	7.55	8.12	7.44	8.28	7.85
			Protein yield, kg/ha		
0	356.26	316.72	276.71	295.02	311.17
150	735.94	631.50	771.38	829.58	742.15
300	1017.62	1122.00	1124.00	861.28	1031.23
450	1032.80	1026.55	1156.32	1169.00	1096.17

*Protein was derived from %N x 6.25.

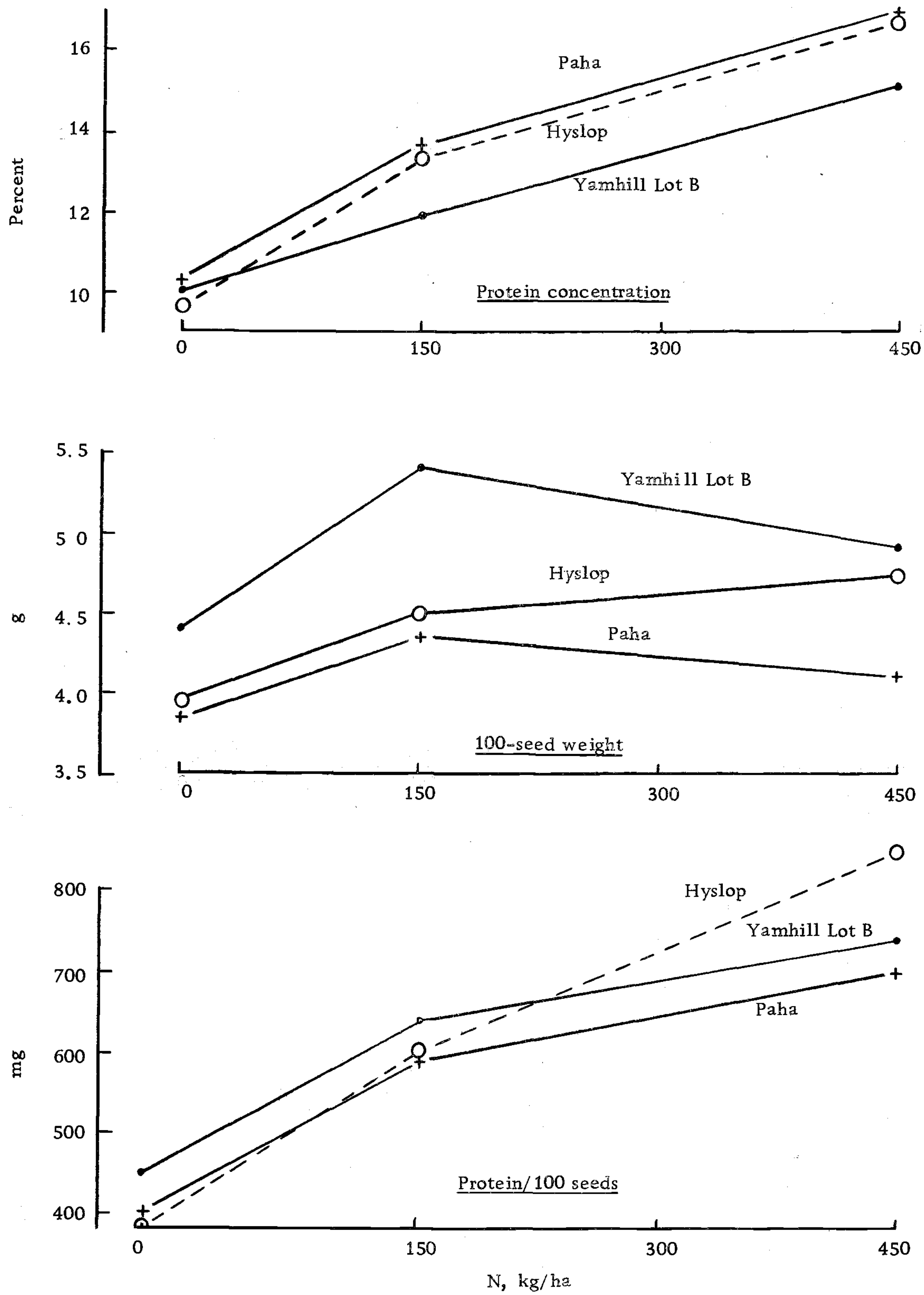

Figure 5. Effect of N on seed weight and protein content of Paha, Hyslop and Yamhill wheat Lot B.

cultivar, darker seeds were higher in protein. The increase in protein concentration in the seed can be attributed to the N supplied at anthesis. Several researchers have concluded that spring application of N (near flowering) has a direct effect on the protein content of seeds. Timing is important, because the bulk of N accumulated in the seed comes from reduction of soil N absorbed by roots after anthesis (Neals, Anderson and Wardlaw, 1963). This would be even more important in the high protein varieties (Mikessel and Paulsen, 1971).

Potassium fertilization produced a slight increase in the percent protein, especially in the presence of N fertilization (Table 3). Phosphorus did not affect the percent protein content.

Protein yield per hectare was also increased with each additional application of N (Figure 1, and Table 3). This is a direct consequence of increases in grain yield and protein concentration in the seed.

The increase in seed yield, percent protein, protein yield per hectare, and seed size with N fertilization differs from frequently published results where N fails to increase protein and yield or seed size at the same time. The increase of all these seed quality components may have been due to the timing of N fertilization and the irrigation provided during seed development. Former studies were oriented to improve the food value of the crop, with N application at one time during plant development and no additional irrigation.

A direct effect of increased protein concentration and seed size from N was an increase in protein per seed (Table 3). Percent protein and amount of protein per seed were increased with adequate N rates in combination with K or P, with 300-0-160 giving the highest amount of protein per seed (8.82 mg/seed) followed by 300-90-0 (8.40 mg/seed).

Seed Size and Protein Content. Differences in protein content between seed sizes within high and low protein seed lots are presented in Figure 6. Changes in percent protein with change in seed size were small in the high protein group of seeds. In the low protein seed lot, the small seeds showed a higher protein percentage.

The amount of protein per seed decreased as seed size decreased within both the high and low protein seed lots. This is attributed mostly to the change in seed weight with seed sizes. For equivalent seed sizes, seeds which contained a higher protein percentage also showed a higher amount of protein per seed. This is attributed mostly to differences in protein concentration and to a small degree to differences in seed weight. These results indicate that the factor contributing most effectively to seed protein content is protein concentration. The smallest seeds with a high protein percentage contained almost as much protein per seed as the largest seeds of low protein percentage.

Seed Color and Protein Content. The protein contents of dark

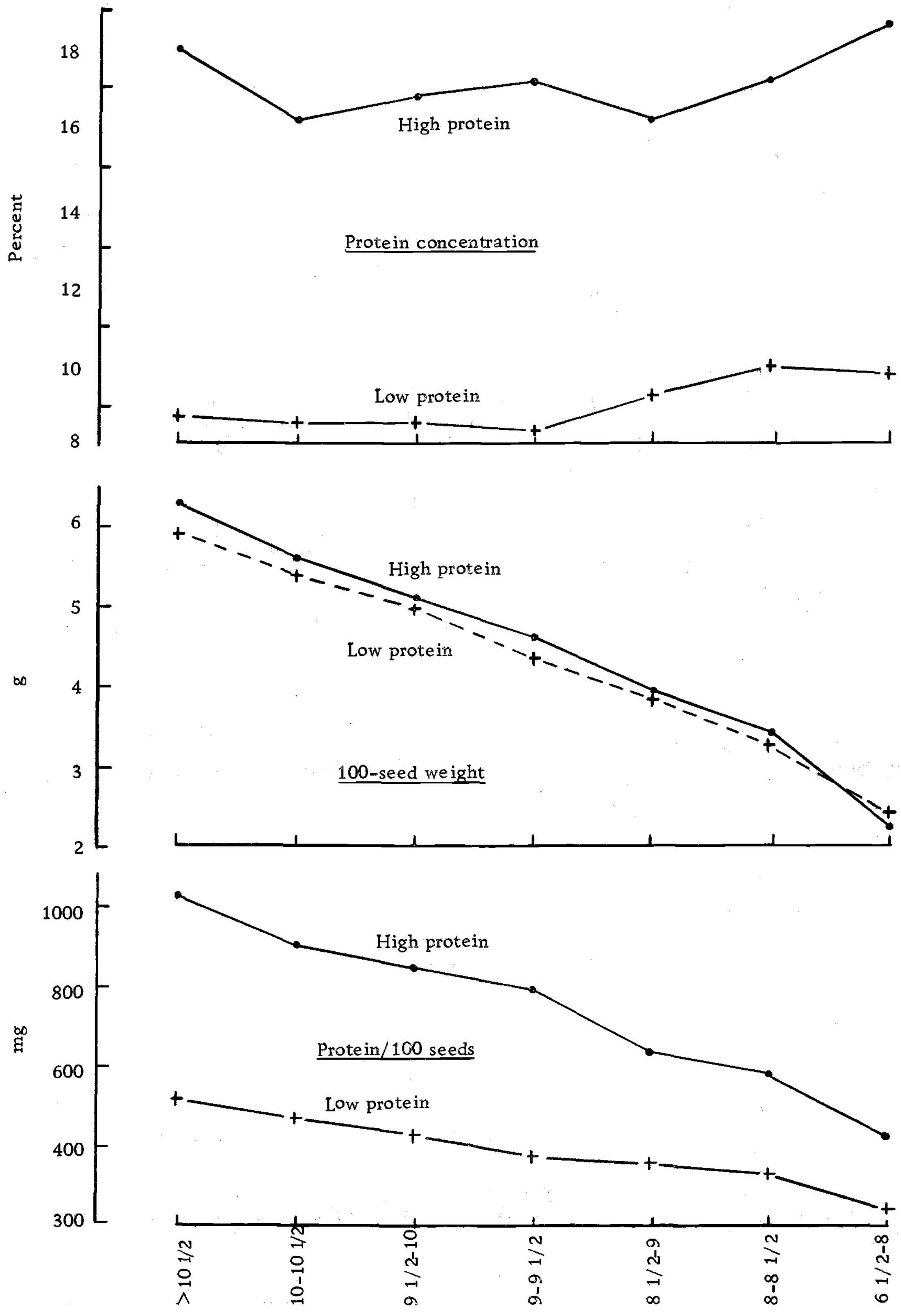

Figure 6. Weight and protein content of seeds associated with seed size of Yamhill wheat Lot A.

vitreous and white amylaceous seeds for four smaller seed sizes are presented in Figure 7. These white amylaceous and dark vitreous seeds came from the same head of plants with no added N. Within each seed size, the dark vitreous seeds were from 2.5 to 3.5% higher in protein than white amylaceous seeds of the same size.

This difference in protein percent between white amylaceous and dark vitreous seeds explains the increased protein percentage in the smaller sizes, which showed more dark vitreous seeds than the larger seeds. This also indicates that a visual estimation of protein level could be accomplished by an examination of the proportion of dark and light seeds.

Ash and Mineral Content of Seeds

Ash Content. Both percent ash and amount of ash per seed decreased as nitrogen fertilization increased (Figure 8). The low percent ash is typical of the soft white common wheat. Ash content varied with seed size as well. Within both the high and low protein seed lots, smaller seeds contained a greater percent ash, but the variation was greater in the high protein seed lot. The amount of ash per seed, however, was proportional to change in weight per seed.

Nitrogen Fertilization and Mineral Composition of Seeds. The mineral composition of seeds of two seed lots of Yamhill, Hyslop

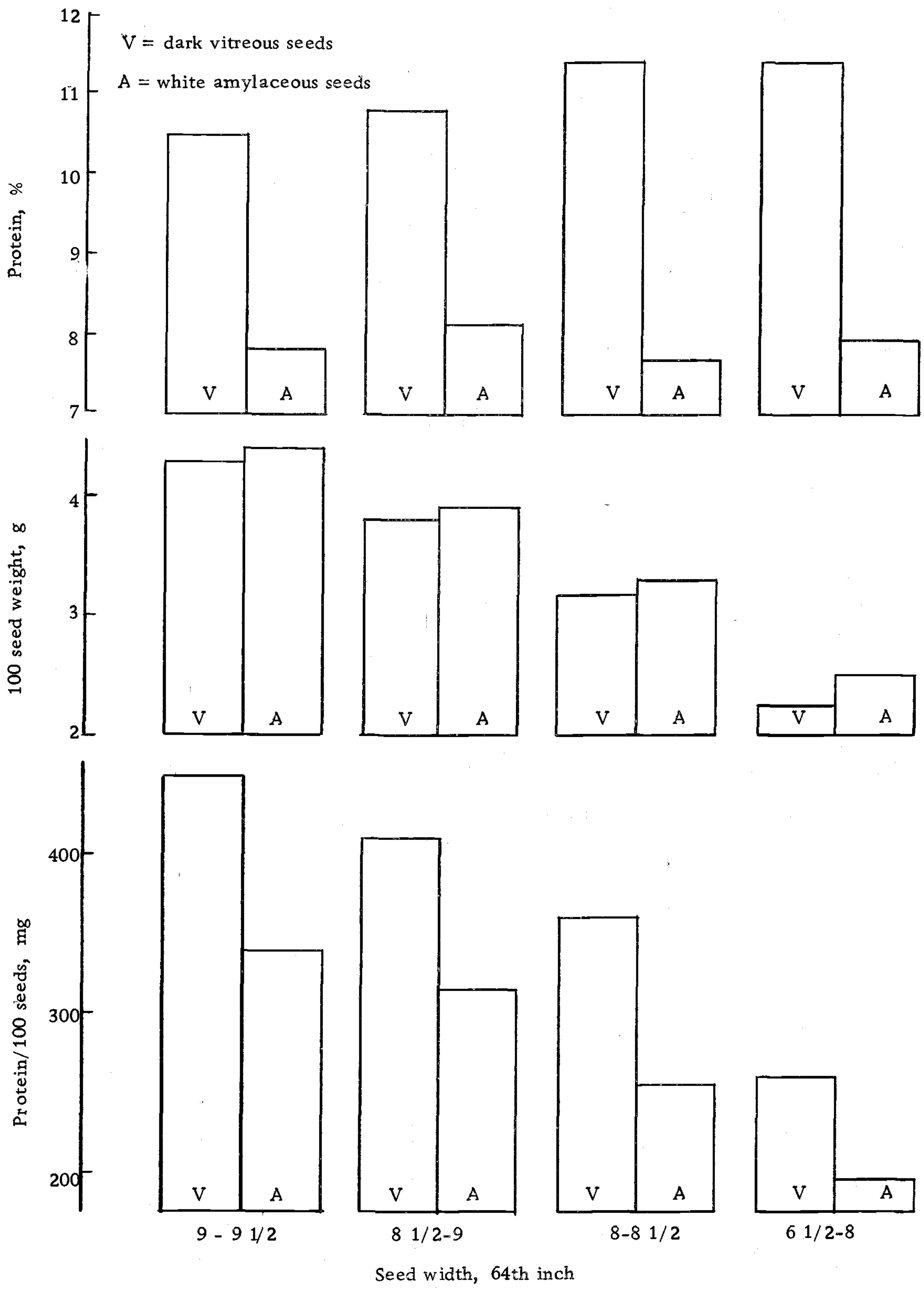

Figure 7. Weight and protein content of dark vitreous and white amylaceous seeds of Yamhill wheat Lot A. Seeds produced with no added N.

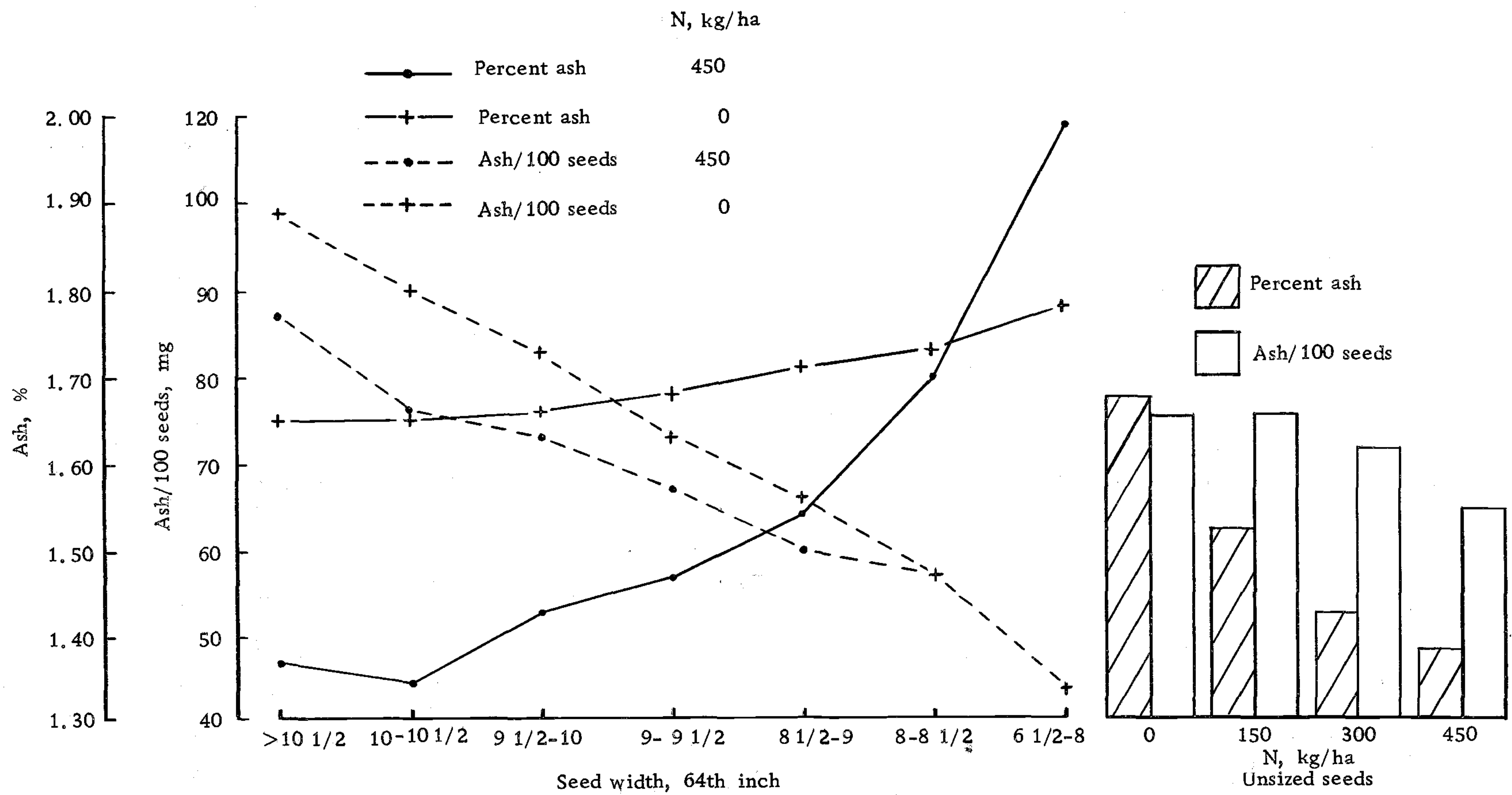

Figure 8. Effect of N on ash content in seeds of Yamhill wheat Lot A.

and Paha is presented in Table 4. The concentration and amount of K, P and Al per seed decreased in every cultivar as N fertilization increased. On the other hand, Mg, Mn, Fe and Zn increased in concentration and amount per seed with intermediate levels of N fertilization. Highest levels of N, however, decreased both concentration and amount of these elements per seed.

The concentration of Ca showed no change in Yamhill Lot A, but showed a slight increase in Yamhill Lot B, Paha and Hyslop as N rate increased. The amount of Ca per seed paralleled the change of seed weight in every cultivar.

No trend in concentration was observed for Cu; but the amount per seed paralleled the change in seed weight.

Seed Size and Mineral Content. The mineral content of the different seed sizes within high and low protein seeds of Yamhill Lot A is presented in Table 5. The concentration of K, P and Zn was higher as seed size decreased in both high and low protein seeds. The increased concentration of these elements can be traced to the change in ash content. The concentration of Mn and Fe decreased as seed size decreased; on the other hand, Ca, Mg, Cu and Al did not show much change with seed size.

The amount of each element per seed decreased as seed size decreased within both the high and low protein seeds.

Seed Color and Mineral Composition of Seeds. The mineral

Table 4. Effect of N on chemical composition of wheat seed cultivars.

Cultivar	N	%				ppm					mg/100 seeds								
	kg/ha	K	P	Ca	Mg	Mn	Fe	Cu	Zn	Al	K	P	Ca	Mg	Mn	Fe	Cu	Zn	Al
Yamhill (Lot A)	0	.50	.53	.03	.08	64	129	3	37	5	23.13	53.00	1.36	3.65	.29	.59	.014	.186	.021
	150	.42	.52	.03.	.08	64	182	3	44	4	21.55	52.75	1.51	4.80	.33	.92	.017	.225	.020
	300	.42	.45	03	.09	66	151	3	48	4	21.01	45.75	1.49	4.50	.33	.75	.015	.241	.019
	450	.44	.39	.03	.08	61	87	3	45	2	20.59	39.75	1.38	3.69	.28	.41	.013	.211	.010
Mean		.44	.47	.03	.08	64	137	3	44	4	21.57	47.81	1.44	4.16	.30	.67	.015	.216	.018
Yamhill (Lot B)	0	.63	.44	.03	.08	41	31	6	39	2	27.90	19.49	1.32	3.54	18	.14	.026	.172	.008
	150	.43	.41	.03	.09	47	49	6	45	1	24.74	22.05	1.61	4.84	.25	.26	.032	.242	.004
	450	.50	.33	.04	08	40	38	5	44	1	24.35	16.07	1.94	3.89	.19	.18	.024	.214	.004
Mean		.53	.39	.03	.08	43	39	6	43	1	25.66	19.20	1.62	4.09	.21	.20	.027	.209	.005
Paha	0	.52	.34	.04	.07	.32	31	5	35	2	20.12	13.15	1.54	2.70	.12	.12	.019	.135	.007
	150	.43	.47	.04	.11	57	95	7	47	2	18.70	20.44	1.74	4.78	.25	.41	.030	.204	.008
	450	.39	.25	.05	.05	38	28	5	40	1	16.02	10.27	2.05	2.05	.16	.12	.020	.164	.004
Mean		.45	.35	.04	.08	42	51	6	40	2	18.28	14.62	1.78	3.18	.18	.22	.023	.168	.006
Hyslop	0	.48	.41	.05	.08	47	41	5	34	4	19.00	16.23	1.98	3.16	.19	.16	.019	.134	.015
	150	.46	.49	.05	.10	66	103	7	45	3	20.79	27.14	2.26	4.52	30	.46	.031	.203	.013
	450	.45	.33	.07	.09	51	32	5	40	1	21.51	15.77	3.34	4.30	.24	.15	.023	.191	.004
Mean		.46	.41	.06	.09	55	59	6	39	3	20.43	18.04	2.52	3.99	.24	.26	.024	.176	.010
Grand Mean		.47	.41	.04	.09	51	71	5	42	3	21.49	24.91	1.84	3.86	.23	.44	.022	.192	.009

Table 5. Effect of N on chemical composition of several seed sizes of Yamhill wheat Lot A.

