AN ABSTRACT OF THE THESIS OF

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Title: EFFECT OF SEED SIZE, SEEDING RATE AND IRRIGATION ON YIELD AND YIELD COMPONENTS OF SPRING WHEAT (TRITICUM AESTIVUM L.)

Abstract approved Redacted for Privacy

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The objective of this experiment was to study the effect of seed size on yield and yield components of spring wheat (Triticum aestivum L.) when planted at different seeding rates under rainfed and irrigated conditions.

The experiment was conducted at the Hyslop Crop Science Field Laboratory at Corvallis in 1976.

Certified seed lots of Fielder soft white spring and Profit 75 hard red spring wheat were separated into large, small and ungraded seed sizes and planted to evaluate their yield responses. Seeds were planted at three seeding rates based on equal numbers of seeds per unit area (228, 293, and 421 seeds/m^2) and one seeding rate based on equal weights of seeds per area (approximately 11 grams/m^2). This study was conducted under rainfed conditions (70.9 mm = 2.79 in) and with supplemental irrigation (290.1 mm = 11.42 in of total water supply).

Development and maturation of the crop were not affected by

seed size, but were delayed by heavy seeding rates and irrigation.

The following results were observed under rainfed conditions:

1. At a seeding rate of 110 kg/ha (98 lb/A), large seed of Fielder yielded 14.2% more than ungraded seed and 18.5% more than small seed. No yield differences due to seed size were evident in Profit 75.

2. With seeding rates based on equal numbers of seeds per plot, large seed yielded 6.1% more than ungraded seed and 9.6% more than small seed when yields were averaged over varieties and seeding rates. Increased yields were due to a larger number of spikes/m^2.

3. At a seeding rate of 228 seeds/m^2, large seed of Fielder yielded 14.7% more than ungraded seed and 21.4% more than small seed. There was no yield difference due to seed size in Profit 75.

4. At seeding rates of 293 and 421 seeds/m^2, yields from the three seed sizes were similar in both varieties.

The following results were observed under irrigated conditions:

1. At a seeding rate of 110 kg/ha (98 lb/A), there was no association between seed size and yield in either variety.

2. With seeding rates based on equal numbers of seeds per plot, large seed yielded 5.9% more than small seed and the same as ungraded seed when yields were averaged over varieties and seeding rates. Yield increases were due to the production of heavier seeds.

3. At a seeding rate of 228 seeds/m^2, large seed of Profit 75

yielded 22.1% more than small seed and the same as ungraded seed. Yields of the three seed sizes of Fielder were similar.

4. At seeding rates of 293 and 421 seeds/m^2, yields from the three seed sizes were similar in both varieties.

It is concluded that producers of spring wheat in the Pacific Northwest can obtain higher yields by sizing their seed and planting only the large seed. Large seed have a greater advantage under stress moisture conditions. Benefits from large seed may vary with the variety or seed lot.

Effect of Seed Size, Seeding Rate and Irrigation on Yield and Yield Components of Spring Wheat (*Triticum aestivum* L.)

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DEDICATION

To my wife Maria Glaci, and my children Cibele, Luis Alberto, Luis Antonio, Marco Aurelio, and Maurice, for their affection and love, I dedicate this thesis.

B. R.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

EFFECT OF SEED SIZE, SEEDING RATE AND IRRIGATION ON YIELD AND YIELD COMPONENTS OF SPRING WHEAT (*TRITICUM AESTIVUM* L.)

INTRODUCTION

Wheat is the most widely cultivated cereal in the world, yielding the highest tonnage of grain and protein of any crop. At the present time over 220 million hectares are planted to this crop annually, thus generating about 340 million tons of grain and more than 300 million tons of edible dry matter.

As available land area is limited and the world's population continues to rise, it becomes necessary to increase wheat yields. Such increases can be achieved through a combination of improved technologies, among them the use of improved seed quality.

Seed quality has been shown to have important effects on crop yields. Many studies have concluded that seed size is correlated with final yield.

The effect of seed size is usually more evident in short-season crops and under stress environmental conditions. Spring wheat, one of the shorter-season crops among cereals, was chosen for this research.

The objectives were to determine the effect of seed size on yield and yield components of spring wheat. Three seed sizes were tested in this experiment, among them the ungraded seed commonly planted by wheat growers. The effects of seed size at different seeding rates and with and without irrigation were also investigated. Two spring wheat varieties commonly grown in the Willamette Valley were included to assess varietal differences in response to seed size effects on yield.

LITERATURE REVIEW

Early Studies of the Effect of Seed Size on Yield of Field Crops

The effects of seed size or seed weight and seeding rate on yield of field crops have been studied to some extent since the 19th Century. Results obtained varied according to the way the seed was graded, the variety studied, and the set of circumstances under which the experiments were carried out.

Since as early as 1866, according to Montgomery (1910), researchers were aware of the possible influence of seed size on yield of field crops. At that time Hamberlandt, working with wheat, first attempted to assess seed size effect on yield. Soon after, in 1889, Churchill, by comparing selections of large and small bean seeds, concluded

> that the larger amount of dry matter contained in the large seed after it becomes converted into available food for the young plants furnishes them with greater power to overcome any adverse condition attending vegetation, transmitting to the plant a more vigorous constitution and furnishing a greater resistive power to the diseases attacking the plant.

Boss (1893), testing heavy versus light oat seeds separated by a fanning mill, stated that heavy seeds yielded 17.4% more seed than light ones. Hicks and Dabney (1896), relying upon data collected from an extensive list of field crops, concluded that it was worthwhile to select for heavier seeds which would produce better crops than lighter seeds. Snyder (1905), citing Hellreigel and others, stated that heavy weight wheat seed always produced better crops, and that the difference was more pronounced on soils of low and medium fertility.

Researchers that followed in this early period, such as Zavitz (1908) and Montgomery (1910), when working with an equal number of seeds per unit area, obtained results similar to those already listed.

Cummings (1914), dealing with different field crops, stated that when comparing weight and size of plants at different stages of growth, a continuous and permanent advantage existed in favor of plants grown from large seeds, which possessed more leaves of greater surface area and hence had greater assimilatory capacity. Findlay (1919), working with various field crops, also observed the advantage of large seeds. He stated that when ungraded seed is sown, plants produced from large seeds have a considerable adverse influence on those produced from small seeds.

Brenchley (1923), studying the effect of seed weight on peas and barley under controlled conditions, concluded that for annual crops, at least, the use of heavy seed leads to a better crop. He stated also that the relative development of shoot and root is influenced by the initial seed weight and may vary with the species and with the amount of available food, but that in long-growing-period crops the advantage of using large seed tends to diminish as the period extends.

Effect of Seed Size on Yield of Cereal Crops

The effect of seed size or seed weight on yield of cereals has been studied in various crops, wheat and barley being the ones more thoroughly investigated. Results obtained varied with the circumstances under which the work was performed, as well as with the genetic makeup of the seeds used and with the way they were graded.

Kiesselbach and Ratcliff (1917) concluded that in oat crops little practical yield improvement could be effected by planting only heavy grade seed obtained from the fanning mill, when equal weights of seed per area were planted, but that large seed yielded 12. 4% more than small ones when equal numbers of seed per area were compared. The variety they used appears to have been a mixture of strains, and this could have influenced their findings.

Kiesselbach and Helm (1917), based on their own experimental results and upon several studies carried out by colleagues dealing with cereal crops, pointed out a series of important aspects related to seed size and yield. Kiesselbach (1924), updating those figures in the light of more recent results, stated that when large and small hand-selected seeds of winter wheat, spring wheat, and oats were compared, small seeds yielded respectively 18. 6, 17. 9, and 17. 4% less seed than large ones, when spaced to permit maximum individual plant development. Yields resulting from small seeds were 8. 1, 15.0 and 6.2% lower than yields from large seeds when equal numbers of seed per area were sown, and respectively 3.9, 9.8 and 1.2% lower when equal weights per area were sown, always at optimum rates for large seed. When unselected seed was used, it yielded respectively 3.4, 4.5 and 3.7% lower than large seed when equal numbers of seed were planted per area. Where equal weights of seed were planted, ungraded yielded 3.1 and 0.8% more than winter and than spring wheat, respectively, and 0.7% less than oats. Results of 17 years of study comparing yields of heavy and light wheat seeds separated by a fanning mill revealed the heaviest one-fourth yielding 0.3% more, and the lightest one-fourth yielding 2.0% less than the unselected seed. Kiesselbach also reported that 18-year-average data for oats showed the heaviest-one-fourth yielding 0.9% more, and the lightest one-fourth yielding 0.7% less than the ungraded seed. The same report revealed that small and unselected seed of spring wheat, planted with equal numbers per unit area, yielded respectively 85 and 96% as much as large seed. When equal weights of seed per area were sown the correspondent yields were 90 and 101%.

Blackman (1919) called attention to the fact that growth of an annual plant, at least in its early stages, follows approximately the "compound interest law." Thus the dry weight attained by a plant at the end of any period of time is dependent on the weight of the seed or seedling at its start, on the average rate at which the plant makes use of the material already present to build up new plant material, and on the period of growth.

Taylor (1928) stated that large seeds outyielded small ones in five of the six years of the experiment, and especially so in the high-yielding years. Seeds were initially sorted into large and small sizes by means of wire screens, and in the following years of the experiment the large seeds were sorted from the crop grown from the large-seeded plots of the previous harvest, and the small seeds from the crop originated from the small-seeded plots. There were, however, indications that the cultivar he used was a mechanical mixture and not a pure strain.

Waldron (1941) concluded that when planting the same number of spring wheat seeds per unit area, plants from large seeds yielded 12% more than those from small seeds, and that when planting equal weights of seed per area large seeds produced 10% more than the small seeds. He stated that under better conditions heavy seeds showed less advantage. He (1943) showed that small-seeded wheat yielded less under nursery conditions when sowed at equal weights per unit area; the greater kernel weight was the main factor in determining yield. When an equal number of large and small seed was sown intermixed in the row, large seeds outyielded small ones by 69%, most of which was due to the greater stooling of the large-seeded plants. Competition was considered to be the main reason for this difference.

Results obtained by Saric (1959), when testing seed lots of cereal crops with different 1,000-seed weight, revealed that large seeds produced higher yields than small ones and concluded that a greater number of seeds per area did not compensate for the small size of the seed, when relating to yield. Kaufmann and McFadden (1960), studying the effect of inter-plant competition in barley in glasshouse and field tests, demonstrated that plants originated from small seeds yielded approximately 77 and 57% as much grain as those grown from large seeds in glasshouse and field, respectively. The percentages were 70 and 54, respectively, when plants were grown under inter-row competition; and 89 and 83, respectively, when not submitted to competition. They also showed that increased competition favored plants from large seeds.

