EFFECT OF ROW WIDTH, INTRAROW PLANT DENSITY, AND PLANT POPULATION ON VARIOUS AGRONOMIC CHARACTERISTICS OF SOME SHORT STATURED BARLEY AND WHEAT SELECTIONS

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ABSTRACT

Plant competition studies involving 11 short barley (*Hordeum vulgare* L.) selections, 'Arivat' barley, and two short wheats (*Triticum aestivum* L.), 'Siete Cerros' and 'A5525-8', were conducted using various row widths, intrarow plant densities, and plant population densities. Date of first pollen, duration of pollen shed, maturity date, and plant height of Arivat and the two wheats were generally unaffected by an increase in population from 322,902 to 1,614,510 plants per ha. The short barley selections had several significant variable responses to the same fivefold increase in plant population. For both date of first pollen shed and duration of pollen shed there were significant entry x plant population interactions which indicate differential responses of entries to changes in population density. One short barley, 74-B-6229-399, was grown at 3 row widths and 3 intrarow plant densities with plant populations ranging from 215,200 to 2,152,000 plants per ha. Yield and yield component data were obtained. Highest grain yield was obtained from population densities of about 1,000,000 plants per ha and head densities of about 750 heads per meter^2. These studies indicate the tremendous variability that exists in the population from which the short barleys were selected and the usefulness of evaluating

selections from similar populations under various seeding patterns and plant population densities.

INTRODUCTION

The phenotype of a mature plant is the net effect of its genetic makeup and its interactions with its environment. Plants of a specific genotype grow similarly in a specific environment. As the environment varies, plants of a given genotype have a range of measurable phenotypic responses. However, plants of different genetic backgrounds often differ from one another in the range and nature of their responses to varying environments.

In cereal crop production the most readily and universally manipulated factors of the growth environment are plant population and planting pattern. The competition for light, air, moisture, and nutrients which occurs between plants and between tillers of the same plant change with variations of plant populations and planting patterns. Plant competition can affect plant growth. Competition differences can be detected as differences in phenotypic characters. Not all crops nor all genotypes of the same crop respond similarly to differing plant populations and planting patterns. For instance Blum (1970) found that an early maturing grain sorghum (*Sorghum bicolor* (L.) pers.) hybrid yielded best at high plant populations, and a late maturing one yielded most at low populations. Stickler and Younis (1966) found a differential response of sorghum height and stand density. Tall genotypes yielded most at low plant densities and the corresponding short isogenic types yielded most at high densities. The results of these studies suggest the usefulness of investigating the responses of diverse plant types to plant population and seeding pattern.

In barley (*Hordeum vulgare* L.) several highly diverse male sterile facilitated recurrent selection populations have been established. The populations include germ plasm from the entire U. S. Department of Agriculture World Collection of barleys. Separate populations have been established by recurrent selection for such phenotypic attributes as short plant height, high tillering ability, and large seed size. In alternate generations recombinant plants selected for a desired attribute were intercrossed and the resulting hybrid seed was harvested in bulk. Recurrent selection accompanied by recurrent intercrossing soon produced highly heterogeneous populations which expressed selected attributes.

The establishment of the recurrent selection population of short barleys has been described by Ramage (1974). In the first cycle of selection several hundred agronomically promising short barleys were selected and bulk selfed lines were obtained from those selections. Reduced plant height is the only visual feature common among the selected lines. As a group they express a remarkable diversity of morphological and physiological characters. They are different from tall barleys and they are different from one another. Further illucidation of those differences must be made in the field environment--and that is the task of the present study.

LITERATURE REVIEW

Responses of Tall vs. Short Plant Types to Plant Population and Seeding Pattern

Most grain sorghums grown in the U. S. are short combine types. Comparing tall and short sorghum types, Hadley, Freeman, and Javier (1965) and Casady (1965) observed that the tall types had superior yield potential. In Casady's study the tall plants of three isogenic lines exceeded the short plants in grain weight, tillering, and yield per unit area, when grown in 102 cm rows at a plant population of 64,616 plants per hectare. Stickler and Younis (1966), however, found that low plant densities and wide row spacings do not allow short sorghum types to express their optimum yields. Tall and short isogenic lines were grown in 51 and 102 cm width rows at three population densities (42,995, 64,617, and 129,233 plants per ha). Although both tall and short types responded best to the narrower row width spacing, they responded differently to stand density. The tall types yielded best at the two low plant densities, whereas the short types had highest yields at the high population density. The superior yields of short plants types at high densities was due to an increased number of heads per unit area. As plant density increased, the short plants tended to have fewer seed per head and diminishing seed weight. Generally, tall plants had greater seed weight but fewer seed per head than short plants. Stickler and Younis concluded that although the tall types may exceed the short types in yield potential, the short forms may be able to withstand the severe competition of high planting rates.

The ability of a short plant type to respond to high seeding rates has also been demonstrated in rice (*Oryza sativa* L.). Owen (1968) compared the yield and yield component responses of tall and short rice lines at two plant populations; 2,214,240 and 4,428,481 plants per ha. At both rates the short line exceed the tall line in grain yield and heads per unit area.

In contrast to the differential responses of plant height types found in sorghum, Pendleton and Seif (1961) showed that the yields of a brachytic 2 dwarf corn (*Zea Mays* L.) were not raised by increasing plant population significantly above the recommended level for normal height corn. The corn was tested in 51, 76, and 102 cm width rows at populations ranging from 29,652 to 79,072 plants per ha. In two years and at two locations, the brachytic 2 dwarf corn yielded best in 76 cm rows at a population of 49,420 plants per ha. Average ear weight decreased significantly as population increased. In another corn study Sowell, Ohlrogge, and Nelson (1961) grew a normal height corn variety, 'Hy', and a *compactum* mutant at 128,492 plants per ha in 51 cm rows. Only 38% of the normal height corn produced grain compared to 95% of the compactum plants. Although ear shoots of both plant types initiated simultaneously, the ability of the compactum plants to produce grain under the high plant population was attributed to its termination of vegetative growth at an earlier stage of development than the normal height plants.

Most of the world's highest yielding wheats (Triticum aestivam L.) are now semidwarf and triple dwarf plant types. When comparing seeding rate responses of semidwarf 'Era' with two other normal height wheats, Oelke (1971) found that both plant types responded similarly. In weed free fields neither plant type showed significant yield increases when seeding rates were increased above 45 kg per ha (about 470,000 plants per ha). Maya de Leon (1975) reports similar findings with Mexican semidwarf wheats which generally respond the same to 15, 30, and 45 cm row widths and yield the same from seeding rates above 40 kg per ha. CIMMYT (1973) agronomists found very similar responses in the triple dwarf 'Yecora 72' wheat. They reported no yield differences among row spacings (15, 30, and 45 cm) and a slightly negative yield response as seeding rates were increased from 40 to 100 kg per ha. Singh, Singh, and Paliwal (1971), however, found continued yield increases in 'Sonora 64' and 'Lerma Roja' semidwarf wheats as sowing rates increased to 72 kg per ha. Stoskopf (1967) studied row spacing and plant density responses of short strawed, upright leafed, winter wheat selections. He found that the short plants responded best to the narrow rows (9-11 cm) at a 134 kg per ha sowing rate.

The plant population at which short plant types achieve optimum yields is generally higher than that of tall plant types. However, Mexican and 'Era' semidwarf wheats and a brachytic 2 dwarf corn were found to respond like tall plant types to plant population and planting pattern. It is apparent that not all short plant types respond alike to population density and planting pattern.