N	Seed width	%				ppm					mg/100 seeds								
kg/ha	64th inch	K	P	Ca	Mg	Mn	Fe	Cu	Zn	Al	K	P	Ca	Mg	Mn	Fe	Cu	Zn	Al
0	> 10 1/2	.39	.39	.04	.09	69	89	4	46	3	24.80	24.80	2.54	5.72	.44	.57	.025	.292	.019
	10-10 1/2	.34	.35	.03	.08	59	81	3	42	3	19.10	19.67	1.68	4.49	.33	.46	.016	.236	.016
	9 1/2-10	.40	.38	.03	.07	58	95	3	45	3	20.40	19.38	1.53	3.57	.30	.48	.015	.229	.015
	9-9 1/2	.46	.40	.03	.08	60	77	2	46	2	21.02	18.28	1.37	3.65	.27	.35	.009	.210	.009
	8 1/2-9	.51	.40	.03	.07	54	69	1	47	2	12.73	15.48	1.16	2.70	.21	.27	.003	.181	.006
	8-8 1/2	.51	.40	.03	.08	51	69	3	46	3	17.18	13.48	1.01	2.69	.17	.23	.010	.155	.010
	6 1/2-8	.66	.43	.03	.08	54	46	2	49	3	14.71	9.58	.67	1.78	.12	.10	.004	.109	.006
	Mean	.47	.39	.03	.07	58	75	3	46	3	19.56	17.23	1.41	3.51	.26	.35	.012	.202	.012
450	> 10 1/2	.47	.52	.04	.10	71	129	2	36	4	27.87	30.83	2.37	5.93	.42	.76	.011	.213	.023
	10-10 1/2	.48	.52	.03	.09	73	124	1	36	3	26.06	28.23	1.62	4.88	.39	.67	.005	.195	.016
	9 1/2-10	.50	.50	.03	.09	67	102	3	36	4	25.00	25.00	1.50	4.50	.34	.51	.015	.180	.020
	9-9 1/2	.51	.50	.03	.08	59	119	2	38	3	22.23	21.80	1.30	3.48	.26	.51	.008	.165	.013
	8 1/2-9	.54	.52	.03	.09	59	114	3	39	4	20.79	20.02	1.15	3.46	.23	.43	.011	.150	.015
	8- 8 1/2	.64	.53	.03	.08	55	117	2	40	3	21.12	17.49	.99	2.64	.18	.39	.006	.132	.009
	6 1/2-8	.63	.59	.03	.11	61	111	4	51	5	15.62	14.63	.74	2.72	.15	.28	.009	.126	.012
	Mean	.54	.53	.03	.09	64	117	2	39	4	22.67	21.14	1.38	3.94	.28	.51	.009	.165	.015
	Grand Mean	.51	.46	.03	.08	61	96	3	43	4	21.12	19.19	1.40	3.73	.27	.43	.011	.184	.014

content of dark vitreous and white amylaceous seeds within four seed sizes is presented in Table 6. In every seed size, dark vitreous seeds showed higher concentrations of K, P, Mg, Mn, Zn and Cu than white amylaceous seeds. Differences between colors were greater in the smallest seed sizes. Concentration of Ca did not show a trend with seed color.

Although the white amylaceous seeds were heavier than dark vitreous seeds in every seed size, the amount of K, P, Mg, Mn, Cu, and Zn per seed was greater in the dark vitreous seeds.

Mineral elements are very important for certain enzymatic activities during glycolysis, tricarboxylic acid cycle and electron transport system (Evans and Russell (1964). Therefore, an adequate amount of elements will favor a good utilization of reserve substrates and production of energy for growth.

In the soil, these elements will be supplied via root uptake after the transpirational stream is established. However, a good pool of these elements in the seed is of great importance until such a stage has been ensured.

The amount of these elements should not be lowered to a level where energy production would be jeopardized in the awakening embryo and/or germinating seedlings. In this study, the highest rates of N decreased the amount of K, P and Fe, but increased other elements. In spite of these changes, seedling performance

Table 6. Chemical composition of dark vitreous and white amylaceous seeds of Yamhill wheat Lot A. Seeds produced with no added N.

Seed width 64th inch	Seed type	%				ppm			mg/100 seeds						
		K	P	Ca	Mg	Mn	Zn	Cu	K	P	Ca	Mg	Mn	Zn	Cu
9-9 1/2	Vitreous	.62	.56	.03	.10	66	59	7	26.53	23.96	1.28	4.28	.28	.25	.029
	Amylaceous	.52	.55	.03	.10	63	57	7	22.72	24.03	1.31	4.37	.32	.24	.034
8 1/2-9	Vitreous	.64	.61	.03	.10	67	63	6	24.44	23.30	1.14	3.82	.26	.24	.022
	Amylaceous	.53	.47	.03	.07	60	51	5	20.61	18.28	1.16	2.72	.23	.20	.019
8-8 1/2	Vitreous	.73	.66	.04	.13	70	65	7	23.21	20.98	1.27	4.13	.22	.21	.022
	Amylaceous	.60	.51	.03	.04	46	54	5	19.86	16.88	.99	2.31	.15	.18	.016
6 1/2-8	Vitreous	.77	.59	.04	.12	66	62	6	17.40	13.33	.90	2.71	.15	.14	.013
	Amylaceous	.56	.46	.03	.08	53	54	4	13.88	11.40	.74	1.98	.13	.13	.009
Grand Mean	Vitreous	.69	.61	.04	.11	67	62	7	22.90	20.39	1.15	3.74	.23	.21	.022
	Amulaceous	.55	.50	.03	.07	56	54	5	19.26	17.64	1.05	2.85	.21	.19	.019

was highest from high rates of N, indicating that the chemical pool was within adequate range. From this study it is not possible to establish the extent of the beneficial or detrimental effect caused by changes in the chemical pool due to high N rates. However, a study consisting of foliar application of micronutrients, in combination with optimum rates of N for highest protein content, would be able to elucidate the importance of the amount of these elements in energy production for biosynthesis. It was of interest, however, to learn that, regardless of protein concentration, larger seeds always contained a higher amount of every element. The greater availability of chemical cofactors could contribute to a good breakdown of substrates and greater production of energy in seedlings from larger seeds.

Association of Protein Content and Seed Size with Some Physiological and Biochemical Quality Components of Seeds

Protein Content of Embryos

The effect of N rates on the protein content of embryos is presented in Figure 9. Embryos contained a considerably higher protein percentage than whole seeds. The protein percentage of embryos of low protein seeds was four times higher than that of the whole seed; while in embryos of high protein seeds, the protein percentage was

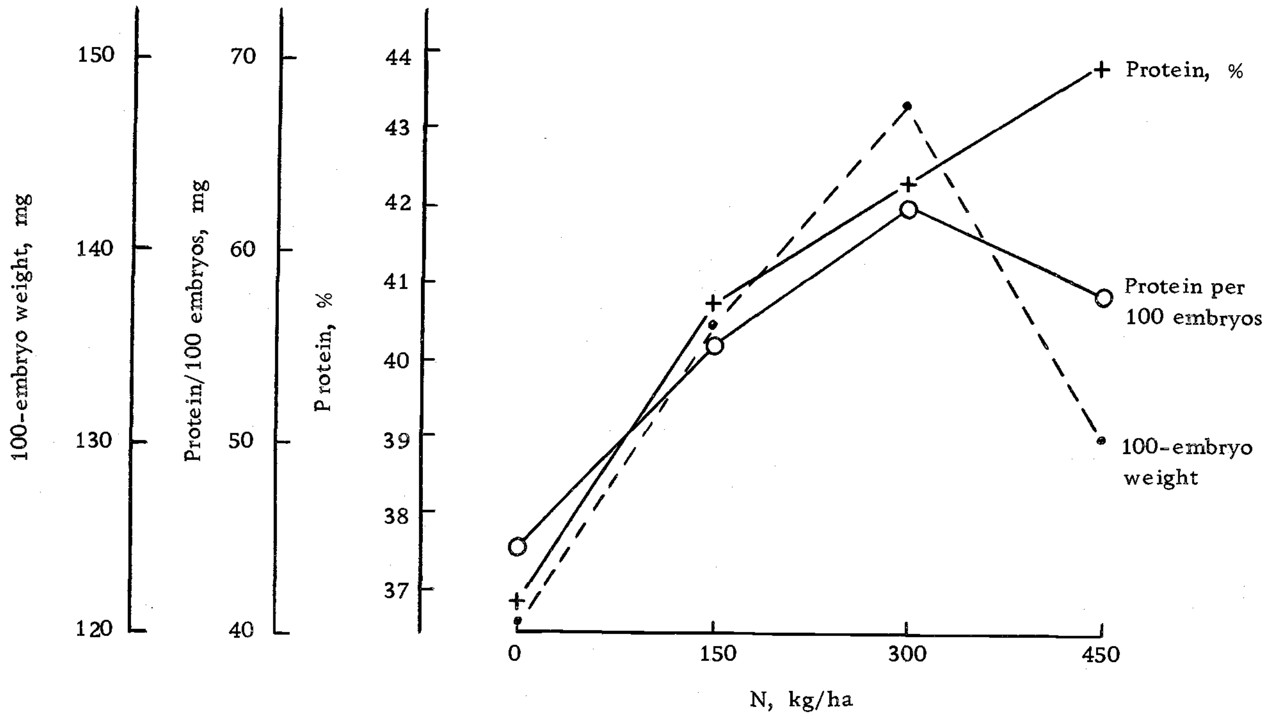

Figure 9. Effect of N on size and protein content of embryos of Yamhill wheat Lot A.

2.5 times that of the whole seed. In general the protein percentage in the embryo increased as rate of N increased. Higher N applications also caused a larger quantity of protein per embryo, reaching a peak at 300 kg N/ha, then decreasing in seeds produced from 450 kg N/ha. The weight of embryos also increased with fertilizer rate except the highest rate of 450 kg N/ha which resulted in smaller seeds and smaller embryos. These results differ from data obtained by Lowe and Ries (1973) and Lopez (1972) who reported that neither protein per embryo nor embryo size was affected by N fertilization.

Although the embryo has about 2.5 to 4 times higher concentration of protein than the whole seed, embryo protein only constituted about 7 to 10% of the total protein of the whole seed. However, embryo proteins consist of nucleoproteins, albumens and globulins (Abrol, 1971).

Amino Acid Composition of Seeds

Based on the amount of amino acids per sample (Table 7), the percent true protein of seeds was 6.85% with no added N, 8.89% with 150, 12.22% with 300 and 11.21% with 450 kg N/ha. This contrasts with the 8.62% with no added N, 11.87% with 150, 14.93% with 300 and 16.75% with 450 kg N/ha when percent protein was estimated by % N x 6.25. This indicates that a high proportion of N is evidently in the form of true protein, but some N in the seed is also present in the form of other N-containing compounds. Some of these compounds would be nucleotides, ammonia, nitrate, nitrite, amides, etc. Further, these results indicate that the amount of nonproteinaceous-N-containing compounds increased as rate of N application increased.

The amino acid composition of wheat seeds produced under four N rates is presented in Table 7. When the amino acid composition was compared on a mole percent basis, an increase of glutamic acid and proline with increasing N rates was apparent. These increases of specific amino acids are apparently from endosperm proteins which include prolamin and glutelin (components of the storage protein gluten). Prolamin and glutelin are known to be rich in glutamic acid, proline, leucine and pnenylalanine (Abrol, 1971). Although no change was observed in phenylalanine content, leucine increased at the highest level of N.

The mole percent of lysine, histidine, threonine, glycine, alanine and tyrosine decreased as the N rate increased. Arginine, aspartic acid, alanine, valine, leucine and isoleucine decreased with intermediate levels of N, but increased with the highest N rates. The decrease observed in the relative proportion of these amino acids is in agreement with results presented by Abrol (1971) and others who indicated that prolamin and glutelin are deficient in lysine, threonine, valine, isoleucine and tyrosine.

The proportions of serine and cysteine increased with

Table 7. Effect of N on amino acid content of seeds of Yamhill wheat Lot A.

Amino acids	N, kg/ha															
	0	150	300	450	0	150	300	450	0	150	300	450	0	150	200	450
*True protein, %	6.84	8.89	12.22	11.21	6.85	8.89	12.22	11.21	6.85	8.89	12.22	11.21	6.85	8.89	12.22	11.21
	Mole percent				Weight percent of true protein				Amino acid/100 seeds mg				Amino acid yield kg/ha			
Lysine	3.4	3.0	2.4	2.6	3.9	3.4	2.8	3.0	12	15	17	15	11	19	26	20
Histidine	2.1	2.0	1.9	1.7	2.6	2.4	2.3	2.1	8	11	20	11	7	13	31	14
NH_4	21.4	23.3	22.4	25.6	3.3	3.5	3.4	3.9	10	15	21	20	9	19	32	26
Arginine	4.9	4.8	3.7	4.1	6.9	6.7	5.2	5.7	22	29	32	29	20	37	48	39
Aspartic acid	6.2	5.5	5.2	5.6	6.4	5.7	5.4	5.8	20	25	33	29	18	31	50	40
Threonine	3.8	3.6	3.5	3.4	3.5	3.3	3.2	3.1	11	14	20	16	9	18	30	21
Serine	6.2	6.9	6.6	6.1	4.9	5.4	5.2	4.7	15	24	32	24	14	29	48	32
Glutanic acid	24.7	27.1	29.2	29.9	28.7	31.3	33.7	34.4	91	138	209	174	81	173	315	237
Proline	10.7	11.1	12.8	11.4	9.4	9.6	11.1	9.9	30	42	69	50	27	53	53	68
Glycine	8.1	7.2	7.1	7.0	4.2	3.7	3.6	3.6	13	16	22	18	12	20	17	24
Alanine	6.6	5.9	5.0	5.7	4.2	3.7	3.2	3.6	13	16	20	18	12	20	15	24
Cysteine	.7	.8	1.1	.2	.6	.7	1.1	.2	2	3	7	1	2	4	5	1
Valine	5.1	5.0	4.3	4.8	4.6	4.5	3.8	4.2	14	19	23	21	13	25	18	28
Isoleucine	4.0	3.7	3.2	3.8	4.1	3.8	3.2	3.8	13	17	20	19	12	21	15	26
Leucine	7.3	7.1	6.6	7.6	7.5	7.2	6.7	7.6	24	32	41	38	21	40	32	52
Tyrosine	2.3	2.2	2.1	2.1	3.3	3.2	3.0	3.0	11	14	19	15	9	18	14	20
Phenylalanine	3.9	4.1	3.9	4.0	5.2	5.4	5.2	5.3	17	24	32	27	15	30	25	36

*Percent protein was derived from u grams of amino acids per sample. Amino acid/100 seeds and amino acid yield are based on true protein.

intermediate levels of N, while seeds produced under the highest level of N were lower in these amino acids than seeds receiving no N.

Calculation of the amino acids as a weight percent of true protein showed the same relationship to N rate as the mole percent basis.

The yield of amino acids per hectare showed the same trend as the protein yield per hectare. Application of 150 and 300 kg N/ha increased the amount of each amino acid/ha. On the other hand, 450 kg N/ha reduced the amino acid yield below that obtained at 300 kg N/ha.

The change in relative proportion of amino acids is of importance in the nutritional value of a unit weight of grain. In seeds, the measurement of substrates per biological unit (one seed) is of greater importance. In this study, although the relative proportion of each amino acid changed with N rates, the absolute amount of each amino acid per seed increased with 150 and still further with 300 kg N/ha. The increase is partially attributed to the increase in seed size and amount of protein per seed. In seeds, it is not known yet whether low amounts of specific amino acids may be limiting seed quality. However, if any amino acid was of great importance, the amount of that amino acid could be increased by improving seed size and amount of protein per seed.

Free Amino Acid, Soluble Sugar and Starch Content of Seeds

The concentration and amount of free amino acids, soluble sugars and starch for different seed sizes within high and low protein seeds are presented in Table 8.

Free Amino Acids. When averaged over seed sizes, the high protein seeds contained about ten times more concentration and amount of free amino acids than the low protein seeds. These results are in agreement with results reported by Finlayson *et al.* (1970), who increased the free amino acid composition of rape (*B. napus*) seeds with addition of ammonium nitrate. Similar results have been reported in rice by Cruz *et al.* (1970).

Within each protein level, the larger seeds had a lower free amino acid concentration than the medium size seeds, which in turn were lower than the small seeds. These results are in agreement with data presented by Hoseney and Finney (1967), who reported that the concentration of free amino acids in small immature seeds was high and decreased during seed maturation.

Large seeds within the high protein seeds showed the highest amount of free amino acids per seed. On the other hand, the amount of free amino acids per seed within the low protein seeds did not change with seed size.

Soluble Sugars. When averaged over seed sizes, the low protein seeds contained about 1.3 times higher concentration and amount of soluble sugars than the high protein seeds. Within each protein level, the concentration of soluble sugars was higher in the smaller seeds, but the amount of soluble sugars per seed was proportional to seed size.

Starch. When averaged over seed sizes, the low protein seeds showed a slightly higher starch concentration. These results are in agreement with results obtained by Sheck and Fetzer (1950) and Lopez (1972) who reported reduced starch concentration with high N rates.

Within the low protein seeds, a slight increase in percent starch occurred in smaller sizes. The amount of starch per seed within each protein level was related to seed size, equivalent seed sizes from high and low protein seeds containing the same amount of starch per seed. These results are in agreement with data reported by Chang and Robertson (1968), who showed that large seeds contained about 1.3-2.3 times as much starch as the smallest seeds in barley.

The same workers found that for a given seed size, there was no difference in the amount of total avialable carbohydrates regardless of N fertilization.

Regardless of seed size, a seed of 16.75% protein contained 1.88 times protein; 0.93 times starch; 0.73 times soluble sugar and 10.67 times free amino acid per seed, compared to a seed of 8.62% protein. These results indicate that the different rates of N fertilizer

Table 8. Starch, soluble sugar and free amino acid content associated with protein content and seed size of Yamhill wheat Lot A.

Crude protein	Seed width	Starch		Soluble sugars		Free amino acids	
%	64th inch	%	g/100 seeds	%	mg/100 seeds	%	mg/100 seeds
16.75	Unsized	51.39	2.37	.78	36.21	.71	32.96
	>10 1/2	51.86	3.05	.59	34.63	.71	41.70
	9-9 1/2	51.83	2.24	.77	33.26	.84	36.12
	6 1/2-8	51.19	1.22	1.04	24.87	.86	20.65
	Grand mean	51.56	2.22	.80	32.24	.78	32.86
8.62	Unsized	52.96	2.42	1.02	46.39	.08	4.09
	>10 1/2	50.61	3.14	.90	55.83	.05	2.83
	9-9 1/2	60.07	2.71	.98	44.08	.07	3.14
	6 1/2-8	56.71	1.34	1.24	29.30	.10	2.28
	Grand mean	55.06	2.40	1.03	43.89	.07	3.08

on parent plants had changed the quantity of food reserves. The most striking change was the change in the ratio of starch to protein from 2.95 in high protein seeds to 6.25 in low protein seeds.

Free Amino Acid, Soluble Sugar and Energy Status of Dry Embryos

The size, amount of soluble sugars, free amino acids and the adenylate energy status of dry embryos from two seed sizes within high and low protein seeds are presented in Table 9.

Embryo Size. Within each protein level, the larger seeds possessed larger embryos. In equivalent seed sizes, however, the low protein seeds possessed slightly larger embryos in terms of weight.

Free Amino Acids. The embryos from high protein seeds contained a higher concentration and amount of free amino acids than embryos from low protein seeds. Although high protein seeds contained about ten times more free amino acids than low protein seeds, the embryos from high protein seeds contained only about two times more free amino acids than embryos from low protein seeds.

The concentration of free amino acids did not change with embryo size within the high protein seeds. On the other hand, within the low protein seeds, the smaller embryos showed a higher free amino acid concentration than embryos from large seeds. The total amount of free amino acids was related to embryo size in high protein seeds; however, in the low protein seeds, the smaller embryos contained more amino acids than larger embryos.

Existing free amino acids in the embryo and whole seed would readily provide the units required for synthesis of functional proteins during the awakening of the embryo. From the differences observed in this study, it can be speculated that high protein seeds, which also showed greater free amino acid content, would have some advantage.

Soluble Sugars. For comparable seed sizes, the embryos from high protein seeds showed a slightly higher concentration of soluble sugars. Within the same protein level, the concentration of soluble sugars was similar for large and small embryos, but the amount of soluble sugars was larger in larger embryos. For comparable seed sizes, there was no difference in the amount of soluble sugar in the embryos of high and low protein seeds.

Adenylate Energy Status. When averaged over embryo sizes, the embryos from high protein seeds contained about 1.50 times ATP, 1.25 times ADP, 0.23 times AMP, and 1.06 times total AP, than that of embryos from low protein seeds. These adenylates are pre-existing from the seed maturation period. There was about ten times more ADP per embryo than ATP, regardless of size and seed protein content. This ADP will be immediately phosphorylated to ATP at the expense of oxidation of soluble sugars, immediately after

Table 9. Free amino acid, soluble sugar, and adenylate energy status of dry embryos associated with seed protein content and seed size of Yamhill wheat Lot A.

	Protein, 16.75%			Protein, 8.62%		
	Seed width, 64th inch		Average	Seed width, 64th inch		Average
	> 10 1/2	6 1/2-8		> 10 1/2	6 1/2-8	
Weight per embryo, mg	1.12	.62	.87	1.21	.72	.97
Free amino acids, %	7.14	6.78	6.96	2.13	4.44	3.29
Free amino acids per embryo, µg	160.00	84.10	122.05	52.04	64.00	58.02
Soluble sugars, %	11.28	12.87	12.08	10.37	10.90	10.64
Soluble sugars per embryo, µg	252.60	152.60	206.10	253.20	157.00	205.10
ATP, nmole/embryo	0.16	0.08	.12	0.10	0.06	.08
ADP, nmole/embryo	1.26	0.99	1.13	1.17	0.59	.88
AMP, nmole/embryo	0.15	0.00	.08	0.41	0.19	.30
Total AP, nmole/embryo	1.59	1.02	1.31	1.59	0.85	1.22
Energy charge (EC)	.50	.57	.54	.43	.42	.43

the activation of mitochondria. Ching (1972) reported that mitochondria in seeds of many species become active instantly upon hydration. She also indicated that reserved sugars, free amino acids, purines, adenosine, and phytate in seeds provide substrates for synthesis of nucleotides.

Within each protein level the larger embryos contained more ATP, ADP, AMP and total AP, than smaller embryos.

When comparing embryos from equivalent seed sizes, the embryos from high protein seeds were 1.29 times higher in energy charge (EC) than embryos from low protein seeds. This indicates that for an equivalent amount of total adenylates, the embryos from high protein seeds contain more of the high-energy phosphates than embryos from low protein seeds. Within the low protein seeds, no difference in EC was found between embryo sizes; but in the high protein seeds the smaller embryos showed a slightly higher energy charge.

Free Amino Acids and Soluble Sugars in Seedlings

The amount of soluble sugars and free amino acids per seedling for two seed sizes and two seed protein levels are presented in Figure 10.

Soluble Sugars. The seedlings produced from high protein seeds had a slightly higher amount of soluble sugars than seedlings from low protein seeds. Much greater amounts of soluble sugars were observed in large seeds four days after planting than in small seeds, regardless of protein level. The difference first became evident two days after planting.

Soluble sugars are readily available for respiration and to energize the developing seedlings. The bulk supply of soluble compounds could come from the storage reserves such as protein, fats, and starches after an enzymatic breakdown. These soluble compounds are translocated to seedlings for respiration to produce energy and to provide building blocks for cell components during seedling growth.

Free Amino Acids. For comparable seed sizes, the seedlings from high protein seeds had a considerably higher amount of free amino acids than seedlings from low protein seeds. Within each protein level, seedlings from larger seeds showed a higher free amino acid content than seedlings from small seeds. The amount of free amino acids was highest in the high protein - large seeds, especially after four days of germination. The greater avialability of free amino acids in seedlings from high protein seeds gives the seedling a great advantage. The free amino acid pool would be used to synthesize functional proteins, structural proteins, and the overall energy producing machinery, in the developing seedling.

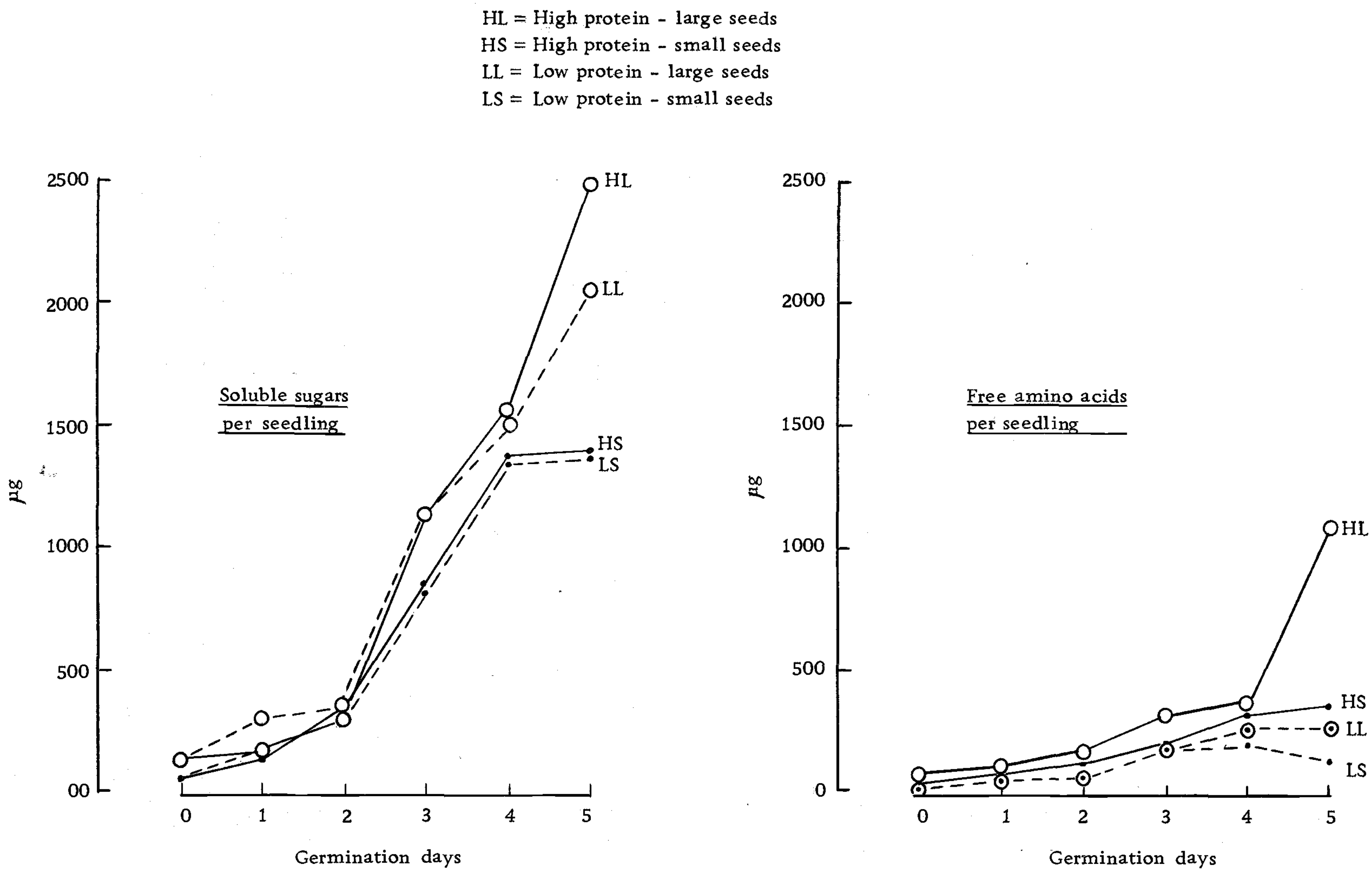

Figure 10. Effect of seed protein content and seed size on soluble sugar and free amino acid content of seedlings of Yamhill wheat Lot A.