Bremner et al. (1963) stated that plant size was reduced in plants originated from seeds with small endosperm, but not from those with small embryo. The rate at which endosperm was used depended on the amount present and the seedling growth rate; after endosperm exhaustion, all relative growth rates were similar. They suggested that the relationship between seed size and plant growth was governed basically by the amount of endosperm reserves in the seed.

McFadden et al. (1960) found that loose smut (Ustilago nuda) infection in barley was greater in the case of small- and medium-sized seeds than in large ones. Lavery (1965), in similar work with barley, reached the same conclusion, proving that the percentage of embryos infected with loose smut and the percentage of smutted spikes in the crops were inversely related to the size of seed planted.

Demirlicakmak et al. (1963), working with three barley cultivars at three different seeding rates and with three sizes of seed, concluded that seed size did not affect emergence, but that the number of culms and grain yield were higher for large seed over all rates and cultivars used. Kaufmann and McFadden (1963) compared barley yields from four seed sizes and reached similar conclusions. Petrov and Stefanov (1968) reported that yield increased 7.5 to 9.5% when large-sized barley seed was compared to standard size.

Borojevic (1964) proved that yields of wheat crops from large seed were 20% higher than from small seed. Vlach (1964), working with three winter wheat and two spring barley varieties, found only one wheat variety in which larger seeds outyielded medium and small ones. Parshakova (1965) concluded that wheat plants from large seed yielded more than those originating from small seeds, and that under favorable conditions, such as irrigation or use of fertilizer, the difference was increased, while under adverse situations, the advantage was reduced slightly.

Pinthus and Osher (1966) found that when large and small-sized seed of wheat, durum wheat, and six-rowed barley were sown at a constant seeding rate, plants grown from large seed yielded 24% more. Tandon and Gulati (1966), working with barley genotypes in which seeds differ in size, concluded that large seeds originated from central flowers produced taller, earlier-maturing plants, giving more tillers, a higher 1,000-seed weight, and higher yields when compared to the smaller seeds originated from lateral flowers with a similar genotypic background.

Studying the effect of seed size on spring wheat, Geiszler and Hoag (1967) found that, when sown to obtain equal numbers of plants per unit area, larger light seeds outperformed small light ones, and that large heavy seeds did not excel small heavy ones. With equal weights of seeds planted per unit area, small light seeds yielded lower than the other three classes.

Kaufmann and Guitard (1967), working with barley cultivars in glasshouse trials, found that the size of seedlings and of the first two leaves was greater in plants grown from large than from small seeds. The large seeds weighed about double the small ones. They also concluded that plant growth from small seed was superior to that from large seed with 50% of the endosperm removed, and was in most cases superior to that in which 25% of the endosperm had been removed.

Vishnyakova (1969) reported that wheat plants from large seeds outyielded those from unsized seed, used as the control; plants from small seed yielded lower, and those from medium-sized seed produced similarly to the control on field trials. Voronin et al. (1969) showed that medium and small seeds of spring wheat yielded respectively 92.3 and 84.6% as much as large seed. For barley the corresponding figures were 95.8 and 78.9%; and for sorghum 96.1 and 90.9%, respectively.

Results obtained by Singh (1970), studying dwarf wheat cultivars, and by Singh and Randhawa (1970), with barley and wheat, led them to similar conclusions: large size seed outyielded the other three sizes (medium, small and bulk) by 10.3, 24.4 and 10.8%, respectively, in the first study, and by 10.5, 28.6 and 9.0%, respectively, in the second study. Goydani and Singh (1971) reported that large seeds of four winter wheat cultivars excelled medium and small size classes by 19.1 and 77.9%, respectively. Bulk seeds produced 1.6% higher yield than did large seed class. The poor yield obtained with small seeds was basically attributed to a decrease in germination, in number of ear-bearing tillers per plant and in the number of surviving plants at harvest.

Austenson and Walton (1970) found that the initial seed size was correlated with total yield, seed yield, and straw yield in spring wheat. Tsepenko et al. (1973) found that there was a positive correlation between grain yield and growth rate of plants in early stages, and that growth rate depended essentially on seed size.

Studying the effect of seed size on yield of winter wheat under irrigation, Gasanenko and Piskun (1971) found that large seeds outyielded medium, small, and bulk seeds by 4.2, 12.4, and 6.2%, respectively.

Mathiasson and Sällvik (1973) graded barley and oat seeds into six sizes by means of slotted screens, to study emergence and yield in field trials under constant weight of seed per area. They found that field emergence was higher for large-sized seed, but with a lower number of plants per meter of row. They also discovered that the largest barley class yielded 18.4 and 28.2% over the smallest during the two-year experiment, and that the largest oat class outperformed the smallest by 7.7% (one year data). Furthermore, they found that in the second year the fifth largest seed class excelled the largest one by 9.9% in barley and 5.1% in oats. Randhawa et al. (1973), testing dwarf wheat seeds sized into five classes, showed that the largest-sized seed yielded more than the other four categories, which yielded 95.1, 94.8, 88.9 and 87.9% of the large seed, respectively, for the fourth largest to the smallest size. Randhawa et al. (1974), studying seed size and seeding rate effects on dwarf wheat yields, using sorted bold, sorted small, and unsorted bulk seeds under four seeding rates, found that the average increases in yield from bold seeds over small and unsorted were 16.1 and 7.4%, respectively.

In studies conducted in a glasshouse with large and small seeds of two wheat cultivars in mixed and pure stands, Roy (1973) observed that plants from large seeds yielded 60.5% more than those from small seeds when grown in competition with them. When sown in a pure stand, large seeds yielded 18.9% less than small ones; the probable reason was its canopy density, which was markedly above optimum.

Morrison et al. (1973), after a three-year study of the effect of seed size on yield of Nugaines wheat, testing large, medium and small size seed at six different sites, found that large seed outyielded medium and small size seed by 4.9 and 14.7% respectively, as a mean from five sites, and by 1.4 and 8.5%, respectively, at the sixth site, this one with better than average rainfall.

Grabe and Garay (1975), after growing crops from farmers' seed lots of Hyslop and Yamhill wheat produced at different locations, observed that the lowest yielding lots usually had the smallest seeds in Hyslop, but not necessarily so in Yamhill. Grabe (1975) tested seed from 18 lots of Hyslop wheat obtained from several counties in Oregon, after grading each lot into two sizes, each one weighing approximately 50% of the lot. He reported that the average yield of the larger seeds was 3.4 bu/A greater than the unsized ones, when grown in the Willamette Valley, under 40 plus inches of average rainfall and 1.8 bu/A greater than the unsized seed when grown in the Columbia Plateau, under 8-10 inches of average rainfall. In the second-year field test, when seeds from nine lots were graded into four sizes, the two larger sizes yielded more than the ungraded seed in the Willamette Valley, the largest ones yielding 5.2 bu/A more than the ungraded, and the two smaller sizes produced less than the ungraded. In the Columbia Plateau no yield differences were detected, probably due to non-uniform plot stands.

Other researchers found no effect, or even a negative response, to seed size or seed weight in field trials when testing for seed yield. This happened mainly when equal weights of seed per unit area were tested.

McNeal and Berg (1960), when evaluating spring wheat seed from different sources, concluded that weight per bushel of seed testing 55 pounds or more had little effect on yield.

Rothman and Bowman (1967), studied yield effects of low test weight seeds in winter oats using seed lots with test weights ranging from 28.3 to 46.3 kg/hl. They found no difference in yield when testing three rates of seeding, and there was no relationship between initial seed weight and seed weight of the resulting crop.

Postygin and Torskii (1969), dealing with spring wheat, concluded that medium-sized seeds produced highest yields, large seeds ranking second with 88.4%, and small seeds third, with 77.0% of the yield of large seeds. The crop grown from medium-sized seeds exhibited higher seed weight than either of the other two fractions. Srivastava and Nigan (1973), working with four wheat cultivars, found that seed size did not have a significant effect on seed yield.

Reisenauer and Morrison (1976), working with three winter wheat varieties at four field locations for two consecutive years, studied the association of seed size with yield at a constant number of seeds per area. They found that emergence of large and medium size seed was significantly greater than small seed, and that greater plant height and tiller number were correlated with higher yields. From the three varieties studied, Wanser showed no difference in yield due to seed size, Paha exhibited the highest yield from medium size seed, and Nugaines had the highest yield from large size seed.

Effect of Seed Size on Yield Components of Cereal Crops

The importance of the various components of yield of cereal crops has been a deep concern among researchers. Engledow and Wadham (1923) attempted to divide cereal crop yields into its component parts. Characteristics such as the number of plants per unit area, number of spikes per plant, number of seeds per spike, and seed weight were regarded as the units from which high yield might be developed. Since then many studies of the association between morphological characters and the yield of cereal crops have been undertaken. Among them, research on the influence that seed size may exercise on yield of cereals stands as one of the widely studied aspects.

Taylor (1928), working with wheat, showed that large seed produced a higher percentage of large grains than did small seed in each of the five years that data were recorded. The average percentage of large grains in the large-seeded plots was 35.5, as compared to 17.8% in the small-seeded plots.

Studies conducted more recently reached conclusions that do not always agree with each other. Kaufmann and McFadden (1960, 1963), working with barley, found that superior production from large seed resulted mainly from a greater number of spikes per plant. Randhawa et al. (1973) achieved the same results with dwarf wheat, and pointed out that plant height was also correlated with seed size. Reisenauer and Morrison (1976), working with winter wheat, concluded that only tiller number was affected by seed size.

Borojevic (1964) reported that a high percentage of large grains accounted for the higher yields produced by large-seeded wheat plants. Vishnyakova (1969), conducting experiments with winter and spring wheat, discovered that 1,000-seed weight of spring varieties was positively related to the size of the seed planted, while for winter varieties that did not happen. Pustygin and Torskii (1969) achieved different results and concluded that a spring wheat crop grown from medium-sized seeds was higher in seed weight and yield. Demirlicakmak _et al_. (1963) stated that seed size affected the number of culms, as well as grain yield, of barley cultivars.

Pinthus and Osher (1966) reported that for common wheat, durum wheat, and six-rowed barley, plants from large seeds yielded better than plants from small seeds, mainly as a result of an increased number of spikes per plant and kernels per spike. Austenson and Walton (1970) stated that seed size in spring wheat was correlated with the number of spikes per plant and with the number of kernels per plant, but not with seed weight or number of kernels per spike. Kikot' (1973) contended that a decrease in tillering and in seed weight was the reason why small-seeded plants produced lower yields than large-seeded ones.

Petrov and Stefanov (1968) showed that yield of barley plants, number of fertile tillers, and number of kernels per spike was higher from large-seeded plants. Gasanenko and Piskun (1971) concluded that under irrigation, large-seeded winter wheat yielded best due to the increase in tillering and number of kernels per spike.

