THE EFFECT OF PROTEIN CONTENT OF SEED
UPON SUBSEQUENT YIELD OF WHEAT

by

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INTRODUCTION

The importance of employing practices to improve the efficiency of crop production has never been greater than in this modern day agriculture. Through increased yields and improved quality of grain crops, producers are able to lower their per unit cost of production and thus realize greater profits.

It has been established that yielding ability, quantity and quality of protein in wheat are inherited characteristics, but are influenced greatly by a complexity of environmental factors. It is known that wheat from the Great Plains is high in protein while wheat from eastern parts of the United States is low in protein.

Agronomic practices such as fallowing, crop rotation and the application of fertilizer have been shown to influence protein synthesis in wheat. Yield of wheat has been shown to be influenced by such agronomic practices as kind, rate and placement of fertilizer. It has also been shown to be influenced by seeding rate, date of planting, plant spacing and depth of planting.

Very little research has been conducted to determine if yield of wheat is influenced by the chemical composition, particularly protein content, of the seed planted.

The primary objective of this study was to determine the effect of protein content of the wheat seed planted on the yield of the crop harvested. Factors measured in addition to yield included (1) germinating ability, (2) seedling emergence, (3) seedling vigor, (4) tillering capacity and (5) date of heading.

REVIEW OF LITERATURE

Effect of Climate and Other Environmental Factors on Protein Content

Studies have been conducted as early as the last half of the eighteenth century on the variation in the composition of plants of the same species when grown under different conditions.

LeClerc (16)[1/] in his well known trilocal experiments on the influence of environment on the composition of wheat, concluded that apparently the crop is not at all influenced by the composition of the seed or by its origin. He further concluded that wheat of the same variety obtained from different sources, and possessing widely different chemical and physical characteristics, when grown side by side in one locality yields crops which are almost the same in appearance and in composition.

Mangels (18) discovered from a four year study of the effect of climate and other factors on the protein content of North Dakota wheat that no area within the state, except for one small area, produced wheat of high protein content consistently; that samples showed considerable variation in protein content within counties; that some high protein wheat was found each season; and that wheat following legumes was higher in protein than other samples in the same area. Contrary to the usually accepted theory of that day that high protein was usually associated with low yields and low rainfall, he explained that the

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1/ Number in parentheses refers to "Literature Cited", page 44.

difference in average protein content of wheat was due to the variation in mean daily temperature since the lowest average protein content and lowest rainfall were found in the same year. The highest protein was produced in two of the years having the highest rainfall during the months of June and July. The mean daily temperatures for those months were above normal.

Variation occurs in the percentage of protein in the grain of a single plant. Gericke (9) has shown that the percentage of protein in wheat is directly related to that of the supply of N available to the plants at different growth periods - the later in growth a given supply is absorbed the higher the protein content of the grain. The parent stalk usually ripens first and produces higher protein. This study also showed that the length of interval between the ripening of the grain of two stalks on a plant or that of different plants grown under similar conditions appears to be of considerable importance and related to variation in the protein content.

A three year study conducted by Austin et al. (2) on protein and gluten contents of some improved Inidan wheats as influenced by varietal and seasonal differences showed varietal differences to be highly significant with less significant differences due to season. The protein and gluten contents were generally parallel.

Malloch and Newton (17) tested the relationship between yield and protein content of wheat as affected by variations in the soil and by pruning the plants. They found that yield as affected by soil heterogeneity was more variable than protein and that high yield was associated with low protein content. The removal of tillers and removal of heads at flowering time increased protein. It was concluded that reduction in yield by pruning will increase the protein content of the grain.

Effect of Certain Agronomic Practices on Protein Content

Summer Fallowing

Hill (12) studied the effects of "trash cover" fallow, black fallow, spraying with 2, 4-D for weed control, and the application of N upon the protein content of wheat. He found that higher protein wheat was usually produced on the fallowed land compared to that grown on stubble. There was no striking difference in protein content of wheat grown on "trash cover" fallow and black fallow. Spraying with 2, 4-D for weed control did not affect protein percentage, but the application of N either as fertilizer to the soil or as an urea spray to the plants at the flowering stage usually raised the protein content of the grain. He emphasized, however, that the overriding factor affecting the protein content of hard red spring wheat grown on the Canadian prairies is the weather. Generally speaking, in seasons of above normal moisture, yield is higher and protein content lower than average. The reverse situation usually prevails in very dry seasons. This is in agreement with many other authors (16, 18, 17, 9, 2).

McKercher (19) working in seeded fields which were in fallow the year previous studied the variations in protein of wheat resulting from micro-environmental and zonal climatic changes, and fertility treatments. He found that the change in protein content, reflecting broad differences in climate, were generally smaller than those noted for the different fields within any one soil zone. Fertilization (phosphorus or nitrogen) had no effect on protein value though substantial yield responses were recorded. The range in protein content between grain samples taken on different slope positions was frequently greater than that between mean percent protein of grain from widely separated fields. McKercher attributed the difference in protein to the difference in soil profile type within fields. These profiles represent differences in drainage and micro-climate which affect soil moisture conditions and hence can be expected to have an influence on plant characteristics.

Fertilizer Treatments

Eck et al. (7) in studying the influence of fertilizer treatment on yield, grain protein, and heading dates of five wheat varieties, found that N fertilizer increased grain protein. The initial 20 pound increment of N had more effect on grain protein than successive increments. An average of 25.8 pounds of N was required to raise grain protein content by 1%. They found no significant variety fertilizer interaction in grain protein.

Stickler et al. (22) working with four wheat varieties at different levels of nitrogen fertilization for a period of two years showed that both N fertilizer level and varieties significantly affected wheat protein content and sedimentation value. Wheat protein content increased linearly over the entire range of N fertilizer levels. The difference between varieties was slight. These data suggest that deposition of protein in the mature kernel increased with increments of available soil nitrogen up to a certain limiting value. Kinra et al. (15) in studies on the effect of seeding rate, row spacing, and rate and placement of fertilizer on winter wheat performance in Michigan, found a decrease in protein in the grain as the seeding rate was increased from 4 to 6 pecks at one farm. They suggested that this may have merely represented a dilution of nitrogen in the grain due to associated increases in yield.

Effects of Inheritance on Protein Content of Wheat

Protein Synthesis

Graham et al. (10) in studying the protein bodies and protein synthesis in developing wheat endosperm found that during the period of rapid increase of protein in the endosperm there is a related increase in ribonucleic acid per grain, but little change in desoxyribonucleic acid per grain after about the fourteenth day following the mean flowering date. He explained this development as being mainly due to increase in dry weight of previously formed cells, and not due to cell division. He stated that the accumulation of protein occurs in the bodies and that they increase in size and number during development. It was concluded from this study, in which 3 varieties were used, that changes in protein composition during development of the endosperm are quantitative rather than qualitative.

Protein Synthesis by Certain Varieties and Variety Crosses

Seth et al. (21) in studying nitrogen utilization in high and low protein wheat varieties found no significant differences among 4 varieties in protein content of the tops or roots at the rosette, jointing, and heading stages of growth. At the milk stage and at maturity, the roots of the high protein varieties had a lower protein content than those of the low protein varieties. During the period of kernel formation, the percent protein of the heads increased more rapidly in the high protein varieties. It was conluded from this experiment that the differences in protein content appear to be associated with a difference in the rate of protein synthesis in the developing kernels. It was concluded that the varietal differences in protein content of the kernels are not associated with possible differences in the root systems or in the rhizospheric microflora of the varieties.

The study conducted by Haunold et al. (11) on variation in protein content of the grain in four varieties of wheat agrees closely with that of Seth et al. (21) and Johnson et al. (13). They stated that the protein in the grain of wheat results from the translocation of nitrogenous compounds from other parts of the wheat plant. The level of N in the wheat plant, in turn, is affected by the availability of nitrogen in the soil in which the wheat grows. This study showed that Atlas 66, a high protein wheat, produced significantly more protein in its grain than other varieties studied provided N in the soil was not limiting. At low levels of soil nitrogen, available grain protein was negatively correlated with yield in all varieties.

Davis et al. (6) using four crosses made between varieties of known quality determined that heritability estimates for percent protein were large in all four populations studied. In general, the heritabilities indicated the presence of considerable genetic variability for percent protein in all four populations. A negative correlation resulted for high protein and high yield for both phenotypes and genotypes.