Adenylate Energy Status and Energy Charge of Seedlings

The ATP, ADP and AMP in seedlings from two seed sizes and two protein levels are presented in Figure 11. Total adenosine phosphate (AP) and energy charge (EC) are presented in Figure 12.

Adenylates. The seedlings from high protein seeds had a higher amount of ATP than that of low protein seeds. Within each protein level, the increase in ATP during the five days of germination was related directly to seed size. This relationship has been reported by Ching (1973).

The change in ADP followed the same trend as that of ATP. The AMP content fluctuated in the seedlings from high protein seeds and from low protein - small seeds. The low protein - large seeds showed a different pattern than the others as far as the pool of AMP is concerned.

The total amount of adenylate phosphates (AP) showed the same trend as ATP and ADP. The five-day old seedlings contained ATP, ADP and AP in the following order from highest to lowest: High protein - large, low protein - large, high protein - small and low protein - small seeds. The high protein - small seeds contained almost as much ATP, ADP and AMP as the low portein - large seeds, and considerably higher ATP, ADP and AP than low protein - small seeds. This occurred in spite of high protein - small seeds being about 2. 7 times smaller than the low protein - large seeds.

Energy Charge. The greater availability of readily metabolizable solubles would stimulate greater biosynthesis of AMP. This in turn would provide more substrates for the synthesis of ADP and ATP, and this would stimulate a greater utilization of ATP by energy requiring (endergonic) biosynthetic pathways, however the production and use of ATP is controlled not only by the absolute amount of ATP or AMP present, but by their relative concentrations. A measure of the relative concentration is the energy charge (EC) as defined by Atkinson (1968). If all the adenine nucleotide in the cell is ATP, the system is saturated with high energy and would have an energy charge of 1. 0. At the other extreme, if all the adenine nucleotide is present as AMP, the system is lacking of high energy and has an energy charge of 0. 0. None of these extremes could happen in living organisms, however.

EC increased considerably with germination age up to three days, indicating that at the early stages of germination a relatively larger portion of substrates was utilized to produce high energy phosphates for the needs of biosynthesis in seedlings. At each germination stage studied, the high protein - large seeds were consistently higher in energy charge than low protein - large, high protein - small and low protein - small seeds. This can be partly attributed to the higher amount of soluble sugars and free amino acids available

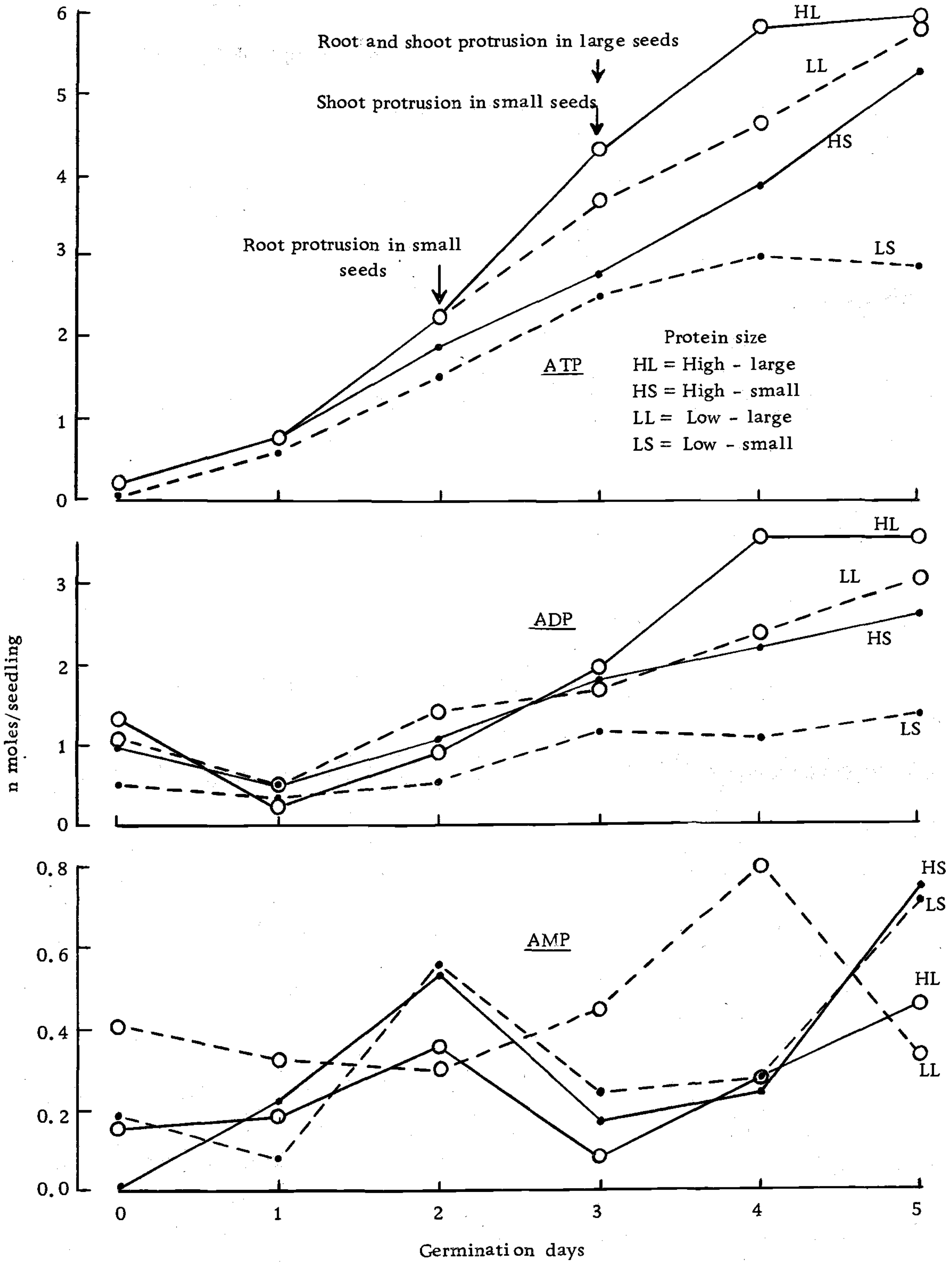

Figure 11. Effect of seed protein content and seed size on adenosine triphosphate (ATP), adenosine diphosphate (ADP) and adenosine monophosphate (AMP) content of Yamhill wheat Lot A seedlings.

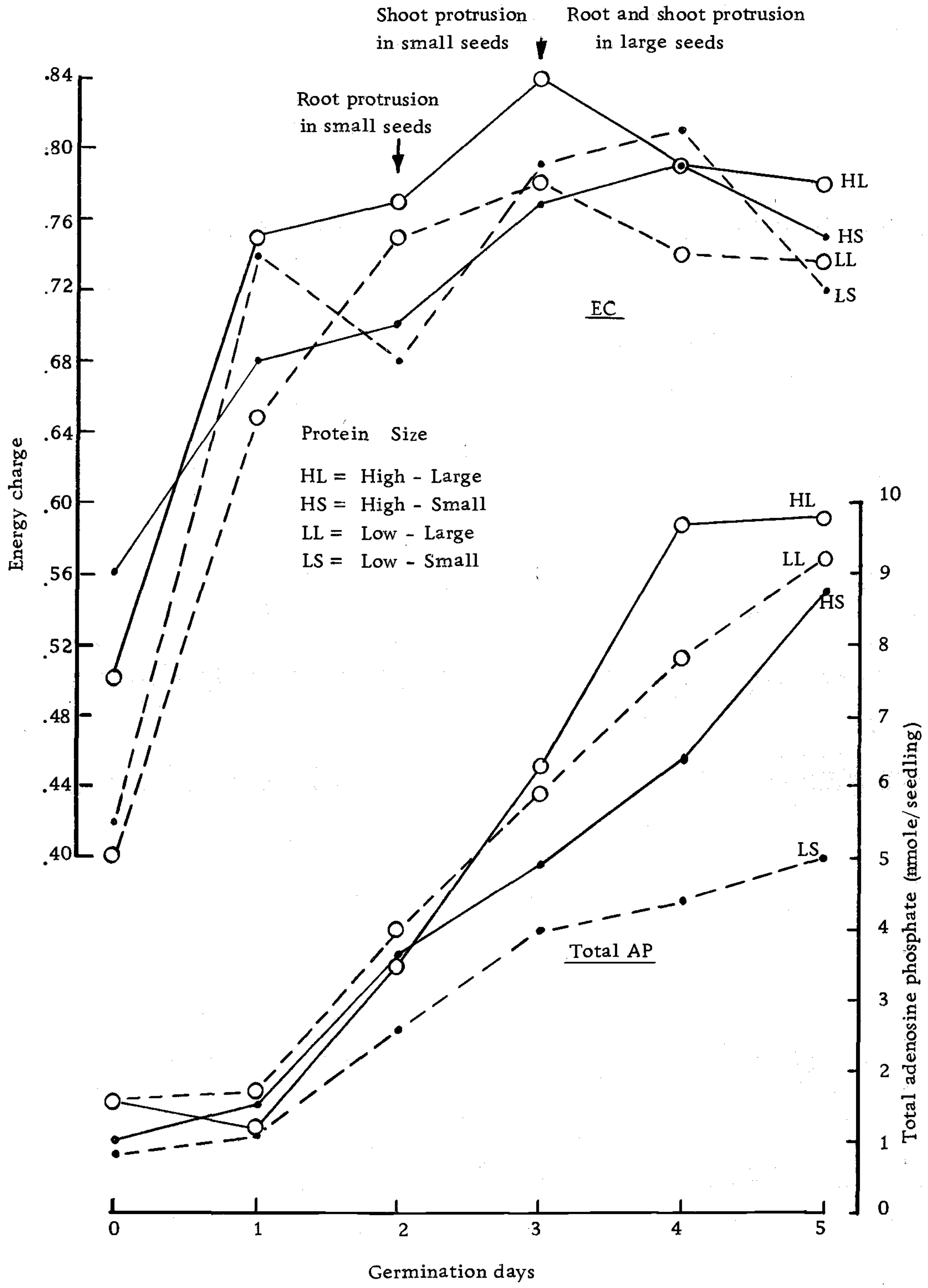

Figure 12. Effect of seed protein content and seed size on energy charge (EC) and total adenosine phosphate (AP) of Yamhill wheat Lot A seedlings.

for oxidation to the seedlings of high protein - large seeds, and partly to the more efficient mitochondria that usually exist in larger seeds (McDaniel, 1969).

After three-day germination, the EC leveled off or dropped, indicating that major biosynthesis of cellular components in young seedlings had been accomplished and the demand for high energy compounds was lessened.

The energy charge controls the pathways that produce and utilize high energy phosphate bonds. By this fine control mechanism, each seed could make the best use of its available substrates to produce a seedling without over-spending its resources to achieve a determined developmental pattern.

The amount of high energy adenylates and the high energy charge observed in the seedlings of high protein and large seeds is an indication of a more efficient biosynthetic system and good enzymatic and organellar machinery. The large amount of ATP in the seedling could result in greater biosynthetic ability. As a consesequence, the seedlings from high protein and large seeds showed greater growth rate in the laboratory and greenhouse studies, and higher yielding ability.

Effect of Protein Content and Seed Size on Seed Performance

Moisture Uptake

Water Imbibition. The rate of water uptake from germination blotters by large and small seeds within high and low protein seeds is shown in Figure 13. The smaller seeds imbibed water at a faster rate than the larger seeds. This indicates that small seeds would apparently reach the minimum water requirement for activation of enzymes faster than larger seeds. The effect of seed size on moisture uptake is in agreement with results presented by Harper and Benton (1966) who reported that smaller seeds imbibe faster because of a larger area of contact between seed and moist substrate in relation to seed volume. Keller and Bleak (1970) also reported that in crested wheatgrass the smaller seeds imbibe faster.

In the large seeds the low protein seeds showed a slightly faster rate of imbibition than high protein. This is in agreement with data presented by Dungan (1924) who found that low protein corn seeds absorbed water at a faster rate than high protein seeds which exhibited a hard vitreous texture in the grain. In wheat, high protein levels in the endosperm also gave the seed a hard vitreous texture and higher density, especially in the larger sizes.

The high protein - small seeds showed a slightly faster imbibition than low protein - small seeds. The high protein - small seeds were generally shriveled without a hard vitreous texture, and most of them were immature. The small seeds also contained a greater concentration of osmoticants which probably gave a lower water potential, causing faster uptake.

Lopez (1972) reported that high protein seeds imbibed moisture at a faster rate than low protein seeds. His study involved unsized seeds where high protein seeds were of smaller size.

Equilibrium Moisture Content. The equilibrium moisture content of high and low protein seeds is presented in Figure 14. The low protein seeds averaged .62% more moisture content at the three relative humidities studied. This difference in moisture holding ability by seeds of different protein levels may have implications in the storability of seeds.

Germination

Speed of Germination in Laboratory Germination Media. The effect of seed sizes within high and low protein seeds on the speed of radicle protrusion is presented in Figure 15. Within each protein level the smaller seeds started germinating earlier than the next larger seeds. These differences are probably related to the speed of moisture imbibition (Figure 13), and to a lesser degree of metabolic blockage. Due to faster moisture uptake and earlier activation

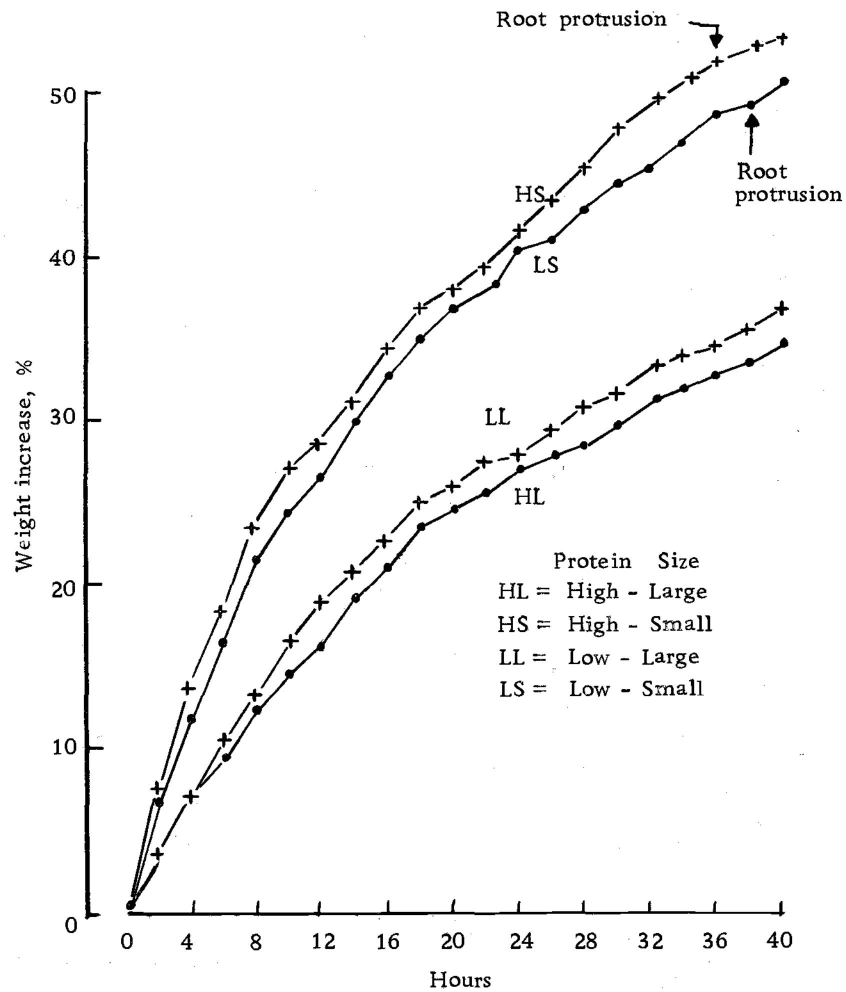

Figure 13. Effect of seed protein content and seed size on moisture uptake during germination of Yamhill wheat Lot A.

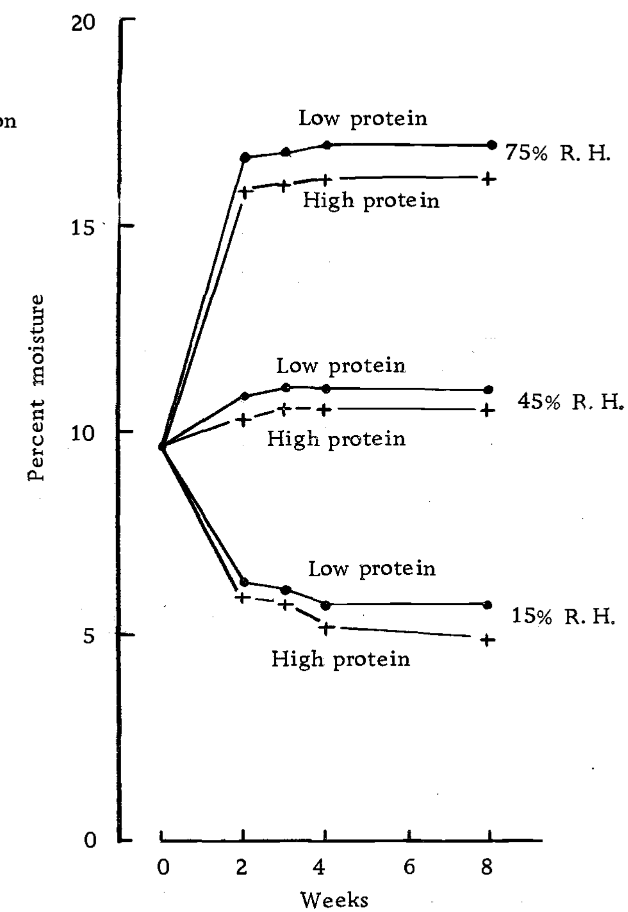

Figure 14. Effect of seed protein content on equilibrium moisture content of Yamhill wheat Lot A.

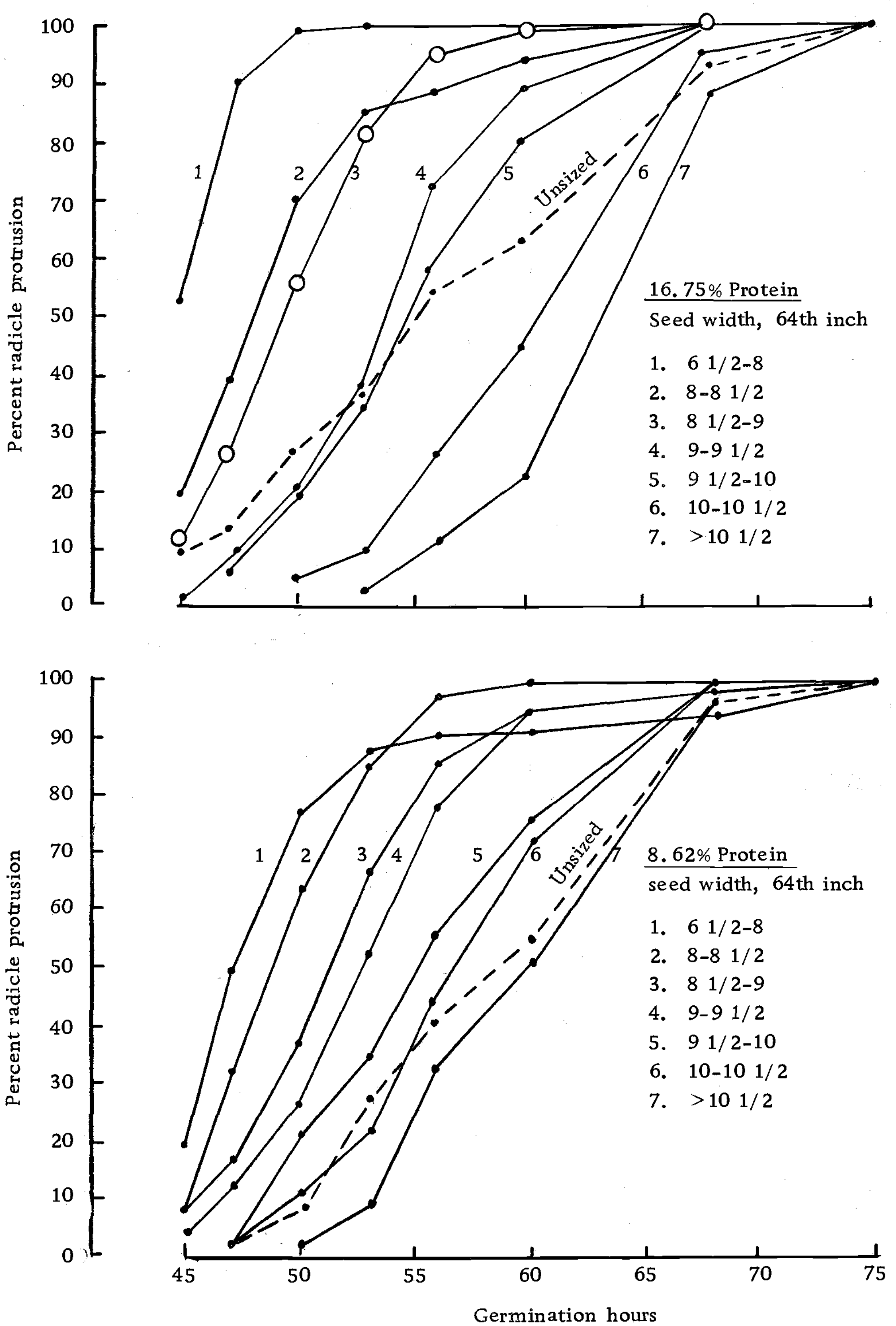

Figure 15. Effect of seed protein content and seed size on speed of radicle protrusion in Yamhill wheat Lot A.

of organelles and enzymes, breakdown of reserves and translocation of soluble substrates to developing seedling may have been earlier. Once germination started, the smaller-seeded samples reached total germination in a shorter time than the larger-seeded lots.

Regardless of size and protein level, all seed samples reached 100% germination. This is in agreement with results presented by Beyer (1973). He reported that germination was the same for different seed sizes in sorghum. Sheek and Fetzer (1950) and Kamal (1953) reported higher germination for high protein seeds. Semeniuk (1964), on the other hand, reported higher germination for low protein seeds. These differences may have been due to other unknown factors. Deterioration, lodging and sprouting on the head before harvesting, dormancy, etc. could have been some possible reasons. Many reports support the concept that current year seeds will germinate equally well regardless of seed protein concentration or seed size.

When compared at one germination age, small seeds of high protein content germinated faster than small seeds of low protein content. On the other hand, the large seeds of high protein content germinated slower than large seeds of low protein content.