Effect of Seeding Rate on Yield of Cereal Crops

Studies of the effect of seeding rate on yield of cereal crops have been conducted since early in this century. Grantham (1917) found that with low seeding rates it was possible to obtain yields similar to those obtained with much higher rates, because plants under a thin stand develop more fully. Percival (1921) stated that optimum seeding rate varies according to climatic conditions: in areas of low rainfall and short growing season seeding rates are often low, while in regions under high rainfall conditions rates of seeding become fairly high. Martin (1926), based on data from several researchers, concluded that the appropriate rate of seeding is practically independent of soil type, moisture, locality, date of seeding, cultural treatment, and variety. Rates of 30 to 45 lb/A were adequate in terms of number of plants per unit area. However, he indicated that higher seeding rates were more practical, in order to overcome the adverse effects of field conditions. Woodward (1956) obtained similar yields when sowing 30 to 50 lb/A, as well as when sowing up to 140 lb/A of seed, in irrigated fields. He concluded that with a firm, moist seedbed it is possible to obtain maximum yields by seeding 50 to 80 lb/A.

Pendleton and Dungan (1960), working with winter wheat, observed that the highest yields had been produced with seeding rates between 90 and 135 lb/A, but he recommended the use of 90 lb/A because of the resultant lodging with higher seeding rates. Nelson (1960) reported that spring wheat yields increased with increasing plant populations up to 290 plants/m^2. McNeal and Berg (1960) obtained the highest average yield at 323 seeds/m^2, testing different sources of seed of spring wheat at six seeding rates and four locations. They concluded that source, test weight (above 55 lb/bu) and protein content had little effect on yield.

Wilson and Swanson (1962) observed a significant reduction in winter wheat yield when population was lowered below 215 plants/ m^2, attributable basically to a reduction in heads per unit area. Demirlicakmak et al. (1963) observed no yield differences between the two highest seeding rates of 1120 and 1680 barley seeds per plot. Stickler and Pauli (1964) reported that barley yields were increased when seeding rates increased from 129 to 387 viable seeds/m^2, basically due to a large increase in number of fertile tillers per unit area, despite a small decrease in the number of seeds per spike.

Puckridge and Donald (1967) stated that wheat yields showed peak values at intermediate seeding rates (35 and 184 plants/m^2). They concluded that low yields at low densities were due to the uneven pattern of light utilization, because of the wide spacing of plants, and that low yield at high seeding rates was due to leaf and tiller senescence.

Mela and Paatela (1974), studying the effect of population density on yield of spring wheat and oats, commented that the relation between them was parabolic in shape. They obtained the highest yields with stands of 320 to 600 plants/m^2, within a range from 80 to 2400 plants/ m^2. In addition they found that spring wheat and oats only partly compensated for the decrease of stand density by new tillers, and that the number of seeds per spike of secondary tillers was much lower than that of primary tillers. The highest yields were obtained when the number of secondary tillers was low.

Many researchers from different parts of the world reported that it is possible to obtain highest yields from lower seeding rates. Guitard et al. (1961) stated that at the lower seeding rates there were significant increases in yield of wheat with increases in seeding rate, but generally nonsignificant increases in yields of oats and barley. Khalifa (1970) reported that seeding rates of 187 and 125 kg/ha of wheat seed produced lower grain yields than 62 kg/ha, and concluded that the reduction in yield was due to the decrease in the number of grains per head. Willey and Holliday (1971) noted that a significant decrease in wheat yield occurred at high populations, attributable to the decrease in number of seeds per unit area. Larter et al. (1971) obtained the highest yields of wheat at the two lowest seeding rates, 25 and 50 kg/ha, observing a significant yield reduction with seeding rates of 100 kg/ha or above. They suggested the sowing of 68 to 102 kg/ha, for these seeding rates provide a margin of safety in adverse field conditions.

It has been reported by many researchers, working under a wide range of conditions, that differences in seeding rates produced very little or no effect on seed yield. Middleton et al. (1964) found no difference in barley yields when using seeding rates varying from

3/4 bushel to 6 bushels per acre, when planting three different varieties under near optimum conditions. Ali's (1968) conclusions were that wheat varieties behaved differently within the several rates used, but that the mean yields for all varieties did not differ due to seeding rates. Day and Thompson (1970), studying dates and rates of seeding with barley, concluded that when planting is done beyond the optimum period, the rate of seeding should be increased because plants grown from later plantings had a shorter vegetative period for tillering and development of roots. He advised that for maximum returns seeding rates and dates must be established for each specific situation.

Finlay et al. (1971) reported that seeding rate did not influence yield of spring barley, despite having affected various yield components, either when considered alone or when interacting with cultivars. Research conducted over three complete fallow-crop periods under low rainfall conditions in Central Plateau of Turkey, reported by Bolton (1974), led him to conclude that seeding rates of at least 90 kg/ha are required for maximum yield. Results also indicated that there was no difference among yields obtained by planting 90, 120 and 150 kg of seeds per hectare.

Effect of Seeding Rate on Yield Components of Cereal Crops

Several researchers have studied this subject, and among the first was Grantham (1917). He indicated that the increased space provided more food and moisture for the individual plant, and that the number of tillers per plant decreased in direct proportion to the decrease in space. He observed that tillering is a varietal characteristic that is not fully offset by the environment. He also pointed out that the number of spikes per area increased as the seeding rates increased, and that plants from low tillering varieties produced seeds of poorer quality.

Nelson (1960) reported that both the number of spikes per wheat plant and seed weight decreased as the seeding rate increased. Pendleton and Dungan (1960) reached similar conclusions working with seeding rates ranging from 45 to 270 lb/A.

Guitard et al. (1961), working with wheat, barley, and oats, noted that an increase in seeding rate caused a small decrease in 1,000-seed weight, a moderate decrease in the number of seeds per spike, a linear increase in the number of plants per unit area, and a curvilinear decrease in the number of fertile tillers per plant. They concluded that the number of plants per area and the number of fertile tillers per plant were the most important yield components. Demirlicakmak et al. (1963) stated that barley yields appeared to be more closely correlated with 1,000-seed weight or with number of seeds per fertile tiller than with the number of fertile tillers per acre. On the average, seed weight showed highest levels at the lowest seeding rates and was little affected by size of the seed planted. They observed that tillering capacity might be expected to be lost when plants grow under heavy competition.

Middleton _et al._ (1964) contended that in barley the number of fertile tillers per unit area increased with heavier seeding rates, the opposite being true for the number of seeds per spike. They found no difference in seed weight due to seeding rates. Stickler and Pauli (1964) reported that barley yields increased with increasing seeding rates. This was attributed to a large increase in the number of spikes per area, despite its association with a decrease in the number of seeds per spike. They found no significant difference in seed weight. They also pointed out that the number of fertile tillers per area increased as the seeding rate increased.

Kirby (1969) reported an increase in the number of spikes per unit area as the seeding rate increased. He also noted that increasing seeding rates caused a decrease in the number of seeds per spike, and a reduction in seed weight. Severson and Rasmusson (1968) found that the average number of tillers per barley plant increased in reponse to spacing increments. In addition they stated that when seeding rate decreased from 41.5 to 13.8 kg/ha, the average number of seeds per spike increased significantly.

Puckridge and Donald (1967) observed in their studies of wheat that as the seeding rate increased, the number of tillers per plant decreased, the number of spikes per area increased and the number of seeds per spike decreased. They observed that the lower seeding rates produced the highest seed weight and concluded that low seed weight values at low seeding rates might be the effect of extreme intertiller competition within plants or might be due to small seed produced by late tillers.

Pelton (1969) observed a significant increase in the number of spikes per unit area when comparing the lowest (22. 4) and the highest (100. 8 kg/ha) seeding rates, but with a concurrent decrease in the number of seeds per spike. He also showed that low seeding rates produced heavier kernels.

Khalifa (1970) concluded that in wheat the effect of seeding rate on tillering and on seed weight was negligible, and that the number of seeds per spike decreased at the highest seeding rates.

Day and Thompson (1970), working with barley under irrigation, noted that seed weight was slightly lower at the higher seeding rates. Finlay et al. (1971) reported that the number of spikes per area increased, and that the number of seeds per spike decreased as seeding rate increased.

Simonyan and Babayan (1973) observed that the length of the spike, its number of seeds, seed weight, and protein percentage decreased as seeding rate increased. They obtained maximum yields under medium to high seeding rates, and noted that the number of fertile tillers per area increased with denser seeding rates. Sing and Sharma (1973) working with wheat, found that seeding rates increasing from 75 to 125 kg/ha promoted an increase in stand density, and a decrease in seed weight and in the number of seeds per spike.

Stand density affected seed size of spring wheat and oats, according to Mela and Paatela (1974). They reported that the proportion of small seed decreased and that of large seed increased with increasing closeness in the sparser spring wheat stands. In the denser stands the distribution of the harvested seed remained unchanged, or resembled that of the sparser stands. Oat plots revealed opposite effect. Results of the first year showed that the proportion of small grain increased and that of large grain decreased as stand density increased. On the second year the increase in density only slightly affected seed size. Güler (1975), working with winter wheat under three different environments, studied the effect of seeding rate on yield and other agronomic characteristics of seven cultivars. He concluded that as seeding rate increased, the number of tillers per plant, number of seeds per spike and seed weight decreased, and that number of plants as well as number of spikes per unit area increased.

MATERIALS AND METHODS

Experiments were conducted to determine the effect of three seed sizes on yield and yield components of two spring wheat varieties at three seeding rates under rainfed and irrigated conditions.

Varieties and Seed Lots

"Fielder" (Triticum aestivum L.) is a medium maturing, semi-dwarf, stiff-strawed, soft white spring wheat. It has erect to inclined, awned, middense spikes, and soft, white, ovate, and midlong seeds. This variety produces high test weight grain. It was developed by Dr. Donald W. Sunderman at Idaho State University and released in 1974. Seed from a single lot of Idaho certified seed was used in this study.

"Profit 75" (Triticum aestivum L.) is an early, midtall hard red spring wheat. It has inclined, shattering-resistant, awned, middense spikes, and hard, red, ovate, and midlong seeds. It has a midstrong hollow stem. It was developed by Dr. Alfredo Garcia for World Seeds Inc., California, and released in 1974. Seed from a single lot of Oregon certified seed was used in this work.

Large and small seed were obtained from each lot by screening.

Fielder seed was graded on a Clipper M-2B (A. T. Ferrell & Co., Saginaw, Michigan) air-screen machine, using a 3.57 mm

(9/64 in) round holed top screen and a 3. 18 mm (8/64 in) bottom screen.

The seed that went through the bottom screen represented 15. 97% of the weight and 22. 98% of the number of seeds of the lot and was designated Fielder Small Seed.

The seed retained by the top screen was screened a second time, using a 2. 78 x 19. 05 mm (7/64 x 3/4 in) slotted screen. The large seed retained represented 24. 40% of the weight and 18. 99% of the number of seeds of the lot and was designated Fielder Large Seed.