Johnson et al. (13) in determining the agronomic and quality characteristics of high protein F_2 - derived families from a soft red winter x hard red winter wheat cross found that they appear to have the capacity to produce additional protein in their grain without an associated decrease in grain production. There was also evidence to indicate that expression of the high protein characteristics in these families does not depend on high soil nitrogen, but might be detectable at low soil nitrogen levels. Stuber et al. (25) in studying grain protein content and its relationship to other plant and seed characters in the parents and progeny of a cross of wheat, found grain protein content to be significantly correleated with short plant height, low tillering number, low grain yield and late flowering. Also high yielding plants that produced grain with high protein content were found in the F_2 population.

Effects of Fertilizer and Other Agronomic Factors on Yield

Inheritance

Agronomists for many years have been studying the factors which affect yield in wheat. Inheritance studies have played a major role in increasing yield. Davis et al. (6) in their study to obtain information about yield and kernel texture, found that predicted gains for yield indicate a gain of approximately 9 percent or greater in three of four populations studied.

Fertilizer Treatments

Kinra et al. (15) studying the effect of seeding rate, row spacing, and rate and placement of fertilizer on winter wheat performance in Michigan showed that the fertilizer rate of 600 pounds of 8-20-20 per acre resulted in significant reduction of the fall culm count in 3 of the 4 experiments. They attributed this to fertilizer injury to the seed. They reported that maximum benefits were obtained from the 300 pound rate of application, however, yields were significantly lower on plots with contact placement than on plots with side dress.

Tucker et al. (26) have conducted numerous field experiments throughout Oklahoma to determine the effects of fertilizer treatment on yield and quality. They have found the application of N fertilizer to be generally profitable through increased grain yields and quality. Eck et al. (7) found that when adequate phosphorus was supplied, applied nitrogen increased yields and when adequate nitrogen was supplied, applied phosphorus increased yields. They also reported a significant variety-fertilizer interaction for grain yield. Carpenter et al. (4) in studying nitrogen uptake by wheat in relation to nitrogen content of soil found that the uptake of nitrogen fell off rapidly after heading on low nitrogen soils but continued on the high nitrogen soils. They reported that nitrogen in plants at all stages was closely associated with grain yields with the amount in plants at jointing giving the best estimate of yield. Studies conducted by Bolaria and Mann (3) on the effect of fertilizer treatments on the root weight and uptake of nitrogen and potassium by two wheat varieties showed that the dry weights produced by the wheat roots were higher under treatments including nitrogen. The uptake of nitrogen was higher than phosphorus at all stages. The uptake of potassium was almost as high as nitrogen; however, the application of potassium had no effect on its uptake. They concluded that the application of nitrogen alone or in combination with phosphorus or potassium definitely increased the dry weight of roots of wheat about 3 times as compared to the control.

Fallowing

Hill (12) reported that yields of wheat on fallow are generally higher than those on stubble and that it was probably due to the fact that more nitrogen was available on fallow. He also reported that wheat yields on "trash-cover" fallow was equal to those on plowed (or black) fallow.

Asana and Mani (1) in their study on the influence of soil-drought on the relation between yield and spike characters in wheat showed that under adequate soil moisture, spike number had consistently the most dominant effect on yield, whereas under restricted soil moisture, grain number per spike and sometimes 1000-gram weight were as effective as spike number.

Effects of Seeding Rate, Plant Spacing, and Depth of Planting on Yield

Seeding Rate

Clements et al. (5) found that lowering the seeding rate of Marquis spring wheat to half of the normal resulted in more heads per plants, greater height, and larger heads, but reduced yield and kernel weight.

Plant and Row Spacing

Percival's (20) work showed that increasing the area for a single plant from 6 to 18, 36, 72 and 144 square inches gave progressively lower plot yields. The weight of seed per head and head number per plant increased with decreased plant population. Kinra et al. (15) in studying the effect of seeding rate, row spacing, rate and placement of fertilizer on winter wheat performance in Michigan showed that row spacings greater than 7 inches were associated with significantly smaller numbers of culms per square foot in the fall in 3 out of 4 cases, and significantly smaller numbers of culms per square foot in row spacings greater than 7 inches the following summer at all locations. Yield was reduced by an increase in row spacings in all cases except one. The greatest reduction in yield was between the 11 to 14 inch spacing.

Stickler (24) determined that yields were influenced much more by row width than by seeding rate. He concluded that a decreased number of heads per unit area was mainly responsible for the yield reduction. Wilson and Swanson (28) found that moisture and seeding date profoundly influenced the optimum rate of seeding. High moisture and late seeding favor heavy seeding rates while light rates are common where low moisture and early seeding prevail. Their findings coincided generally with those of Kinra et al. (15), Clements et al. (5), Percival (20) and Stickler (24) in that significant reductions in yield were obtained upon lowering the plant population below 15 plants per square foot, which resulted in lowering the number of heads per square foot. They concluded that reduced yields, due to thinning, can be attributed largely to fewer seed-bearing heads per square foot and decreased test weight.

Depth of Planting

Stickler (23) reported that in one out of 3 years a significant (1% level) increase in yield of Kansas wheat occurred with the 2½-inch seeding depth over the 1½-inch depth. Also, significant (5% level) increases in yield over that of the check occurred by using both the 1" X 10" and 2" X 26" seed-firming press wheels. It was concluded that the main effect of use of press wheels seemed to be a higher level of winter-hardiness in the plants.

Effect of Protein Content of Seed on Seedling Vigor

Fox and Albrecht (8), working with wheat, found that seedling development is influenced by the nutritive environment in which the parent plant of the seed was grown. Balanced nutrition of the parent plant was indicated as being an important factor in determining seed quality. Emergence of seedlings was improved when N of the grain was increased. Nitrogen which moved into the grain late decreased the index of seedling vigor. The use of moderate amounts of phosphorus improved seed quality, but higher rates decreased emergence. These workers also found that high total yield of seed grain does not necessarily indicate high quality seed.

Kamal (14) using seed of low, medium and high protein levels of four hard red winter wheat varieties also found a definite relationship between the germination vigor of high, medium and low protein seed. It was the highest in the high protein seed, intermediate in the medium and lowest in the low protein seed. This relationship was most apparent in the germinator, less apparent in the greenhouse flats and almost non-existent in the field test. Green and dry forage weights taken from the greenhouse plantings varied in relation to the protein content of the seed planted with the greatest amount of forage harvested from the high protein level. His studies showed no definite relationship of protein content of the seed to tillering, plant height, date of heading and yield.

MATERIALS AND METHODS

Experimental Materials

The three hard red winter wheat varieties used in this study were Triumph (C. I. 12132), early maturing; Kaw (C. I. 12871), medium maturing; and Tascosa (C. I. 13023), late maturing. Seed of low, medium and high protein content of each variety was used for planting. The seed used for both field and greenhouse plantings was produced from a single nursery at the Oklahoma Agricultural Experiment Station Agronomy Farm, Perkins, Oklahoma in 1963. The varieties, protein levels, quality and quantity of seed planted for each variety and protein level are given in table 1. Seeding rates were adjusted to that of the low protein level of Triumph wheat.

Table 1.--Variety, protein level and quality of seed used in test.

Variety	C.I.*	Protein Level	Protein	Germ.	Purity	P.L.S.	Wt. per 1000 Kernels	Seed Planted
			(%)	(%)	(%)	(%)	(gms.)	(gms.)
Triumph	12132	Low	9.99	84	98.88	83.05	31.91	30.09
		Medium	11.90	93	98.32	91.44	31.25	26.76
		High	15.35	94	98.38	92.47	29.67	25.12
Kaw	12871	Low	9.65	85	98.65	83.85	29.83	27.86
		Medium	11.58	95	99.05	94.09	28.85	24.01
		High	14.94	94	98.69	92.77	28.14	23.75
Tascosa	13023	Low	9.54	85	98.43	83.66	29.72	27.82
		Medium	11.82	89	98.13	87.33	28.60	25.64
		High	15.04	89	97.17	86.49	27.68	25.06

* C. I. refers to accession number of the U.S.D.A. Division of Cereal Crops and Diseases.

Germination and purity determinations on the seed planted for each variety and protein-level were conducted in accordance with the rules and regulations under the Federal Seed Act (27). The pure-live-seed content was determined by multiplying the percent germination by the percent purity and dividing by 100.