Effect of Plant Population and Seeding Pattern on Plant Height

The effects of plant population and seeding pattern on plant height varies considerably between varieties and crops. Many studies revealed that increased plant populations resulted in increased plant heights. Stickler et al. (1960) compared responses of grain sorghum grown at 4 row widths and 5 population densities. Plant heights did not differ between row widths but tended to increase with plant density increases. Pendleton and Seif (1961) observed the same tendency in the brachytic 2 dwarf corn. Plant heights increased with increments in plant populations ranging from 29,652 to 79,072 plants per ha. In another study, Giesbrecht (1969) found plant heightening effects from increased plant populations of four corn hybrids. Puckeridge and Donald

(1967), working with high tillering 'Insignia 49' wheat, found that plants grew taller as plant populations were increased. The same heightening response to increased populations was noted in winter wheats by Kinra et al. (1963) and in 'Gaines' wheat by Briggle, Petersen, and Hayes (1965).

Other workers have reported a negative response of plant height to population density. In 'Chinook' spring wheat Pelton (1969) found that low seeding rates (22 to 67 kg per ha) produced significantly taller plants than a high seeding rate of 101 kg per ha. Salih (1975) observed a similar negative height response to increasing populations in two-rowed 'Hannchen' barley. Plant heights decreased steadily as plant populations were augmented from 246,914 to 2,222,222 plants per ha. Comparing rates and dates of fall planted spring barleys, Day and Thompson (1970) found that plant heights increased as rates decreased in early plantings, but tended to decrease as rates increased in late plantings.

Row width can have a greater effect on plant height than population density. Robinson et al. (1964) compared grain sorghum responses at 4 row widths and 3 plant populations ranging from 193,746 to 774,985 plants per ha. Plant heights did not differ between population treatments but tended to increase as row spacings increased from 25 to 102 cm.

Welty (1973) compared plant heights of 4 spring barley cultivars planted in varying hill spacings and numbers of plants per hill. Plant height increased slightly as hill spacing increased from 15 to 30 cm, but decreased sharply as hill spacing was augmented to 60 cm. Plant height increased significantly as the number of plants per hill increased from 1 to 5, but remained unchanged in treatments with more than 5 plants per hill.

In contrast to all of the above studies, Stickler and Younis (1966) found that neither row width nor stand density significantly affected sorghum plant height.

Effect of Plant Population and Seeding Pattern on the Number of Days from Planting to Flowering

Increased population densities have generally been found to lengthen the time period between planting and flowering. Colville (1962) observed that as corn hybrid populations were increased from 29,652 to 69,188 plants per ha, tasseling and silking were delayed at the higher populations. Kohnke and Miles (1951) remarked that the number of days to corn silking increased steadily with increasing populations. There was a six day difference between corn populations of 7,413 and 74,130 plants per ha. They concluded that silking was delayed one day for every additional 7500 to 10,000 kernels planted per hectare.

Welty (1973) noted significant hill spacing effects on the number of days to heading in barley.

Generally, as hill spacings increased, the number of days to heading decreased. In Salih's (1975) experiment, two-rowed Hannchen barley also headed earlier in wider hill spacings.

When studying sorghum responses to 3 plant populations and 4 row spacings, Robinson et al. (1964) concluded that there were no significant treatment effects on heading date. In a similar row width and plant density experiment Brown, Cobb, and Wood (1964) observed no significant treatment effects on sorghum heading date in two out of three years. However in one year, when the rains were inadequate, the date of heading was significantly earlier in the 102 cm row width treatments than in the 51 cm treatments.

Kirby (1967) observed quite a different trend in heading date response. When conducting a greenhouse experiment on the effects of barley plant density, he noted that the earliest dates of head emergence were observed in plants grown in the greatest densities.

Effects of Plant Population and Seeding Pattern on the Number of Days from Planting to Maturity

In Colville's (1962) hybrid corn study in which populations ranged from 29,652 to 69,188 plants per ha, the maturity date was delayed at higher populations. In small grains the opposite effect of population on maturity date has been noticed. Pelton (1969) noted that the maturity date of 'Chinook' spring wheat planted at the high rate of

101 kg per ha was 3 to 5 days earlier than at the low rate of 22 kg per ha. Day and Thompson (1970) observed a similar trend of earlier maturity dates with increasing planting rates in a spring barley study. In Welty's (1973) barley experiment, the date of maturity was not significantly affected by hill spacing or number of plants per hill. However, maturity dates did differ significantly between cultivars.

MATERIALS AND METHODS

Experiment I

Twelve six-row barley lines and two wheat lines were planted at Tucson, Arizona on a slightly alkaline Grabe loam soil under normal irrigated conditions on November 15, 1974. Eleven of the barley lines were short strawed selections made in the first cycle of the male sterile facilitated recurrent selection population for short plants of the U. S. Department of Agriculture hybrid barley program. Ten of the lines were bulk F_4's from single F_3 plants. The eleventh line, 74-B-6229-399, was a bulk F_4 from a single F_2 plant. 'Arivat' barley was included as a tall plant type check. The two wheats were a semidwarf cultivar, 'Siete Cerros', and an experimental triple dwarf line, 'A5525-8'. The experimental wheat was developed at the Mesa, Arizona experiment station by R. K. Thompson. All germ plasm will be referred to as entries in the following text.

All seed was sieved over a 6/64 x 3/4 inch screen and overplanted by 3% in order to promote uniform germination and a closely approximated stand.

The experiment was arranged in a randomized complete block design with three replications. Each block consisted of 28 treatment plots representing 14 entries planted at 2 population densities, 322,902 and 1,614,510 plants per ha.

Uniform 3.04 x 1.83 m plots consisted of six 3.04 m rows spaced 30.4 cm apart. The sampling unit was considered to be the group of plants in the center 1.83 meters of the two middle rows in each plot. Dates of first pollen shed, last pollen shed, and maturity were recorded for each sampling unit. Average plant heights and plant internode lengths were also collected at the time of plant maturity. Plant internode length data were averages of 10 tillers gathered from 10 randomly selected plants in each sampling unit.

All data were analyzed using standard analysis of variance with the following sources of variation and degrees of freedom:

Source of Variation	Degrees of Freedom
Total	83
Blocks	2
Treatments	27
Entries	13
Plant Densities	1
Entries x Plant Densities	13
Error	54

Mean differences were detected by using the Student-Newman-Keul Multiple Range test described by Steel and Torrie (1960).

Experiment II

Siete Cerros and A5525-8 wheats were planted with a hand planter on November 17, 1974 at the same location as Experiment I. The experiment was arranged in a completely randomized block design with three replications. Within blocks each wheat was planted at 3 row widths (23, 30.5, and 46 cm) and 3 intrarow plant densities (10, 29.5, and 49 seed per meter). The 3 x 3 factorial treatment combinations resulted in the 9 plant populations listed in Table 1.

Table 1. Plant populations of row width and intrarow plant density treatments of Experiments II and III.

Intrarow plant densities (plants/m)	Plants per hectare		
	Row widths (cm)		
	23	30.5	46
10	430,536	322,902	215,268
29.5	1,291,608	968,706	645,804
49	2,152,680	1,614,510	1,076,340

In order to achieve uniform plot size of 1.83 x 2.44 m, different numbers of 1.83 m rows were planted for each row width treatment. Ten, 8, and 5 rows were planted in the plots of the 20, 30.5, and 46 cm row width treatments respectively. Similarly, in order to achieve a uniform sampling size of .56 m^2 in each plot, the sampling unit consisted of the center 61 cm of the middle 4, 3, and 2 rows of the 23, 30.5, and 46 cm row width treatments respectively.

Dates of first pollen shed, last pollen shed, and maturity were recorded. Data were analyzed using standard analysis of variance with the following sources of variation and degrees of freedom:

Source of Variation	Degrees of Freedom
Total	53
Blocks	2
Treatments	17
Entries	1
Row Widths	2
Intrarow Plant Densities	2
Entries x Row Widths	2
Entries x Plant Densities	2
Row Widths x Plant Densities	4
Entries x Row Widths x Plant Densities	4
Error	34

Means were compared as in Experiment I

Experiment III

The short strawed, free tillering barley entry, 74-B-6229-399 was planted with a hand planter on November 16, 1974 at the same location as the other two experiments.