Profit 75 seed was graded using a 2. 58 x 19. 05 mm (6 1/2/64 x 3/4 in) top screen and a 2. 38 x 19. 05 mm (6/64 x 3/4 in) bottom screen. The largest and smallest seeds were then screened further by means of a laboratory tester set of 228. 6 x 228. 6 mm (9 x 9 in) screens, shaken by an electric vibrator (Syntron Jogger). The largest-size seed was screened by a 3. 37 mm (8 1/2/64 in) round holed screen. The retained portion was designated Profit 75 Large Seed. It represented 24. 70% of the weight and 19. 49% of the number of seeds of the lot.

The smallest seed was screened with a 3. 18 mm round holed screen. The portion of seed that went through the sieve was called Profit 75 Small Seed. It represented 18. 89% of the weight and 25. 59% of the number of seeds of the lot.

Ungraded seeds of each variety were used for check treatments.

The three seed sizes of both varieties were tested (Table 1) for purity and germination according to the Association of Official Seed Analysts Rules for Testing Seeds (1970), and 1, 000-seed weight was calculated according to the Brazilian Rules for Testing Seeds (1967). Pure live seed percentages were also calculated.

Table 1. Purity, germination, pure live seed, and 1, 000-seed weight for the three seed sizes of the two varieties.

Test	Variety	Seed size Small	Ungraded	Large
Pure seed, %	Fielder	97. 94	99. 38	99. 96
	Profit 75	97. 60	99. 14	99. 66
Germination, %	Fielder	90	92	96
	Profit 75	92	96	97
Pure Live Seed, %	Fielder	88. 15	91. 43	95. 96
	Profit 75	89. 79	94. 18	96. 67
Thousand-seed weight, g	Fielder	26. 13	37. 60	48. 30
	Profit 75	24. 40	33. 06	41. 90

Field Experiments

Field studies were conducted at the Hyslop Crop Science Field Laboratory, Corvallis, on a well-drained Woodburn silt loam soil with pH around 6. 2. The field had been in winter wheat production the previous year. The soil was well prepared and 12 days before planting was fertilized with 71. 4 kg of nitrogen/ha (80 lb N/A) as urea (46% N), uniformly distributed and disc-incorporated in the top 5 to 7.5 cm (2-3 in) of soil. Adequate levels of phosphorus and potassium were present and these elements were not supplied.

The yield trials were planted on April 27 and 28, 1976 with a belt type hand planter. Seeding depth was 3.8 cm (1 1/2 in).

Each plot consisted of four rows 6.10 m (20 ft) in length spaced 0.31 m (1 ft) apart. Plots were 0.61 m (2 ft) apart with 1.22 m (4 ft) alleys. Replications were square blocks 13.41 m (44 ft) on each side.

All three seed sizes were planted at seeding rates of 228, 293, and 421 live seeds/m^2 (Table 2). The 293 seeds/m^2 seeding rate for ungraded seed approximates a recommended seeding rate of 110 kg/ha (98 lb/A) for the Willamette Valley.

The 421 small seeds/m^2, 293 ungraded seeds/m^2, and 228 large seeds/m^2 were the result of planting an equal weight of 11 gm/m^2 of each seed size.

Table 2. Seeding rates based on numbers and on weight of seed per unit area.

Seed size		
Small	Ungraded	Large
- - - - no. of seeds/m^2 - - - -		
228	228	<u>228</u>
293	<u>293</u>	293
<u>421</u>[+]	421	421

[+]Underlined figures made up the treatment with equal weights of seeds/m^2.

Five replications were sown in a randomized complete block design.

To be able to study seed size and seeding rate effects under different water supply regimes, the experiment was run under rainfed and irrigated conditions. These two areas were about 11. 0 m (36 ft) apart.

The rainfed experiment received, besides a high water supply before planting, 29. 0 mm rain in May, 11. 9 mm in June, 22. 9 mm in July, and 7. 1 mm in August, making a total of 70. 9 mm (2. 79 in) of water (Anonymous, 1975).

The irrigated area, besides the cited amount of rainfall, received sprinkler irrigation two times in June (44. 5 mm each), two times in July (47. 6 mm each), and once in August (35. 0 mm), totaling 219. 2 mm (8. 63 in). Together with rainfall, the total water supply was 290. 1 mm (11. 42 in).

Birds began to pick up seeds at and after germination. The problem was solved by spreading seeds around the plots. Weeds were hoed whenever necessary. Powdery mildew (Erysiphe graminis De Candolle) attacked both varieties during the flowering period, mainly on the irrigated area, but no serious injury was detected. Aphids attacked the crop before anthesis and control was achieved by applying 1. 12 kg/ha (1 lb/A) of malathion active ingredient. Gophers represented a problem throughout the season. Control was achieved by using poisonous bait in the burrows and no significant crop injury resulted.

During the maturation period seed moisture content was determined for each variety, seeding rate, and seed size, under rainfed and irrigated situations. Moisture tests consisted of putting the seeds in the oven at 100° C for 24 hours and calculating the moisture percentage on a wet weight basis.

Before harvesting the plots, yield components were determined on 1 meter of plants from one central row of each plot. Spikes were counted and then threshed to calculate spikes/m^2, seeds per spike, and 1,000-seed weight. The number of spikes/m^2 was determined by dividing the number of spikes by the area covered by the meter of row and converting into spikes/m^2. The number of seeds per spike was obtained by dividing the number of seeds by the number of spikes. Thousand-seed weight was calculated by dividing the weight of the seeds by the number of seeds and converting into 1,000-seed weight. The total number of seeds was mechanically counted with a laboratory seed counter (Count-A-Pak no. 701 Seedburo, Seedburo Equipment Co., Illinois).

Profit 75 rainfed plots were harvested on the 108th day after planting, the irrigated ones on the 116th day. Rainfed plots of Fielder were harvested on the 115th day after planting, the irrigated ones on the 120th day. Three square meters per plot were harvested for yield (4.92 m of each of the two central rows). One replication was non-uniform and was discarded.

Harvesting was done with a two-row sickle bar mower. Bundles were threshed in a stationary plot threshing machine, and the seeds were cleaned with a seed blower before weighing. Plot yields were adjusted to 13% moisture by the formula

$$\text{Yield} = \frac{\text{Plot yield (100 - \% moisture content)}}{87}$$

Statistical Procedures

Analysis of variance was used to evaluate yield and yield components. The F Test was utilized to determine significant differences. Tukey's Test (H. S. D.) was used to test for significance among treatments as well as among grand means. Coefficient of Variation was calculated to provide measure of precision. Simple correlation was used to estimate the degree of association among seed size, yield, and yield components (Steel and Torrie, 1960).

RESULTS AND DISCUSSION

Crop Development and Maturation

The first seedlings emerged on the 6th day after planting. Stands were very uniform. Tillering was observed as early as the 20th day after sowing. Profit 75 reached anthesis 4 days before Fielder and harvest maturity was about a week earlier.

Maturation curves for the two varieties are shown in Figures 1 and 2. The rainfed plots were approximately 4 days ahead of the irrigated plots at dough stage, and about a week ahead at harvesting time. Heavy seeding rates caused a delay in maturity.

Seed size had no effect on the rate of development and maturation of the grain crop.

Rainfed Treatments

Seeding Rates Based on Equal Numbers of Seeds/m^2

Yields produced by large, ungraded and small seed planted in equal numbers per unit area are shown in Table 3.

When yields were averaged over varieties and seeding rates, large seed produced 6.1% (137 kg/ha) more than ungraded seed, and 9.6% (210 kg/ha) more than small seed. These data are consistent with the findings of Kiesselbach (1924), Waldron (1941), Geiszel and

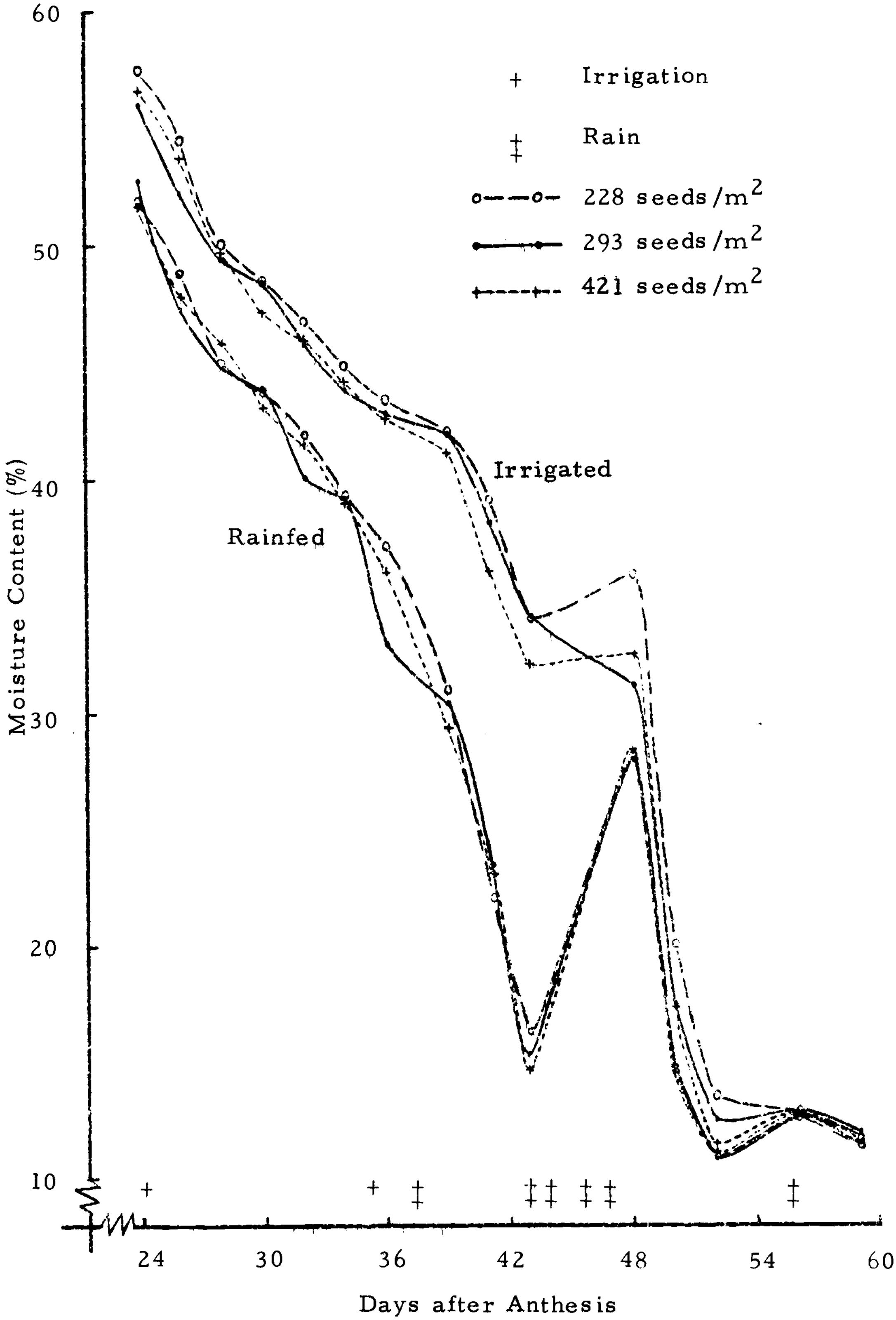

Figure 1. Seed moisture content during maturation of Fielder wheat at three different seeding rates, under irrigated and rainfed conditions.