Experimental Methods

Field Studies

Field plantings were made at the Agronomy farm, Stillwater, Oklahoma October 1, 1963 and at the Wheatland Conservation Experiment Station, Cherokee, Oklahoma October 3, 1963. A randomized block design with four replications was used for both tests.

The seed bed was prepared in the usual manner and seeded at the rate of one bushel of pure-live-seed per acre. The surface moisture at seeding time was good at both locations. All plantings were seeded with a 4-row belt planter in four 10-foot rows.

Seedling emergence counts were taken daily following first emergence and continued through the tenth day when all plants had seemingly emerged. Counts were taken from the center 12 inches of row in the two center rows of each replication at both field locations.

Heading dates were recorded for each variety and protein-level at each of the two field tests when 75% of the spikes were fully emerged from the boot.

Tillering capacity was measured at each field location. Two of the four rows in each replication were selected as being most representative of the replication. The plots consisted of 12 inches of row selected at random. Culms with fertile heads were counted in each plot.

Plant height measurements, excluding awns, were determined for each variety and protein level at each of the two field tests after full heading. Three measurements were taken at random within each of the 4-row replications and averaged.

All plots at both locations were harvested at maturity for each of the varieties. Yield determinations in bushels per acre were based on seed harvested from 16 feet of the two rows within each replication chosen previously as being most representative.

Greenhouse Studies

On January 29, 1964 these same varieties, using the same source of seed, were planted in the greenhouse in wooden flats measuring approximately 20" X 14" X 3½". The flats were filled with a soil mixture consisting of 5 parts washed river sand, 2 parts soil and 1 part peat moss. The flats were divided into 10 rows, 13 inches long, 2 inches apart and ½ inch deep with a corrugated row marker which fitted the inside of the flats. Twenty-four seeds representing a single protein level and variety were evenly spaced in two rows. Each flat consisted of two-row plantings of the low, medium and high seed protein levels of the same variety. Each treatment was separated by a void row. An additional planting was made in the outside row of each flat to reduce border effect. Each treatment was replicated four times. The flats were irrigated immediately following seeding and optimum moisture and temperature conditions for germination and seedling growth were maintained throughout the experiment.

Seedling emergence counts were made daily beginning five days following planting and continuing through the twelfth day. Plant height measurements from the soil surface to the tip of the leaf were made during the first leaf stage of growth. These measurements were recorded daily from 6 plants of each replication beginning 7 days following planting and continuing through 12 days. The same procedure was employed for measuring the daily height of each plant in the second leaf stage except that it included the distance from the soil surface to the tip of the newly developed second leaf. The second leaf measurements began 13 days following planting and continued 9 days.

On March 2, green weights in grams were determined for each replication from above-ground clippings of all seedlings within each replication. Dry weights in grams were determined for each replication after seven days of air drying.

EXPERIMENTAL RESULTS

Seed Germination

The details of the germination of the seed of the 3 varieties of wheat with variable protein contents used in the experiment are given in table 2.

The analysis of variance shows a highly significant difference at both the 5% and 1% levels of confidence among varieties and among protein-levels of seed. Although there was very little difference in total germination between the two high germinating varieties Triumph and Kaw, they were considerably higher than Tascosa. A similar situation existed among protein-levels where a very small difference in total germination occurred in the seed with medium and high protein-levels. The seed of low protein content was considerably lower in germination than the two higher levels. The germination capacity of the seed increased with each increased level of protein except with the variety Kaw where the seed of the medium level of protein germinated 0.75% more than that of the high level of protein.

Field Studies

Seedling Emergence

The average number of plants observed in 2 feet of row 10 days following planting at both the Stillwater and Cherokee field locations are given in table 3. Varietal differences as well as the variety X protein-level interaction were significant at the Stillwater location.

Table 2.--Average germination of the 3 varieties of hard red winter wheat with variable protein contents.

(Seed Source 1964 Stillwater)

Protein Level	Varieties Triumph	Kaw	Tascosa	Average
Low	84.50	85.50	85.00	85.00
Medium	93.75	95.00	89.00	92.58
High	94.75	94.25	89.25	92.75
Average	91.00	91.58	87.75	90.11

Germination was conducted in the laboratory. Each of four replications consisted of 100 seeds.

Table 3.--Average number of seedlings in 2 linear feet 10 days after planting of 3 hard red winter wheat varieties.

Protein Level	Varieties			
	Triumph	Kaw	Tascosa	Average
		Stillwater		
Low	57.00	57.50	56.00	56.83
Medium	66.50	54.00	46.50	55.67
High	47.50	80.00	46.50	58.00
Average	57.00	63.83	49.67	56.83
		Cherokee		
Low	28.75	37.50	31.00	32.42
Medium	40.50	36.50	38.50	38.50
High	36.00	33.00	33.50	34.17
Average	35.08	35.67	34.33	35.03

No significant differences among varieties or protein-levels were found at the Cherokee location. Seedling emergence was highest for the Kaw variety at both field locations and lowest for the Tascosa variety. No definite relationship of seedling emergence to protein-level existed within varieties at either location.

Number of Days to Complete Emergence

The number of days to complete seedling emergence at the Stillwater and Cherokee field locations are presented in table 4. There was no significant difference among varieties or among protein-levels in the number of days required for the seedlings to reach complete emergence. Complete seedling emergence was reached slightly earlier in the Triumph variety than in the other two varieties. Although it was indicated that the rate of seedling emergence in Triumph was positively related to the level of protein in the seed planted, this relationship did not exist among seed protein-levels of the other varieties tested.

Table 4.--Average number of days to complete emergence of the 3 varieties of hard red winter wheat.

Protein Level	Varieties: Triumph	Kaw	Tascosa	Average
Stillwater				
Low	9.25	8.75	9.25	9.08
Medium	8.25	9.00	9.25	8.83
High	8.25	9.00	9.50	8.92
Average	8.58	8.92	9.33	8.94
Cherokee				
Low	9.25	9.50	8.75	9.17
Medium	9.00	9.50	9.25	9.25
High	8.50	9.50	9.00	9.00
Average	8.92	9.50	9.00	9.14

Tillering Capacity

Table 5 shows the tillering capacity of each of the three wheat varieties tested at the Stillwater and Cherokee field locations respectively as it is related to protein level of seed planted. No significant differences among varieties or protein levels were present. The varietal tillering capacity followed the same pattern at both field locations. Their ranking in the order of highest tillering capacity to lowest were Tascosa, Kaw and Triumph. All varieties at the Stillwater location followed the same pattern of relationship of protein-level of seed planted to tillering capacity. Seed of the medium level of protein produced the greatest number of tillers per two feet of row, while seed of the highest level of protein produced the least number of tillers. This same relationship of protein-level of seed planted to tillering capacity did not exist at the Cherokee field location.

Number of Days From Complete Seedling Emergence to Heading

Table 6 shows the number of days from complete seedling emergence to heading of the three wheat varieties tested at the Stillwater and Cherokee field locations respectively. An analysis of variance showed no significant differences among varieties or among protein levels of seed planted. The period of time from complete emergence to heading was slightly less for Triumph than the other varieties tested, however, it was not appreciable. There appeared to be a definite relationship existing both within and among varieties at the Cherokee location in protein-level of seed planted to number of days from seedling emergence to heading. This was particularly true for the medium protein-level where the period of time in question was slightly less. This was not apparent, however, at the Stillwater location.

Table 5.--Average number of tillers with fertile heads in 2 linear feet of 3 varieties of hard red winter wheat.

Protein Level	Varieties: Triumph	Kaw	Tascosa	Average
	Stillwater			
Low	115.75	110.75	129.00	118.50
Medium	121.00	130.75	130.50	127.42
High	116.50	110.00	127.50	118.00
Average	117.75	117.17	129.00	121.31
	Cherokee			
Low	108.00	121.25	132.00	120.42
Medium	111.75	122.25	119.50	117.83
High	119.25	115.50	129.75	121.50
Average	113.00	119.67	127.08	119.92

Table 6.--Average number of days from complete seedling emergence to heading of 3 varieties of hard red winter wheat.