Speed of Germination under Moisture Stress. The effect of seed sizes within high and low protein seeds on the speed of germination at several osmotic potentials are presented in Figure 16. Radicle protrusion was delayed with increasing moisture stress. When

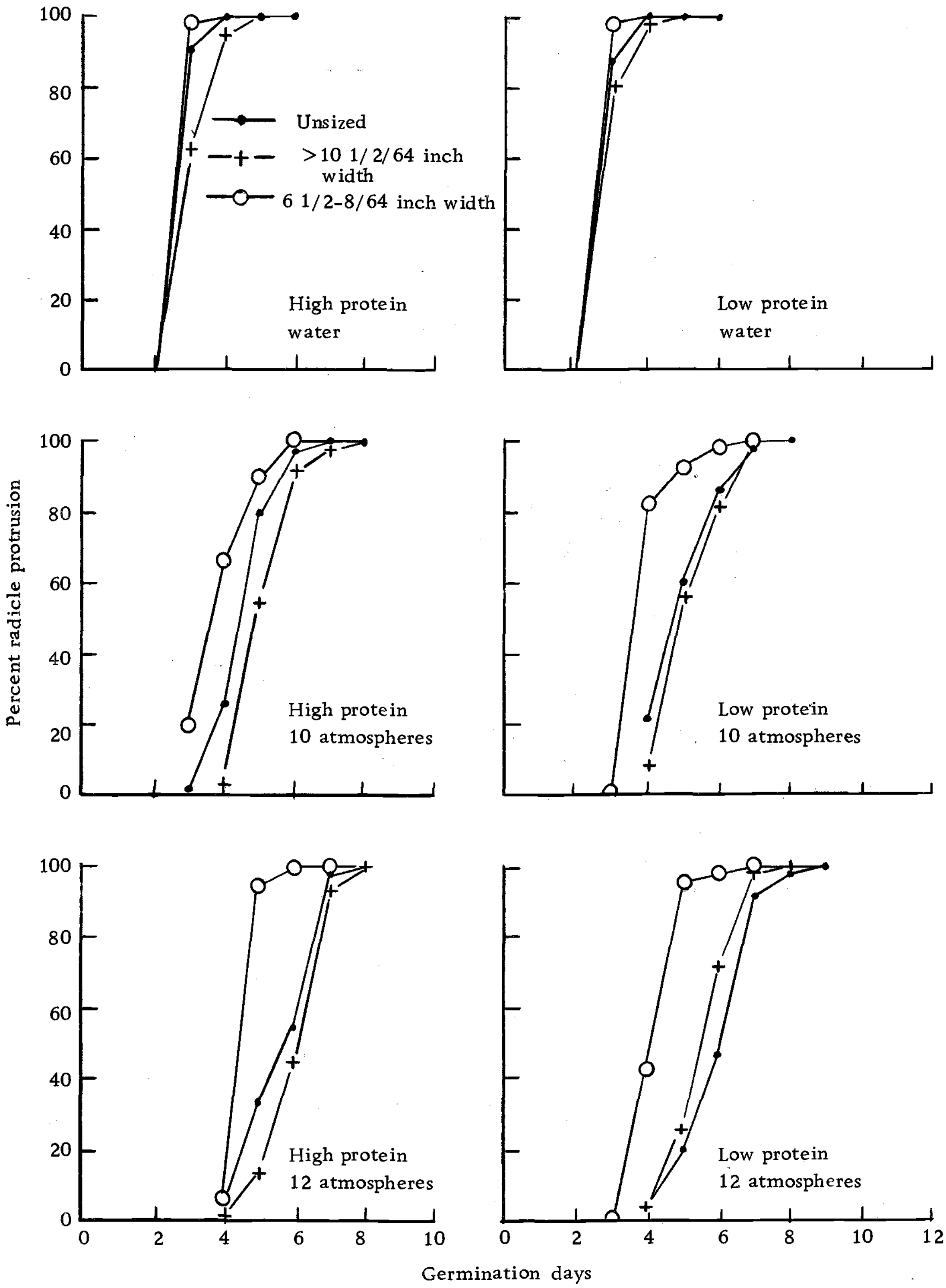

Figure 16. Effect of seed protein content and seed size on percent radicle protrusion of Yamhill wheat Lot A seeds under osmotic pressures. (continued on next page)

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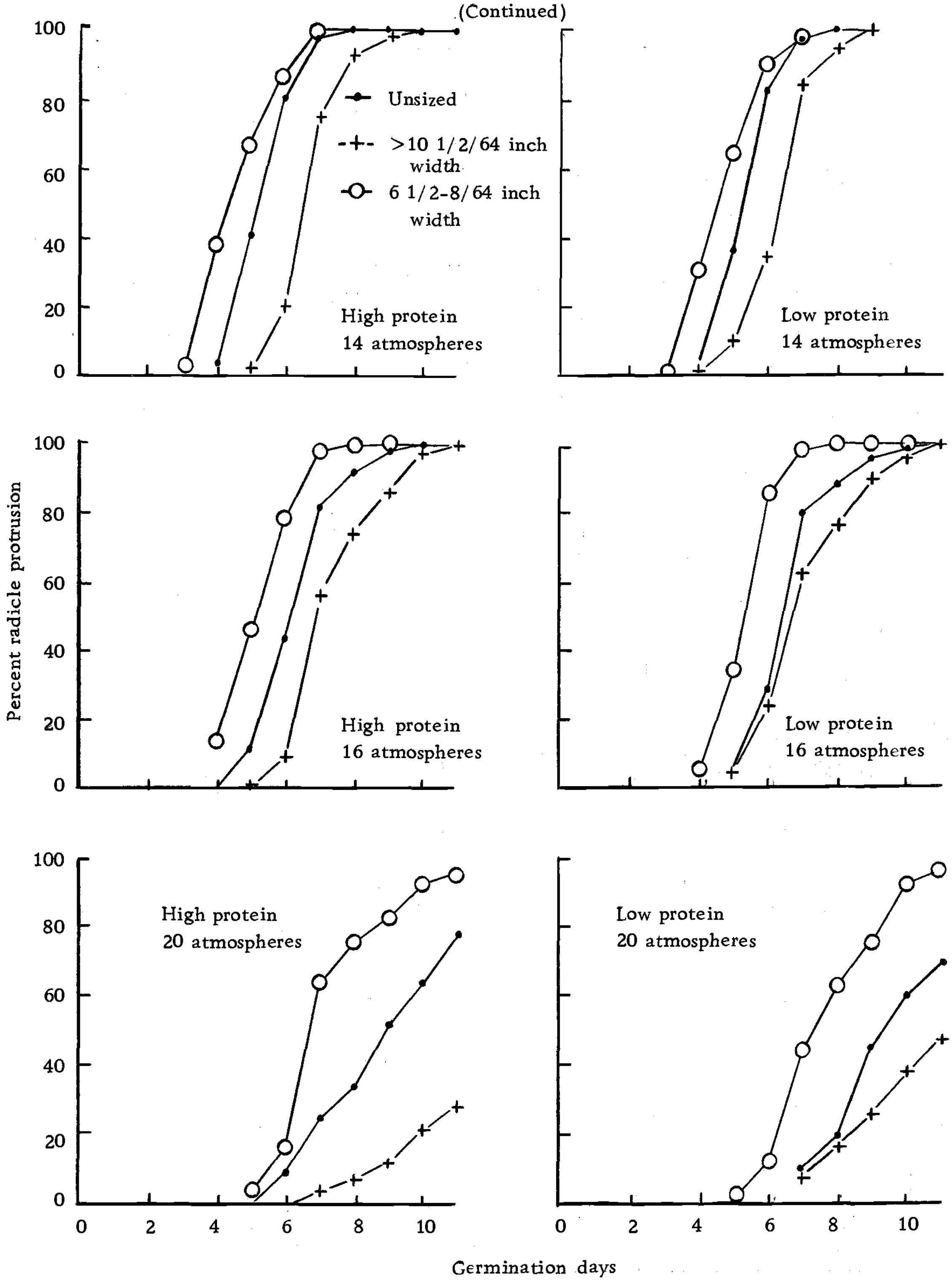

Figure 16. Effect of seed protein content and seed size on percent radicle protrusion of Yamhill wheat Lot A under osmotic pressures.

enough time was allowed, every seed class reached 100% germination. This is in agreement with results obtained by Wiggans and Gardner (1959) who reported that increasing osmotic concentrations progressively delayed germination, but total germination percentage was not reduced in radish and sorghum.

Regardless of protein level, the germination of small seeds was faster than germination of ungraded seeds, which in turn was faster than germination of large seeds. The difference in germination speed between seed sizes was greater with increased moisture stress. These results are in agreement with results reported by Harper and Benton (1966) who showed that small seeds were less sensitive than large seeds to moisture stress.

Food Reserve Translocation from Endosperm to Developing Seedlings

The rates of food reserve translocation in seven seed sizes within high and low protein seeds are presented in Table 10. Regardless of the protein content, the smaller seeds showed faster translocation of substrates than larger seeds. This could be attributed partly to the faster germination and faster breakdown of substrates caused by earlier activation of enzymes. The faster translocation confirms the accepted knowledge that smaller seeds run out of substrates sooner.

For comparable seed sizes and comparable germination age, food reserves were translocated faster from high protein seeds than from low protein seeds, especially after six days. The absolute amount of reserve translocated to the seedling, however, was directly related to seed size and protein content (Table 11). Seedlings from larger seeds started from larger embryos and showed higher dry weight than the next smaller seed sizes. This was consistent within high and low protein seeds.

There has been a belief that when seeds are planted in the field the amount of reserve would not be so important, because seedlings would photosynthesize right after emergence. This belief also implied that a large portion of reserve food in large seeds would be wasted. It should not be forgotten that in many wheat growing areas, it takes a considerably long time for emergence, due to unavailable moisture, low temperatures, compaction, deep planting, etc. Under these situations, the seeds with greater quality and quantity of food reserves will perform better. Even after emergence, the seedling may still depend on reserves in the seed, as Cooper and McDonald (1970) have demonstrated. Working with corn, they found that endosperm utilization and growth rates were similar in light and dark until the two leaf stage (ten days after germination). Further, photosynthesis was negligible until this stage in spite of abundant light.

Table 10. Effect of seed protein content and seed size on rate of substrate translocation from endosperm to root-shoot axis of Yamhill wheat Lot A.

Crude protein	Seed width	Germination, days									
		1	2	3	4	5	6	7	8	10	12
%	64th inch	Dry weight of root-shoot axis/root-shoot + caryopses, %									
16.75	> 10 1/2	2.44	3.22	3.37	6.40	10.32	15.09	28.63	33.75	49.50	61.74
8.62	> 10 1/2	2.74	3.31	3.95	7.40	11.31	--	26.23	31.81	47.91	60.20
16.75	10-10 1/2	2.45	3.25	4.29	6.99	11.00	18.30	30.39	34.93	51.50	65.04
8.62	10-10 1/2	2.78	3.62	4.64	9.30	12.90	17.84	26.86	34.27	50.00	65.15
16.75	9 1/2-10	2.54	3.56	4.80	6.94	14.84	20.16	34.30	38.26	58.64	70.31
8.62	9 1/2-10	2.56	3.48	5.20	9.35	11.57	18.98	31.16	37.21	53.54	63.97
16.75	9-9 1/2	2.67	3.15	6.00	8.67	16.41	20.04	37.14	41.90	59.56	80.00
8.62	9-9 1/2	2.69	3.60	6.22	9.45	15.60	20.76	30.89	38.55	50.33	75.23
16.75	8 1/2-9	3.15	4.59	5.95	11.76	19.22	23.58	42.60	45.74	69.13	85.00
8.62	8 1/2-9	2.70	3.69	5.43	9.73	18.17	23.40	37.15	43.25	59.23	75.00
16.75	8-8 1/2	3.37	4.88	6.92	12.87	24.00	28.75	54.20	55.59	75.51	88.00
8.62	8-8 1/2	2.65	4.15	6.26	13.38	21.21	27.81	41.29	45.14	59.38	76.92
16.75	6 1/2-8	3.60	6.10	8.91	12.63	29.45	38.78	52.57	72.65	83.98	90.00
8.62	6 1/2-8	3.06	4.68	6.90	13.60	22.83	31.15	38.88	44.60	64.29	76.74

Table 11. Effect of seed protein content and seed size on dry weight increase of root-shoot axis of Yamhill wheat Lot A.

Crude protein	Seed width	Germination, days										
		0	1	2	3	4	5	6	7	8	10	12
%	64th inch	Dry weight of root-shoot axis, mg										
16.75	> 10 1/2	1.12	1.40	1.91	1.94	3.62	5.79	8.03	14.28	16.24	21.60	24.50
8.62	> 10 1/2	1.21	1.46	1.74	2.11	3.84	5.88	--	12.84	14.71	20.01	23.10
16.75	10-10 1/2	1.16	1.28	1.73	2.31	3.16	5.33	8.73	13.63	15.01	20.31	25.90
8.62	10-10 1/2	1.12	1.40	1.75	2.26	4.60	5.98	8.28	12.14	14.87	18.61	24.34
16.75	9 1/2-10	1.14	1.33	1.70	2.20	3.20	6.49	8.69	13.32	14.91	19.34	22.60
8.62	9 1/2-10	1.10	1.21	1.57	2.26	2.44	5.14	7.56	12.05	14.81	18.99	21.35
16.75	9-9 1/2	.96	1.15	1.57	2.30	3.73	6.55	7.67	12.19	1 .59	17.40	21.70
8.62	9-9 1/2	1.14	1.05	1.42	2.00	3.64	5.73	7.53	10.23	12.89	15.16	20.60
16.75	8 1/2-9	.94	1.15	1.59	2.09	4.06	6.38	7.54	12.18	13.34	17.18	19.80
8.62	8 1/2-9	1.00	.97	1.27	1.87	3.26	5.71	7.28	11.33	11.84	15.27	17.67
16.75	8-8 1/2	.72	.97	1.37	1.87	3.94	6.54	8.11	14.45	13.06	15.48	17.85
8.62	8-8 1/2	.92	.79	1.23	1.85	3.91	6.16	7.33	10.70	11.11	12.66	15.80
16.75	6 1/2-8	.62	.85	1.22	2.05	3.39	6.26	7.68	9.81	11.77	12.38	13.95
8.62	6 1/2-8	.72	.70	1.07	1.57	3.15	4.94	5.90	7.56	7.38	11.85	12.41

Emergence and Coleoptile Length

Emergence. The emergence of seeds of seven sizes and four protein levels from three planting depths is presented in Table 12. The high protein seeds and small seeds showed faster emergence from 2 and 6 cm planting depths. No differences between seed protein levels and seed sizes were found in total emergence at the 2 and 6 cm depths. At the 12 cm planting depth, a more stressed situation, the high protein seeds and the larger seeds showed greater total seedling emergence.

Coleoptile Length. The effects of protein levels and seed sizes on coleoptile length are presented in Figure 17. The high protein seeds and the larger seeds showed longer coleoptiles than low protein seeds and smaller seeds. These results help to explain why high protein seeds and larger seeds showed greater total emergence at deeper plantings. Inouye et al. (1970), working with naked barley and intermediate wheatgrass, reported increased coleoptile length for larger seeds.

Seedling Growth in Germination Towels

The effects of protein levels and seed sizes on root and shoot growth rates in germination towels are presented in Table 13. Growth of roots and shoots was directly related to the protein content and

Table 12. Effect of seed protein content and seed size on speed of emergence and total emergence of Yamhill wheat Lot A from three planting depths.

Crude protein	2 cm		6 cm		12 cm	
	Initial*	Total	Initial	Total	Initial	Total
%			Effect of protein, averaged over seed sizes			
8. 62	22. 85b	95. 08	77. 71ab	94. 94	71. 42b	84. 38b
11. 87	23. 19b	92. 46	72. 19b	92. 46	73. 61b	85. 52ab
14. 93	25. 71ab	92. 37	73. 42b	92. 28	82. 66a	90. 66a
16. 75	41. 23a	94. 28	84. 00a	94. 08	83. 04a	90. 66a
H. S. S. 05	13. 76		6. 25		5. 88	4. 68
H. S. D. 01	16. 93		7. 69		7. 24	5. 76
Seed width, 64th inch			Effect of seed sizes, averaged over protein levels			
>10 1/2	13. 50b	93. 16	59. 00b	93. 16	74. 16ab	90. 66ab
10-10 1/2	27. 50ab	91. 16	75. 66a	90. 82	80. 00ab	92. 16a
9 1/2-10	30. 16ab	96. 24	81. 16a	95. 81	80. 83ab	91. 33ab
9-9 1/2	21. 66ab	92. 66	80. 33a	92. 66	84. 83a	91. 66ab
8 1/2-9	40. 00a	93. 99	78. 50a	93. 99	77. 33ab	87. 00ab
8- 8 1/2	27. 91ab	92. 64	79. 83a	92. 66	75. 50ab	83. 50b
6 1/2-8	37. 00ab	94. 99	83. 33a	94. 99	71. 16b	74. 83c
H. S. D. 05	21. 01		9. 55		8. 98	7. 15
H. S. D. 01	25. 11		11. 41		10. 73	8. 54
C. V. %	59. 20		9. 89		9. 20	6. 51

Means followed by the same letter do not differ at the . 01 level of significance by H. S. D. (Honestly significant difference, Tukey's Test).
*Initial count for 2 cm was made at 4 days; for 6 cm, at 5 days; and for 12 cm, at 7 days from planting.

Table 13. Effect of seed protein content and seed size on root and shoot growth rate of Yamhill wheat Lot A. Seeds germinated in paper towels.

		Roots			Shoots		
Crude protein	Seed width	3-day root length	10-day root length	Growth rate	3-day shoot length	16-day shoot length	Growth rate
%	64th inch	cm	cm	cm/day	cm	cm	cm/day
8.62	Unsized	1.88	26.85	3.56	.42	25.58	1.93
11.87	Unsized	2.22	27.60	3.62	.44	25.79	1.94
14.93	Unsized	2.63	28.67	3.72	.49	27.98	2.11
16.75	Unsized	2.58	27.72	3.59	.49	29.37	2.22
8.62	> 10 1/2	2.14	25.53	3.34	.45	26.08	1.97
8.62	9-9 1/2	2.48	25.62	3.30	.54	25.54	1.93
8.62	6 1/2-8	2.53	21.80	2.75	.59	23.33	1.74
16.75	> 10 1/2	1.34	28.34	3.86	.29	29.40	2.24
16.75	9-9 1/2	2.61	28.47	3.69	.54	29.36	2.21
16.75	6 1/2-8	3.35	24.12	2.96	.66	24.46	1.83

seed size. For comparable seed sizes, the high protein seeds showed greater root and shoot growth rate than low protein seeds. These results are in agreement with the current knowledge that larger seeds and high protein seeds have a greater growth rate.

Seedling Growth in Greenhouse

Effect of Protein Content. The effect of protein levels on the width and length of first leaf, plant height, fresh and dry weight of shoots, and dry weight of roots is presented in Table 14. Although plants were irrigated with complete Hoagland's solution (which contains 30 mM nitrate), seedlings from the high protein seeds showed wider and longer first leaf, greater fresh and dry weight of shoots and greater dry weight of roots than the low protein seeds two weeks after planting. Differences were found at the .01 level. No statistical difference in plant height was found, but high protein seeds produced taller plants.

Differences in seedling growth disappeared after three weeks. One possible reason for this may have been the limiting and confined environment inside the gallon cans. This does not indicate that differences could also disappear in the field.

Effect of Protein and Seed Size. The effect of protein content and seed size on plant height is presented in Figure 18, on length and width of first leaf in Figure 19, on fresh weight of shoots in

Table 14. Effect of seed protein content on plant growth of Yamhill wheat Lot A in the greenhouse. Plants were irrigated with complete Hoagland solution.

Crude protein	2 weeks from planting						3 weeks from planting					
	First leaf		Plant	Shoot	Shoot	Root	First leaf		Plant	Shoot	Shoot	Root
	Width	Length	height	Fresh wt.	Dry wt.	Dry wt.	Width	Length	height	Fresh wt.	Dry wt.	Dry wt.
%	mm	cm	cm	-------- g/20 plants		--------	mm	cm	cm	----- g/20 plants		-----
8.62	4.00b	11.08B	33.50	6.39B	.80b	.29bc	4.20b	11.30B	40.50	19.35	2.56	1.04
11.87	4.57ab	11.59AB	33.50	6.01B	.86ab	.28c	4.33ab	11.48AB	40.50	18.75	2.43	.98
14.93	4.60ab	11.98AB	36.25	7.36AB	1.01ab	.39ab	4.63ab	12.65A	40.50	20.24	2.68	1.15
16.75	4.70a	12.64A	36.50	8.40A	1.12a	.42a	4.68a	12.20AB	40.00	19.48	2.72	1.09
H.S.D.05	.51	1.28	15.71	1.91	.23	.07	.34	1.30	12.51	4.10	.40	.32
H.S.D.01	.69	1.73	21.18	2.58	.31	.10	.45	1.75	26.31	6.35	.54	.43
C.V. %	5.18	4.93	20.35	12.30	11.02	9.38	3.41	4.92	21.90	10.95	7.03	13.54

Means followed by the same letter do not differ at the .01 level of significance by H.S.D. (Honestly significant difference, Tukey's Test). Means followed by the same capital letter do not differ at the .05 level of significance.

Figure 20, on dry weight of shoots in Figure 21, and on dry weight of roots in Figure 22.

This study was done to learn whether seed protein content and seed size could have an additive effect on plant growth.

Although plants were irrigated with complete Hoagland's solution, the plant height, length and width of first leaf, fresh and dry weight of shoots and dry weight of roots was greater as seed protein content and seed size increased. These results are in agreement with results presented by Ries and Everson (1973). They reported that seedling vigor (dry weight of shoots) was better correlated with amount of protein per seed. In their study, Hoagland's nutrient solution containing 3 mM nitrate was applied ten days after planting. As a consequence, if seed protein concentration can be increased by adequate N supply to the mother plant, and if seeds could be sized and only the larger seeds planted, the plant producing ability of the seeds could be improved. These differences can be traced back to higher quality and quantity of substrates, and to higher energy content for biosynthesis.

Plant height and fresh and dry weight of shoots was also studied under irrigation with Hoagland-N. In absence of N, difference in plant growth was relatively easier to detect, with high protein seeds and larger seeds showing better growth (Figures 18, 20, and 21). This type of comparison is only of academic importance, since crop

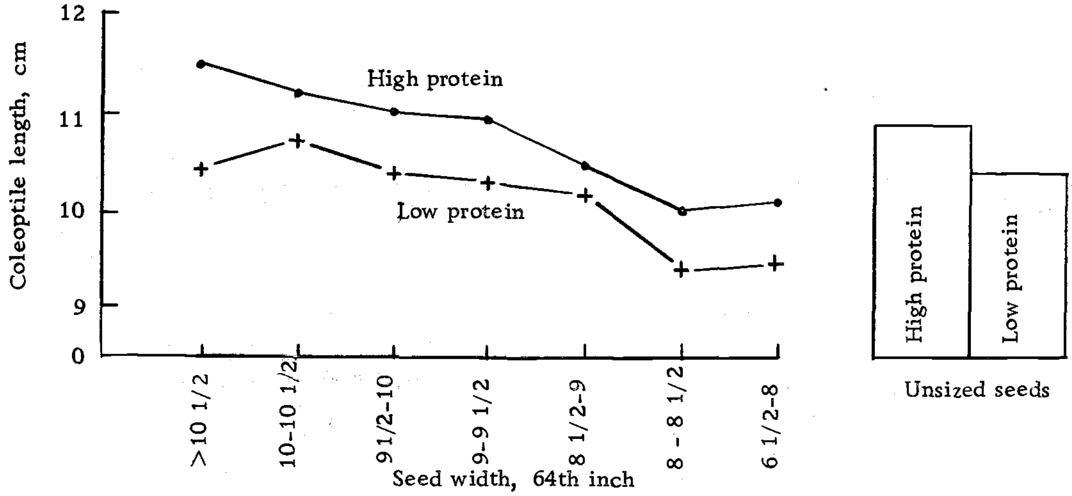

Figure 17. Effect of seed protein content and seed size on coleoptile length of Yamhill wheat Lot A. 12 cm planting depth.