Experimental design, row width and intrarow plant density treatments, and experimental and sampling units were the same as those outlined in Experiment II. In this experiment, however, there were six replications.

One month after emergence the intrarow bounds of the sampling units were marked off with small plastic stakes in order to facilitate harvesting.

Dates of first pollen shed, last pollen shed, and maturity were recorded for each sampling unit. Average plant height data were obtained at maturity.

A total of 54 sampling units representing the six replications of the nine spacing treatments were harvested by hand on May 29, 1975. A uniform .56 m^2 area was harvested for each sampling unit. The total number of head bearing tillers, the total number of seed, and the total seed weight were determined for each sampling unit. The number of heads per $meter^2$ was determined by multiplying 1.78 by the number of head bearing tillers per sampling unit. The average number of seed per head was determined by dividing the number of seed per sampling unit by the number of head bearing tillers. Weight of 1000 seed was determined by dividing the product of 1000 times the total seed weight by the number of seed in the sampling unit. The yield per $meter^2$ was determined by multiplying 1.78 and the total seed weight per sampling unit.

Data were analyzed using standard analysis of variance with the following sources of variation and degrees of freedom:

Sources of Variation	Degrees of Freedom
Total	53
Blocks	5
Treatments	8
Row Widths	2
Intrarow Plant Densities	2
Row Widths x Plant Densities	4
Error	40

Means were compared as in the preceding experiments.

RESULTS AND DISCUSSION

Experiment I

Days to First Pollen Shed

The fourteen entries of this experiment represented a remarkable diversity of morphological plant characters. One barley entry shed pollen when the heads were still enclosed by the flag leaf. Siete Cerros wheat plants did not shed pollen until up to two weeks after head emergence. The traditional estimation of 50% heading date would have yielded little reliable information about comparable flowering dates. It was decided, then, to note the date of first pollen shed observed in the sampling unit of each plot.

The means of the number of days to first pollen shed for each entry at each planting rate are listed in Table 2. Analysis of variance shows that the greatest source of variation was due to differences between entries. Arivat barley shed pollen before all other entries. Siete Cerros wheat was the last entry to begin pollen shed. In the overall experiment the low seeding rate treatment resulted in earlier pollen shed than the high seeding rate. However, one entry, 74-B-6229-331, shed pollen significantly earlier at the low rate compared to the high rate of

Table 2. Effect of planting rate of 14 barley and wheat entries on the number of days from planting to first pollen shed.

	Mean number of days from planting to first pollen shed		
Entry	Low seeding rate 322,902 pl/ha	High seeding rate 1,614,510 pl/ha	Entry mean
74-B-6229-2	125 a*	128 a	126.8 bc+
-104	132 a	133 a	132.8 de
-146	127 a	126 a	127 bc
-201	131 a	129 a	130.6 cde
-255	140 a	142 a	141.3 f
-278	132 a	129 a	130.6 cde
-290	122 a	123 a	122.5 a
-311	127 a	129 a	128.3 c
-331	126 a	133 b	129.8 cd
-385	132 a	135 a	134.1 de
-399	137 a	140 a	138.8 f
Arivat	124 a	124 a	124 ab
Siete Cerros	145 a	145 a	145.6 g
A5525-8	141 a	142 a	141.6 f
Seeding Rate Mean	131.8 a‡	133 b	

C.V. = 2%

*+‡Means followed by the same letter are not significantly different at the .05 level according to the Student-Newman Keul multiple range test.

*Comparisons made among seeding rates within entries.

+Comparisons made among entry means.

‡Comparisons made among seeding rate means.

seeding. Two other barley entries showed a reversed, but not significant, response to seeding rates. In those entries the number of days to first pollen shed was greater at the low seeding rate than at the high rate. The reversed responses caused a variety x plant density interaction which was significant at the 10% level.

Duration of Pollen Shed

Most of the short strawed barley entries had been originally selected for their ability to tiller freely at low plant populations. The tillering rate in barley and wheat generally decreases as plant population increases. Since tillering can occur over an extended period of time, it was decided to compare the time intervals between first and last pollen shed for each entry at each seeding rate.

The means of pollen shed duration are compared in Table 3. The high seeding rate treatment of every entry except Arivat resulted in the shortest duration of pollen shed. There was no significant difference between high and low seeding rates of Arivat. Although there were significant differences between barley entries, the most remarkable contrast was between the wheats and the barleys. The average duration of pollen shed for the wheats was 10.5 days compared to 24.3 days for the barleys. There was a significant entry x plant density interaction. This was due to the differential responses of entries to plant densities.

Table 3. Effect of planting rate of 14 barley and wheat entries on the duration of pollen shed.

Entry	Mean duration of pollen shed, days: Low seeding rate 322,902 pl/ha	Mean duration of pollen shed, days: High seeding rate 1,614,510 pl/ha	Entry mean
74-B-6229-2	27 a*	21 b	24.5 cd+
-104	26 a	18 b	22.5 c
-146	25 a	23 a	24.5 cd
-201	30 a	24 b	27.1 d
-255	23 a	21 a	22.6 c
-278	27 a	19 b	23.2 cd
-290	23 a	20 a	21.8 c
-311	27 a	20 b	23.8 cd
-331	30 a	24 b	27 d
-385	34 a	27 b	30.5 e
-399	28 a	23 b	25.5 cd
Ariyat	19 a	19 a	19 b
Siete Cerros	10 a	8.6 a	9.3 a
A5525-8	12.6 a	10.6 a	11.6 a
Seeding Rate Mean	24.6 a‡	20.1 b	

C.V. = 10.8%

*+‡Means in the same column or row followed by the same letter are significantly different at the .05 level according to the Student-Newman-Keul multiple range test.

*Comparisons made among seeding rates within entries.

+Comparisons made among entry means.

‡Comparisons made among seeding rate means.

There was no response difference in Ariyat when the plant density was increased, while there was at least a 7 day decrease in pollen shed duration when plant density was increased in 4 of the short barley lines.

Number of Days from Last Pollen Shed
to Maturity

The difference between maturity date and the date of last pollen shed was calculated in order to approximate the grain filling period for each treatment. The treatment means are listed in Table 4. There was a trend for grain filling to be slightly prolonged at the high seeding rate. Among entries the average grain filling periods ranged from 27.3 days to 44 days. The short strawed barley entries spanned the entire range with 74-B-6229-399 at 27.3 days and 74-B-6229-290 at 44 days.

Number of Days from Planting to
Maturity

The entry and rate means of the number of days from planting to maturity are compared in Table 5. In most entries the number of days from planting to maturity was delayed at the low planting rate. The maturity date of one short strawed barley, 74-B-6229-278, was significantly delayed by 10 days at the lower seeding rate. There were significant maturity date differences between entries. Ariyat was the first to mature and 74-B-6229-255 matured 16 days after Ariyat. Although the wheats matured relatively

Table 4. Effect of planting rate of 14 barley and wheat entries on the number of days from last pollen shed to maturity.

Entry	Mean number of days from last pollen shed to maturity		
	Low seeding rate 322,902 pl/ha	High seeding rate 1,614,510 pl/ha	Entry mean
74-B-6229-2	35.6 a*	37.6 a	36.6 bcd+
-104	35.3 a	38.6 a	37.0 bc
-146	38.0 a	39.0 a	38.5 bc
-201	30.3 a	36.6 b	33.5 cd
-255	34.0 a	33.6 a	33.8 cd
-278	39.0 a	40.6 a	39.8 b
-290	44.0 a	44.0 a	44.0 a
-311	36.3 a	39.0 a	37.6 bc
-331	38.0 a	35.3 a	36.6 bcd
-385	30.0 a	33.6 a	31.8 d
-399	27.3 a	27.3 a	27.3 e
Arivat	38.0 a	39.0 a	38.5 bc
Siete Cerros	33.6 a	35.0 a	34.2 bcd
A5525-8	35.0 a	35.0 a	35.0 bcd
Seeding Rate Mean	35.3 a‡	36.7 b	

C.V. = 8.9%

*+‡Means followed by the same letter are not significantly different at the .05 level according to the Student-Newman-Keul multiple range test.