Protein Level	Varieties: Triumph	Kaw	Tascosa	Average
	Stillwater			
Low	200.50	202.75	202.75	202.00
Medium	201.25	202.75	202.50	202.17
High	201.50	202.75	202.25	202.17
Average	201.08	202.75	202.50	202.11
	Cherokee			
Low	199.00	199.50	200.75	199.75
Medium	199.25	198.75	199.00	199.00
High	199.50	199.25	199.75	199.50
Average	199.25	199.17	199.83	199.42

Heights of Plants

The heights in inches of the three varieties of wheat, each with 3 different protein-levels, are shown in table 7. A significant difference at the 5% level was found among varieties at the Stillwater location. No significant difference among protein-levels was found at either location. Kaw was the tallest variety and Tascosa the shortest variety at both field locations. There appeared to be no relationship between the protein-level of seed planted and plant height either within or among the varieties tested at both locations.

Table 7.--Average height of plants of the 3 varieties of hard red winter wheat.

Protein Level	Varieties			Average
	Triumph	Kaw	Tascosa	
		Stillwater		
Low	31.07	29.62	29.45	30.05
Medium	30.52	31.82	29.90	30.75
High	30.97	31.57	28.87	30.47
Average	30.85	31.00	29.40	30.42
		Cherokee		
Low	28.87	29.62	27.50	28.66
Medium	27.87	28.37	29.00	28.41
High	27.50	28.87	29.12	28.50
Average	28.08	28.95	28.54	28.52

Yield of Grain

Yields, recorded in bushels per acre, are presented for each variety and treatment in table 8. Significant and highly significant varietal differences were found at the Stillwater and Cherokee field locations respectively. Also significant differences were found at the Cherokee location due to protein-level of seed planted X variety interaction effects. Kaw was the highest yielding variety at both locations. The difference in the average yield of Triumph and Tascosa was very slight. Although there appears to be no consistent relationship of protein-level of seed planted to yield within varieties, it does appear rather consistent among treatments at both field locations. At each location the highest average grain yields were obtained from the plots planted with seed of the lowest protein-level. With the exception of the medium protein-level at the Stillwater location, yields were inversely related to protein-level of seed planted.

Table 8.--Average yield of grain of the 3 varieties of hard red winter wheat.

Protein Level	Varieties: Triumph	Kaw	Tascosa	Average
Stillwater				
Low	42.47	45.40	41.82	43.23
Medium	40.17	44.75	41.40	42.10
High	41.77	45.55	41.20	42.84
Average	41.47	45.23	41.47	42.72
Cherokee				
Low	41.45	46.80	37.20	41.81
Medium	39.37	40.75	42.95	41.02
High	38.60	43.60	40.55	40.91
Average	39.80	43.71	40.23	41.25

Greenhouse Studies

Percentage Seedling Emergence

The percent seedling emergence by variety and protein-level is given in table 9. No significant differences were found among varieties, however, highly significant differences were found among levels of protein content of the seed planted. The percentage of seedling emergence was positively related to protein-level among varieties although the difference between the medium and high levels was minor. This same relationship did not exist within all varieties. With the exception of the Tascosa variety the highest percentage of seedling emergence occurred from seed planted containing the medium level of protein.

Table 9.--Average percent seedling emergence of the 3 varieties of hard red winter wheat grown in flats in the greenhouse.

Stillwater				
Protein Level	Varieties			Average
	Triumph	Kaw	Tascosa	
Low	76.03	74.99	76.02	75.68
Medium	92.70	91.66	85.41	89.92
High	91.66	88.53	92.70	90.96
Average	86.80	85.06	84.71	85.52

Number of Days to Complete Seedling Emergence

The number of days required for complete seedling emergence of each variety and protein-level is presented in table 10. Highly significant differences were found among protein-levels. The variety X protein-level interaction approached the 5% level of significance. The Tascosa variety required the least number of days to reach complete emergence followed consecutively by Kaw and Triumph. With the exception of the Kaw variety, the same relationship of protein-level of seed planted to number of days to complete seedling emergence existed both within the varieties and among the varieties. In each case seedling emergence was more rapid from seed planted of the medium protein-level and followed consecutively with seed planted of the high protein-level and seed planted of the low protein-level. Seedling emergence was always slower from seed planted of low protein-level.

Table 10.--Average number of days to complete seedling emergence of the 3 varieties of hard red winter wheat grown in flats in the greenhouse.

Stillwater				
Protein Level	Varieties			
	Triumph	Kaw	Tascosa	Average
Low	10.25	8.75	7.50	8.83
Medium	6.25	8.25	6.00	6.83
High	7.50	6.50	7.25	7.08
Average	8.00	7.83	6.92	7.58

First Leaf Growth Measurements

The total growth of plants in the first leaf stage of development for each variety and protein-level is presented in table 11. Significant differences among protein-levels were found. Kaw produced the greatest total growth followed by Tascosa and Triumph. Except for the Triumph variety the same relationship of protein-level to total growth existed both within and among varieties. In each instance, the medium protein-level of seed produced the greatest total seedling growth. The high and low protein-levels followed in consecutive order. Plant growth was always slower from seed planted with the low protein-level.

Table 11.--Average total growth of plants in millimeters in the first leaf stage of the 3 varieties of hard red winter wheat grown in flats in the greenhouse.

Stillwater

Protein Level	Varieties			Average
	Triumph	Kaw	Tascosa	
Low	95.95	109.74	102.74	102.81
Medium	111.27	118.99	113.99	114.75
High	113.04	116.41	113.87	114.44
Average	106.75	115.05	110.20	110.67

Second Leaf Growth Measurements

The total growth of plants in the second leaf stage of development for each variety and protein-level is presented in table 12. Highly significant differences among varieties were found. Also significant differences among protein-levels of seed were found. Consistent with the first leaf stage of growth, Kaw produced the greatest total seedling growth followed by Tascosa and Triumph in that order.

A positive relationship of protein-level of seed planted to total growth, both within varieties and among the varieties tested, is indicated. Total growth increased with each increased level of protein content of the seed planted.

Table 12.--Average total growth of plants in millimeters in the second leaf stage of the 3 varieties of hard red winter wheat grown in flats in the greenhouse.

Stillwater

Protein Level	Varieties			Average
	Triumph	Kaw	Tascosa	
Low	84.16	101.95	81.78	89.30
Medium	88.07	113.62	92.78	98.16
High	92.77	114.83	94.17	100.59
Average	88.33	110.13	89.58	96.01

Forage Green Weights

The green weights of all of the above ground portions of the seedlings harvested from each variety and protein-level are shown in table 13. Significant differences among protein-levels of seed planted were found. Kaw ranked first in green forage production followed by Triumph and Tascosa in that order. A positive relationship of protein-level of seed planted to forage produced was apparent among the varieties tested. Within varieties, however, this same relationship did not hold true. With the exception of the Kaw variety, the medium protein-level of seed planted produced the greatest amount of forage followed by that planted of the high and low protein-levels respectively.

Forage Air-Dry Weights

The air dry weights of the forage harvested from each variety and protein-level are presented in table 14. No significant differences were found among varieties or among protein-levels of seed planted. Triumph rather than Kaw ranked first in air dry forage produced. Kaw and Tascosa ranked second and third respectively. With the exception of the Kaw variety the same relationship of air dry forage produced to protein-level of seed planted existed both within varieties and among varieties. The medium protein-level of seed planted produced the greatest amount of air dry forage followed consecutively by that planted with high and low protein-levels.

Table 13.--Average green forage weight in grams of the 3 varieties of hard red winter wheat grown in flats in the greenhouse.

Stillwater

Protein Level	Varieties			Average
	Triumph	Kaw	Tascosa	
Low	5.50	6.05	5.37	5.64
Medium	7.87	8.00	7.12	7.66
High	7.40	8.70	6.80	7.63
Average	6.92	7.58	6.43	6.98

Table 14.--Average air dry forage weights in grams of the 3 varieties of hard red winter wheat grown in flats in the greenhouse.