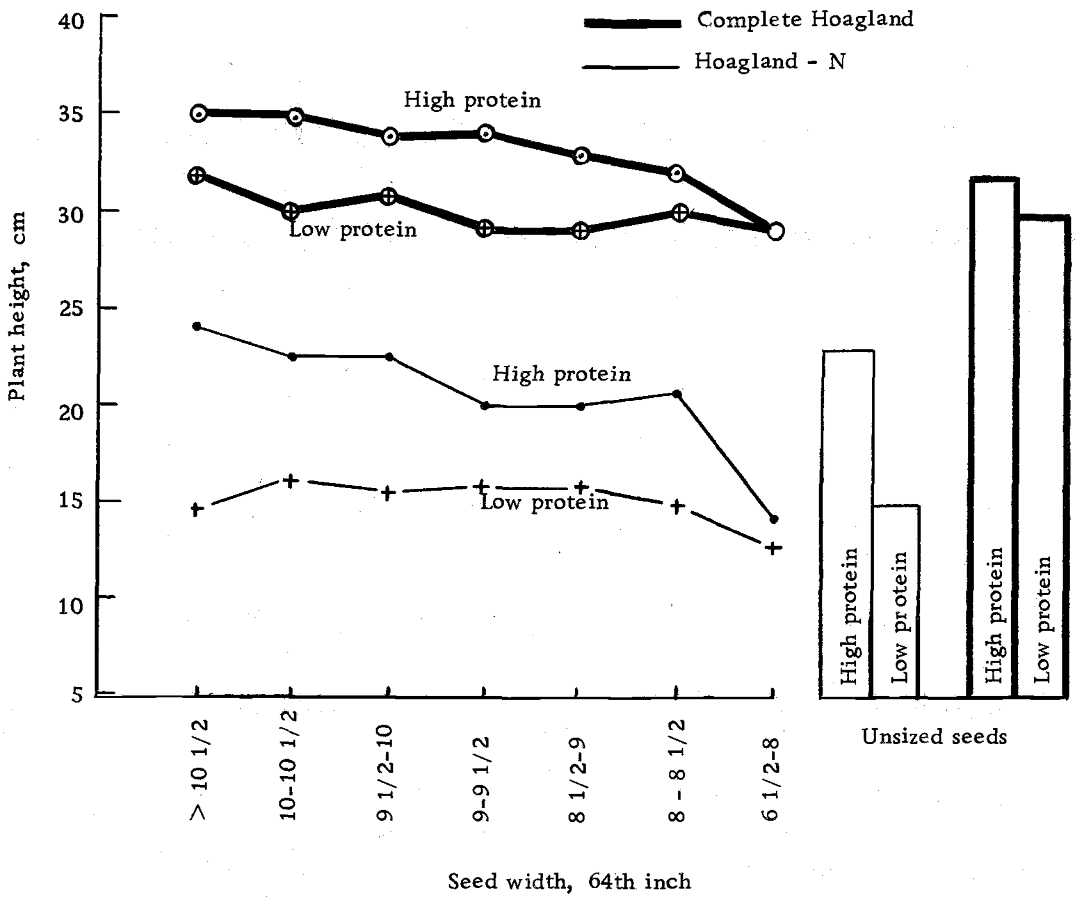

Figure 18. Effect of seed protein content and seed size on plant height of Yamhill wheat Lot A two weeks after planting.

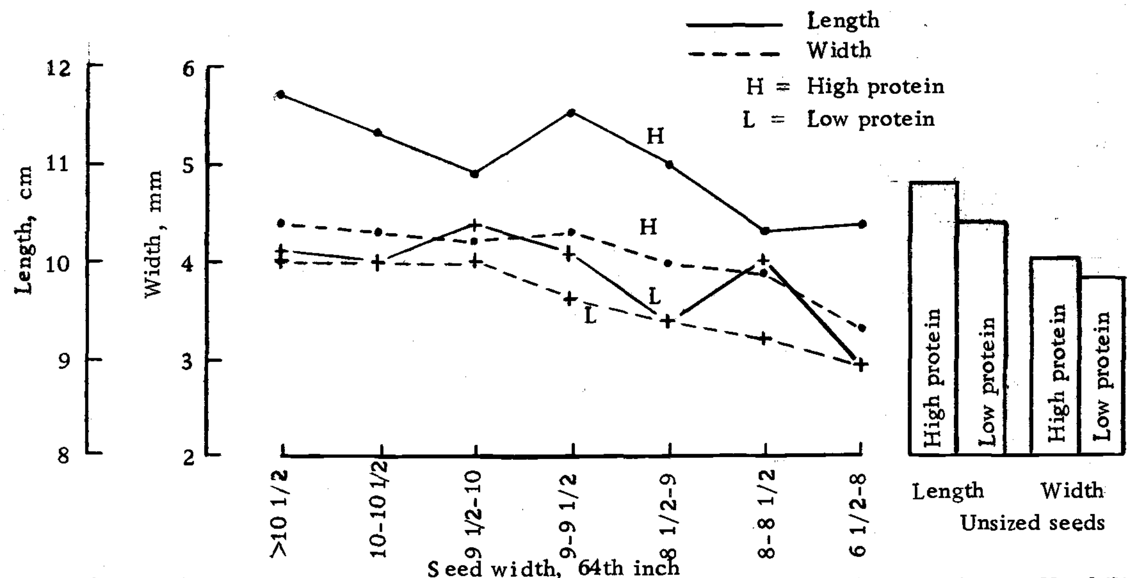

Figure 19. Effect of protein content and seed size on length and width of first leaf of Yamhill wheat Lot A two weeks after planting. Plants were irrigated with complete Hoagland.

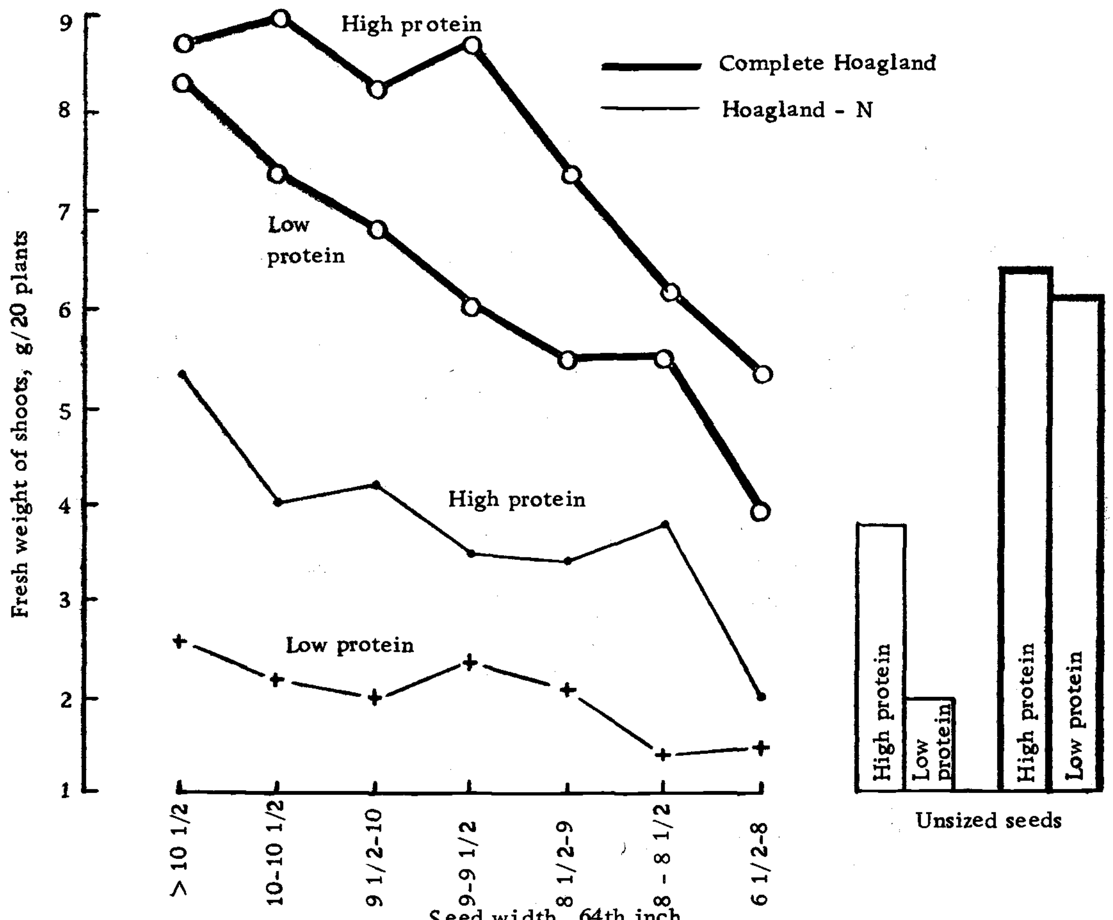

Figure 20. Effect of protein content and seed size on fresh weight of shoots of Yamhill wheat Lot A two weeks after planting.

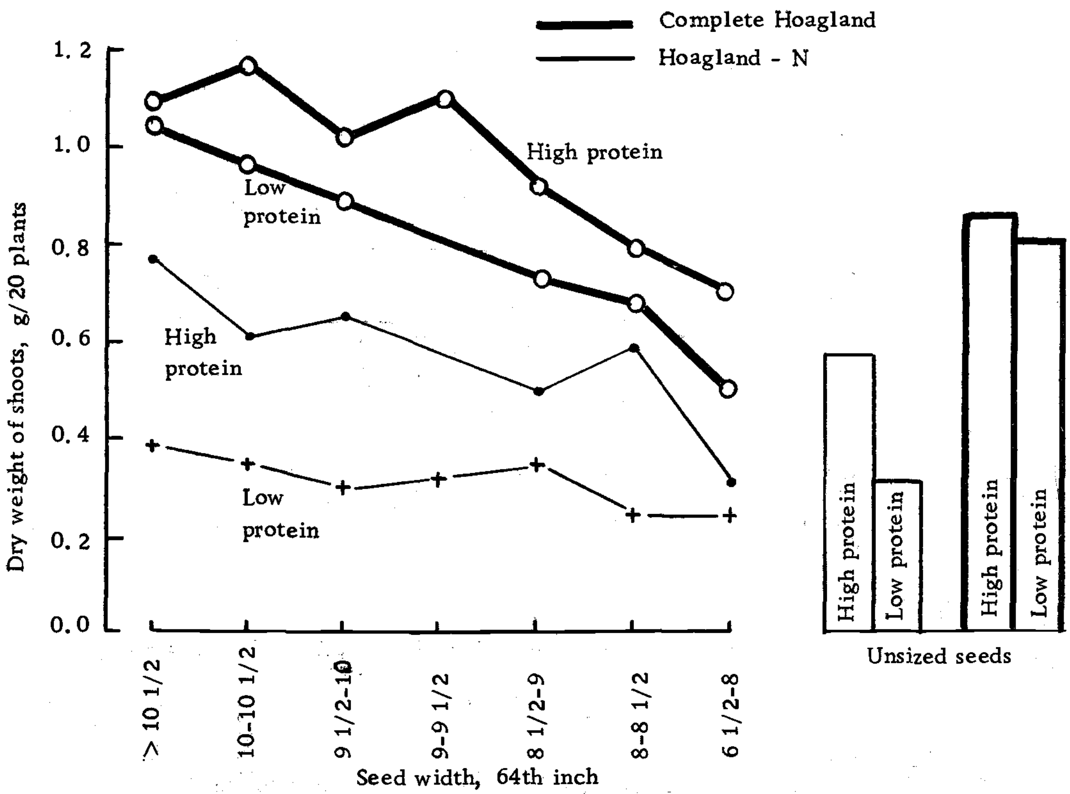

Figure 21. Effect of protein content and seed size on dry weight of shoots of Yamhill wheat Lot A two weeks after planting.

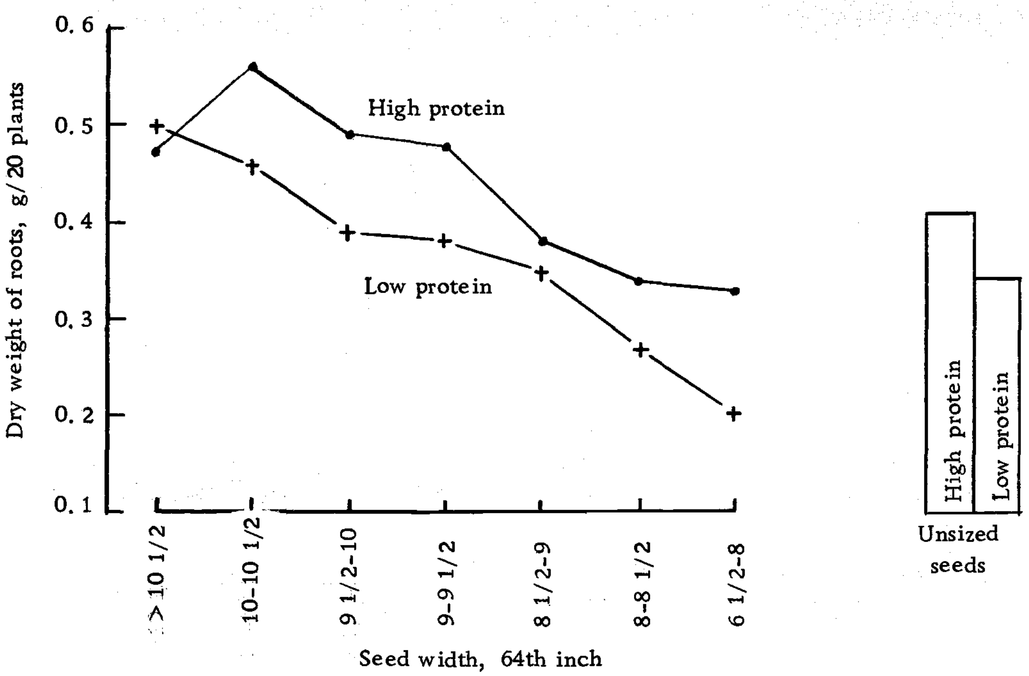

Figure 22. Effect of protein content and seed size on dry weight of roots of Yamhill wheat Lot A two weeks after planting. Plants were irrigated with complete Hoagland.

production is not practiced in the absence of N.

Effect of Protein Content on Yield

The effect of seed protein levels on yield of Hyslop, Paha and two lots of Yamhill under two N fertilization rates is presented in Figure 23.

When averaged over varieties and seed protein content, the yield was 3, 225 kg/ha without N fertilization compared to 8, 177 kg/ha when 120 kg N/ha was applied.

No difference in yield due to seed protein content was found when N was not applied; on the other hand, high protein seeds produced greater yield than low protein seeds when N was applied. The increase in yield due to protein content ranged from 11% in Hyslop to 18% in Yamhill Lot A. The average over cultivars showed 7, 606, 8, 303 and 8, 625 kg/ha of grain yield for low, intermediate and high protein seeds. Differences were present at the . 01 level. The difference found is a true effect of seed quality, since the same number of plants per unit area was maintained. Unfortunately no attempt was made to evaluate yield components. However, in the spring and up until heading, plants from high protein seeds were greener and more vigorous.

These results are in agreement with results reported by Schweizer and Ries (1969) in oats; Ries (1971) in beans, and

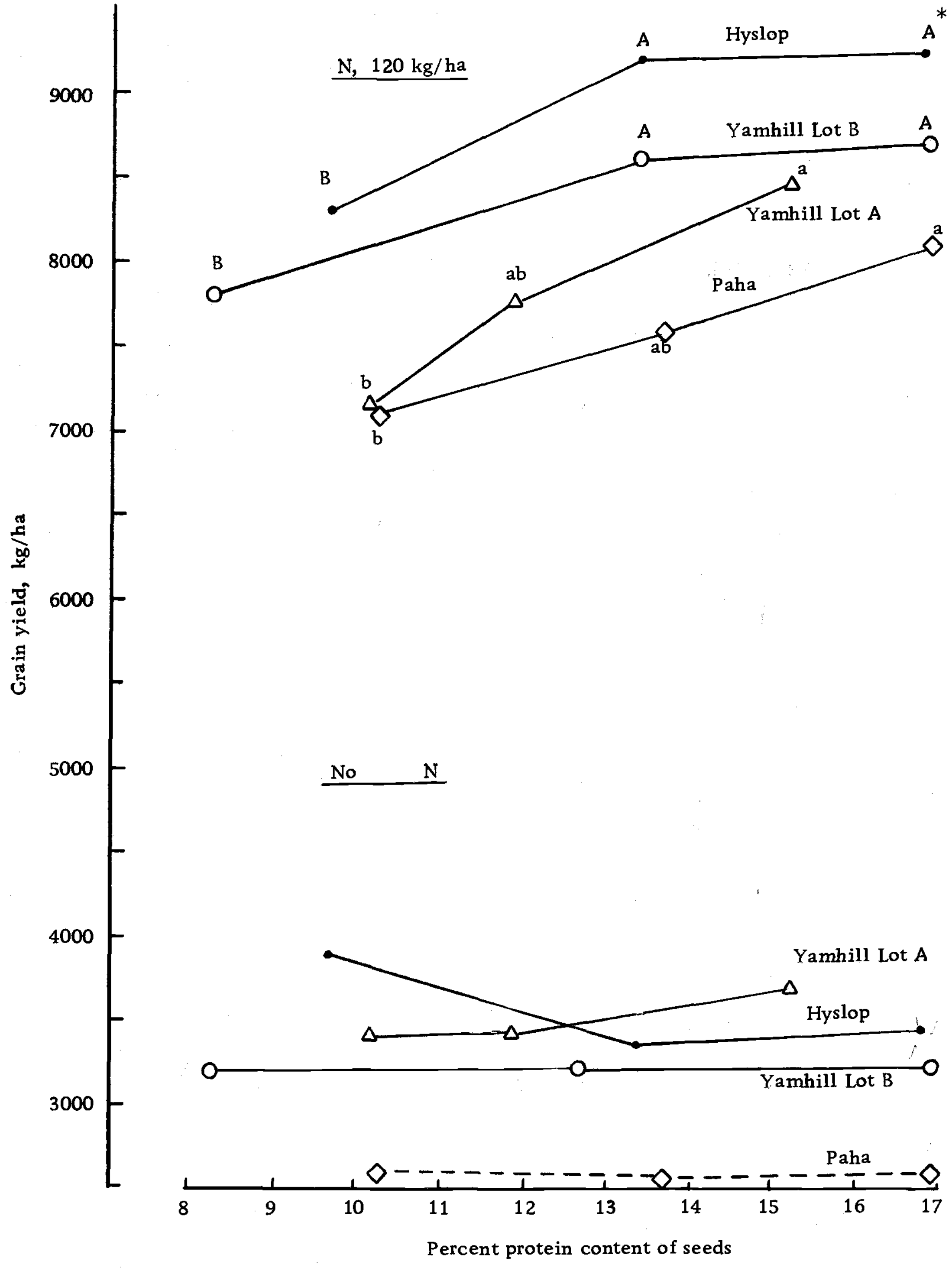

Figure 23. Effect of seed protein content on yield of wheat under two N rates.

*Within each cultivar or seed lot, means followed by same small letters are not different at the .01 level, means followed by same capital letters are not different at the .05 level of significance by H. S. D. (Tukey's Test).

Ries _et al._ (1970) in wheat, where higher protein seeds produced greater yields. In wheat, Ries _et al._ (1970) found yield improvements with high protein seeds in Genesee winter wheat and Inia spring wheat, and Ciano spring wheat with no added N, but not with Ciano spring wheat in Mexico at 120 kg N/ha. Unfortunately, in these studies the planting rate was not reported, hence it is not known whether yielding ability of the same number of plants was compared.

The higher yielding ability of high protein seeds under adequate N supply only, was of considerable interest. It is speculated that when N is lacking in the soil for plant growth, the difference in plant biosynthetic ability could not be expressed in productivity. This speculation may also explain the frequent lack of response to planting rate and more strikingly the failure of high yielding varieties to outyield the poor yielding varieties when N is not supplied at optimum rates. In other words, the higher efficiency of genes or the higher functional biochemical and physiological machinery would not be expressed in higher yield if essential substrates such as N-containing solubles are limiting the biosynthetic ability of plants.

GENERAL DISCUSSION

Ther are many kinds of proteins in seeds. One group involves storage proteins, which provide substrates for the synthesis of functional proteins in seedlings. A second group includes pre-existing enzymes, structural proteins and factors conserved from the maturation period, all of which are activated upon hydration. A third group involves proteins that influence the genetic program or developmental patterns of the seed. Histones and acidic chromosomal proteins are in this last group.

No information was obtained in this study about the changes in the relative quantities of the various proteins in these seeds. However, the storage proteins were increased by N applications and any other N-containing compounds such as nucleotides and coenzymes may also have been affected. A suggestion of changes in addition to the quality of food reserves comes from recent work by Timmis and Ingle (1973) who found heritable changes caused by successive N applications in flax. The nucleus of large flax genotrophs (of greater plant weight) produced by successive N fertilization contained 16% more DNA than normal. The increased DNA was associated with increased number of copies of ribosomal RNA genes.

While increasing seed protein content, N also affected other biochemical seed quality components and the relative ratio of starch to protein. It was of interest that high protein seeds contained a greater amount of free amino acids and only slightly less soluble sugars than low protein seeds. These solubles are pre-existing from the maturation period. It is speculated that in a high quality wheat seed the starch to protein ratio should be low, although from this study it is not possible to identify what the optimum ratio would be. In Yamhill, this ratio was about 3 in the highest quality seed and about 6 in the lowest quality seed. The ratio is important because storage protein will provide substrates to synthesize functional proteins and energy producing machinery, while starch will provide sugars for respiration, to energize the system, and to provide the carbon backbone for synthesis of cell components. After the ratio of all the biochemical compounds is fixed by adequate N supplied to the mother plant, the average amount of each compound per seed could be increased by using sizing screens to discard the smaller seeds.

Embryos from high protein seeds showed a greater free amino acid content, greater protein concentration and a greater amount of protein. Furthermore, embryos from high protein seeds showed a better adenylate energy status. This indicates that the quality of embryos, and not only the storage protein compounds, is improved by adequate N fertilization. It is of particular importance that embryos from high protein seeds contained more ATP, ADP, energy charge, free amino acids and soluble sugars than embryos from low protein seeds. These substrates and energy would be immediately available for biosynthesis of enzymes to break down storage compounds and to produce cell structures during the early stages of germination.

The higher vigor of seedlings from high protein seeds may be explained partially by the increased availability of soluble sugars and free amino acids in the seedlings, together with more high-energy phosphate bonds available for biosynthesis. Further, the rate and net translocation of food reserves to developing seedlings was greater. Availability of soluble sugars may become limiting in seedlings from small seeds regardless of seed protein content, and the free amino acid content may become limiting in seedlings from low protein seeds regardless of seed size. This was noticeable three or four days after planting.

Low availability of soluble sugars and free amino acids was reflected in a lower adenylate energy status of seedlings. The adenylate content is the result of many biochemical pathways of synthesis and utilization, and a high content indicates efficient synthesis and represents only what is left after its use for energy-requiring biosynthesis. High adenylate content also reflects better organellar machinery as indicated by McDaniel (1969). He reported that seedlings produced from heavier seeds showed a greater proportion of mitochondrial protein, which was indicative of a higher respiratory rate and a greater amount of energy (ATP) production in barley. High protein wheat seeds also have a higher rate of oxygen consumption during germination (Lopez, 1972).

The greater yielding ability of high protein seeds is related to the greater biosynthetic ability of these seeds as indicated by the greater adenylate energy status of their seedlings. Increased yielding ability of high protein seeds was also reported by Schweizer and Ries (1969), Ries (1971) and Ries et al. (1970). These results should encourage the use of high protein seeds for planting purposes. However, more research is still needed to develop economical and efficient ways of increasing seed protein content.

Our results indicate that high protein seeds from a specific location may produce higher yields than low protein seeds from that same location. It is recognized that seeds from different locations also vary in protein content, but modifying factors such as seed size, maturity, availability of mineral cofactors, degree of deterioration and handling during processing may mask the effect of protein content on yield. The effect of seed sources, seed protein content, and seed sizes are currently being investigated at Oregon State University, with special emphasis on the energy status of seedlings, seedling vigor, and yielding ability.

Seed size was used as one variable in comparing high and low protein seeds. The concentration of some biochemical and chemical substances changed with seed size. Within each protein level, the smaller seeds had a higher concentration of ash, some chemical elements, free amino acids and soluble sugars, probably indicating a degree of immaturity in spite of the seeds being allowed to develop under ideal moisture. Regardless of differences in concentration, the total amount of each compound was related to seed size and as a consequence, the high protein - large seeds gave seedlings with greater adenylate content, greater energy charge, and greater growth potential.

Seed size had an important influence on seedling performance. Regardless of protein concentration, the smaller seeds absorbed water at a faster rate and germinated faster. Seed protein content did not have a consistent effect on germination speed if equivalent sizes were compared. As a consequence, it is important to consider these modifying factors when comparing high and low protein seeds since high N rates frequently decrease seed size.