*Comparisons made among seeding rates within entries.

+Comparisons made among entry means.

‡Comparisons made among seeding rate means.

Table 5. Effect of planting rate of 14 barley and wheat entries on the number of days from planting to maturity.

Entry	Mean number of days from planting to maturity		
	Low seeding rate 322,902 pl/ha	High seeding rate 1,614,510 pl/ha	Entry mean
74-B-6229-2	188 a*	187 a	188 b+
-104	190 a	191 a	190.6 bc
-146	191 a	189 a	190 bc
-201	192 a	190 a	191.3 bc
-255	198 a	197 a	197.8 e
-278	198 a	188 b	193.6 cd
-290	188 a	187 a	188.2 b
-311	190 a	189 a	189.8 bc
-331	194 a	192 a	193.5 cd
-385	196 a	196 a	196.5 de
-399	192 a	191 a	191.6 bc
Arivat	181 a	182 a	181.5 a
Siete Cerros	189 a	189 a	189.2 bc
A5525-8	189 a	187 a	188.3 b
Seeding Rate Mean	191.5 a‡	189.9 b	

C.V. = 1.4%

*+‡Means followed by the same letter are not significantly different at the .05 level according to the Student-Newman-Keul multiple range test.

*Comparisons made among seeding rates within entries.

+Comparisons made among entry means.

‡Comparisons made among seeding rate means.

early, they did not significantly differ from 7 of the short strawed barley entries.

Plant Height

The mean plant heights are compared within and among entries and seeding rates in Table 6. In twelve out of the fourteen entries the plots sown at the high seeding rate had taller plants than those sown at the low rate. Arivat and one short barley, 74-B-6229-385, however, showed a slight reversed height effect with the taller plants found in the plots seeded at the low rate. Although most of the entries showed only a slight to moderate height response to seeding rates, two barleys grew significantly taller when seeded at the high rate.

There were significant plant height differences between entries. Arivat and the semidwarf Siete Cerros did not differ in height but they both were significantly taller than the triple dwarf wheat A5525-8. The mean heights of Arivat and Siete Cerros were 92 and 95.8 cm whereas the mean height of the triple dwarf wheat was 77.6 cm. The triple dwarf wheat was significantly taller than all of the short barley entries. Among the short barley entries there were also slight but significant plant height differences. The heights ranged from 52.5 to 67.8 cm.

Table 6. Effect of planting rate of 14 barley and wheat entries on average plant height.

Entry	Average plant height, cm Low seeding rate 322,902 pl/ha	High seeding rate 1,614,510 pl/ha	Entry mean
74-B-6229-2	62 a*	73 a	67.8 c+
-104	58 a	62 a	60 ab
-146	57 a	65 b	60.8 b
-201	57 a	58 a	57.5 ab
-255	56 a	63 a	59.2 ab
-278	56 a	63 a	59.8 ab
-290	52 a	61 b	56.5 ab
-311	54 a	56 a	54.6 ab
-331	60 a	64 a	62.3 b
-385	53 a	52 a	52.5 a
-399	61 a	65 a	62.8 b
Arivat	93 a	91 a	92 e
Siete Cerros	92 a	99 a	95.8 e
A5525-8	76 a	79 a	77.6 d
Seeding Rate Means	63.5 a‡	67.8 b	

C.V. = 4.6%

*+‡Means followed by the same letter are not significantly different at the .05 level according to the Student-Newman-Keul multiple range test.

*Comparisons made among seeding rates within entries.

+Comparisons made among entry means.

‡Comparisons made among seeding rate means.

Plant Internode Lengths

Plant culm internode lengths were measured in order to locate those internodes which increased or decreased significantly with the change in planting rate. The peduncle was considered as the first internode.

Although only 3 entries showed significant plant height differences in the two planting rates, ten entries had significant length differences in at least one internode. Significant internode length responses to plant density for each entry are indicated in Table 7. The two wheat entries and two short barley entries, 74-B-6229-104 and -385, showed no significant length differences in any of the internodes when seeding rates were increased. The peduncle of Arivat, however, decreased with increased seeding rate while the fourth, fifth, and sixth internodes increased in length. The compensating changes of different internode lengths resulted in no net total plant height differences between the two seeding rates. One short barley entry, B-6229-201, also had a significantly shortened peduncle at the high seeding rate. None of the entries showed significant length differences in the second uppermost internode between the high and low seeding rates. However, nine entries had significant length increases in 2 or more of the lower 5 internodes when rates were increased.

Table 7. Effect of planting rate of 14 barley and wheat entries on plant internode lengths.

	B-6229 -2	-104	-146	-201	-255	-278	-290	-311	-331	-385	-399	Arivat	S.C.	A5525 -8
Total plant ht.	*↑	+	*↑	+	+	+	*↑	+	+	+	+	+	+	+
Internode #1 (peduncle)	+	+	+	*↓	+	+	+	+	+	+	+	*↓	+	+
Internode #2	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Internode #3	+	+	*↑	+	+	*↑	+	+	*↑	+	+	+	+	+
Internode #4	*↑	+	*↑	+	*↑	*↑	*↑	*↑	*↑	+	+	*↑	+	+
Internode #5	*↑	+	*↑	+	*↑	*↑	*↑	*↑	+	+	+	*↑	+	+
Internode #6	*↑	+	+	+	*↑	+	+	+	*↑	+	*↑	*↑	+	+
Internode #7	*↑	+	+	+	+	+	+	no 7th inter-node	+	+	*↑	+	no 7th internode	

*Significant internode or plant length response to planting rate at the .05 level.
↑Significant increase of length when planting rate increased from 322,902 pl/ha to 1,614,510 pl/ha.
↓Significant decrease of length when planting rate increased from 322,902 pl/ha to 1,614,510 pl/ha.
+No significant internode or plant length response to planting rate at the .05 level.

Average internode lengths were compared in order to determine the plant proportions of each entry. The Average internode lengths for each entry are listed in Table 8. The relative plant heights and internode lengths of each entry are illustrated in Figure 1. The two wheats and one short barley, 74-B-6229-311, had only six internodes. The 11 other entries all had 7 internodes. In all of the entries the peduncle was the longest internode, comprising 26.9 to 36% of the total plant heights. Both wheats had longer peduncles and larger peduncle length/plant height fractions than Arivat. Arivat had a longer peduncle but smaller peduncle length/plant height fraction than all of the short barleys. The second uppermost through sixth internodes of the short barleys were all generally shorter than the corresponding internodes of Arivat. The seventh internodes of the short barleys varied in lengths. One short barley had no seventh internode, 7 had the same seventh internode length as Arivat, and two short barley entries had longer seventh internodes than Arivat. The two wheats had the same second internode length as Arivat, but generally had shorter third through sixth internodes.

Discussion

The greatest contrasts detected in this experiment were between the short barleys as a group, Arivat, and the short wheats as a group.

Table 8. Average internode lengths of 14 barley and wheat entries.