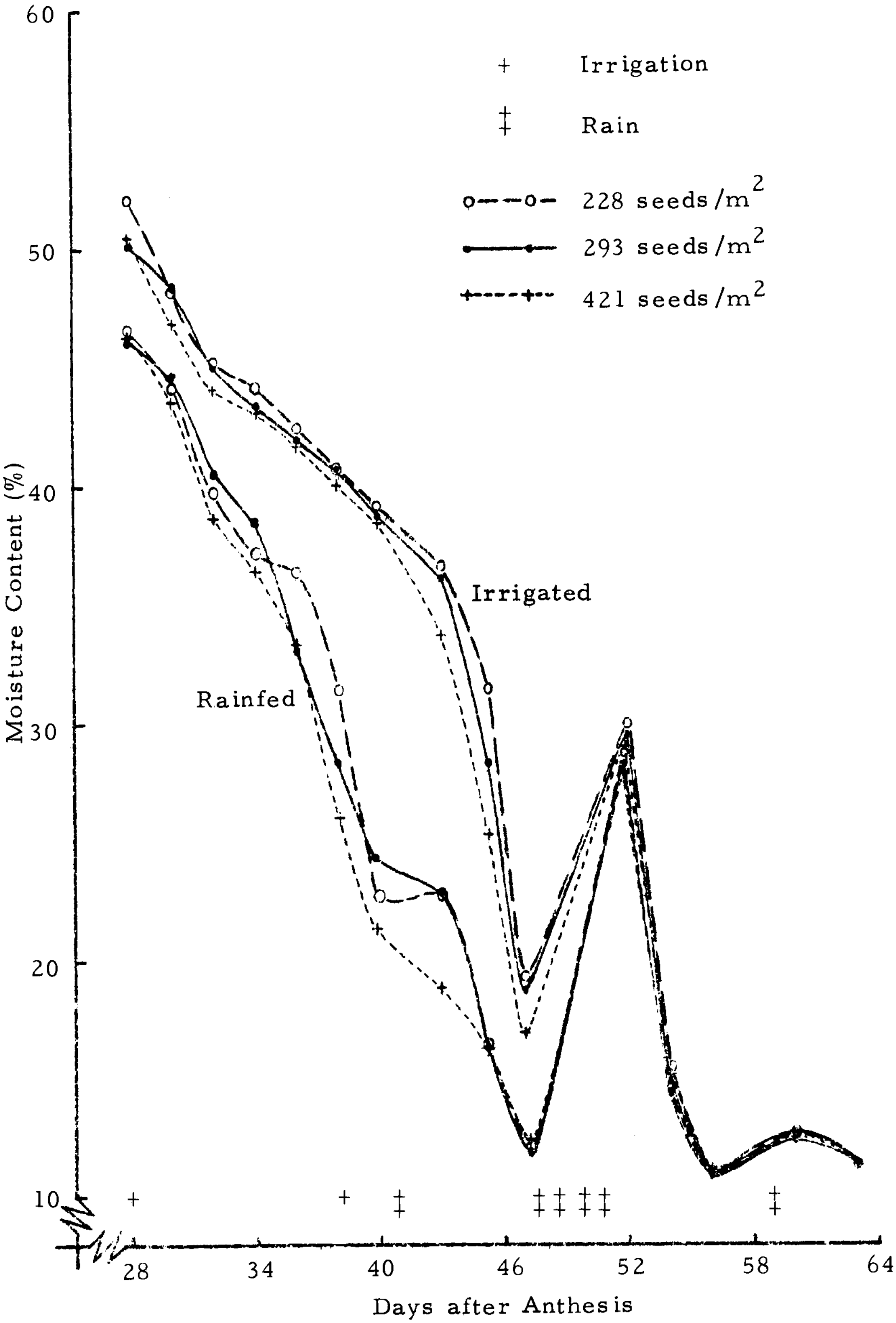

Figure 2. Seed moisture content during maturation of Profit 75 wheat at three different seeding rates, under irrigated and rainfed conditions.

Table 3. Effect of seed size and seeding rate on yields of two varieties of spring wheat under rainfed conditions. Equal numbers of seeds planted per plot.

Seeding rate	Seed size	Variety: Fielder	Variety: Profit 75
seeds/ m^2		---------kg/ ha---------	
228	Small	2, 262	2, 022
	Ungraded	2, 394	2, 150
	Large	2, 745	2, 251
293	Small	2, 390	2, 111
	Ungraded	2, 404	1,991
	Large	2, 492	2, 182
421	Small	2, 316	2,001
	Ungraded	2, 522	2, 082
	Large	2, 458	2, 238
H. S. D.[+] (5%) for any two means		425	

Summary of grand means

Seed size	Yield	Seeding rate	Yield	Variety	Yield
	kg/ha	seeds/ m^2	kg/ha		kg/ ha
Small	2, 184	228	2, 304	Fielder	2, 442
Ungraded	2, 257	293	2, 262	Profit 75	2, 114
Large	2, 394	421	2, 269		
H. S. D. (5%)	114		114		77
H. S. D. (1%)	144		144		103

[+]H. S. D. = Honestly significant difference (Tukey's Test).

Hoag (1967), Voronin et al. (1969), and Austenson and Walton (1970) in their experiments with spring wheat.

The higher yields from large seeds were due mainly to the production of more spikes/m^2 (Table 4). The number of seeds per spike and seed weight remained relatively constant when averaged over planting rates and varieties.

The effect of seed size on yield was dependent on the seeding rate. The most striking response was obtained at the lowest seeding rate used, 228 live seeds/m^2. At this low seeding rate enough nutrients were probably available for plants to reach full development, giving large seed a considerable advantage over small seed. This is also shown by the larger number of spikes/m^2 produced by large seed. The advantage exhibited by large seed of Fielder over small seed was 21.4% (483 kg/ha). The difference of 14.7% over ungraded seed (351 kg/ha) was not significant when varieties were analyzed together. When individual variety data were analyzed separately, however, (Appendix Tables 6 and 7), the difference in yield of large and ungraded seed of Fielder was significant. There was no yield difference due to seed size in Profit 75 at this low planting rate.

As the population density increased, the advantage exhibited by large seed decreased. Since early plant growth rate is essentially dependent on seed size (Bremner et al., 1963; Tsepenko et al., 1972), interplant competition was present earlier among plants grown from

Table 4. Effect of seed size and seeding rate on yield components of two varieties of spring wheat under rainfed conditions. Equal numbers of seeds planted per plot.

		Yield components					
		Spikes/ m^2		Seeds/ spike		Seed weight	
Seeding rate	Seed size	Fielder	Profit 75	Fielder	Profit 75	Fielder	Profit 75
seeds/ m^2						---- g/ 1, 000 -----	
228	Small	217.36	220.64	28.68	28.16	36.09	33.21
	Ungraded	228.02	220.64	29.86	27.69	36.44	32.44
	Large	247.70	250.16	29.89	28.23	37.51	32.07
	Average	231.03	230.48	29.48	28.03	36.68	32.57
293	Small	251.80	253.44	25.83	26.86	35.66	32.78
	Ungraded	246.88	250.16	27.27	26.14	35.35	30.85
	Large	264.11	265.75	26.55	26.59	35.71	31.81
	Average	254.26	256.45	26.55	26.53	35.57	31.81
421	Small	295.28	278.05	24.42	24.83	34.18	30.12
	Ungraded	277.23	265.75	25.08	24.11	35.30	31.69
	Large	302.66	298.56	23.07	21.85	34.12	30.51
	Average	291.72	280.79	24.19	23.60	34.53	30.77
H. S. D.[+] (5%):	for any two means	54.19		7.69		3.38	
	for seed size	14.55		2.06		0.91	
	for seeding rate	14.55		2.06		0.91	
	for variety	9.87		1.40		0.61	

[+]H. S. D. = Honestly significant difference (Tukey's Test).

large seeds, and their relative advantage over small seeds was lessened. The lower yield differential between large and small seeds is also reflected in smaller differences in numbers of spikes/m^2 among the seed sizes.

The highest yields of both varieties were obtained with large seed at the rate of 228 viable seeds/m^2.

Correlation studies (Table 5) revealed that yield was positively associated with the size of the planted seed. The number of spikes/m^2 was also associated with seed size, thus confirming the results graphically shown in Figures 3 and 4.

Table 5. Correlation coefficients among seed size, yield, and yield components under rainfed conditions. Equal numbers of seeds planted per plot.

	Yield	Spikes/m^2	Seeds/spike	Seed weight
Seed size	0.4831**	0.2423*	-0.0151	0.1967
Yield		0.1708	0.2927*	0.6377**
Spikes/m^2			-0.5698**	-0.2446*
Seeds/spike				0.4076**

*, **Significant at 5% level and 1% level, respectively.

When averaged over varieties and seed size, yields were equal at all three seeding rates. As the seeding rate increased the number of spikes/m^2 increased, but the number of seeds per spike and 1,000-seed weight decreased, thus nullifying the effect on yield.