Stillwater

Protein Level	Varieties			Average
	Triumph	Kaw	Tascosa	
Low	1.15	1.12	1.02	1.10
Medium	1.68	1.40	1.37	1.48
High	1.45	1.52	1.27	1.41
Average	1.42	1.35	1.22	1.33

DISCUSSION AND CONCLUSIONS

It is known that the type and amount of protein have a marked influence on baking quality of wheat. Adequate information appears to be lacking, however, on the influence of protein content of the seed planted upon subsequent yield and upon the reproductive and other functions of the plant which may affect yield. The main objective of this study was to determine the effect of protein content of the wheat seed planted on the yield of the crop harvested therefrom. Other objectives were to determine the effect of protein content of seed upon several factors which may influence yield such as (1) seed germinating ability, (2) seedling emergence, (3) rate of seedling growth, (4) tillering capacity and (5) date of heading.

Seed Germination

Kaw seed germinated the highest of the three varieties tested in the seed germinator followed by Triumph and Tascosa in that order. The difference in germination between Kaw and Triumph was small. Tascosa germinated considerably lower than the other two varieties which would indicate this to be a varietal characteristic. The highly significant and positive effects found among protein levels of seed planted to germination agrees generally with that found by Kamal (14).

Field Studies

Seedling Emergence

Seedling emergence in both field tests conformed to the rate of seed germination in the laboratory as to variety. Kaw, the highest germinating variety in the laboratory, produced the greatest number of seedlings per 2 feet of row at both field locations. Triumph and Tascosa followed in that order. The significant difference found among varieties and variety X protein-level interaction at the Stillwater location is illustrated in Figure 1 which shows Kaw producing the greatest number of seedlings at the highest level of protein.

Number of Days to Complete Emergence

This study showed that the protein level of seed planted had no significant effect upon the rate of seedling emergence. Triumph, however, did show a positive relationship of seedling emergence rate to seed protein-level. This may well indicate that the protein-level of the seed planted is, in fact, being expressed through the rate of seedling emergence, but that it is being masked or retarded by the complexities of the micro-environment.

Tillering Capacity

Tillering cpacity appeared to be a varietal characteristic. Tascosa ranked first at both field locations, followed by Kaw and Triumph in that order. The protein-level of seed planted was not expressed in number of tillers produced under the conditions tested.

Number of Days from Complete Seedling Emergence to Heading

The protein level of seed planted had no significant effects on the number of days from seedling emergence to heading. Although the medium protein-level seed tended to shorten the interval between seedling emergence and heading at Cherokee, it did not follow this pattern at Stillwater. The prevailing environmental factors appear to have

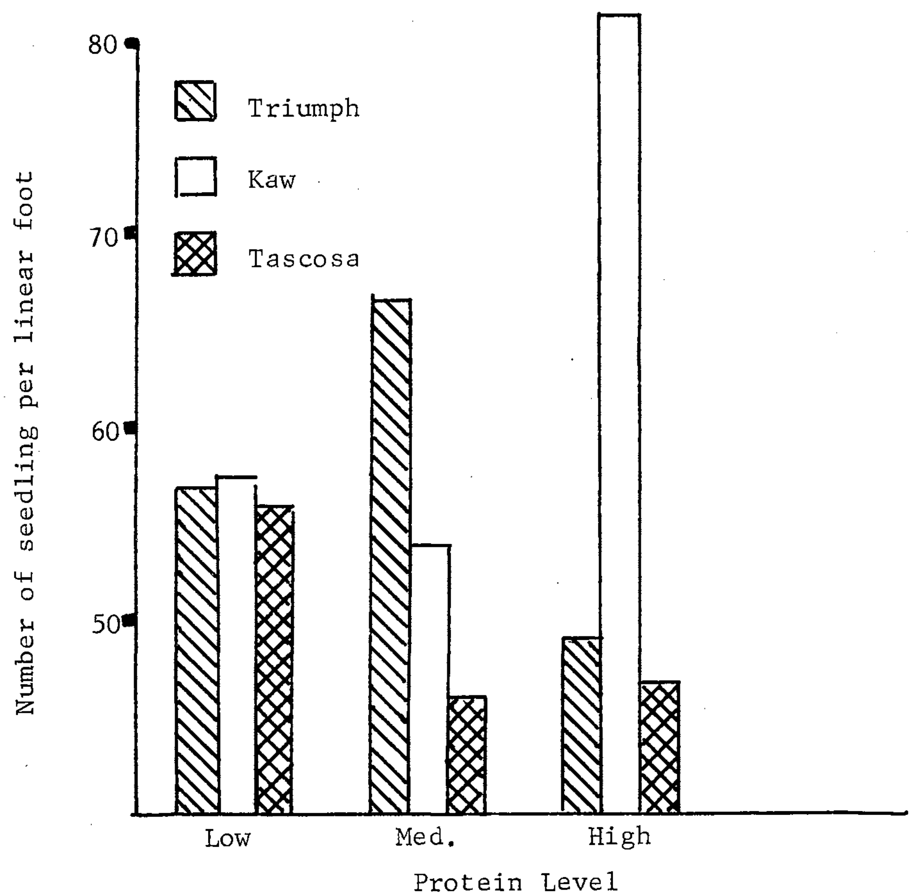

Figure 1.--The relationship between protein-level of seed planted and number of seedlings in 2 linear feet of 3 wheat varieties with 3 levels of protein. Stillwater

more profound effects than the protein-level of seed planted in determining the period of time from seedling emergence to heading. This agrees in general with Le Clerc's (16) findings.

Height of Plants

The only significant difference in plant height was due to variety. The protein-level of seed planted exerted no influence on plant height under the climatic conditions which prevailed at the two field locations.

Yield of Grain

Significant differences in yield were due to variety. Kaw was the highest yielding variety at both locations. The significant differences due to protein-level of seed planted X variety interaction effects at the Cherokee location resulted from the high yield of Kaw obtained from the seed planted by the low protein-level as shown in Figure 2. Soil heterogeniety and its effects upon yield and protein content of wheat as discussed by Mallock and Newton (17) and other authors (16,19) may well explain this.

Greenhouse Studies

Percentage Seedling Emergence

No significant differences among varieties was found in percent seedling emergence when grown in flats in the greenhouse. However, significant differences were found among protein-levels. The relationship of protein-level of seed planted to percent seedling emergence was positive. The data indicate that seed containing high levels of crude protein is much superior to that of low levels of crude protein in seedling emergence. This agrees generally with that found by Kamal (14) who found that high protein content seed had the highest

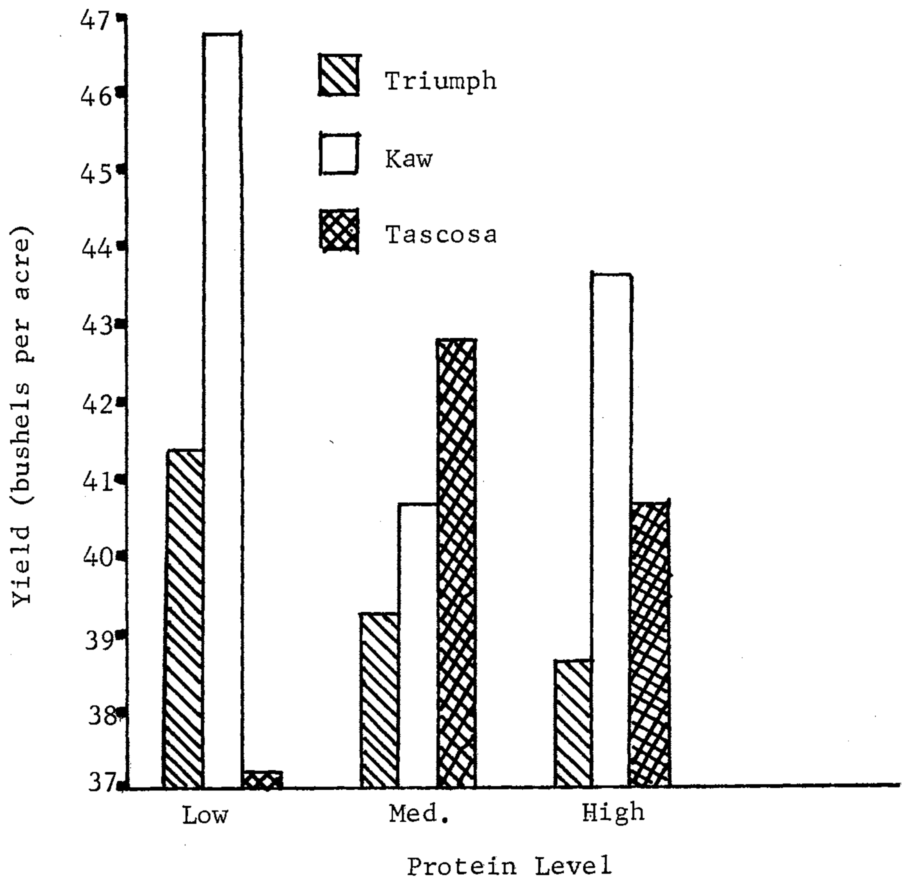

Figure 2.--The relationship between protein-level of seed planted and yield of 3 wheat varieties with 3 levels of protein. Cherokee

germination, medium protein had intermediate germination and low protein seed had the lowest germination.