	74-B-6229 -2	-104	-146	-201	-255	-278	-290	-311	-331	-385	-399	Ari-vat	S.C.	A5525 -8
Total plant height	67.8	60.0	60.8	57.5	59.2	59.8	56.5	54.6	62.3	52.5	62.8	92.0	95.8	77.6
Internode														
1	23.1 bc*	17.9 a	18.0 a	19.8 ab	21.7 b	16.9 a	17.6 a	19.4 a	18.3 a	17.0 a	20.5 ab	24.8 cd	31.4 e	26.3 d
2	10.0 b	9.2 a	12.9 c	10.5 b	10.7 b	11.0 b	10.6 b	10.3 b	11.0 b	9.6 ab	11.6 bc	16.4 c	16.7 c	15.8 c
3	8.4 a	7.7 a	8.5 a	7.6 a	7.3 a	8.4 a	7.8 a	7.4 a	8.2 a	7.5 a	7.1 a	14.9 d	13.3 c	9.8 b
4	8.0 b	7.1 ab	7.4 ab	6.8 ab	6.4 a	7.7 ab	7.4 ab	6.4 a	7.4 ab	6.8 ab	6.3 a	15.6 d	10.4 c	6.4 a
5	7.0 c	5.7 b	4.6 ab	4.8 ab	5.1 ab	5.8 b	4.8 ab	3.3 a	4.8 ab	4.3 ab	5.7 b	11.6 d	8.0 c	5.3 b
6	3.6 fe	2.9 de	1.7 bc	1.8 bc	2.4 cd	2.8 de	2.3 d	.8 a	2.0 bcd	1.7 bc	3.8 ef	4.5 f	1.1 ab	.2 a
7	.6 bc	.9 c	.1 a	.1 a	.2 a	.4 ab	.4 ab	0.0 a	.2 a	.1 a	1.0 c	.2 a	0.0 a	0.0 a

*Means in the same row followed by the same letter are not significantly different at the .05 level according to the Student-Newman-Keul range test.

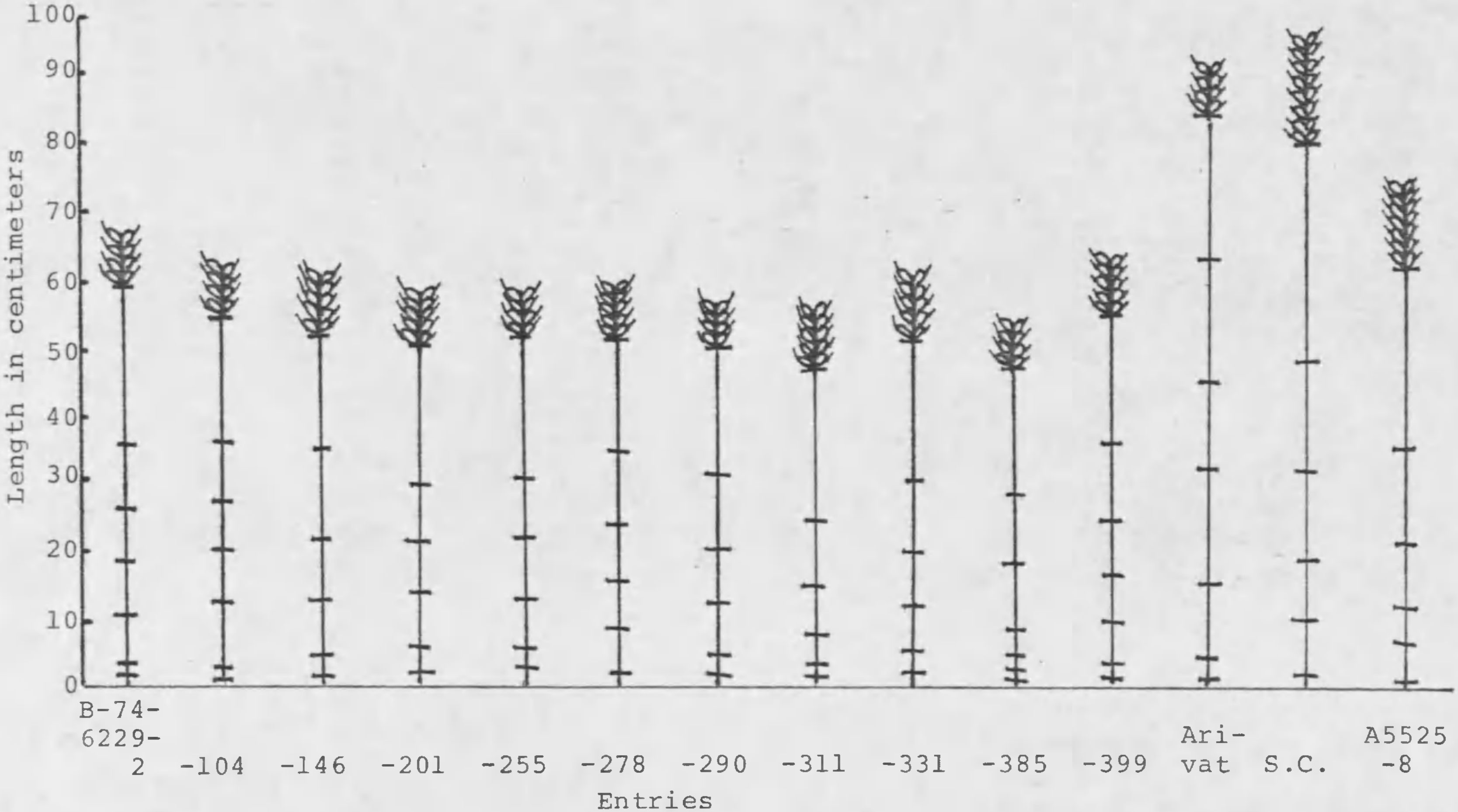

Figure 1. Relative plant heights and internode lengths of 14 barley and wheat entries -- Head lengths are not drawn to scale since some heads were erect and others were nodding.

Compared to all the other entries in this experiment Arivat shed pollen very early and over a short period of time, matured the earliest, was relatively tall, and had the smallest peduncle length/plant height fraction. Arivat was remarkably unaffected by seeding rate. However at the high rate Arivat's peduncle shortened and its three lower internodes lengthened.

The short wheats shed pollen late and over a very short period of time, matured slightly early, were moderately tall, had very long peduncles and a high peduncle length/plant height fraction. Neither of the short wheats had over 6 plant nodes. The wheats were relatively unaffected by the fivefold change in plant density.

The short barleys displayed considerable differences between entries. They began pollen shed over a wide range of dates and, due to their high tillering capacities, shed pollen over a long time. They matured early to very late. Their plant heights were all significantly shorter than the triple dwarf wheat and ranged from 52 to 68 cm. They all had shorter internodes than Arivat, but their peduncle length/plant height fractions were all greater than that of Arivat.

Quinby and Karper (1945) have reported that sorghum height can be associated with plant internode number. In sorghum, maturity genes affect the duration of vegetative growth and consequently the number of plant internodes.

Among the short barleys and wheats surveyed in this study there was no association between lateness to bloom and internode number. Internode number, in turn, did not affect the total plant height. There were two short barleys which showed a relatively well developed seventh internode. One barley, 74-B-6229-104 began pollen shed early, matured early, and was not significantly taller than 10 of the other short barleys. Another barley, 74-B-6229-399, began pollen shed late, matured early, and was not significantly taller than 8 of the other short barleys. Among the selections in this experiment, plant internode number was not affected by the duration of vegetative growth nor was plant internode number related to total plant height.

Barley plant height was determined by plant internode lengths. The relative internode proportions of the short barleys were very different than those of Arivat. The peduncles were relatively longer, the second uppermost internode was approximately the same, but the 3rd through 6th internodes were all relatively more compact than those of Arivat. The wheats also had relatively short bottom internodes and very long peduncles. Campbell, Casady, and Crook (1975) have shown that isogenic dwarf sorghums have the same number of plant internodes as the tall types but that the actual peduncle lengths of the dwarfs are longer. Casady (1965, 1967) and Campbell et al. (1975) have pointed out in numerous studies the greater yield potential of tall sorghums compared to their isogenic dwarf types. A short peduncle is essentially a short route from the flag leaf to the inflorescence. Perhaps the short peduncle length character of the tall sorghums and of Arivat barley contributes to their high grain yields and yield stabilities.

In contrast to the response stability found in Arivat and the two wheats, the short barleys displayed a wide range of responses to seeding density. The short barleys in this experiment were generally very responsive to the change in seeding density. It would be instructive to study the yield responses of the more promising selections under a wider range of plant population and seeding pattern.