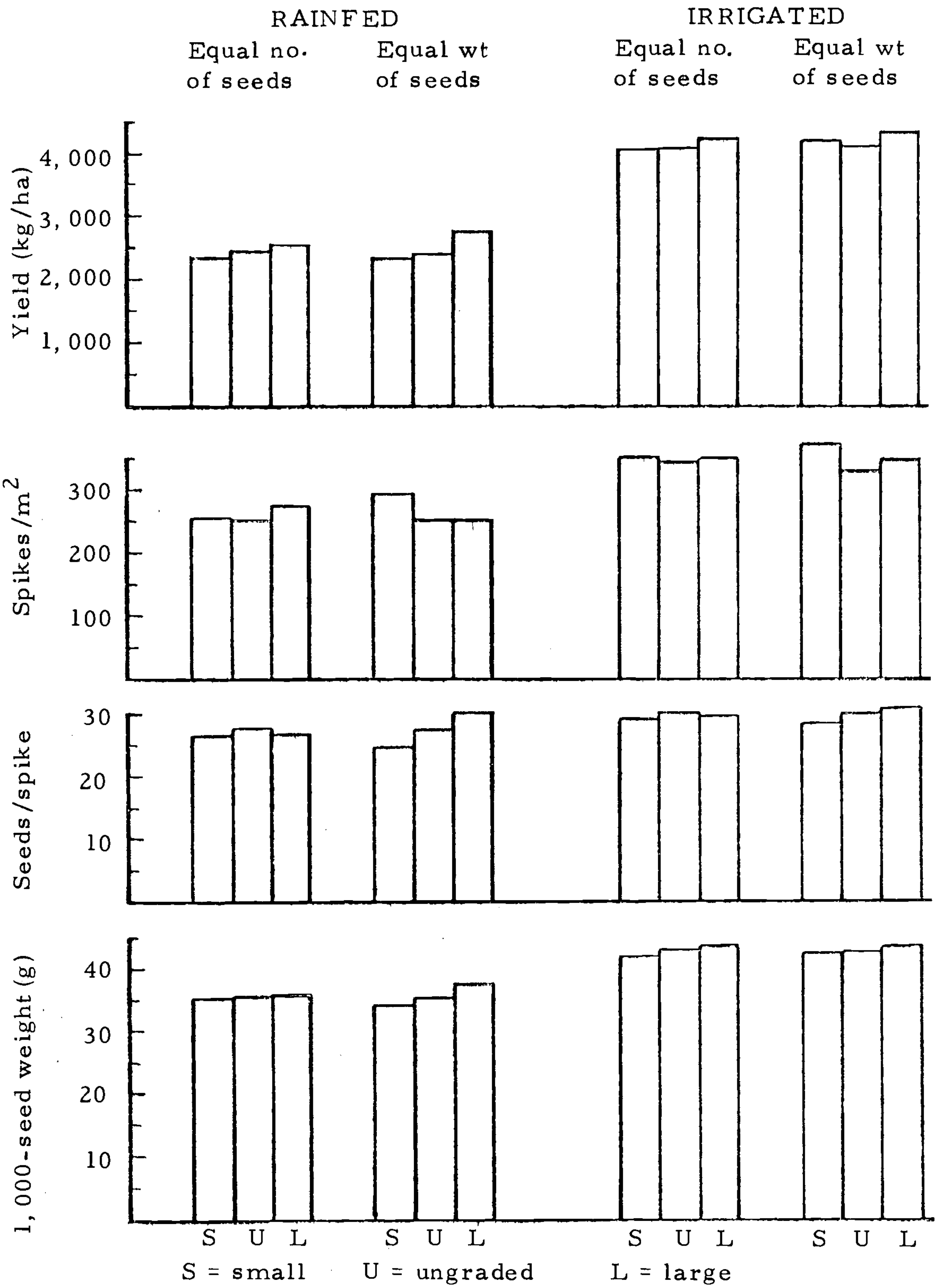

Figure 3. Effect of three seed sizes on yield and yield components of Fielder wheat under rainfed and irrigated conditions. Planted with equal numbers and equal weights of seeds per unit area.

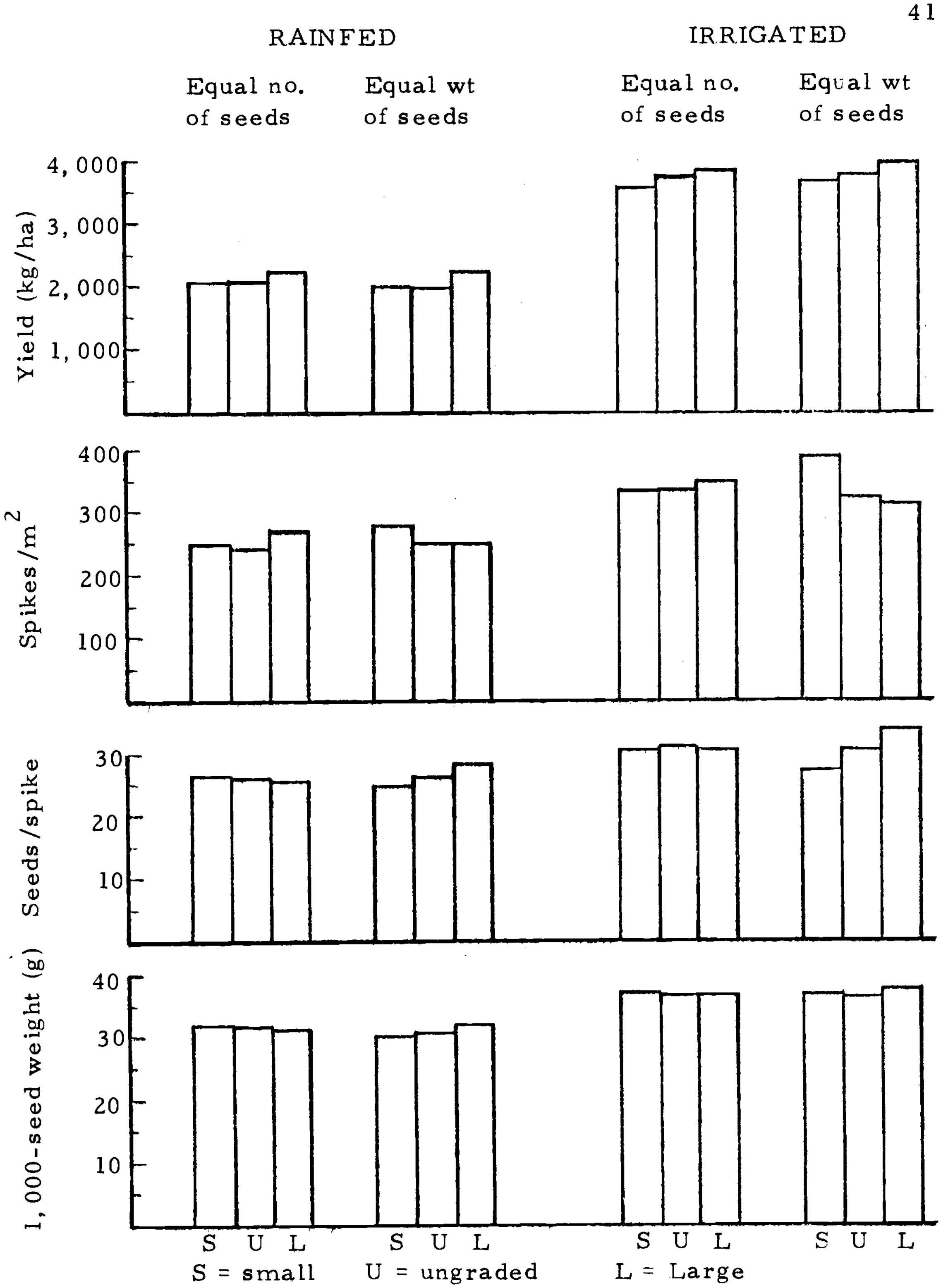

Figure 4. Effect of three seed sizes on yield and yield components of Profit 75 wheat under rainfed and irrigated conditions. Planted with equal numbers and equal weights of seeds per unit area.

When averaged over seed size and seeding rate, Fielder yields were 15.5% (328 kg/ha) higher than Profit 75.

Seeding Rates Based on Equal Weights of Seeds/m^2

Yields produced by large, ungraded and small seed planted with equal weights per unit area are shown in Table 6.

When yields were averaged over varieties, large seed yielded 13.7% (300 kg/ha) more than ungraded seed, and 15.7% (340 kg/ha) more than small seed. These results agree with the findings of Waldron (1941), Geiszler and Hoag (1967), and Voronin *et al.* (1969) in their experiments with spring wheat. Kiesselbach (1924) reported that ungraded seed of spring wheat outyielded large seed by 1.0%.

Large seed of Fielder yielded 14.2% (341 kg/ha) more than ungraded seed, and 18.5% (429 kg/ha) more than small seed. No yield differences due to seed size were evident in Profit 75 when varieties were analyzed separately (Appendix Tables 9 and 11).

The higher yields from large seeds were due to the production of heavier seeds and a larger number of seeds per spike (Table 7), despite the decrease in number of spikes/m^2. When the same weights of the three seed sizes were planted, the number of small seeds per plot was nearly 85 and 46% higher than the number of large and ungraded seed, respectively, so the lower number of spikes/m^2 was expected from large seed.

Table 6. Effect of seed size and seeding rate on yields of two varieties of spring wheat under rainfed conditions. Equal weights of seeds planted per plot.

Seeding rate		Seed size	Variety	
			Fielder	Profit 75
g/m^2	$seeds/m^2$		-------- kg/ha --------	
11	421	Small	2, 316	2,001
11	293	Ungraded	2,404	1,991
11	228	Large	2,745	2,251
H. S. D.[+] (5%)			325	
H. S. D. (1%)			410	

Summary of grand means

Seed size	Yield	Variety	Yield
	kg/ha		kg/ha
Small	2, 158	Fielder	2, 488
Ungraded	2, 198	Profit 75	2,081
Large	2, 498		
H. S. D. (5%)	183		123
H. S. D. (1%)	241		170

[+]H. S. D. = Honestly significant difference (Tukey's Test).

Table 7. Effect of seed size on yield components of two varieties of spring wheat under rainfed conditions. Equal weights of seeds planted per plot.

	Yield components					
	Spikes/ m^2		Seeds/spike		Seed weight	
Seed size	Fielder	Profit 75	Fielder	Profit 75	Fielder	Profit 75
					----g/1,000-----	
Small	295.28	278.05	24.42	24.83	34.18	30.12
Ungraded	246.88	250.16	27.27	26.14	35.35	30.85
Large	247.70	250.16	29.89	28.23	37.51	32.07
Average	263.29	259.46	27.19	26.40	35.68	31.01
H.S.D.[+] (5%): for any two means	58.59		7.71		3.25	
for seed size	33.05		4.37		1.84	
for variety	22.13		2.92		1.23	

[+]H.S.D. = Honestly significant difference (Tukey's Test).

Correlation studies (Table 8) showed that yield, as well as number of seeds per spike and 1,000-seed weight, were positively associated with the size of the planted seed. Number of spikes/m^2 was negatively associated with seed size.

When yield was averaged over seed size, Fielder yielded 19.6% (407 kg/ha) more than Profit 75, primarily due to its heavier seeds.

Table 8. Correlation coefficients among seed size, yield and yield components under rainfed conditions. Equal weights of seeds planted per plot.

	Yield	Spikes/m^2	Seeds/spike	Seed weight
Seed size	0.6254**	-0.5168**	0.5512**	0.5608**
Yield		-0.1424	0.5571**	0.8171**
Spikes/m^2			-0.5440**	-0.2271
Seeds/spike				0.4221*

*, **Significant at 5% level and 1% level, respectively.

Irrigated Treatments

When seeding rates were based on equal numbers of seeds per area, irrigated plots yielded 71.9% (1,637 kg/ha) more than rainfed plots (Figures 3 and 4). When equal weights of different seed sizes were planted per area, the yield of irrigated plots was 74.9% (1,711 kg/ha) more than that of rainfed plots. These results are in good agreement with the findings of Gasanenko and Piskun (1971) in their experiments with irrigated wheat.