There appears to be a threshold of seed protein-level beyond which there is no additional benefit in seedling emergence as evidenced among protein-levels of two out of three wheat varieties tested.

Number of Days to Complete Seedling Emergence

The rate of seedling emergence followed approximately the same pattern as seedling emergence. Highly significant differences were found among protein-levels in the rate of seedling emergence. In two of the three wheat varieties tested (Triumph and Tascosa), the rate of seedling emergence was highest from seed planted of the medium protein level. This would also indicate that maximum benefits of crude protein content of seed planted to rate of seedling emergence may not exceed the medium level which in this study ranged from 11.58% to 11.90%. The higher rate of seedling emergence due to planting seed of high protein content agrees with the study conducted by Fox and Albrecht (8) on the emergence of wheat seedlings according to the crude protein of the wheat grain using seed of high (14.4%) and low (11.0%) protein content. They found that seedling emergence at 6 and 10 days after planting was 4.9% and 6.7% higher for the high protein wheat than the low protein wheat respectively.

First Leaf Growth Measurements

The variety Kaw produced the greatest total seedling growth. Although significant differences were found among protein-levels of seed, they were very small between the high and medium levels. The daily growth rate was much higher for those seedlings produced from the high and medium protein-levels of seed than that produced from the low level. The difference in rate of growth between the high and medium levels was small. Although seed of the high protein-level produced more total plant growth than either the medium or low protein-level in Triumph, Figure 3 shows it to have the same daily growth pattern as the other two varieties tested. In these tests plants produced from seed containing high and medium levels of protein grew at approximately the same rate and at a much greater rate than those produced from seed containing low levels of protein. This study shows that seedling vigor in wheat is related to protein content of seed planted but that it is not expressed above a certain level.

Second Leaf Growth Measurements

The Kaw variety produced the greatest total seedling growth which would indicate this to be a varietal characteristic.

The relationship of protein-level of seed to rate of seedling growth varied somewhat in the second leaf stage from that in the first leaf stage of growth in that there was a straight forward positive relationship of protein-level to rate of growth. Significant differences among protein-levels were found; however, small differences were found among the high and medium protein-levels. Figure 4 shows that the greatest total growth within the Tascosa variety occurred from that seed planted with the medium protein-level. It will be noted that at the time growth measurements began, plant growth representing the medium protein-level of seed planted measured 104.6 mm compared to 95.5 mm and 89.5 mm for the high and low seed protein-levels respectively.

Forage Green Weights

It is apparent from this study that the protein-level of seed

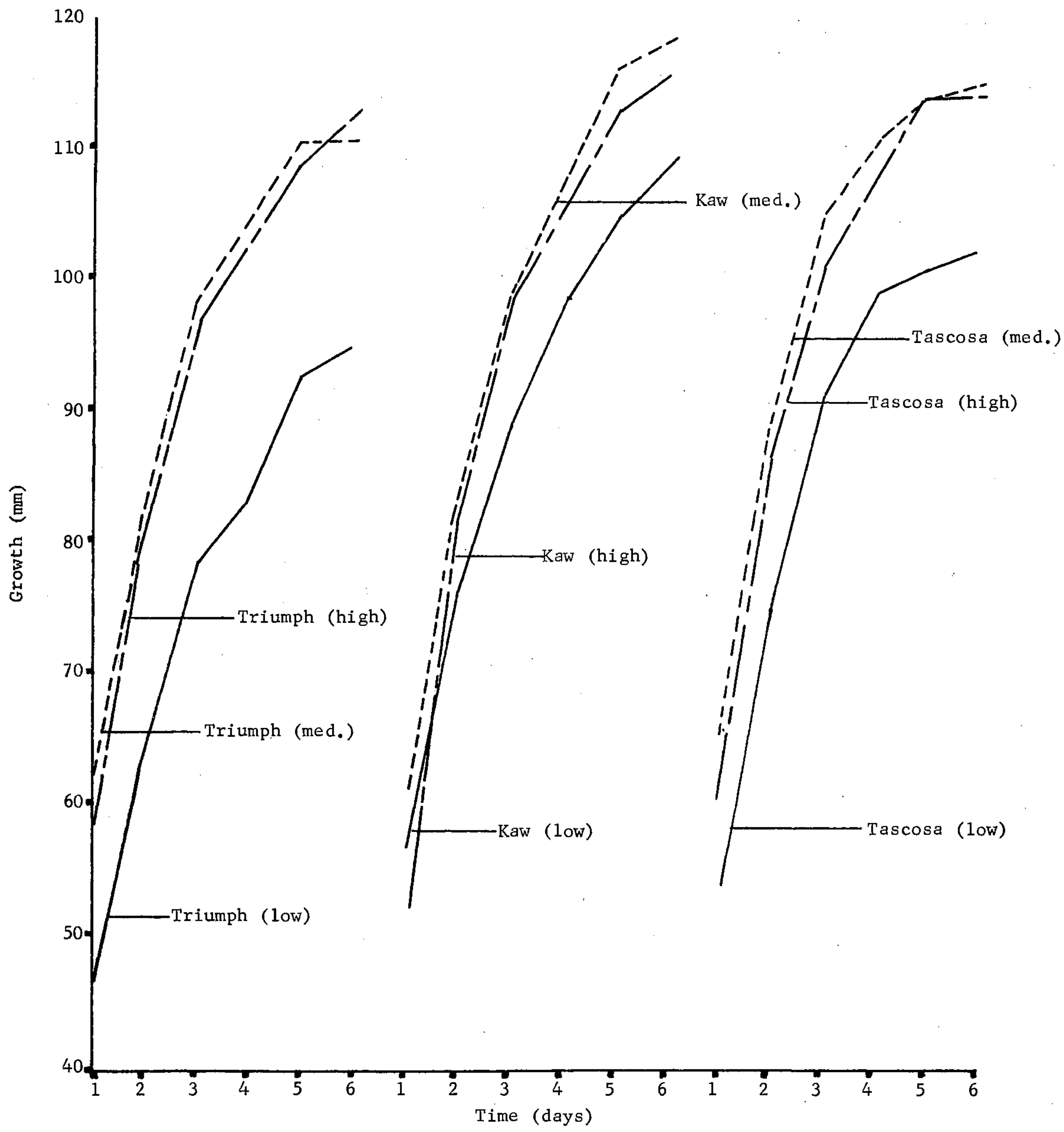

Figure 3.--Average daily height of 3 wheat varieties with 3 levels of protein in the first leaf stage of growth.