The seed size studies showed that the quality of food reserves is more important than seed size alone. The high protein - small seeds, which were shriveled and about 2. 7 times smaller than the low protein - large seeds, contained almost as much protein per seed, provided more free amino acids to seedlings, and contained almost as much ATP, ADP, and total AP. Lopez (1972) and Ries and Everson (1973) also showed that small seeds with high protein content produce seedlings with better performance than larger seeds with low protein content.

Results suggest that a high quality seed should be large and have a high protein concentration. Numerous studies have shown that larger seeds perform better than smaller seeds. For future studies on the effects of seed size to be more meaningful, the composition of the seed should be considered in conjunction with size.

These and other studies indicate the potential for improving the general quality of wheat seed by applying specialized management practices for seed production rather than managing as for grain production. Protein content may be increased without decreasing yield or seed size by applying split applications of N or combinations of soil and foliar applied N. An early application will insure a high yield and a second application at anthesis will insure a high protein content. The optimum timing and rates of soil and foliar applied N, as well as the effects of irrigation, still need to be determined. Adequate seed size may be maintained by a split application of N and sufficient moisture, and also by screening seed lots to remove the smaller seeds.

SUMMARY AND CONCLUSIONS

Applications of 150 and 300 kg N/ha increased the grain yield and protein yield per hectare, seed size, and percent and amount of protein per seed of Yamhill wheat.

N applications caused several biochemical changes in the food reserve of the seeds. These included increases in the amounts of gluten, each amino acid studied and free amino acids. The amount of soluble sugars decreased slightly and starch remained constant with high rates of N.

N also caused several biochemical changes in embryos. These included increases in: free amino acids and soluble sugars; protein concentrations and amount per embryo; ADP, ATP and energy charge. Regardless of protein concentration, the quantities of solubles and adenylate phosphates were higher in larger embryos.

Biochemical changes in seedlings associated with N applications and higher protein content included: more sugars and free amino acids; higher amounts of ATP, ADP and total AP; and faster rate and higher net translocation of food reserves.

Small seeds contained a higher concentration of ash, some mineral elements, soluble sugars and free amino acids. The total amount of these compounds per seed, however, was related to protein content and seed size.

The large seeds with high protein concentration produced seedlings with the highest ADP, ATP and total AP content, energy charge and growth potential.

Smaller seeds absorbed water and germinated faster than larger seeds. Seedlings from small seeds produced longer roots and shoots during the early stages of growth, but their growth rate was slower at later stages.

High protein seeds of Hyslop, Paha and Yamhill outyielded low protein seeds by 12 to 17%. Yield differences were obtained when N was added to the crop, but not in the absence of added N.

These and other studies indicate the potential for improving wheat seed and quality by applying specialized management practices for seed production rather than managing as for grain production.

BIBLIOGRAPHY

Abernethy, R. H., L. N. Wright, and K. Matsuda. 1973. Relationship of the adenylate energy charge to seed weight and seedling vigor of blue panicgrass (Panicum antidotale Retz.). Agron. Abstr. 1973. p. 18.

Abrol, Y. P. 1971. Soil fertilizer levels and protein quality of wheat grains. Aust. J. Agr. Res. 22:195-200.

Alsberg, C. D., and E. P. Griffing. 1934. Environment, heredity, and wheat quality. Stanford U. Food Res. Inst.: Wheat studies 10:229-249.

Altaf, A., T. M. Atkins, L. W. Rooney, and K. B. Porter. 1969. Kernel dimensions, weight, protein content and milling yield of grain from portions of the wheat spike. Crop Sci. 9:329-330.

Alten, F., and E. Schulte. 1942. The effect of fertilizers on the speed of germination of cereal grains. Chem. Abstr. 36:6332.

Ames, J. W., G. E. Boltz, and J. A. Stenius. 1912. Effect of fertilizers on the physical and chemical properties of wheat. Ohio Agr. Exp. Sta. Bul. 293. 22 p.

Atkins, R. E., G. Stanford, and L. Dumenil. 1955. Effect of nitrogen and phosphorus fertilizer on yield and malting quality of barley. J. Agr. Food Chem. 3:609-615.

Atkinson, D. E. 1968. The energy charge of the adenylate pool as a regulatory parameter. Interaction with feedback modifiers. Biochemistry 7:4034-4039.

Austenson, H. M., and P. D. Walton. 1970. Relationships between initial seed weight and mature plant characters in spring wheat. Can. J. Plant Sci. 50:53-58.

Austin, R. B. 1966a. The growth of watercress (Rorippa nasturtium aquaticum (L) Hayek) from seed as affected by the phosphorus nutrition of the parent plant. Plant and Soil 24:113-120.

Austin, R. B. 1966b. The influence of the phosphorus and nitrogen nutrition of pea plants on the growth of their progeny. Plant and Soil 243:359-368.

Austin, A., and R. K. Miri. 1961. Effect of nitrogen and irrigation on the protein and gluten content of some New Pusa wheats. Indian J. Plant Physiol. 4:150-155.

Baez. 1971. Investigation of protein content, yellow pigmentation, calorific value and yield of Triticum durum Desf. in Balcarce, Buenos Aires, Argentina. Revista de la Facultad de Agronomia, Universidad Nacional de la Plata. 47:1-18. (In Field Crop Abstr. 26:1541. 1973.)

Baker, G. O., and S. C. Vandecaveye. 1935. Effect of fertilizers, soil type and certain climatic factors on the yield and composition of oats and vetch. J. Agr. Res. 50:961-974.

Barber, S. A., and R. K. Stivers. 1963. Phosphorus fertilization of field crops in India-research prior to 1963. Ind. Agr. Expt. Sta. Res. Bul. 759. 28 p.

Barley, K. P. J. 1960-1961. Response of wheat varieties to applied nitrogen. Adelaide U. Waite Agr. Res. Inst. Rpt. p. 4.

Baroccio, A. 1961. Phenomenes de synergisme molybdene-potassium daus la nutrition potassique des plants. Phenomena of molybdenum-potassium synergism in the potassium nutrition of plants. Rome. Sta. Chim. Agr. Sper. Ann. 182:1-4.

Baumeister, W. 1939. The influence of mineral fertilization upon yield and composition of grain of spring wheat. Chem. Abstr. 33:3953.

Bayfield, E. G. 1936. The influence of climate, soil and fertilizers upon quality of soft winter wheat. Ohio Agr. Expt. Sta. Bul. 563. 77 p.

Beletskii, S. M., and L. G. Kovalev. 1969. (Seed size and yield). Selekts. Seme. nov. No. 4. 60-3 (Ru; Okl. Sel-skdkhoz. Opytn. Stan., Lugans K. USSR. (In Field Crop Abst. 23:5. 1970.)

Benchat, L. K., D. H. Smith, and C. T. Young. 1974. Effect of foliar fungicides on aflatoxin, oil and protein content and maturing rate of peanut kernels. Sci. Food and Agric. 25: 477-482.

Bennet, W. F., G. Stanford, and L. Dumeril. 1953. Nitrogen, phosphorus, and potassium content of the corn leaf and grain as affected by nitrogen fertilizer and yield. Proc. Soil Sci. Soc. Amer. 17:252-258.

Berecks, R. 1939. The influence of mineral fertilization upon the chemical composition of barley and oat grains. Chem. Abstr. 33:3952.

Beyer, D. 1973. Chemical and physiological properties of grain sorghum seed of different sizes. Agron. Abstr. 1973. p. 157.

Birecka, H., M. Wlodkowski, and J. Skupinska. 1962. Phosphorus metabolism in pea plants grown from seeds of different phosphorus content. Roezn. Nauk. Rol. Ser. A, Roslinna 85:29-46. (In Biol. Abstr. 41:11913. 1963.)

Black, J. N. 1957. The early vegetative growth of three strains of subterranean clover (Trifolium subterraneum L.) in relation to size of seed. Aust. J. Agr. Res. 8:1-14.

Black, J. N., and G. N. Wilkinson. 1963. The role of time of emergence in determining the growth of individual plants in swards of subterranean clover (Trifolium subterraneum). Aust. J. Agr. Res. 14:628-638.

Boatwright, G. O., and F. G. Viets, Jr. 1966. Phosphorus absorption during various growth stages of spring wheat and intermediate wheatgrass. Agron. J. 58:185-188.

Botkin, C. W. 1935. The protein and moisture content of wheat grown in New Mexico. New Mex. Agr. Exp. Sta. Bul. 230. 16 p.

Boyd, W. J. R., A. G. Gordon, L. J. LaCroix. 1971. Seed size, germination resistance and seedling vigor in barley. Can. J. Plant Sci. 17:93-99.

Bremmer, P. M., R. N. Eckersall, and R. K. Scott. 1963. The relative importance of embryo size and endosperm size in cuasing the effects associated with seed size in wheat. J. Agr. Sta. 61:139-145.

Burke, T. W. L. 1930. Studies of water absorption and germination with varieties of Triticum vulgare and T. durum). Sci. Agr. 10:369-388.

Campbell, A. R., and R. C. Pickett. 1968. Effect of nitrogen fertilization on protein quality and quantity and certain other characteristics of 19 strains of Sorghum bicolor (L). Crop. Sci. 8:545-547.

Chambers, S. C. 1963. Bare patch and poor emergence of cereals - factors under investigation. IV. Quality of the seed. West Austral. Dept. Agr. J. 4:230-232.

Chang, L. Y., and J. A. Robertson. 1968. Growth and yield of progeny of nitrogen and phosphorus fertilized barley plants. Can. J. Plant Sci. 48:57-66.

Chaplin, M. H., and A. R. Dixon. 1974. A method for analysis of plant tissue by direct reading spark emission spectroscopy. Applied Spectroscopy. 28(1):5-8.

Chapman, A. G., L. Fall, and D. E. Atkinson. 1971. The adenylate energy charge in E. coli during growth and starvation. J. Bact. 108:1072-1086.

Ching, T. M. 1972. Metabolism of germinating seeds. In T. T. Kozlowski (ed.). Seed biology II. 103-218. Acad. Press. N. Y.

Ching, T. M. 1973. Adenosine triphosphate content and seed vigor. Plant Physiol. 51:400-402.

Ching, T. M. 1974. Seed physiology laboratory guide. Associate professor of Agronomic Crop Science, Oregon State University, Corvallis, Oregon. 37 p.

Ching, T. M., and K. K. Ching. 1972. Contents of adenosine phosphate, and adenylate energy charge in germinating ponderosa pine seeds. Plant Physiol. 50:536-540.

Ching, T. M., and R. Danielson. 1972. Seedling vigor and adenosine triphosphate level of lettuce seeds. Proc. Assoc. Off. Seed Anal. 62:116-124.

Ching, T. M., and W. E. Kronstad. 1972. Varietal differences in growth potential, adenylate energy level, and energy charge of wheat. Crop Sci. 12:785-789.

Chmeleva, Z. V., S. L. Tyuterev, and M. I. Rudenko. 1972. Protein and lysine contents in high-quality wheats. Byulleten' Vsesyuznogo Ordena Lenina Instituta Rastenievodstva im N. I. Vavilova. No. 24:42-45 (Ru). Leningrad USSR. (In Field Crops Abstr. 1052. 1973.)

Christian, C. S., and S. G. Gray. 1935. Interplant competition in mixed wheat population and its relation to single plant selection. J. Council Sci. Ind. Res. (Australia) 8:1-7.

Coic, Y., G. Fancanean, R. Pion, F. Busson, Ch. Lesaint, and F. Labone. 1963. Influence of mineral nutrition on the composition of cereal grain protein (wheat and barley). Ann. Physiol. Veg. 5:281-292.

Cooper, C. S., and P. W. McDonald. 1970. Energetics of early seedling growth in corn (Zea mays L.). Crop Sci. 10:136-139.

Croy, L. T., and R. H. Hageman. 1970. Relationship of nitrate reductase activity to grain protein production in wheat. Crop Sci. 10:280-285.

Cruz, L. J., G. B. Cagampang, and B. O. Juliano. 1970. Biochemical factors affecting protein accumulation in the rice grain. Plant Physiol. 46:743-747.

Currah, I. E., and P. J. Salter. 1973. Some combined effects of size grading and "hardening" seed on the establishment, growth, and yield of four varieties of carrots. Ann. Bot. 37:709-719.

Das Gupta, P. R., and H. M. Christensen. 1971. Interrelationships among seed vigor standard yield in wheat. Agron. Abstr. 1971. p. 42.

Davidson, J. 1922. The effect of nitrates applied at different stages of growth on the yield, composition and quality of wheat. J. Am. Soc. Agron. 14:118-122.

Davidson, J., and J. A. LeClerc. 1923. Effect of various inorganic nitrogen compounds, applied at different stages of growth, on the yield, composition, and quality of wheat. J. Agr. Res. 23: 55-68.

Day, A. D., and M. A. Barmore. 1971. Effects of soil moisture stress on the yield and quality of flour from wheat (Triticum aestivum L.). Agron. J. 63:115-116.

Demirlicakmak, A., M. L. Kaufmann, and L. P. V. Johnson. 1963. The influence of seed size and seeding rate on yield and yield components of barley. Can. J. Plant Sci. 43:330-337.

Dungan, G. H. 1924. Some factors affecting the water absorption and germination of seed corn. J. Amer. Soc. Agron. 16:473-481.

Eck, H. V., and B. A. Stewart. 1954. Wheat fertilization studies in western Oklahoma. Oklahoma Agr. Exp. Sta. Bul. B 432. 16 p.

Eck, H. V., B. B. Tucker, and A. M. Schlehuber. 1963. Influence of fertilizer treatments on yield, grain protein, and heading dates of five wheat varieties. Agron. J. 55:556-558.

Edward, C. J., Jr., and E. E. Hartwig. 1971. Effect of seed size upon rate of germination in soybeans. Agron. J. 63:429-430.

Edwards, I. B., R. C. Frohberg, and E. L. Deckard. 1973. Nitrate reductase activity and nitrogen translocation in conventional height and semidwarf spring wheat varieties. Agron. Abstr. 1973. p. 32.

Ellis, J. R. S., and A. D. Hanson. 1974. Tests for cereal yield heterosis based on germinating seeds. A warning. Euphytica 23:71-77.

Evans, H. J. and S. Russell. 1964. The role of minerals in plant metabolism and the relationship of mineral nutrition to plant composition. University of Kentucky Tobacco and Health Workshop Proceedings, 1964. 63-83.

Evans, H. J. and G. J. Sorger. 1966. Role of mineral elements with emphasis on the univalent cations. Ann. Rev. Plant Physiol. 17:47-75.

Ewald, E., and G. Wenzel. 1967. Effect of N fertilization on protein and amino acid content of wheat grain. Qualitas Pl. Mater. veg. 14:98-104. (In Field Crop Abstr. 20:1525. 1967.)

Feather, J. T., C. O. Qualset, and H. E. Vogt. 1968. Planting depth critical for short-statured wheat varieties. Calif. Agr. 22:12-14.

Fernandez, R. G., and R. J. Laird. 1959. Yield and protein content of wheat in Central Mexico as affected by available soil moisture and nitrogen fertilization. Agron. J. 51:33-36.

Finlayson, A. J., C. M. Christ, and R. K. Downey. 1970. Changes in the nitrogenous components of rape seed (Brassica napus) grown on a nitrogen and sulfur deficient soil. Canad. J. Plant Sci. 50:705-709.

Finney, K. F., J. W. Meyer, F. W. Smith, and H. C. Fryer. 1957. Effect of foliar spraying of Pawnee wheat with urea solutions on yield, protein content, and protein quality. Agron. J. 49: 341-347.

Fitzgerald, P. J., F. H. Siddoway, and J. V. Mannering. 1958. The effect of nitrogen fertilization on yield and quality of hard red winter wheats grown on dryland in southern Idaho. P. N. W. F. C. 9:21028.

Freeney, J. R. 1965. Increased growth and uptake of nutrients by corn plants treated with low levels of simazine. Aust. J. Agr. Res. 16:257-263.

Fuehring, H. D. 1969. Irrigated wheat on a calcareous soil as affected by application of nitrogen, phosphorus, potassium, and zinc. I. Yield, composition, and number of heads. Agron. J. 61:591-594.

Gassi, S., J. L. Tikoo, and S. K. Banerjee. 1973. Changes in protein and methionine content in the maturing seeds of legumes. Seed Res. 104-106.

Geiszler, G. N., and B. K. Hoag. 1967. Wheat seed size influences yield. N. Dak. Farm Rev. 24(11):12-14.

Ghaderi, A., E. H. Everson, and W. T. Yamazaki. 1971. Test weight in relation to the physical and quality characteristics of soft winter wheat (T. Aestivum L.) Crop Sci. 11:515-518.

Gomez, K. A., and S. K. DeDatta. 1973. Protein yield of rice in relation to environmental and cultural practices. Agron. Abstr. 1973. p. 190.

Goodchild, N. A., and M. G. Walker. 1971. A method of measuring seed germination in physiological studies. Ann. Bot. 35:615-621.

Gordon, A. G. 1971. The germination resistance test - a new test for germination quality of cereals. Can. J. Plant Sci. 51:181-183.

Grabe, D. F. 1973. Components of seed vigor and their effects on plant growth and yield. Seed World 111(7):4, 6, 8, 9.

Guidy, M. M., C. A. Lamb, and R. C. Burrell. 1957. Influence of variety, fertilizer treatment, and soil on the protein content and mineral composition of wheat, flour and flour fractions. Cereal Chem. 34:185-195.

Gunthardt, H., and J. McGinnis. 1957. Effect of nitrogen fertilization on amino acids in whole wheat. J. Nutr. 61:167-176.

Gupta, Y. P., and N. B. Das. 1956. The quality of wheat as affected by manures and fertilizers. II. Thiamine, riboflavin and niacin contents. J. Indian Soc. Soil Sci. 4:121-126.

Hadas, A. 1970. Factors affecting seed germination under soil moisture stress. Israel J. Agr. Res. 20:3-14.

Haikerwal, M., and A. R. Mathieson. 1971. The protein content and amino acid composition of sorghum grain. Cereal Chem. 48:690-699.

Hamid, A. 1972. Efficiency of N uptake by wheat, as affected by time and rate of application, using N^{15}-labeled ammonium sulfate and sodium nitrate. Plant and Soil 37:389-394.

Hanumaiah, L., and C. H. Andrews. 1973. Effect of seed size in cabbage and turnip on performance of seeds, seedlings and plants. Proc. Assoc. Offi. Seed Anal. 63:117-125.

Hanway, J. J., and C. R. Weber. 1971. Accumulation of N, P and K by soybean (Glycine max L. Merrill) plants. Agron. J. 63:406-408.

Harper, J. L., and R. A. Benton. 1966. The behaviour of seeds in soil, part 2, the germination of seeds, on the surface of a water supplying substrate. J. Ecol. 54:151-166.

Harper, J. L., and M. Obeid. 1967. Influence of seed size and depth of sowing on the establishment and growth of varieties of fibre and oil seed flax. Crop Sci. 7:527-532.

Harper, J. E., and G. M. Paulsen. 1967. Changes in reduction and assimilation of nitrogen during the growth cycle of winter wheat. Crop Sci. 7:205-209.

Harrington, J. F. 1960. Germination of seeds from carrot, lettuce and pepper plants grown under severe nutrient deficiencies. Hilgardia 30:219-235.

Hatfield, A. L. 1961. Effect of time and rate of application of ammonium nitrate on wheat. Ky. Agr. Expt. Sta. Annu. Rept. 74. 23 p.

Hatfield, A. L. 1961. Source, rate, particle size, and time of application of nitrogen for wheat under field conditions. Ky. Agr. Expt. Sta. Annu. Rept. 74. 22 p.

Haunold, A., V. A. Johnson, and J. W. Schmidt. 1962. Variation in protein content of grain in four varieties of T. aestivum L. Agron. J. 54:121-125.

Hepburn, F. N., and W. B. Bradley. 1965. The amino acid composition of hard wheat varieties as a function of nitrogen content. Cereal Chem. 42:140-149.

Hewitt, E. H., E. W. Bolle-Jones, and P. Miles. 1954. The production of copper, zinc and molybdenum deficiencies in crop plants with special reference to some effects of water supply and seed reserves. Plant and Soil 5:205-222.

Hill, K. W. 1964. Protein content of wheat as affected by agronomic practices. Can. J. Plant Sci. 44:115-122.

Hojjati, S. M., and M. Maleki. 1972. Effect of potassium and nitrogen fertilization on lysine, methionine, and total protein contents of wheat grain (T. aestivum L. em Thell). Agron. J. 64:46-48.

Hoseney, R. C., and K. F. Finney. 1967. Free amino acid composition of flours milled from wheats harvested at various stages of maturity. Crop Sci. 7:3-5.

Hough, H. W., L. I. Painter, P. C. Singleton, J. R. Partridge, M. E. Fischer, and W. D. Anderson. 1962. Summary of fertilizer studies conducted in Wyoming during 1961. Wyo. Agr. Expt. Sta. Mimeo C 172. 13 p.

Hough, H. W., L. I. Painter, P. C. Singleton, J. R. Partridge, W. G. Jones, and J. W. Swartz. 1963. Summary of fertilizer studies conducted in Wyoming during 1962. Wyo. Agr. Expt. Sta. Mimeo C 182. 13 p.

Hucklesby, D. P., C. M. Brown, S. E. Howell, and R. H. Hageman. 1971. Late spring application of nitrogen for efficient utilization and enhanced production of grain and grain protein of wheat. Agron. J. 63:274-276.

Huffaker, R. C., M. D. Miller, K. G. Baghott, F. L. Smith, and C. W. Schaller. 1967. Effect of field application of 2, 4-D and iron supplements on yield and protein content of wheat and barley and yield of beans. Crop Sci. 7:17-19.

Humbert, R. P. 1963. Potassium and water economy of plants. A definite report. Better Crops Plant Food. 47:24-27, 32-37.

Hunt, O. J., and D. G. Miller. 1965. Coleoptile length, seed size, and emergence in intermediate wheatgrass (Agropyron intermedium (Host) Beauv). Agron. J. 57:192-195.

Hunter, A. S., C. J. Gerard, H. M. Waddoups, W. E. Hall, H. E. Cushman, and L. A. Alban. 1958. The effect of nitrogen fertilizers on the relationship between increases in yields and protein content of pastry-type wheats. Agron. J. 50:311-314.

Hunter, A. S., C. J. Gerard, H. M. Waddoups, W. E. Hall, H. E. Cushman, and L. A. Alban. 1961. Fertilizer needs of wheat in the Columbia Basin dryland wheat area of Oregon. Ore. Agr. Exp. Sta. Tech. Bul. 57. 60 p.

Ingle, J., D. Beitz and R. H. Hageman. 1965. Changes in composition during development and maturation of maize seeds. Plant Physiol. 40:835-839.

Inouye, J., H. Seko and K. Ito. 1970. Studies on the seedling emergence in crops. Effects of soil moisture content and seed size on the strength of plumule elongation in naked barley plants. Proc. Crop Sci. Soc. Japan 39:41-45.

Iwata, M., and Y. Eguchi. 1958. Effects of phosphorus and potassium supplied for the various stages of growth, on the yield and quality of seeds of Cjinese cabbage. J. Hort. Assoc. Japan 27:171-178.

Jackson, E. T. 1962. Use of carbowaxes (Polyethylene Glycols) as osmotic agents. Plant Physiol. 37:513-519.

Janssen, J. G. 1973. A method of recording germination curves. Ann. Bot. 37:705-708.

Johnson, V. A., P. J. Mattern, and J. W. Schmidt. 1967. Nitrogen relations during spring growth in varieties of T. aestivum L. differing in grain protein content. Crop Sci. 7:664-667.

Jones, R. W., and R. J. Dimler. 1962. Electrophoretic composition of glutens from air-classified flour. Cereal Chem. 39:336-340.

Kamal, S. 1953. The influence of protein level of the grain on germination, plant vigor and grain yield in four varieties of hard red winter wheat. M. S. thesis. Oklahoma State University. 33 numb. leaves.

Kamal, M. A. M., M. I. Naguib, and F. Y. Refai. 1956. Carbohydrate fractions in different varieties of Egyptian wheat kernels with reference to the influence of some fertilizer treatments and locations. Ann. Agric. Sci. 1:95-110. (In Biol. Abstr. 35: 5493, 1960.)

Kashirad, A. 1970. Effect of nitrogen, zinc, copper and manganese on yield and chemical composition of irrigated winter wheat in Iran. The Israel. Agr. Res. 20:179-182.

Kaufman, M. R., and K. J. Ross. 1970. Water potential temperature and kinetin effects on seed germination in soil and solute systems. Hort. Abstr. 41:128. 1971.

Kaufmann, M. L. 1958. Seed size as a problem in genetic studies of barley. Proc. Genetics Soc. Can. 3:30-32.

Kaufmann, M. L., and A. A. Guitard. 1967. The effect of seed size on early plant development in barley. Can. J. Plant Sci. 47:73-78.