For two of the variables considered, days to first pollen shed and duration of pollen shed, there were significant entry x plant density interactions. That differential response of the entries to plant density suggests that it might be worthwhile to evaluate future such short straw barley selections under different plant densities.

Experiment II

The two wheat entries, Siete Cerros and A5525-8, were grown at 3 row widths and 3 intrarow plant densities for a total of nine spacing and population treatments. Four variables were determined for each treatment; the number of days from planting to first pollen shed, the duration of pollen shed, the number of days from planting to maturity, and the average plant height.

Days from Planting to First Pollen Shed

The mean number of days from planting to first pollen shed of each spacing and entry treatment are listed and compared in Table 9. Intrarow plant density had no significant effect on the date of first pollen shed. However row width did make a difference. As row widths were increased from 23 to 30.5 cm and then to 46 cm, the date of first pollen shed decreased one day for each row width increment. Siete Cerros began pollen shed about 6 days later than A5525-8. There were no significant row width, intrarow plant density, or entry combination interactions.

Duration of Pollen Shed

The duration of pollen shed for the entries and spacing treatments are listed in Table 10. Generally the duration of pollen shed increased as the plants were spaced farther apart, both within and between the rows. When plant density decreased from 29.5 to 10 plants per meter in the row there was an increase in pollen shed duration by 1.3 days. As row widths increased from 23 to 30.5 cm the duration of pollen shed increased from 10 to 11.5 days. A further increase in row width to 46 cm prolonged pollen shed duration to 12.7 days. Siete Cerros shed pollen over

Table 9. Effect of row spacing and intrarow plant density on the number of days from planting to first pollen shed of two wheat entries.

		Mean number of days from planting to first pollen shed			
		Entries			
Row width (cm)	Intrarow plant density (# pl/m)	Siete Cerros	A5525 -8	Row width means	Intrarow plant density means
23	10	149	143		
	29.5	149	145		
	49	149	145	146.8 a*	
30.5	10	148	143		
	29.5	149	143		
	49	148	144	145.8 b	
46	10	148	141		145.3 a+
	29.5	148	141		145.9 a
	49	147	141	144.2 c	145.6 a
Entry Means		148.4 a‡	142.5 b		

C.V. = 0.9%

*+‡Means followed by the same letter are not significantly different at the .05 level according to the Student-Newman-Keul multiple range test.

*Comparisons made among row width means.

+Comparisons made among seedling density means.

‡Comparisons made among entry means.

Table 10. Effect of row spacing and intrarow plant density on the duration of pollen shed of two wheat entries.

Row width (cm)	Intrarow plant density (# pl/m)	Mean duration of pollen shed, days			
		Entries		Row width means	Intrarow plant density means
		Siete Cerros	A5525 -8		
23	10	10	11		
	29.5	9	9		
	49	10	10	10.0 a*	
30.5	10	12	13		
	29.5	10	13		
	49	10	11	11.5 b	
46	10	12	14		12.1 a+
	29.5	12	12		10.8 b
	49	12	14	12.7 c	11.3 b
Entry Means		10.8 a‡	12 b		

C.V. = 15%

*+‡Means followed by the same letter are not significantly different at the .05 level according to the Student-Newman-Keul multiple range test.

*Comparisons made among row width means.

+Comparisons made among seedling density means.

‡Comparisons made among entry means.

10.8 days; whereas the more freely tillering A5525-8 shed pollen over a period of 12 days. There were no significant interactions.

Days from Last Pollen Shed to Maturity

The difference between maturity date and last pollen shed date was calculated for each treatment and the means were analyzed and compared. No significant differences were detected among treatments or between the two wheat entries.

Days from Planting to Maturity

The maturity dates are compared in Table 11 for each wheat entry and each spacing treatment. There were no significant row width or entry differences, but there was a slight differential response to intrarow plant density. As the density was increased from 10 to 29.5 plants per meter the maturity date decreased by almost 2 days.

Average Plant Height

Average plant heights are listed and compared for each treatment in Table 12. There were no significant height differences between row width treatments. However, plant heights increased significantly with increases in intrarow plant density. When the density was increased from 10 to 29.5 plants per meter Siete Cerros grew 3 cm taller and A5525-8 increased 4.6 cm in height. When

Table 11. Effect of row spacing and intrarow plant density on the number of days from planting to maturity of two wheat entries.

		Mean number of days from planting to maturity			
		Entries			
Row width (cm)	Intrarow plant density (# pl/m)	Siete Cerros	A5525 -8	Row width means	Intrarow plant density means
23	10	191	189		
	29.5	188	188		
	49	188	188	188.5 a*	
30.5	10	190	190		
	29.5	188	189		
	49	188	188	188.8 a	
46	10	190	190		190.1 a+
	29.5	188	189		188.3 b
	49	187	189	189.0 a	188.0 b
Entry Means		188.7 a‡	188.9 a		

C.V. = .7%

*+‡Means followed by the same letter are not significantly different at the .05 level according to the Student-Newman-Keul multiple range test.

*Comparisons made among row width means.

+Comparisons made among seedling density means.

‡Comparisons made among entry means.

Table 12. Effect of row spacing and intrarow plant density on average plant height.

Row width (cm)	Intrarow plant density (# pl/m)	Average plant height, cm: Entries: Siete Cerros	Entries: A5525-8	Row width means	Intrarow plant density means
23	10	101	79		
	29.5	104	83		
	49	105	86	92.8 a*	
30.5	10	97	79		
	29.5	102	85		
	49	106	86	92.5 a	
46	10	98	78		88.6 a+
	29.5	100	82		92.5 b
	49	103	85	90.9 a	95.1 c
Entry Means		101.7 a‡	82.5 b		

C.V. = 3.4%

*+‡Means followed by the same letter are not significantly different at the .05 level according to the Student-Newman-Keul multiple range test.

*Comparisons made among row width means.

+Comparisons made among seedling density means.

‡Comparisons made among entry means.

seedling density was further increased to 49 plants per meter the heights of Siete Cerros and A5525-8 increased 2.6 and 2.3 cm respectively. The average height of the semi-dwarf Siete Cerros was 101.7 cm compared to 82.5 cm for the triple dwarf wheat A5525-8. There were no significant interactions.

Discussion

The two wheats had only slightly varying responses to the wide range of population and seeding pattern treatments used in this experiment.

One remarkable characteristic observed in the two wheats was the two to three week period between head extrusion and pollen shed. By the time pollen shed began all of the spikelets on all of the heads of the same plant were well developed. The awns were fully exposed to sunlight at least two weeks before pollination began. Pre-pollination spikelet development promoted uniform pollen shed of florets of the same head and of heads on the same plant. Uniform pollen shed within plots resulted in uniform plot maturity.

Experiment III

One short barley entry was selected for a more detailed study of the effects of plant population, row width, and intrarow plant density. The selected barley line, 74-B-6229-399, is characterized by profuse tillering, long lax heads, and small seed.

Grain Yield per Hectare

Grain yield means for the spacing treatments are compared in Table 13. Grain yield was significantly influenced by both row width and intrarow plant density. However, analysis of variance shows that the greatest portion of grain yield variation was due to intrarow seedling density. Average grain yields of each row width are illustrated as functions of intrarow seedling densities in Figure 2. Generally, the grain yield increased as row widths decreased. At all row widths grain yields increased significantly when plant density was changed from 10 to 29.5 plants per meter. When plant density was further increased to 49 plants per meter the grain yield decreased appreciably at the two narrower row widths but did not change significantly at the widest row width. The highest grain yields were obtained in the plots planted in 23 or 30.5 cm row widths with an intermediate plant density of 29.5 plants per meter.

Number of Heads per Meter^2

The mean number of heads per meter^2 are compared in Table 14. For all seedling densities there was a general increase in number of heads per unit area as the row widths decreased from 46 to 23 cm. For all row widths the number

Table 13. Effect of row width and intrarow plant density on yield per hectare of the short barley, 74-B-6229-399.