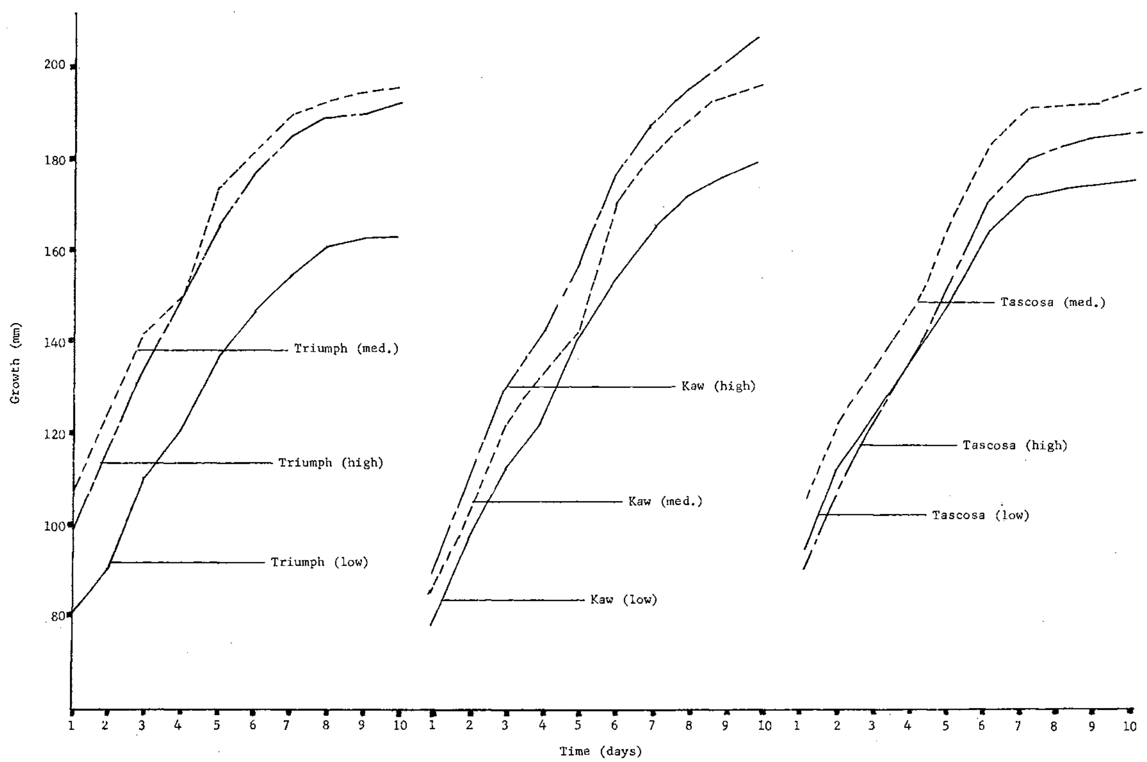

Figure 4.--Average daily height of 3 wheat varieties with 3 levels of protein in the second leaf stage of growth.

planted affects early seedling growth. The seedlings harvested had progressed to and beyond the third leaf stage of development.

The significant differences among protein-levels of seed planted to forage green weight agrees with that found in the growth rate in the first and second leaf stages of seedling development as a measure of seedling vigor. As seen in Figures 5, 6 and 7, forage weight increases generally with increased plant emergence and plant height. It will be noticed that there are small differences between the medium and high protein-levels of seed planted in seedling emergence, forage weight and plant height respectively as compared to that between the low and medium protein-levels of seed planted.

Forage Air-Dry Weights

No significant differences were found among protein-levels of seed planted as measured by air dry forage weights of seedlings harvested. This does not agree with the results obtained from the green forage weights but may be explained in that the ratio of green weight to dry weight of forage harvested for Triumph was 1:4.825 compared to 1:5.584 for Kaw. This indicates that Kaw produces a more succulent plant than either Triumph or Tascosa and may account for the non-significant differences among varieties based on air dry forage weight.

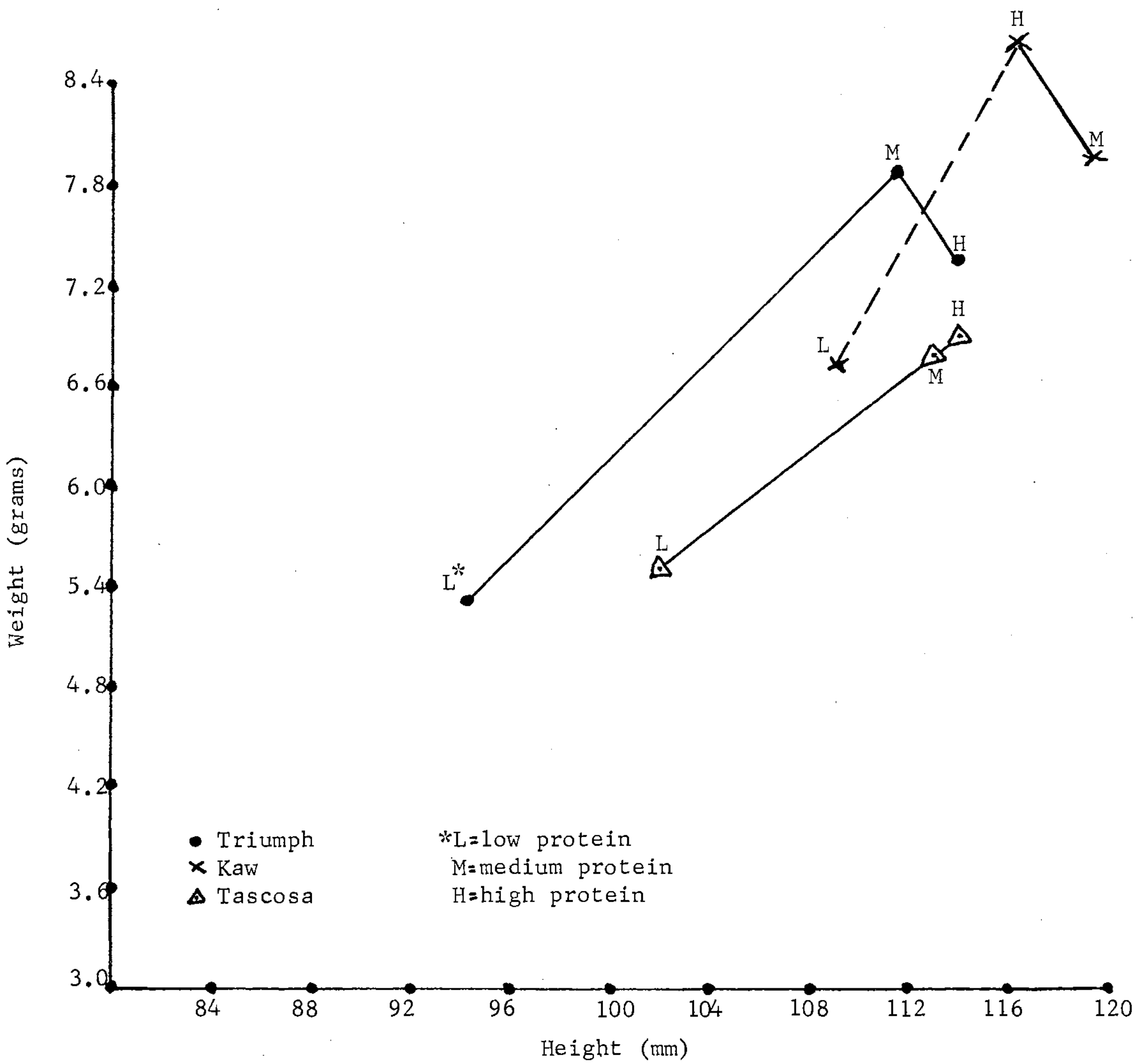

Figure 5.--The relationship between green weight and the growth of the first leaf of 3 wheat varieties with 3 levels of protein.