Kaufmann, M. L., and A. D. McFadden. 1963. The influence of seed size on results of barley yield trials. Can. J. Plant Sci. 43:51-58.

Keeney, D. R. 1969. Potassium boosts corn grain quality. Better Crops Plant Food 53:22-23.

Keller, W., and A. T. Bleak. 1970. Factors influencing water absorption by seeds of the crested wheatgrass complex. Crop Sci. 10:422-425.

Khadr, F. H. 1970. Seed weight, seed dimensions and protein content from portions of the wheat spike. Alexandria Agr. Res. 241-244. (In Field Crops Abstr. 26:1049. 1973).

Khera, M. S., H. C. Kapoor, and Y. P. Gupta. 1972. Critical available soil phosphorus level of Indian soils in relation to protein quality of wheat. Agr. J. 64:406-407.

Kiesselbach, T. A. 1924. Relation of seed size to yield in small grain crops. J. Amer. Soc. Agron. 16:670-682.

Kiesselback, T. A., and W. E. Lyness. 1954. Growing the winter wheat crop. Nebr. Agr. Exp. Sta. Bul. 389. 32 p.

Kittock, D. L., and A. G. Law. 1968. Relationship of seedling vigor to respiration and tetrazolium chloride reduction by germinating wheat seeds. Agron. J. 60:286-288.

Klages, M. G., and C. A. Watson. 1958. The effect of fertilizer on bread wheat quality. P. N. W. F. C. 9:29-34.

Kneebone, W. R., and C. L. Cremer. 1955. The relationship of seed size to seedling vigor i some native grass species. Agron. J. 47:472-477.

Knott, D. R., and B. Talukdr. 1971. Increasing seed weight in wheat and its effect on yield, yield components, and quality. Crop Sci. 11:280-283.

Koehler, F. E. 1961. Fertilizer and wheat quality. P. N. W. F. C. 12:73-78.

Krieg, D. R., R. G. Stevens. 1974. Chemical composition of sorghum grain as influenced by nitrogen fertilization. Agron. Abstr. 1974. p. 106.

Lal, K. N., and G. Prashad. 1947. Studies in crop physiology. Growth characters and seed quality in wheat as influenced by nitrogen, phosphoric acid, and potash. Proc. Nat. Acad. Sci. India 17B(2):83. (In Biol. Abstr. 26:4316. 1952).

Lamb, C. A. 1967. Physiology. In K. S. Quisenberry and L. P. Reitz (eds.). Wheat and wheat improvement. Agronomy series of monographs 13. p. 211.

Lang, R. W., and J. C. Holmes. 1964. The growth of the swede crop in relation to seed size. J. Agr. Sci. 63:221-227.

Langer, R. H. M., and F. K. Y. Liew. 1973. Effects of varying nitrogen supply at different stages of the reproductive phase on spikelet and grain production and on grain nitrogen in wheat. Aus. J. Agr. Res. 24:647-656.

Larsen, I., and J. D. Nielsen. 1966. The effect of varying nitrogen supplies on the content of amino acids in wheat grain. Plant and Soil 24:299-308.

Larter, E. N., and J. Whitehouse. 1958. A study of yield and protein response of malting barley varieties to different fertilizers. Can. J. Plant Sci. 38:430-439.

Laude, H. H., and A. W. Pauli. 1956. Influence of lodging on yield and other characteristics in winter wheat. Agron. J. 48:432-455.

Lindstrom, M. J., and F. E. Koehler. 1973. A model to predict emergence of winter wheat (Triticum aestivum L.) based on soil temperature, water potential and depth of coverage. Agron. Abstr. 1973. p. 125.

Littler, J. W. 1967. Nitrogen raises sorghum yield and protein. Queensland Agr. J. 93:193-196.

Lipsett, J. 1963. Factors affecting the occurrence of mottling in wheat. Aust. J. Agr. Res. 14:303-314.

Long, O. H., and J. A. Ewing. 1949. Fertilizer studies on small grains with special emphasis on time and rate of nitrogen applications. Tenn. Ag. Exp. Sta. Bul. 209. 21 p.

Long, O. H., and C. D. Sherbakoff. 1951. Effect of nitrogen on yield and quality of wheat. Agron. J. 43:320-321.

Lopez, A. 1972. Effect of seed protein content on plant growth of barley and wheat. M. S. thesis. Oregon State University, Corvallis, Ore. 87 numb. leaves.

Lowe, L. B., S. K. Ries. 1972. Effects of environment on the relation between seed protein and seedling vigor in wheat. Can. J. Plant Sci. 42:157-164.

Lowe, L. B., and S. K. Ries. 1973. Endosperm protein of wheat seed as a determinant of seedling growth. Plant Physiol. 51: 57-60.

Lowe, L. B., G. S. Ayers, and S. K. Ries. 1972. The relationship of seed protein and amino acid composition to seedling vigor and yield of wheat. Agron. J. 64:608-611.

Lucena, Coude, F., and L. Sanchez de la Puente. 1963. La influencia de la fertilizacion en la composicion mineral de la planta cultivada en dieciseis suelos tipicos de la provincia de Salamanca. Interacceones nitrogeno, fosforo, potasio. Agrochimica F: 226-235.

Mack, A. R. 1973. Influence of soil temperature and moisture conditions on protein production of Manitou and two semidwarf Mexican spring wheats. Can. J. Plant. Sci. 53:721-735.

MacLeod, A. M. 1969. The utilization of cereal seed reserves (Plant metabolism, barley). Sci. Progr. (London) 57:99-112.

Makrushin, M. M. 1969. (Dependence of photosynthetic activity of winter wheat plants on seed size.) Peredgirne to gips'ke zemlerokstvo i tvarinnitstvo. Resp. mixhvid. Temat. nauk. 2b. 7:36-41) (In Field Crop Abstr. 24:1592. 1971.)

Mangels, C. E. 1927. Pre-harvest factors that affect wheat quality. Cereal Chem. 4:376-388.

McCalla, A. G. 1933. The effect of nitrogen nutrition on the protein and protein nitrogen of wheat. Can. J. Res. 9:542-570.

McDaniel, R. G. 1969. Relationship of seed weight, seedling vigor and mitochondria metabolism in barley. Crop Sci. 9:823-827.

McDermott, E. E., and J. Pace. 1960. Comparison of amino acid composition of the protein on flour and endosperm from different types of wheat with particular reference to variation in lysine content. J. Sci. Food Agric. 11:109-115.

McGregor, J. M., L. T. Taskowitch, and W. P. Martin. 1961. Effect of nitrogen fertilizer and soil type on the amino acid content of corn grain. Agron. J. 53:211-214.

McNeal, F. H., and M. A. Berg. 1960. The evaluation of spring wheat seed from different sources. Agron. J. 52:303-304.

McNeal, F. H., M. A. Berg, P. L. Brown, and C. F. McGuire. 1971. Productivity and quality response of five spring wheat genotypes (_T. aestivum_ L.) to nitrogen fertilizer. Agron. J. 63:908-910.

McNeal, F. H., and D. J. Davis. 1954. Effect of nitrogen fertilization on yield, culm number and protein content of certain spring wheat varieties. Agron. J. 46:375-378.

McNeal, F. H., and D. J. Davis. 1966. Protein content of wheat kernels from different parts of the spike. Agron. J. 58:635-636.

Measures, M., and P. Weinberger. 1973. Effect of an audible sound frequency on total amino acids and major free alcohol-soluble amino acids of Rideon wheat grains. Can. J. Plant Sci. 53:737-742.

Michael, G. 1963. Effect of fertilization on protein quality and protein fractions of food plants. Qualities Plant Mater. Veg. 5:248-265.

Michalczyk, J. 1972. (Effect of 2, 4-D and atrazine on the amino acid and protein content of spring barley grain.) Bioletyn

Institutu Hodowli i Aklimatyzacji Roslin 1, 2:3-6. (In Field Crop Abstr. 26:1605. 1973)

Mikessell, M. E., and G. M. Paulsen. 1971. Nitrogen translocation and the role of individual leaves in protein accumulation in wheat grain. Crop Sci. 11:919-922.

Miller, E. C. 1939. A physiological study of the winter wheat plant at different stages of its development. Kans. Ag. Exp. Sta. Tech. Bul. 47. 167 p.

Miller, L. B., and F. C. Bauer. 1944. Soil treatments for winter wheat: a summary of field experiments. Ill. Ag. Exp. Sta. Bul. 503. 211 p.

Moore, S., D. H. Spackman and W. H. Stein. 1958. Chromatography of amino acids are sulphonated polystyrene resins. An improved system. Anal. Chem. 30:1185-1190.

Morrison, K.,J., P. E. Reisenauer, F. M. Entenmann and A. Suderland. 1973. Effect of seed size on the yield of Nugaines wheat. Agron. Abstr. 1973. p. 165.

Mortenson, W. B., and A. S. Baker. 1973. Black kernel. A discoloration of sweetcorn related to excessive sulfur fertilization. Agron. Abstr. 1973. p. 107.

Morton, R. K., and J. K. Raison. 1964. The separate incorporation of amino acids into storage and soluble proteins catalyzed by two independent systems isolated from developing wheat endosperm. Biochem. J. 91:528-538.

Morton, R. K., J. K. Raison, and J. R. Smeaton. 1964. Enzymes and ribonucleic acid associated with the incorporation of amino acids into proteins of wheat endosperm. Biochem. J. 91:539-546.

Neals, T. F., M. J. Anderson, and I. F. Wardlaw. 1963. The role of the leaves in the accumulation of nitrogen by wheat during ear development. Aust. J. Agr. Res. 14:725-736.

Nerson, H., and Z. Karchi. 1972. A comparative study of soil versus foliar application of ammonium nitrate to wheat under different moisture regimes. Israel J. Agr. Res. 22:171-177.

Norden, A. J., E. C. Rossman, and E. J. Benne. 1952. Some factors that affect protein content of corn. Mich. Ag. Exp. Sta. Quart. Bul. 35:210-225.

Olsen, R. A., and H. F. Rhoades. 1953. Commercial fertilizers for winter wheat in relation to the properties of Nebraska soils. Nebr. Ag. Exp. Sta. Res. Bul. 172. 84 p.

Ozanne, P. G., and C. J. Asher. 1965. The effect of seed potassium on emergence and root development of seedlings in potassium deficient sand. Aust. J. Agr. Res. 16:773-784.

Parmar, M. T., and R. P. Moore. 1968. Carbowax 6000, manitol, and sodium chloride for simulating drought conditions in germination studies of corn (Zea mays L.) of strong and weak vigor. Agron. J. 60:192-195.

Patrick, R. M. 1971. Protein and amino acid content of rice as affected by environmental modifications. Dissertation Abstracts International. B. 32:2783 (In Field Crop Abst. 26: 2165. 1973.)

Patrick, R. M., F. H. Hoskins, E. Wilson, and F. J. Peterson. 1974. Protein and amino acid content of rice as affected by application of nitrogen fertilizer. Cereal Chem. 51:84-95.

Patterson, H. B. 1952. Effect of nitrogen fertilizer on yield and protein content of winter wheat in Utah. Utah Agr. Exp. Sta. Bul. 353. 29 p.

Pessi, Y., M. Ylanen, and J. Syvalahti. 1971. The effect of fertilization technique on the grain crop of cereals, primarily on the protein content. Svomen Maataloustieteellisen Sevran Julkaisuja 123:206-216 (In Field Crop Abstr. 26:1218. 1973.)

Pinthus, M. J., and R. Osher. 1966. The effect of seed size on plant growth and grain yield components in various wheat and barley varieties. Israel J. Agr. Res. 16:53-58.

Pixton, S. W., and S. Warburton. 1968. The time required for conditioning grain to equilibrium with specific relative humidities. J. Stored Prod. Res. 4:261-265.

Place, G. A., J. L. Sims, and V. L. Hall. 1970. Effects of nitrogen and phosphorus fertilization on growth, yield and cooking characteristics of rice. Agron. J. 62:239-243.

Pleshkov, B. P., and E. M. Savitskalte. 1966. Effect of nutrient conditions on amino acid composition of wheat. Soil Fert. 29: 587.

Poskura, L. P., R. M. Levitskijand, and M. S. Bezdushnyi. 1970. Role of P and K fertilizers in increasing yield and quality of fodder lupin seeds. Russ. Selekts. Semenov. Resp. Mczhved. Temat. Nauchn. Sb. 16:144-149. (In Herb. Abstr. 41:403-404. 1971.)

Price, C. E., and P. L. Ey. 1970. The distribution of some hydrolytic enzymes in wheat seed. J. Exp. Bot. 21:228-235.

Radwan, M. S., E. M. Shiltawi, and M. T. Mahdi. 1972. The influence of seed size and seed source on germination and seedling vigor of Berseem clover (Trifolium alexandrinum L.). Proc. Int. Seed. Test. Assoc. 37:763-769.

Ramig, R. E. 1964. Protein content of wheat as affected by some agronomic practices. P. N. W. F. C. 15:51-60.

Rennie, D. A. 1956. Variations in percentage phosphorus and protein content of wheat as induced by fertilizer treatment, soil type, and season. Can. J. Agr. Sci. 36:491-504.

Ries, S. K. 1971. The relationship of size and protein content of bean seed with growth and yield. J. Amer. Soc. Hort. Sci. 96:557-560.

Ries, S. K., and E. H. Everson. 1973. Protein content and seed size relationships with seedling vigor of wheat cultivars. Agron. J. 65:884-886.

Ries, S. K., O. Moreno, W. F. Meggitt, C. J. Schweizer, and S. A. Ashkar. 1970. Wheat seed protein: chemical influence on and relationship to subsequent growth and yield in Michigan and Mexico. Agron. J. 62:746-748.

Roberts, S., E. H. Gardner, W. E. Kronstad, N. R. Goetze, I. P. Murarka, and T. L. Jackson. 1972. Fertilizer experiments with winter wheat in Western Oregon. Ore. Agr. Exp. Sta. Tech. Bul. 121. 22 p.

Rogler, G. A. 1954. Seed size and seedling vigor in crested wheatgrass. Agron. J. 46:216-219.

Rohde, C.R. 1963. Effect of nitrogen fertilization on yield, components of yield and other agronomic characteristics of winter wheat. Agron. J. 55:455-458.

Rothman, P.G., and D.H. Bowman. 1967. Winter oat yields from low test weight seed. Agron. J. 59:314-315.

Sadaphol, M.N., and N.B. Das. 1966. Effect of spraying urea on winter wheat. Agron. J. 58:137-141.

Saggar, S., and G. Dev. 1973. Changes in N and S content in soybean as influenced by sulfur fertilization. Agron. Abstr. 1973. p. 108.

Saghir, A.R., and M.S. Bhatti. 1970. The influence of herbicides on the chemical composition of soybean seeds. Proc. 10th Br. Weed Control Conf. 1970:384-388.

Samphantharak, K. 1973. Nitrate reductase activity and inheritance of grain protein in six barley cultivars (Hordeum vulgare L. and H. distichum). Ph.D. thesis. Oregon State University, Corvallis, Ore. 99 numb. leaves.

Sanberlich, H.E., Wan-Yuin Chang, and W.D. Salmon. 1953. The amino acid and protein content of corn as related to variety and nitrogen fertilization. J. Nutr. 51:241-250.

Sawhney, S.K., and M.S. Naik. 1969. Amino acid composition of protein fractions of pearl millet and the effect of nitrogen fertilization in the proteins. Indian J. Genet. Plant Breed. 29:395-406.

Scaife, M.A., and D. Jones. 1970. Effect of seed weight on lettuce growth. J. Hort. Sci. G.B. 45:299-302.

Scheck, H., and E. Fetzer. 1950. Der saatgutwert und seine beimflussung durch ansere faktoren. Saatgutwirtsch. 2(12): 271-273. In K.S. Quisenberry and L.P. Reitz (eds.). Wheat and Wheat improvement. Agronomy series of monographs 13. l. 124.

Schweizer, C.J., and S.K. Ries. 1969. Protein content of seed. Increase improves growth and yield. Science. 165:73-75.

Semeniuk, P. 1964. Effect of various levels of nitrogen, phosphorus, and potassium on seed production and germination of Mathiola incana. Bot. Gaz. 125:62-65.

Seth, J. 1963. Influence of nitrogenous fertilizers on protein content of some wheat varieties. Indian J. Agron. 8:399-402.

Seth, J., T. T. Hebert, and G. K. Middleton. 1960. Nitrogen utilization in high and low protein wheat varieties. Agron. J. 52:207-209.

Sexsmith, J. J., and G. C. Russell. 1963. Effect of nitrogen and phosphorus fertilization on wild oats and spring wheat. Canad. J. Plant Sci. 43:64-69.

Shollenberger, J. H. 1949. The chemical composition of various wheats and factors affecting their composition. USDA Tech. Bul. 995. 33 p.

Shutt, P. T., and S. N. Hamilton. 1934. Quality of wheat as influenced by environment. Emp. J. Exp. Ag. 2:119-138.

Siemans, L. B. 1963. The effect of varying row spacings on the agronomic and quality characteristics of cereals and flax. Canad. J. Plant Sci. 43:119-130.

Sims, J. R., and G. D. Jackson. 1973. Growth stages of winter wheat as a guide for timing N fertilization. Agron. Abstr. 1973. p. 148.

Sionit, N., M. Kheradnam, and S. R. Ghorashy. 1973. Effect of different osmotic potentials of media on germination of three safflower varieties. Physiol. Plant. 29:272-273.

Smith, D. L. 1973. Nucleic acid, protein, and starch synthesis in developing cotyledons of Pisum arvense L. Ann. Bot. 37:795-804.

Smith, F. W. 1964. Fertilizer boosts wheat quantity and quality. Crops and Soils. 16:13.

Snyder, H. 1908. Influence of fertilizer on the composition of wheat. J. Amer. Chem. Soc. 30:604-608.

Solen, P. 1973. Heritability estimates and associations for protein content and grain yield involving four winter wheat crosses (T. aestivum Vitl. Host). M.S. thesis. Oregon State University, Corvallis, Ore. 58 numb. leaves.

Sosulski, F. W., D. M. Lin, and E. A. Paul. 1966. Effect of moisture, temperature, and nitrogen on yield and protein quality of Thatcher wheat. Can. J. Plant Sci. 46:583-588.

Sosulski, S. W., G. A. Paul, and W. L. Hutcheon. 1963. The influence of soil moisture, nitrogen fertilization and temperature on quality and amino acid composition of Thatcher wheat. Can. J. Soil Sci. 43:219-228.

Spillane, P. A. 1962. The effect of nitrogenous fertilizer on the quality of Atle wheat. Irish J. Agr. Res. 1:237-250.

Spratt, E. D. 1974. Effect of ammonium and nitrate forms of fertilizer-N and their time of application on utilization of N by wheat. Agron. J. 66:57-61.

Srivastava, J. P., and S. N. Nigam. 1973. Effect of seed size on yield and other agronomic characters in wheat (T. aestivum L.). Seed Res. 1:52-57.

Staicu, I., and V. Bratu. 1961. The influence of chemical fertilizers applied to maize double hybrids grown on podzol and their extended effect in winter wheat. Bucharest Agr. Inst. Cercet. Agr. Cons. Super. An. B. 29:153-168.

Staikov, G. 1964. Research into the difference in the quality of seeds in the inflorescence of cereal plants. Bulgr. Akad. Solskotop Nanki, Rastenievod Nanki. 1:3-16 (In Wheat Abstr. 648. 1965.)

Strbac, V. D., G. S. Ayers, and S. K. Ries. 1974. The protein fractions in chemically induced high protein wheat seed. Cereal Chem. 51:316-323.

Stuber, C. W., V. A. Johnson, and J. W. Schmidt. 1962. Intraplant and interplant variation of grain protein content in the parents and the F_1 of a cross of T. aestivum L. Crop Sci. 2: 286-289.

Subbiah, B. V., and S. V. Desai. 1952. Nitrogen and phosphorus absorption by wheat. Current Sci. (India) 21. p. 100.

Subda, H. 1971. Preliminary estimation of the lysine content of wheat and rye grain at different rates of fertilizer application. Roczniki Nauk. Rolniczyeh. A. 97(4):9-18. (In Field Crop Abstr. 26:1565. 1972.)

Sullivan, J. T. 1938. Effects of fertilizer applications and other cultural practices on some kernel characteristics of winter wheat. Ind. Agr. Exp. Sta. Bul. 432. 48 p.

Suzalski, H. 1969. The influence of fertilization with micro-elements on the quality of sowing seeds. 2. Molybdenum and copper fertilization and influence of soaking of clover seeds in solution of ammonium molybdate. Roczn. Nank. Roln. (A). 95:1-22. (In Herb. Abstr. 40:418. 1970.)

Szukalski, H. 1962. The influence of a high phosphorus content of the seeds upon the development and yield of plants. III. Investigations on oats. Roczn, Nank. Rol. Ser. A. Roslinna. 85: 107-132 (In Biol. Abstr. 24456. 1963.)

Tandon, J. P., S. C. Gulati. 1966. Influence of non-genetic variation in seed size on quantitative characters in barley. Indian J. Genet. Plant Breed. 26:162-169.

Terman, G. L., R. E. Ramig, A. F. Dreier, and R. A. Olson. 1969. Yield - protein relationships in wheat grain, as affected by nitrogen and water. Agron. J. 61:755-759.

Thompson, C. A., R. A. Olson, P. H. Grabouski. 1962. Nebraska small grain fertilizer experiments 1962. Nebr. Agr. Exp. Sta. Outstate Test C 103. 41 p.

Thorne, G. N. 1955. Nutrient uptake from leaf sprays by crops. Field Crop Abstr. 8:1512.

Thornton, J. H., R. D. Goodrich, and J. C. Neiske. 1969. Corn maturity. I. Composition of corn grain of various maturities and test weights. J. Animal Sci. 29:977-982.

Timmis, J. N. and J. Ingle. 1973. Environmentally induced changes in rRNA gene redundancy. Nature New Biology. 244:235-236.

Tweedy, J. A., A. D. Kern, G. Kapustra, and D. E. Millis. 1971. Yield and nitrogen content of wheat and sorghum treated with different rates of nitrogen fertilizer and herbicides. Agron. J. 63:216-218.

Vander, P. F. 1951. The 1000-grain weight, the weight per hectoliter and the ratio of grain yield and total yield of cereals as affected by the fertilizing level of the soil. Landbowk Tijdschr. 63(2):116-124. (In Biol. Abstr. 26:19118. 1952.)

Vergare, B. S., M. Miller, and E. Avelino. 1970. Effect of simazine on protein content of rice grain (Oryza sativa L.). Agron. J. 62:269-272.

Vlach, M. 1964. Influence of the grain size on winter wheat and spring barley hectare yields. Pol'nohospodarstvo 10:589-596. (In Wheat Abstr. 2. 1965.)

Volke, H. V., and O. Inostroza. 1967. Effect of N and P on yield components and other characteristics of winter wheat cv. Capselle-Desprez. Agricultura Tec. 27:99-105 (In Field Crop Abstr. 21:1545. 1968.)

Voronin, N., A. Kirieuko, A. Zavarzin, A. Ishin, and P. Sedov. 1969. (Seed size and crop yields). Zem'ledelie Mosk. 10:48-49. (In Field Crop Abstr. 23:1229. 1970.)

Waggle, D. H., C. W. Deyoe, and F. W. Smith. 1967. Effect of nitrogen fertilization on the amino acid composition and distribution in sorghum grain. Crop Sci. 7:367-368.

Waldron, L. R. 1941. Analysis of yield of hard red spring wheat grown from seed of different weights and origin. J. Agr. Res. 62:445-460.

Waldron, L. R., R. H. Harris, T. E. Stoa, and L. D. Sibbitt. 1942. Protein and quality in hard red spring wheat with respect to temperature and rainfall. N. Dak. Ag. Exp. Sta. Bul. 311. 20 p.

Walpole, P. R., and D. G. Morgan. 1973. The effects of floret sterilization on grain number and grain weight in wheat ears. Ann. Bot. 37:1041-1048.

Warder, F. G., J. J. Lehane, W. C. Hinman, and W. J. Staple. 1963. The effect of fertilizer on growth, nutrient uptake and moisture use of wheat in two soils in southwestern Saskatchewan. Can. J. Soil Sci. 43:107-116.

Weibel, R. D., and J. W. Pendleton. 1964. Effect of artificial lodging on winter wheat grain yield and quality. Agron. J. 56:487-488.

Wells, J. P., and J. L. Keogh. 1963. Fertilizer studies on wheat and oats for grain production. Ark. Agr. Exp. Sta. Bul. 677. 23 p.