Seeding Rates Based on Equal Numbers of Seeds/m^2

Yields produced by large, ungraded and small seed planted in equal numbers per unit area are shown in Table 9.

When yields were averaged over varieties and seeding rates large seed produced 5.9% (223 kg/ha) more than small seed. Further analysis of the data for each variety revealed that large seed of Profit 75 outyielded small seed (Appendix Tables 12 and 14), but there was no difference in yield of large and ungraded seed. Yields of the three seed sizes of Fielder were similar. The increased yield from large seed of Profit 75 was due to the increased number of spikes/m^2 (Figures 3 and 4).

As with rainfed treatments, highest yields of both varieties were obtained by planting large seed at the rate of 228 viable seeds/m^2. Fielder produced 4,312 kg/ha and outyielded Profit 75 (3,970 kg/ha) by 8.6%.

Correlation studies (Table 11) showed that yield was positively associated with seed size. Thousand-seed weight was also positively correlated with seed size.

Seeding rate had no effect on yield. As the seeding rate increased the number of spikes/m^2 increased, but the number of seeds per spike decreased, thus nullifying the effect of increased numbers of spikes on yield.

When yields were averaged over seed size and seeding rate Fielder exhibited yields 10.9% (404 kg/ha) higher than Profit 75. This difference was due mainly to the higher average weight of Fielder seeds.

Table 9. Effect of seed size and seeding rate on yields of two varieties of spring wheat under irrigated conditions. Equal numbers of seeds planted per plot.

Seeding rate	Seed size	Variety: Fielder	Variety: Profit 75
seeds/m^2		-------- kg/ha --------	
228	Small	3,922	3,252
	Ungraded	4,006	3,779
	Large	4,312	3,970
293	Small	4,032	3,794
	Ungraded	4,086	3,773
	Large	4,197	3,606
421	Small	4,192	3,641
	Ungraded	4,136	3,687
	Large	4,169	3,919
H.S.D.[+] (5%) for any two means		725	

Summary of grand means

Seed size	Yield	Seeding rate	Yield	Variety	Yield
	kg/ha	seeds/m^2	kg/ha		kg/ha
Small	3,806	228	3,873	Fielder	4,117
Ungraded	3,911	293	3,915	Profit 75	3,713
Large	4,029	421	3,957		
H.S.D. (5%)	195		195		132
H.S.D. (1%)	246		246		175

[+]H.S.D. = Honestly significant difference (Tukey's Test).

Table 10. Effect of seed size and seeding rate on yield components of two varieties of spring wheat under irrigated conditions. Equal numbers of seeds planted per plot.

		Yield components					
		Spikes/m^2		Seeds/spike		Seed weight	
Seeding rate	Seed size	Fielder	Profit 75	Fielder	Profit 75	Fielder	Profit 75
seeds/m^2						----- g/1, 000 -----	
228	Small	333.83	293.64	30.49	32.17	41.61	36.71
	Ungraded	305.94	327.26	32.60	33.44	43.15	35.77
	Large	342.03	313.32	30.74	33.82	43.65	37.47
	Average	327.27	311.41	31.28	33.14	42.80	36.65
293	Small	342.03	324.80	28.39	32.38	41.37	37.57
	Ungraded	328.08	323.98	29.87	30.66	42.32	36.50
	Large	332.19	308.40	30.63	31.54	43.42	36.47
	Average	334.10	319.06	29.63	31.53	42.37	36.85
421	Small	370.73	388.78	27.16	27.07	42.21	37.00
	Ungraded	387.14	360.89	26.56	28.42	43.49	37.68
	Large	366.63	423.23	26.96	26.23	43.93	36.11
	Average	374.83	390.97	26.89	27.24	43.21	36.93
H. S. D.[+] (5%):	for any two means	92.51		7.75		3.13	
	for seed size	24.84		2.08		0.84	
	for seeding rate	24.84		2.08		0.84	
	for variety	16.84		1.41		0.57	

[+]H. S. D. = Honestly significant difference (Tukey's Test).

Table 11. Correlation coefficients among seed size, yield and yield components under irrigated conditions. Equal numbers of seeds planted per plot.

	Yield	Spikes/m^2	Seeds/spike	Seed weight
Seed size	0.3420**	0.0510	-0.0013	0.3393**
Yield		0.4699**	0.0080	0.5036**
Spikes/m^2			-0.5085**	0.0602
Seeds/spike				-0.0759

*, **Significant at 5% level and 1% level, respectively.

Seeding Rates Based on Equal Weights of Seeds/m^2

Yields produced by large, ungraded and small seed planted at equal weights per unit area are shown in Table 12.

Seed size had no effect on yield when averages over variety were compared. This fact suggests that plants from different seed sizes, even though grown at different plant densities, utilized the available food and energy with similar efficiency.

The similar yield results among the different seed sizes were due to the fact that, although the number of seeds per spike and 1,000-seed weight increased as the size of the planted seed increased, the number of spikes/m^2 decreased, thus annulling the effect upon final seed yield (Table 13).

Correlation studies (Table 14) revealed no association between seed size and yield. Seed size was negatively correlated with number

Table 12. Effect of seed size on yields of two varieties of spring wheat under irrigated conditions. Equal weights of seeds planted per plot.

Seeding rate		Seed size	Variety	
			Fielder	Profit 75
gm^2	seeds/m^2		-------kg/ha--------	
11	421	Small	4, 192	3, 641
11	293	Ungraded	4,086	3,773
11	228	Large	4, 312	3, 970
H. S. D.[+] (5%)			676	

Summary of grand means

Seed size	Yield	Variety	Yield
	kg/ha		kg/ha
Small	3, 917	Fielder	4, 197
Ungraded	3, 930	Profit 75	3, 795
Large	4, 141		
H. S. D. (5%)	381		255
H. S. D. (1%)	501		353

[+]H. S. D. = Honestly significant difference (Tukey's Test).

Table 13. Effect of seed size on yield components of two varieties of spring wheat under irrigated conditions. Equal weights of seeds planted per plot.

	Yield components					
	Spikes/ m^2		Seeds/ spike		Seed weight	
Seed size	Fielder	Profit 75	Fielder	Profit 75	Fielder	Profit 75
					----g/ 1, 000 ----	
Small	370.73	388.78	27.16	27.07	42.21	37.00
Ungraded	328.08	323.98	29.87	30.66	42.32	36.50
Large	342.03	313.32	30.74	33.82	43.65	37.47
Average	346.95	342.03	29.26	30.52	42.73	36.99
H. S. D.[+] (5%): for any two means	81.47		7.23		1.99	
for seed size	45.96		4.07		1.14	
for variety	30.78		2.74		0.75	

[+]H. S. D. = Honestly significant difference (Tukey's Test).

of spikes/m^2 and positively correlated with number of seeds per spike.

When yields were averaged over seed size, Fielder exhibited 10.9% (402 kg/ha) higher yield than Profit 75, due mainly to heavier seed weight.

Table 14. Correlation coefficients among seed size, yield and yield components under irrigated conditions. Equal weights of seeds planted per plot.

	Yield	Spikes/m^2	Seeds/spike	Seed weight
Seed size	0.3672	-0.4446*	0.5222**	0.3709
Yield		0.2971	0.0618	0.5707**
Spikes/m^2			-0.5074*	0.0178
Seeds/spike				-0.0628

*, **Significant at 5% level and 1% level, respectively.

GENERAL DISCUSSION

This study represents a segment of a series of investigations that are being conducted at Oregon State University on the effect of seed size on yield of wheat crops.

The information obtained supports the findings of other researchers that increased yields can frequently be obtained by planting large seed.

Several factors contribute to the advantage exhibited by large seed. One obvious factor is the greater available food supply to nourish the young seedling until it is self-supporting. Bremner et al. (1969) proved that early seedling growth rate was greater for seedling from large seeds, but after endosperm exhaustion the growth rate was similar for all seed sizes. McDaniel (1969) showed that seedling fresh weight, seedling mitochondrial protein and mitochondrial biochemical activity were positively correlated with seed weight and concluded that seedlings from heavy seeds have a greater growth potential than seedlings produced from lighter seeds.

Kaufmann and Guitard (1967) reported that the size of the seedlings and of the first two leaves were greater in seedlings from large seeds, and that plants grown from small seeds were in most cases better developed than those from large seeds with 50% or 25% of endosperm removed. Seedlings from large seeds produce a larger number of seminal roots (Voronin et al., 1969; Kir'yan, 1974) than plants from small seeds.

Together these characteristics lead to the development of plants from large seeds that are better able to utilize the environmental resources and produce greater yielding crops than plants from small seeds.

While large seeds of cereals frequently demonstrate a yield advantage, the situation seems to be quite different in forage legumes. Black (1959) concluded that, as a general rule, the final yield of forage legumes under sward conditions was not affected by the size of the planted seed. He concluded that, although the rate of accumulation of dry matter in the early vegetative stages is directly proportional to seed weight, the growth rate of the largest plants is reduced when individual plants begin to compete. There follows a period of differential growth rates with plants from small seeds having greater growth rate since competition levels among them are still low. At the end of the season, or before, total yields of forage legumes reach a similar level regardless of seed size.

The shorter growing season, row planting and lower plant population of spring cereals tend to maintain the competitive advantage of large seeds to a greater extent than in forage legumes.

The question frequently arises whether to conduct seed-size yield trials with equal numbers or equal weights of seeds per plot. Commercial drills are adjusted to seed a certain weight or volume of seeds. Therefore some would argue that plot experiments should also be conducted by sowing equal weights of seeds per plot. Such seeding methods tend to produce a heavy plant population from small seeds and a low population from large seeds. There is then the possibility that the greater number of small seeds would compensate for the small size of the seed, resulting in yields equal to those of large seeds. Saric (1959), however, found that a greater number of seeds per area did not compensate for the small size of the seed.

In the present study, seeding rates were based both on equal weights and equal numbers of the three seed sizes. Under both situations - equal weights and equal numbers of seed per plot - yields from large seeds were superior to those from ungraded seeds.

Evidence is accumulating that the yield advantage of large seed is greater when the crop is grown under stress conditions such as low moisture or fertility levels (Waldron, 1941). The results of this experiment support this view in that large seed was superior to ungraded seed under rainfed conditions but not under irrigation.

The results of the present study, together with numerous reports in the literature, suggest the potential for upgrading seed quality and increasing spring wheat yields through seed sizing. Increased yields can be achieved with little added cost of production, provided income is not sacrificed through sale of the undersized seed as grain.

SUMMARY AND CONCLUSIONS

The effect of seed size on yield of two varieties of spring wheat under different seeding rates and irrigation was studied in the spring of 1976.

Development and maturation of the crop were not affected by seed size, but were delayed by heavy seeding rates and irrigation.