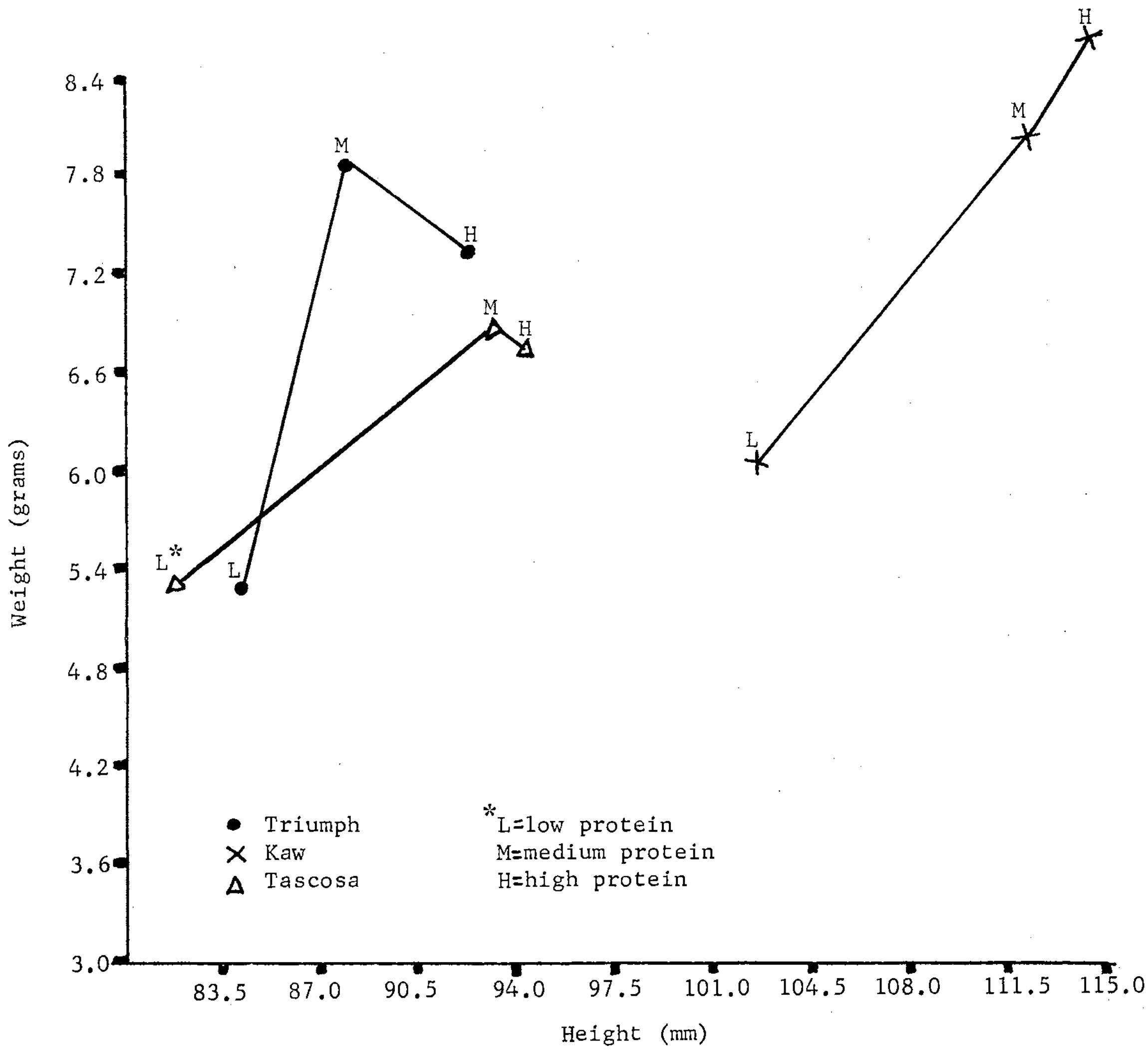

Figure 6.--The relationship between green weight and growth of the second leaf of 3 wheat varieties with 3 levels of protein.

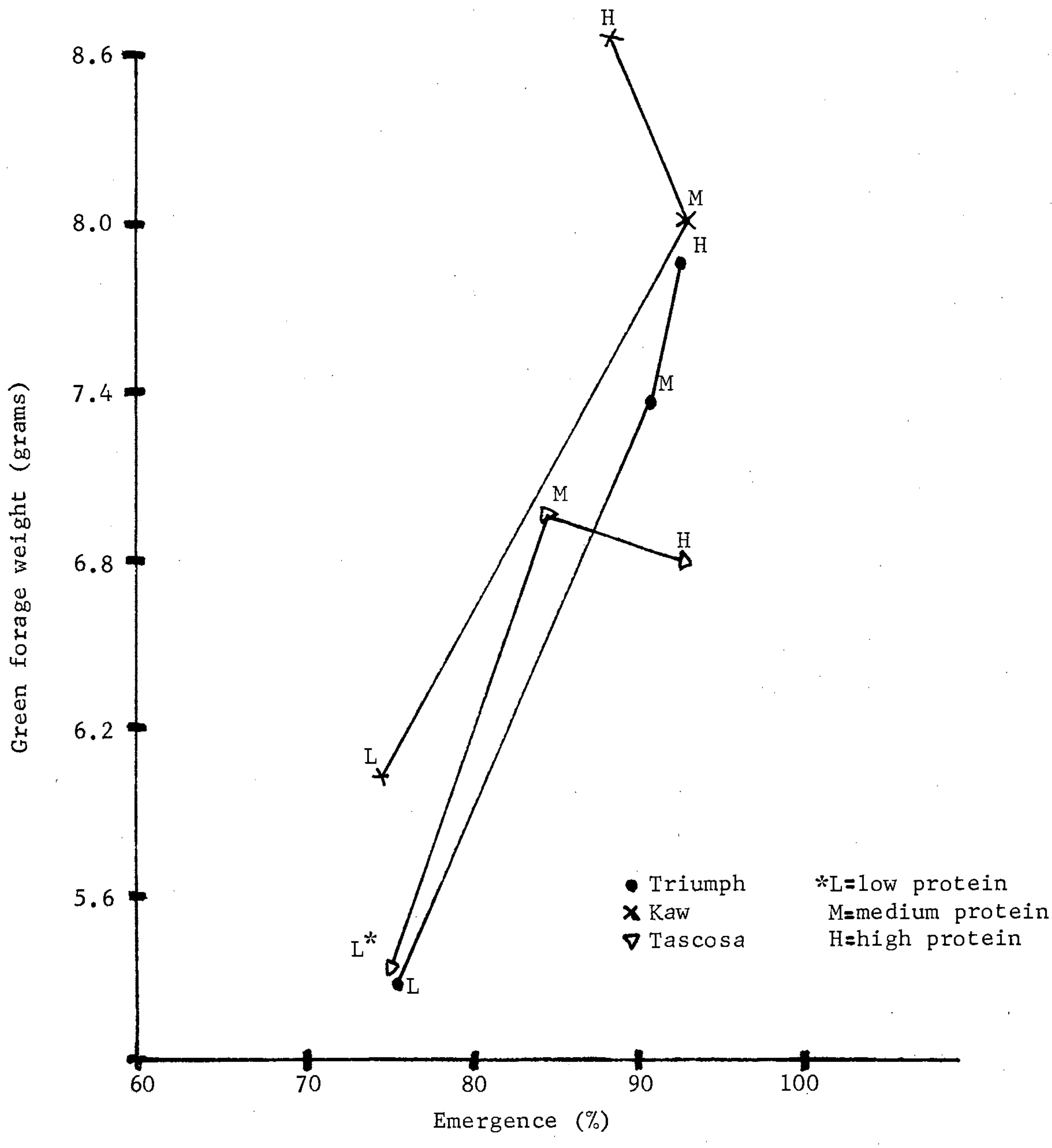

Figure 7.--The relationship between green forage weights and emergence of 3 varieties with 3 levels of protein.

SUMMARY

A study was conducted to determine the effect of protein content of the wheat seed planted on subsequent yield. Seed of low, medium and high protein levels of the hard red winter wheat varieties Triumph, Kaw and Tascosa was used in field plantings at Stillwater and Cherokee, Oklahoma, and in greenhouse plantings at Stillwater.

Other objectives of the research were to determine the effect of protein content of seed upon several factors which may influence yield. They included (1) germinating ability, (2) seedling emergence, (3) seedling vigor, (4) tillering capacity (5) and date of heading.

Seed germinating ability as determined in the laboratory was closely associated with both the variety and protein level. Kaw and Triumph were superior to Tascosa. Seed of high and medium levels of protein content in all varieties tested was much superior to that of the low level.

Field seedling emergence appeared to be associated with the variety although variety X protein level interaction was found at the Stillwater location. Under these field conditions tested, the protein level of seed planted had no significant effects upon (1) rate of seedling emergence, (2) tillering capacity (3) period of time from seedling emergence to heading and (4) height of plants. Differences in plant height and yield were associated with the variety. Although protein-level of seed planted X variety interaction in yield was statistically significant at Cherokee, additional testing would appear

necessary to establish its authenticity.

Greenhouse studies conducted on these three wheat varieties showed significant effects of protein-level of seed on (1) germination, (2) rate of seedling emergence, (3) growth rate and (4) forage green weight. The high and medium levels were significantly higher than the low level in all factors measured. There appears to be a threshold of seed protein-level beyond which there are no additional benefits. In this experiment it appeared to be at the medium level which ranged from 11.58% to 11.90%.

This study showed under environmentally-controlled conditions, that seed of the higher levels of protein enhance the possibility of greater yields through higher germination, more rapid emergence and growth, but that these superior effects are either lost or rendered undectable by the complex and uncontrolled environment in the field. It is reasonable to assume that these effects are being expressed under field conditions and that they may be more profound under environmental conditions different from those under which this test was conducted.

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