Row width (cm)	Intrarow plant density (plants/m)	kg/ha	Row width means	Intrarow plant density means
23	10	7092 ab*		
	29.5	8031 b		
	49	7786 ab	7636 a+	
30.5	10	5863 ab		
	29.5	8133 b		
	49	6814 ab	6937 ab	
46	10	5444 a		6133 a‡
	29.5	7050 ab		7783 b
	49	7221 ab	6572 b	7274 b
Entry Mean		7048		

C.V. = 19.7%

*+‡Means followed by the same letter are not significantly different at the .05 level according to the Student-Newman-Keul multiple range test.

*Comparisons are made among row width-seedling density treatment combination means.

+Comparisons are made among row width means.

‡Comparisons are made among seedling density means.

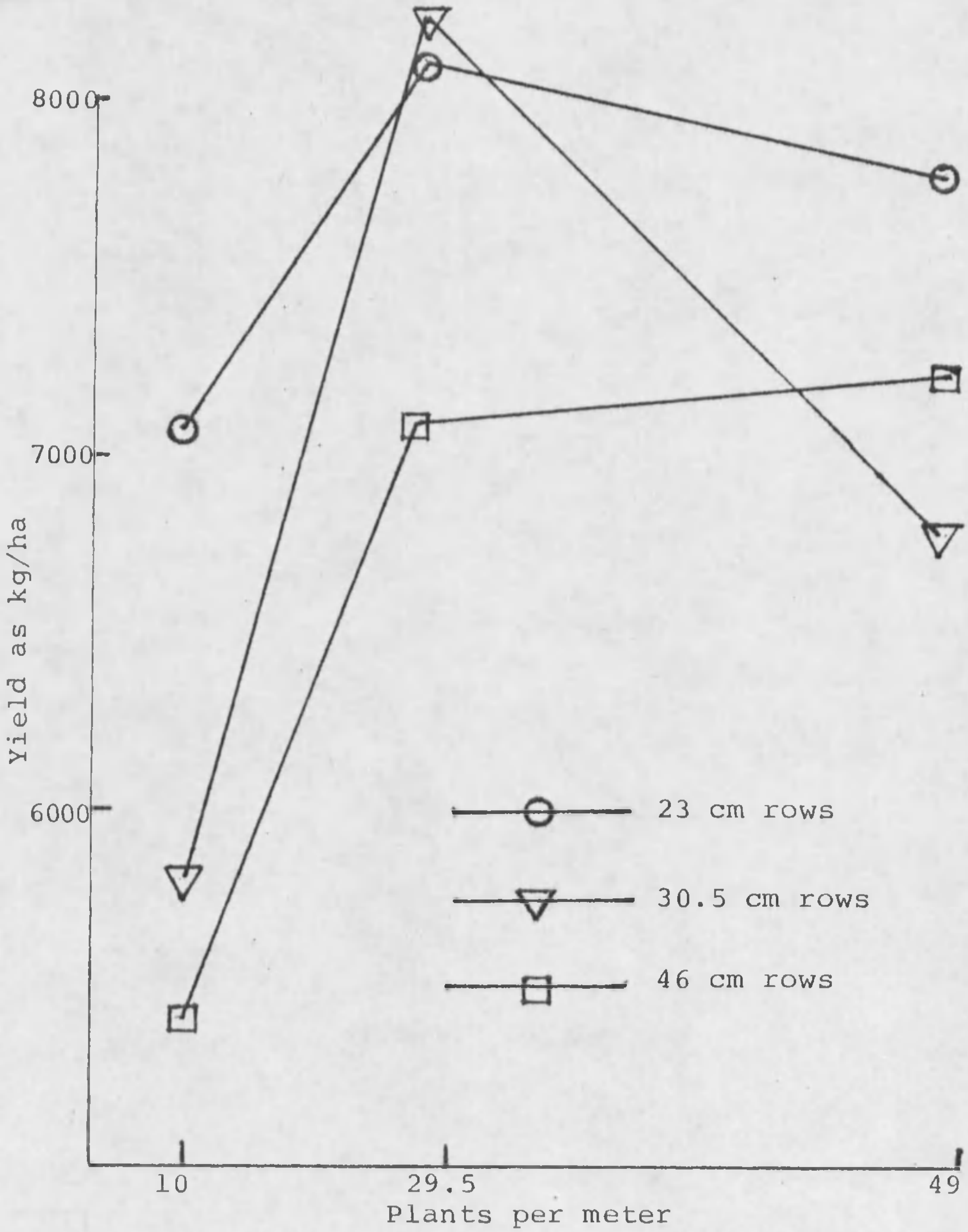

Figure 2. Effect of row width and seedling density on the grain yield of 74-B-6229-399.

Table 14. Effect of row width and intrarow plant density on number of heads per meter^2 of the short barley, 74-B-6229-399.

Row width (cm)	Intrarow plant density (plants/m)	Heads per meter^2	Row width means	Intrarow plant density means
23	10	679 ab*		
	29.5	752 a		
	49	743 a	730 a$^+$	
30.5	10	607 ab		
	29.5	747 a		
	49	663 ab	672 a	
46	10	515 b		606 a‡
	29.5	705 a		735 b
	49	713 a	644 a	707 b
Entry Mean		680		

C.V. = 17.3%

*+‡Means followed by the same letter are not significantly different at the .05 level according to the Student-Newman-Keul multiple range test.

*Comparisons are made among row width-seedling density treatment combination means.

+Comparisons are made among row width means.

‡Comparisons are made among seedling density means.

of heads increased sharply when the density was changed from 10 to 29.5 plants per meter. At the two narrow row widths the head number decreased slightly when the plant density was further increased to 49 plants per meter. The head number, however, continued to increase in the widest row width treatments. The plots with the greatest average number of heads per meter^2 were those planted in the 23 or 30.5 cm rows with the intermediate density of 29.5 plants per meter.

Since head density can also be expressed on a per plant basis, the average number of heads per plant was determined for each treatment by dividing the number of head bearing tillers by the number of plants in each sampling unit. The average number of heads per plant was calculated for each treatment and the means are listed in Table 15. The number of heads per plant was inversely related to the number of plants per plot. The number of heads per plant decreased as the number of plants per plot increased.

Number of Seed per Head

The average number of seed per head is listed in Table 16 for each spacing treatment. As row widths were increased there was a general but slight increase in the number of seed per head. For all row widths there was an increase in number of seed per head for each increase in

Table 15. Average number of heads per plant of 9 row width/intrarow plant density combination treatments of the short barley, 74-B-6229-399.

Row widths (pl/m)	Number of heads per plant		
	23	30.5	46
10	16.1	18.7	23.9
29.5	5.8	7.7	10.9
49	3.4	4.1	6.6

Table 16. Effect of row width and intrarow plant spacing on the number of seeds per head of the short barley, 74-B-6229-399.

Row width (cm)	Intrarow plant density (plants/m)	Seed per head	Row width means	Intrarow plant density means
23	10	50.8 b*		
	29.5	50.1 b		
	49	46.6 b	49.2 a+	
30.5	10	51.3 b		
	29.5	50.8 b		
	49	47.4 b	49.8 a	
46	10	57.1 a		53 a‡
	29.5	49.1 b		50 ab
	49	48.2 b	51.5 b	47.4 b
Entry Mean		50.1		

C.V. = 9.8%

*+‡Means followed by the same letter are not significantly different at the .05 level according to the Student-Newman-Keul multiple range test.

*Comparisons are made among row width-seedling density treatment combination means.

+Comparisons are made among row width means.

‡Comparisons are made among seedling density means.

plant density. The highest number of seed per head was obtained in plots with the widest rows and the smallest plant density. Conversely, the lowest number of seed per head was found in plots with the narrowest rows and the greatest seedling density.