The following results were observed under rainfed conditions:

1. At a seeding rate of 110 kg/ha (98 lb/A), large seed of Fielder yielded 14.2% more than ungraded seed and 18.5% more than small seed. No yield differences due to seed size were evident in Profit 75.

2. With seeding rates based on equal numbers of seeds per plot, large seed yielded 6.1% more than ungraded seed and 9.6% more than small seed when yields were averaged over varieties and seeding rates. Increased yields were due to a larger number of spikes/m^2.

3. At a seeding rate of 228 seeds/m^2, large seed of Fielder yielded 14.7% more than ungraded seed and 21.4% more than small seed. No yield differences due to seed size were evident in Profit 75.

4. At seeding rates of 293 and 421 seeds/m^2, yields from the three seed sizes were similar in both varieties.

The following results were observed under irrigated conditions:

1. At a seeding rate of 110 kg/ha (98 lb/A), there was no association between seed size and yield in either variety.

2. With seeding rates based on equal numbers of seeds per plot, large seed yielded 5.9% more than small seed and the same as ungraded seed when yields were averaged over varieties and seeding rates. Yield increases were due to the production of heavier seeds.

3. At a seeding rate of 228 seeds/m^2, large seed of Profit 75 yielded 22.1% more than small seed and the same as ungraded seed. Yields of the three seed sizes of Fielder were similar.

4. At seeding rates of 293 and 421 seeds/m^2, yields from the three seed sizes were similar in both varieties.

It is concluded that producers of spring wheat in the Pacific Northwest can obtain higher yields by sizing their seed and planting only the large seed. Large seed have a greater advantage under stress moisture conditions. Benefits from large seed may vary with the variety or seed lot.

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APPENDICES

Appendix Table 1. Average rainfall and 1976 rainfall in Corvallis for the spring wheat growing season.

Month	Average rainfall*		1976 rainfall
	mm	in	mm
April	63. 5	2. 50	50. 3
May	45. 0	1. 77	29. 0
June	29. 2	1. 15	11. 9
July	8. 4	0. 33	22. 9
August	14. 0	0. 55	52. 8
Total	160. 1	6. 30	166. 9

*More than 30 years data.

Appendix Table 2. Summary of observed mean squares from analysis of variance for seed yield and yield components of two spring wheat varieties under rainfed conditions. Equal numbers of seeds planted per plot.

Source of variation	df	Seed yield MS	Spikes/m^2 MS	Seeds/spike MS	Seed weight MS
Replication	3	202, 274	613. 257	11. 381	6. 983
Seed size (Size)	2	274, 187**	3, 674. 976**	2. 713NS	0. 024NS
Seeding rate (Rate)	2	12, 226NS	18, 560. 586**	141. 775**	23. 417**
Variety (Var.)	1	1, 941, 816**	172. 949NS	8. 570NS	270. 475**
Var. x Size	2	12, 332NS	44. 981NS	4. 780NS	1. 739NS
Var. x Rate	2	153NS	287. 776NS	3. 124NS	0. 244NS
Size x Rate	4	51, 399NS	322. 354NS	5. 364NS	3. 527NS
Var. x Size x Rate	4	32, 002NS	56. 874NS	0. 261NS	1. 502NS
Error	51	26, 769	434. 453	8. 745	1. 687
Total	71				
Coefficient of variation (%)		7. 18	8. 10	11. 21	3. 86

* = Significant at 5% level.
** = Significant at 1% level.
NS = Nonsignificant.

Appendix Table 3. Summary of observed mean squares from analysis of variance for seed yield and yield components of two spring wheat varieties under rainfed conditions. Equal weights of seeds planted per plot.

Source of variation	df	Seed yield MS	Spikes/m^2 MS	Seeds/spike MS	Seed weight MS
Replication	3	96, 088	630. 227	8. 359	5. 641
Seed size (Size)	2	276, 129**	3, 837. 841*	39. 171NS	14. 323**
Variety (Var.)	1	995, 600**	87. 784NS	3. 816NS	130. 620**
Var. x Size	2	16, 032NS	269. 676NS	2. 290NS	0. 992NS
Error	15	19, 995	648. 905	11. 240	1. 999
Total	23				
Coefficient of variation (%)		6. 19	9. 75	12. 51	4. 24

* = Significant at 5% level

** = Significant at 1% level.

NS = Nonsignificant.

Appendix Table 4. Summary of observed mean squares from analysis of variance for seed yield and yield components of two spring wheat varieties under irrigated conditions. Equal numbers of seeds planted per plot.

Source of variation	df	Seed yield MS	Spikes/ m^2 MS	Seeds/ spike MS	Seed weight MS
Replication	3	861, 569	3, 203. 167	16. 362	1. 225
Seed size (Size)	2	299, 395*	466. 643NS	2. 532NS	3. 505NS
Seeding rate (Rate)	2	42, 248NS	29, 061. 620**	165. 699**	1. 388NS
Variety (Var.)	1	2, 929, 366**	436. 010NS	33. 894NS	644. 764**
Var. x Size	2	37, 149NS	331. 342NS	1. 085NS	8. 820**
Var. x Rate	2	2, 385NS	1, 994. 974NS	4. 712NS	0. 997NS
Size x Rate	4	181, 667NS	623. 811NS	3. 182NS	1. 736NS
Var. x Size x Rate	4	92, 334NS	2, 723. 027NS	5. 853NS	1. 544NS
Error	51	77, 653	1, 265. 958	8. 896	1. 452
Total	71				
Coefficient of variation (%)		7. 12	10. 38	9. 96	3. 13

* = Significant at 5% level.

** = Significant at 1% level.

NS = Nonsignificant.

Appendix Table 5. Summary of observed mean squares from analysis of variance for seed yield and yield components of two spring wheat varieties under irrigated conditions. Equal weights of seeds planted per plot.

Source of variation	df	Seed yield MS	Spikes/ m^2 MS	Seeds/spike MS	Seed weight MS
Replication	3	183, 441	2, 357. 391	2. 568	0. 319
Seed size (Size)	2	126, 405NS	7, 469. 048*	54. 162*	3. 046*
Variety (Var.)	1	969, 820**	145. 288NS	9. 601NS	197. 341**
Var. x Size	2	34, 047NS	1, 093. 909NS	5. 372NS	0. 483NS
Error	15	86, 256	1, 254. 714	9. 888	0. 751
Total	23				
Coefficient of variation (%)		7. 35	10. 28	11. 73	2. 16

* = Significant at 5% level.

** = Significant at 1% level.

NS = Nonsignificant.

Appendix Table 6. Summary of observed mean squares from analysis of variance for seed yield of each variety under rainfed conditions. Equal numbers of seeds planted per plot.

		Variety	
		Fielder	Profit 75
Source of variation	df	MS	MS
Replication	3	115, 561	115, 972
Seed size (Size)	2	176, 235**	110, 453NS
Seeding rate (Rate)	2	5, 376NS	6, 930NS
Size x Rate	4	64, 709**	18, 672NS
Error	24	13, 452	39, 760
Total	35		
Coefficient of variation (%)		4. 75	9. 43

** = Significant at 1% level

NS = Nonsignificant

Appendix Table 7. Effect of seed size and seeding rate on yields of Fielder under rainfed conditions, Equal numbers of seeds planted for plot.

	Seed size		
Seeding rate	Small	Ungraded	Large
seeds/m^2	kg/ha		
228	2, 262	2, 394	2, 745
293	2, 390	2, 404	2, 492
421	2, 316	2, 522	2, 458
H. S. D.$^+$ (1%) for any two means		337	

$^+$H. S. D. = Honestly significant difference (Tukey's Test).

Appendix Table 8. Effect of seed size and seeding rate on yields of Profit 75 under rainfed conditions. Equal numbers of seeds planted per plot.

Seeding rate	Seed size: Small	Ungraded	Large
seeds/ m^2		kg/ ha	
228	2, 022	2, 149	2, 251
293	2, 111	1,991	2, 181
421	2, 001	2, 082	2, 238
H. S. D.[+] (5%) for any two means		480	

[+]H. S. D. = Honestly significant difference (Tukey's Test).

Appendix Table 9. Summary of observed mean squares from analysis of variance for seed yield of each variety under rainfed conditions. Equal weights of seeds planted per plot.

Source of variation	df	Variety: Fielder MS	Profit 75 MS
Replication	3	54, 346	43, 360
Seed size	2	205, 019**	86, 970NS
Error	6	8, 563	40, 657
Total	11		
Coefficient of variation (%)		3.72	9.69

** = Significant at 1% level

NS = Nonsignificant

Appendix Table 10. Effect of seed size on yields of Fielder under rainfed conditions. Equal weights of seeds planted per plot.

	Seed size	Yield
		kg/ha
	Small	2, 316
	Ungraded	2, 404
	Large	2, 745
H. S. D.[+] (1%)		293

[+]H. S. D. = Honestly significant difference (Tukey's Test).

Appendix Table 11. Effect of seed size on yields of Profit 75 under rainfed conditions. Equal weights of seeds planted per plot.

	Seed size	Yield
		kg/ha
	Small	2,001
	Ungraded	1,991
	Large	2,251
H. S. D.[+] (5%)		438

[+]H. S. D. = Honestly significant difference (Tukey's Test).

Appendix Table 12. Summary of observed mean squares from analysis of variance for seed yield of each variety under irrigated conditions. Equal numbers of seeds planted per plot.

		Variety	
		Fielder	Profit 75
Source of variation	df	MS	MS
Replication	3	455,244	526,902
Seed size (Size)	2	109,061NS	227,291*
Seeding rate (Rate)	2	23,374NS	21,308NS
Size x Rate	4	45,314NS	228,747*
Error	24	91,190	58,720
Total	35		
Coefficient of variation (%)		7.33	6.53

* = Significant at 5% level.

NS = Nonsignificant.

Appendix Table 13. Effect of seed size and seeding rate on yields of Fielder under irrigated conditions. Equal numbers of seeds planted per plot.

Seeding rate	Seed size		
	Small	Ungraded	Large
$seeds/m^2$	--------------	kg/ha	--------------
228	3,922	4,006	4, 312
293	4,032	4,086	4, 197
421	4,192	4, 136	4, 169
H. S. D.[+] (5%) for any two means		726	

[+]H. S. D. = Honestly significant difference (Tukey's Test).

Appendix Table 14. Effect of seed size and seeding rate on yields of Profit 75 under irrigated conditions. Equal numbers of seeds planted per plot.

Seeding rate	Seed size		
	Small	Ungraded	Large
$seeds/m^2$	--------------	kg / ha	--------------
228	3, 252	3, 779	3, 970
293	3, 794	3, 773	3,606
421	3, 641	3, 687	3, 919
H. S. D.[+] (5%) for any two means		583	

[+]H. S. D. = Honestly signiricant difference (Tukey's Test).