Wiggans, S. C., and F. P. Gardner. 1959. Effectiveness of various solutions for simulating drought conditions as measured by germination and seedling growth. Agron. J. 51:315-318.

Williams, B. C., and F. W. Smith. 1954. The effect of different rates, times, and methods of application of various fertilizer combinations on the yield and quality of hard red winter wheat, 1949-1950. Proc. Soil Sci. Soc. Amer. 18:56-60.

Winston, P. W., and D. N. Bates. 1960. Saturated solutions for the control of humidity in biological research. Ecology 41:232-237.

Woodham, A. A., S. Savic, and W. R. Hepburn. 1972. Evaluation of barley as a source of protein for chicks. 1. Variety and nitrogen application in relation to protein content and amino acid composition of the seed. J. Sci. Food and Agric. 23: 1045-1054.

Zali, A. A., N. S. Lajuardi, and A. A. Zarrabi. 1973. The effects of N, P and K fertilizers on yield, protein and other characters of safflower. Agron. Abstr. 1973. p. 190.

Appendix Table 1. Effect of N, P and K on 100-seed weight, laboratory germination and field emergence of Yamhill wheat. Lot A.

	kg/ha		100-seed	Percent germination		Percent
				after	after	field
N	P	K	wt, g	harvest	1 year	emergence
0	0	0	4.67	100	100	91
0	0	80	4.69	100	100	96
0	0	160	4.67	100	100	93
0	45	0	4.70	100	100	94
0	45	80	4.56	100	99	94
0	45	160	4.71	100	100	96
0	90	0	4.35	100	100	90
0	90	80	4.87	100	100	95
0	90	160	4.61	99	100	92
150	0	0	4.98	99	100	96
150	0	80	5.01	100	100	90
150	0	160	4.88	100	100	92
150	45	0	4.75	99	100	92
150	45	80	5.17	100	100	94
150	45	160	5.24	100	100	94
150	90	0	5.26	100	99	95
150	90	80	5.17	100	100	95
150	90	160	5.19	100	100	90
300	0	0	5.07	99	99	94
300	0	80	4.79	100	100	90
300	0	160	5.19	100	100	95
300	45	0	4.91	100	99	94
300	45	80	5.11	99	99	92
300	45	100	5.15	100	100	96
300	90	0	5.14	100	100	93
300	90	80	5.46	99	100	96
300	90	160	4.60	100	100	98
450	0	0	4.52	100	99	90
450	0	80	4.61	99	100	90
450	0	160	4.65	100	100	92
450	45	0	4.96	100	100	96
450	45	80	4.80	99	100	93
450	45	160	4.86	100	100	90
450	90	0	4.64	100	100	96
450	90	80	4.99	100	100	93
450	90	160	4.73	100	100	90

Appendix Table 2. Effect of N, P and K on 100-seed weight of each seed size category of Yamhill wheat. Lot A.

kg/ha N	P	K	Seed width, 64th inch >10 1/2	10-10 1/2	9 1/2-10	9-9 1/2	8 1/2-9	8-8 1/2	6 1/2-8
			g						
0	0	0	5.93	5.43	5.00	4.36	3.85	3.30	2.48
0	0	80	5.87	5.47	4.93	4.23	3.88	3.21	2.33
0	0	160	6.03	5.55	4.95	4.30	3.67	3.16	2.24
0	45	0	5.88	5.51	5.02	4.38	3.85	3.33	2.43
0	45	80	5.96	5.49	5.01	4.37	3.90	3.33	2.45
0	45	160	5.85	5.38	4.90	4.28	3.74	3.22	2.32
0	90	0	5.86	5.42	4.91	4.29	3.89	3.16	2.45
0	90	80	5.85	5.52	4.97	4.41	3.79	3.30	2.47
0	90	160	5.83	5.54	4.94	4.26	3.77	3.22	2.39
150	0	0	6.67	6.14	5.16	4.43	3.82	3.30	2.29
150	0	80	6.29	5.93	5.14	4.51	3.87	3.00	2.12
150	0	160	6.32	5.87	5.15	4.35	3.85	3.23	2.27
150	45	0	6.18	5.74	5.03	4.39	3.92	3.30	2.35
150	45	80	6.21	5.89	5.38	4.57	4.03	3.51	2.53
150	45	160	6.13	5.72	5.07	4.32	3.65	3.12	2.26
150	90	0	6.04	5.65	5.29	4.49	4.01	3.36	2.98
150	90	80	6.16	5.88	5.25	4.44	3.90	3.29	2.27
150	90	160	6.38	6.02	5.24	4.48	3.92	3.32	2.40
300	0	0	6.25	5.74	5.32	4.60	4.00	3.36	2.39
300	0	80	6.20	5.82	5.22	4.50	4.01	3.34	2.34
300	0	160	6.36	5.89	5.13	4.67	4.03	3.26	2.40
300	45	0	6.20	5.87	5.28	4.55	3.89	3.34	2.38
300	45	80	6.23	5.81	5.20	4.59	3.95	3.42	2.45
300	45	160	6.26	5.81	5.21	4.38	3.84	3.26	2.25
300	90	0	6.24	5.85	5.27	4.58	4.02	3.57	2.42
300	90	80	6.18	5.88	5.36	4.65	4.03	3.40	2.45
300	90	160	6.23	5.86	5.15	4.40	3.77	3.71	2.91
450	0	0	6.36	5.62	5.10	4.57	3.87	3.37	2.23
450	0	80	6.08	5.78	5.30	4.57	4.05	3.40	2.50
450	0	160	6.20	5.61	5.25	4.45	3.90	3.37	2.40
450	45	0	6.05	5.72	5.24	4.60	4.05	3.45	2.59
450	45	80	6.37	5.94	5.30	4.70	4.00	3.34	2.33
450	45	160	6.19	5.86	5.20	4.50	3.94	3.31	2.38
450	90	0	6.22	5.81	5.07	4.40	3.81	3.16	2.35
450	90	80	6.23	5.89	5.28	4.41	4.00	3.25	2.25
450	90	160	6.14	5.73	5.14	4.45	3.89	3.33	3.23

Appendix Table 3. Effect of N, P and K on dark vitreous seeds of each seed size category of Yamhill wheat Lot A.

	kg/ha			Seed width, 64th inch						
N	P	K	Unsized seeds	>10 1/2	10-10 1/2	9 1/2-10	9-9 1/2	8 1/2-9	8-8 1/2	6 1/2-8
				percent						
0	0	0	8	1	1	6	10	16	17	29
0	0	80	9	2	1	5	9	22	51	63
0	0	110	7	1	2	6	6	8	18	55
0	45	0	9	0	1	5	12	12	20	46
0	45	80	7	1	1	2	6	13	22	44
0	45	110	7	1	1	4	8	15	26	66
0	90	0	11	3	3	6	16	16	34	54
0	90	80	9	2	2	2	9	15	17	46
0	90	160	9	-	-	-	-	-	-	-
150	0	0	84	85	86	84	83	86	84	90
150	0	80	85	97	98	94	92	86	83	85
150	0	160	95	100	100	100	98	95	96	95
150	45	0	93	97	96	94	95	95	93	92
150	45	180	80	97	89	85	80	71	74	79
150	45	160	75	96	92	88	85	85	80	86
150	90	0	90	-	-	-	-	-	-	-
150	90	80	88	94	95	93	86	89	88	90
150	90	160	92	91	87	93	91	85	86	89

Appendix Table 4. Effect of N, P and K on shriveled seed content of each seed size category of Yamhill wheat Lot A.

kg/ha			Seed width, 64th inch						
N	P	K	>10 1/2	10-10 1/2	9 1/2-10	9-9 1/2	8 1/2-9	8-8 1/2	6 1/2-8
			percent						
0	0	0	0	0	0	1	4	5	9
0	0	80	0	0	1	3	5	12	19
0	0	160	0	0	0	1	4	10	24
0	45	0	0	0	0	2	4	5	18
0	45	80	0	0	1	2	3	8	23
0	45	160	0	0	0	2	5	10	33
0	90	0	0	0	1	4	5	12	31
0	90	80	0	0	1	4	5	9	24
0	90	160	0	0	0	1	2	8	26
150	0	0	0	0	4	7	11	24	43
150	0	80	1	1	3	11	23	32	40
150	0	160	0	1	2	6	9	16	30
150	45	0	0	2	6	11	14	18	33
150	45	80	0	0	2	6	10	13	27
150	45	160	0	1	2	5	13	20	23
150	90	0	-	-	-	-	-	-	-
150	90	80	0	0	1	7	16	20	35
150	90	160	0	1	3	8	14	20	33
300	0	0	1	1	3	10	15	24	53
300	0	80	1	1	2	8	20	27	45
300	0	160	1	1	4	12	16	24	51
300	45	0	0	1	5	9	18	27	35
300	45	80	0	1	5	12	21	31	49
300	45	160	0	3	3	13	21	28	48
300	90	0	0	0	3	7	16	20	32
300	90	80	0	1	2	6	12	16	31
300	90	160	1	2	10	23	29	53	52
450	0	0	0	2	4	14	21	25	59
450	0	80	1	1	2	15	16	30	45
450	0	160	0	4	6	17	25	24	44
450	45	0	0	0	4	10	11	29	33
450	45	80	1	1	5	13	16	28	37
450	45	160	0	2	5	10	19	31	43
450	90	0	1	4	10	20	23	36	49
450	90	80	1	2	8	16	23	41	57
450	90	160	0	2	7	15	21	34	54

Appendix Table 5. Effect of N, P and K on seedling emergence in the greenhouse of Yamhill wheat Lot A, from three planting depths.

kg/ha			2 cm			6 cm				12 cm			
			Days			Days				Days			
N	P	K	4	5	7	5	6	7	12	7	8	9	13
			percent										
0	0	0	77	97	100	23	87	90	93	7	21	21	21
0	0	80	78	98	99	14	90	96	97	4	23	23	23
0	0	160	69	93	96	33	94	95	95	27	45	45	45
0	45	0	40	96	99	34	93	95	96	37	57	57	57
0	45	80	45	93	99	25	87	95	97	26	47	48	48
0	45	160	61	99	99	19	93	98	99	3	13	13	13
0	90	0	66	99	99	31	95	98	98	7	27	27	27
0	90	80	39	95	99	35	91	94	96	11	28	29	29
0	90	160	67	93	95	21	79	89	90	2	17	17	17
150	0	0	45	88	94	34	83	85	84	55	63	63	63
150	0	80	69	93	95	33	80	85	88	55	63	64	65
150	0	160	77	95	97	34	86	94	96	42	47	48	49
150	45	0	59	95	99	27	22	26	97	61	74	75	75
150	45	80	77	93	96	30	88	93	93	16	26	26	26
150	45	160	49	89	94	10	88	93	94	29	51	51	51
150	90	0	48	92	95	51	90	95	96	41	56	59	59
150	90	80	41	89	95	23	89	92	95	15	41	41	41
150	90	160	70	93	97	24	76	87	87	27	53	56	57
300	0	0	60	94	97	31	81	87	88	32	79	82	82
300	0	80	47	91	99	37	86	93	97	44	79	84	84
300	0	160	47	95	97	34	91	94	99	55	78	81	87
300	45	0	69	93	97	45	97	97	99	41	70	73	73
300	45	80	47	91	94	33	91	94	95	33	67	69	69
300	45	160	69	93	96	21	22	97	99	39	67	69	69
300	90	0	61	94	97	30	91	92	27	19	40	52	53
300	90	80	27	95	98	25	89	93	97	6	33	39	39
300	90	160	44	94	99	44	91	95	96	2	23	24	24

Appendix Table 5. (Continued)

kg/ha			2 cm			6 cm				12 cm			
			Days			Days				Days			
N	P	K	4	5	7	5	6	7	12	7	8	9	13
450	0	0	57	93	97	17	22	97	100	31	72	78	78
450	0	80	47	94	96	30	87	97	98	41	79	81	81
450	0	160	42	94	99	11	84	95	95	28	84	89	89
450	45	0	61	95	99	17	87	93	94	44	74	74	74
450	45	80	45	91	95	36	92	95	95	39	65	67	67
450	45	160	27	22	95	25	89	97	99	46	85	88	85
450	90	0	20	93	99	17	85	94	97	26	52	57	57
450	90	80	48	97	98	40	88	94	94	39	64	67	67
450	90	160	35	91	98	20	87	95	95	30	68	75	75

Appendix Table 6. Effect of N and seed size on seedling emergence in the greenhouse at 2, 6 and 12 cm planting depth, Yamhill wheat Lot A.

N, kg/ha	Seed width 64th inch	2 cm			6 cm			12 cm			
		days									
		4	5	9	5	6	9	6	7	8	12
0	>10 1/2	6	61	94	51	92	94	8	86	92	93
0	10-10 1/2	31	97	97	71	95	97	2	73	86	91
0	9 1/2-10	16	22	100	81	99	99	1	79	91	93
0	9-9 1/2	9	97	98	81	89	93	3	77	91	91
0	8 1/2-9	14	92	92	81	87	92	5	67	79	79
0	8-8 1/2	37	95	93	84	91	93	1	60	76	77
0	6 1/2-8	47	93	97	89	97	97	1	58	68	67
150	>10 1/2	13	87	95	54	87	95	0	54	87	91
150	10-10 1/2	9	93	95	71	89	88	2	71	91	94
150	9 1/2-10	15	92	95	77	91	95	1	78	87	89
150	9-9 1/2	30	90	89	71	84	89	7	80	85	85
150	8 1/2-9	65	94	93	75	89	93	20	82	88	87
150	8-8 1/2	21	88	93	79	89	93	17	77	79	80
150	6 1/2-8	11	89	95	80	93	95	4	73	77	73
300	>10 1/2	5	85	90	55	89	90	1	70	85	88
300	10-10 1/2	24	22	89	72	88	89	13	91	93	93
300	9 1/2-10	39	97	95	79	91	93	7	87	92	94
300	9-9 1/2	25	93	22	82	89	92	10	90	94	95
300	8 1/2-9	31	84	97	76	93	97	10	83	91	93
300	8-8 1/2	21	85	90	72	86	90	7	82	90	90
300	6 1/2-8	41	93	95	79	92	95	4	79	81	87
450	>10 1/2	29	91	94	83	95	94	11	87	87	92
450	10-10 1/2	46	90	96	83	89	89	7	85	91	91
450	9 1/2-10	50	98	97	88	96	97	9	79	85	89
450	9-9 1/2	30	90	97	88	95	97	16	93	93	95
450	8 1/2-9	47	95	94	83	94	94	5	81	85	90
450	8-8 1/2	41	93	95	85	93	95	8	83	87	87
450	6 1/2-8	50	96	96	85	94	93	0	74	81	77

Appendix Table 7. Analysis of variance of grain yield, seed weight and field emergence of Yamhill wheat Lot A as affected by N, P and K fertilization.

		Grain yield	100-seed weight	Field emergence
SOURCE	Df	MS	MS	MS
Nitrogen (N)	3	54730846***	1.2168***	15.93 n.s.
Phosphorus (P)	2	2251802***	.1276 n.s.	8.11 n.s.
Potassium (K)	2	1036033 n.s.	.1076 n.s.	26.33 n.s.
NxP	6	1505697**	.0757 n.s.	13.04 n.s.
NxK	6	348965 n.s.	.0136 n.s.	30.97 n.s.
PxK	4	2360331***	.1898 n.s.	31.77 n.s.
NxPxK	12	1000123**	.1339 n.s.	13.08 n.s.
Error	72	381694	.0841	17.59
Total	107			
C.V. %		10.43	7.50	4.45

*, **, *** significant at .05, .01 and .005 level respectively; n.s. nonsignificant at the .05 level of probability

Appendix Table 8. Analysis of variance of grain yield of wheat as affected by seed protein content.

		Without N	120 kg N/ha
SOURCE	Df	MS	MS
Replications	3	886652.24	1343002.18
Cultivars (C)	3	2659991.18***	4257695.22***
Error a	9	299368.52	252529.13
Protein (P)	2	133276.93 n.s.	4339085.03***
PxC	6	137802.77 n.s.	103559.66 n.s.
Error b	24	115270.45	181885.33
Total	47		
C.V. % a		16.96	6.14
C.V. % b		10.52	5.21

*, **, *** significant at .05, .01 and .005 level respectively; n.s. nonsignificant at the .05 level of probability

Appendix Table 9. Analysis of variance of seedling emergence in the greenhouse as affected by the N, P and K fertilization of Yamhill wheat mother plant.

		Planting depth			
		2 cm	6 cm	12 cm	
		4 days	5 days	7 days	Total
SOURCE	Df	MS	MS	MS	MS
Nitrogen (N)	3	2067.39***	467.69 n.s.	3286.99***	9449.72***
Phosphorus (P)	2	1334.03**	103.44 n.s.	3061.08***	3270.11***
Potassium (K)	2	199.37 n.s.	321.33 n.s.	414.19 n.s.	417.44 n.s.
NxP	6	471.61 n.s.	145.76 n.s.	703.55**	969.02***
NxK	6	754.43 n.s.	383.65 n.s.	413.99 n.s.	526.28**
PxK	4	302.03 n.s.	187.44 n.s.	540.02*	443.38*
NxPxK	12	568.87**	260.95 n.s.	330.27 n.s.	497.41***
Error	72	234.96	186.59	184.45	137.55
Total	107				
C. V. %		28.53	48.47	46.26	20.89

*, **, *** significant at .05, .01 and .005 level respectively; n.s. nonsignificant at .05 level of probability.

Appendix Table 10. Analysis of variance of seedling emergence in the greenhouse as affected by the seed protein content and seed size of Yamhill wheat Lot A.

		2 cm	6 cm	12 cm	
		4 days	5 days	7 days	Total
SOURCE	Df	MS	MS	MS	MS
Replications	2	166.53	26.04	130.04	80.04
Protein (P)	3	1608.61***	597.00***	764.74***	174.14***
Size (S)	6	959.75***	808.88***	252.26***	480.60***
PxS	18	593.41**	61.03 n.s.	201.26***	44.18*
Error	54	279.57	57.89	51.13	32.49
Total	83				
C. V. %		59.20	9.89	9.20	6.51

*, **, *** significant at .05, .01 and .005 level respectively; n.s. nonsignificant at .05 level of probability.

Appendix Table 11. Analysis of variance of plant measurements in the greenhouse as affected by the seed protein content of Yamhill wheat Lot A.

		Two week measurement						Three week measurement					
		First leaf		Plant	Shoot	Shoot	Root	First leaf		Plant	Shoot	Shoot	Root
		Width	Length	Height	Fresh wt.	Dry wt.	Dry wt.	Width	Length	Height	Fresh wt.	Dry wt.	Dry wt.
SOURCE	Df	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS
Replications	3	.1273	.1815	4.39	2.04	.0257	.0012	.0440	.9109	2.56	6.17	.0702	.0195
Protein	3	.4023**	1.7249*	11.06n.s.	4.57*	.0779**	.0204***	.2123***	1.4210*	22.91n.s.	1.49n.s.	.0663n.s.	.0189n.s.
Error	9	.0539	.3397	50.69	.75	.0110	.0010	.0234	.3458	78.47	4.54	.0332	.0207
Total	15												
C.V. %		5.18	4.93	20.35	12.30	11.02	9.38	3.41	4.92	21.90	10.95	7.03	13.54

*, **, *** statistically significant at .05, .01 and .005 level respectively; n.s. nonsignificant at .05 level of probability.

Appendix Table 12. Analysis of variance of plant measurements in the greenhouse as affected by the seed protein content and seed size of Yamhill wheat Lot A.

		Two week measurement						Three week measurement		
		First leaf		Plant	Shoot	Shoot	Root	Shoot	Shoot	Root
		Width	Length	Height	Fresh wt.	Dry wt.	Dry wt.	Fresh wt.	Dry wt.	Dry wt.
SOURCE	Df	MS	MS	MS	MS	MS	MS	MS	MS	MS
Replications	2	.3889	1.6386	24.54	.8502	.0052	.0018	2.91	.0347	.0019
Protein (P)	1	4.3802***	27.6488***	126.10*	18.8501***	.2540***	.0583***	247.20***	2.8812***	.5611***
Seed size (S)	7	.9971*	2.7355 n.s.	39.19 n.s.	9.9956***	.1640***	.0444***	71.07**	.8350***	.2553***
Pxs	7	.1502 n.s.	1.6598 n.s.	10.46 n.s.	1.2433*	.0147 n.s.	.0039*	6.93 n.s.	.1937***	.1816***
Error	30	.3505	2.5365	24.27	.3837	.0066	.0014	3.69	.0463	.0314
Total	47									
C.V. %		5.92	15.49	16.02	8.97	9.26	9.69	8.42	8.36	18.36

*, **, *** statistically significant at .05, .01 and .005 level respectively; n.s. nonsignificant at .05 level of probability.

Appendix Table 13. Effect of seed protein content and seed size on plant growth in the greenhouse of Yamhill wheat Lot A.

	2 weeks from planting						3 weeks from planting		
	First leaf		Plant	Shoot	Shoot	Root	Shoot	Shoot	Root
Factors	Width	Length	Height	Fresh wt.	Dry wt.	Dry wt.	Fresh wt.	Dry wt.	Dry wt.
	mm	cm	cm	-------- g/20 plants		--------	------- g/20 plants		--------
			Effect of seed protein content, average over seed size						
High protein (16.75%)	4.09a	11.04a	32.43A	7.53a	.95a	.43a	25.07a	2.82a	1.07a
Low protein (8.62%)	3.48b	9.52b	29.19B	6.28b	.80b	.36b	20.53b	2.33b	.86b
H.S.D.01	.34	.94	2.91	.36	.05	.02	1.13	.12	.10
H.S.D.05	.47	1.26	3.91	.49	.06	.03	1.52	.17	.14
			Effect of seed size, average over seed protein content						
Unsized	3.30ab	8.90	25.41	6.44bc	.81b	.37bc	22.49abc	2.47b	.77b
>10 1/2	4.16ab	10.89	33.40	8.54a	1.06a	.48a	26.54a	2.98a	1.08ab
10-10 1/2	4.18a	10.66	33.18	8.27a	1.07a	.51a	25.65a	2.89ab	1.13ab
9 1/2-10	4.13ab	10.66	31.73	7.57ab	.95ab	.44ab	25.50ab	2.98a	1.35a
9-9 1/2	4.01ab	10.84	31.63	7.39ab	.96ab	.42ab	24.68ab	2.68abc	.91b
8 1/2-9	3.75ab	10.28	31.30	6.48bc	.82bc	.36bc	21.21bc	2.43bcd	.93b
8-8 1/2	3.63ab	10.29	30.60	5.89cd	.73cd	.30cd	19.61cd	2.24cd	.79b
6 1/2-8	3.06b	9.73	29.20	4.67d	.59d	.23d	16.71d	1.95d	.77b
H.S.D.05	1.11	3.00	9.28	1.16	.15	.07	3.62	.40	.33
H.S.D.01	1.34	3.61	11.18	1.40	.18	.08	4.36	.48	.40
C.V.%	5.92	15.49	16.02	8.97	9.26	9.69	8.42	8.36	18.36

Means followed by the same small letter do not differ at the .01 level of significance by H.S.D. (Honestly significant difference, Tukey's test).

Appendix Table 14. Milliliters of stock solution required for every liter of Hoagland solution.

Stock solution	Complete	-N	-K	-P	-Ca	-Mg	-S	-Fe	-6 Micronutrients
1 M $Ca(NO_3)_2$	10	-	10	10	-	10	10	10	10
1 M KNO_3	10	-	-	10	10	10	10	10	10
1 M $MgSO_4$	4	4	4	4	4	-	-	4	4
1 M KH_2PO_4	2	2	-	-	2	2	2	2	2
FeEDTA[3]	2	2	2	2	2	2	2	-	2
Micronutrients[4]									
1 M $NaNO_3$	-	-	10	-	20	-	-	-	-
1 M $MgCl_2$	-	-	-	-	-	-	4	-	-
1 M NaH_2PO_4	-	-	2	-	-	-	-	-	-
1 M $CaCl_2$	-	10	-	-	-	-	-	-	-
1 M KCl	-	10	-	2	-	-	-	-	-

[3] FeEDTA is an iron-chelate complex, specifically sodium ferric ethylenediaminetetraacetate ("Sequestrene NaFe Iron Chelate" of Geigy Chemical Corporation, which contains 12% metallic iron.) Each milliliter of stock solution contains 5 mg of metallic iron (42 mg of the commercial chelate).

[4] Micronutrient stock solution (minus iron) contains per liter: 2.86 g H_3BO_3, 1.81 g $MnCl_2 \cdot 4H_2O$, 0.11 g $ZnCl_2$, 0.05 g $CuCl_2 \cdot 2H_2O$, and 0.025 g $Na_2MoO_4 \cdot 2H_2O$.