Weight of 1000 Seed

The average weights of 1000 seed for each of the spacing treatments are listed in Table 17. There was a general tendency for the average seed weight to increase as row widths decreased and plant densities increased. In every row width the seed weight increased with both increments in plant density. The highest average weight of 1000 seed was found in the plots planted in the narrowest row widths (23 cm) and the greatest plant density (49 plants per meter). In contrast, the smallest average weight of 1000 seed was obtained in the plots planted at the two widest row widths and the smallest plant density (3 plants per meter).

Days from Planting to First Pollen Shed

The number of days from planting to first pollen shed is compared in Table 18. When row widths were increased from 23 to 30.5 cm there was a slight decrease in the number of days to first pollen shed. When row widths were further increased to 46 cm there was a sharp decrease in the number of days to first pollen shed. Similarly, as

Table 17. Effect of row width and intrarow plant density on the average weight of 1000 seed of the short barley, 74-B-6229-399.

Row width (cm)	Intrarow plant density (plants/m)	Wt. of 1000 seed (g)	Row width means	Intrarow plant density means
23	10	20.8 abc*		
	29.5	21.3 ab		
	49	22.3 a	21.5 a+	
30.5	10	18.8 c		
	29.5	21.6 ab		
	49	21.8 ab	20.7 ab	
46	10	19.5 bc		19.7 a‡
	29.5	20.4 abc		21 b
	49	20.9 abc	20.3 b	21.6 b
Entry Mean		20.8		

C.V. = 6.6%

*+‡Means followed by the same letter are not significantly different at the .05 level according to the Student-Newman-Keul multiple range test.

*Comparisons are made among row width-seedling density treatment combination means.

+Comparisons are made among row width means.

‡Comparisons are made among seedling density means.

Table 18. Effect of row width and intrarow plant density on the number of days from planting to first pollen shed of the short barley, 74-B-6229-399.

Row width (cm)	Intrarow plant density (plants/m)	Days	Row width means	Intrarow plant density means
23	10	140.6 ab*		
	29.5	141.5 a		
	49	141.5 a	141.2 a†	
30.5	10	139.6 b		
	29.5	141.3 a		
	49	141.3 a	140.7 a	
46	10	135.8 d		138.6 a‡
	29.5	137.3 c		140 b
	49	139.5 bc	137.5 b	140.7 b
Entry Mean		139.8		

C.V. = 0.7%

*†‡Means followed by the same letter are not significantly different at the .05 level according to the Student-Newman-Keul multiple range test.

*Comparisons are made among row width-seedling density treatment combination means.

†Comparisons are made among row width means.

‡Comparisons are made among seedling density means.

the intraplant spacings in the rows became greater and seedling density became less there was a decrease in the number of days to first pollen shed. The plots with the widest rows and the smallest seedling densities had the earliest dates of first pollen shed. The latest plots to begin pollen shed were those planted at the narrowest row widths and greatest seedling density.

Duration of Pollen Shed

The duration of pollen shed for each of the spacing treatments is listed in Table 19. The duration of pollen shed decreased as row widths decreased and plant density increased. This trend held true without exception for every row width and every plant density treatment. Pollen was shed over the longest period of time in the plots planted in 46 cm rows with 10 seedlings per meter. The shortest period of pollination was found in plots containing 23 cm rows with 49 plants per meter.

Days from Last Pollen Shed to Maturity

The means for the number of days from last pollen shed to maturity are listed in Table 20. There was a consistent tendency for the grain filling period to be prolonged as the row widths were decreased and the seedling densities were increased. In every row width the number of days from last pollen shed to maturity increased with the two increments in seedling density.

Table 19. Effect of row width and intrarow plant density on pollen shed duration of the short barley, 74-B-6229-399.

Row width (cm)	Intrarow plant density (plants/m)	Days	Row width means	Intrarow plant density means
23	10	27.0 d*		
	29.5	23.0 ab		
	49	21.5 a	23.8 a†	
30.5	10	27.8 d		
	29.5	24.8 bc		
	49	23.0 ab	25.2 b	
46	10	31.8 e		28.8 a‡
	29.5	30.1 e		25.9 b
	49	26.8 cd	29.5 c	23.7 c
Entry Mean		26.2		

C.V. = 7.2%

*†‡Means followed by the same letter are not significantly different at the .05 level according to the Student-Newman-Keul multiple range test.

*Comparisons are made among row width-seedling density treatment combination means.

†Comparisons are made among row width means.

‡Comparisons are made among seedling density means.

Table 20. Effect of row width and intrarow plant density on the number of days from last pollen shed to maturity.

Row width (cm)	Intrarow plant density (plants/m)	Days	Row width means	Intrarow plant density means
23	10	24.5 b*		
	29.5	25.6 ab		
	49	27.3 a	25.8 a+	
30.5	10	23.6 b		
	29.5	24.5 b		
	49	26 ab	24.7 ab	
46	10	24.1 b		24.0 a‡
	29.5	24.6 b		24.9 ab
	49	24.6 b	24.4 b	25.9 b
Entry Mean		25.0		

C.V. = 6.8%

*+‡Means followed by the same letter are not significantly different at the .05 level according to the Student-Newman-Keul multiple range test.

*Comparisons are made among row width-seedling density treatment combination means.

+Comparisons are made among row width means.

‡Comparisons are made among seedling density means.

Days from Planting to Maturity

The number of days from planting to maturity for each spacing treatment is listed in Table 21. There were very few maturity differences between treatments. For the two highest plant densities there were slight maturity date delays when row widths were changed from 23 to 30.5 cm, then again to 46 cm. For all row widths there was a slight delay in maturity date when plant density was decreased from 49 to 10 plants per meter. The earliest maturing plots were those planted with 23 cm rows and high plant densities of 29.5 or 49 plants per meter. The latest maturing plots were those planted in 23 or 46 cm rows with a low plant density of 10 plants per meter.

Plant Heights

Plant heights are listed and compared in Table 22. Generally, plant heights increased as row widths decreased and intrarow plant density increased. However, there was a significant row width x intrarow plant density interaction. The interaction is illustrated in Figure 3. For the smallest plant density of 10 plants per meter there was an initial height increase when row widths were changed from 23 to 30.5 cm. When row widths were further increased to 46 cm the average plant height decreased slightly. For the intermediate density of 29.5 plants per meter there was a similar response to row width with the tallest plants in

Table 21. Effect of row width and intrarow plant density on number of days from planting to maturity of the short barley, 74-B-6229-399.

Row width (cm)	Intrarow plant density (plants/m)	Days	Row width means	Intrarow plant density means
23	10	192 a		
	29.5	190 a		
	49	190 a	190.9 a⁺	
30.5	10	191 a		
	29.5	190.6 a		
	49	190.6 a	190.8 a	
46	10	192 a		191.7 a‡
	29.5	192 a		191.0 ab
	49	191 a	191.7 a	190.6 b
Entry Mean		191.2		

C.V. = 0.6%

*⁺‡Means followed by the same letter are not significantly different at the .05 level according to the Student-Newman-Keul multiple range test.

*Comparisons are made among row width-seedling density treatment combination means.

⁺Comparisons are made among row width means.

‡Comparisons are made among seedling density means.

Table 22. Effect of row width and intrarow plant density on average plant heights of the short barley, 74-B-6229-399.

Row width (cm)	Intrarow plant density (plants/m)	Height (cm)	Row width means	Intrarow plant density means
23	10	62.6 ab*		
	29.5	66.5 a		
	49	69.5 a	66.2 a†	
30.5	10	63.2 ab		
	29.5	67 a		
	49	65.3 ab	65.2 a	
46	10	57.8 b		61.2 a‡
	29.5	66.3 ab		66.6 b
	49	68.3 a	64.1 a	67.7 b
Entry Mean		65.2		

C.V. = 7.6%

*†‡Means followed by the same letter are not significantly different at the .05 level according to the Student-Newman-Keul multiple range test.

*Comparisons are made among row width-seedling density treatment combination means.

†Comparisons are made among row width means.

‡Comparisons are made among seedling density means.

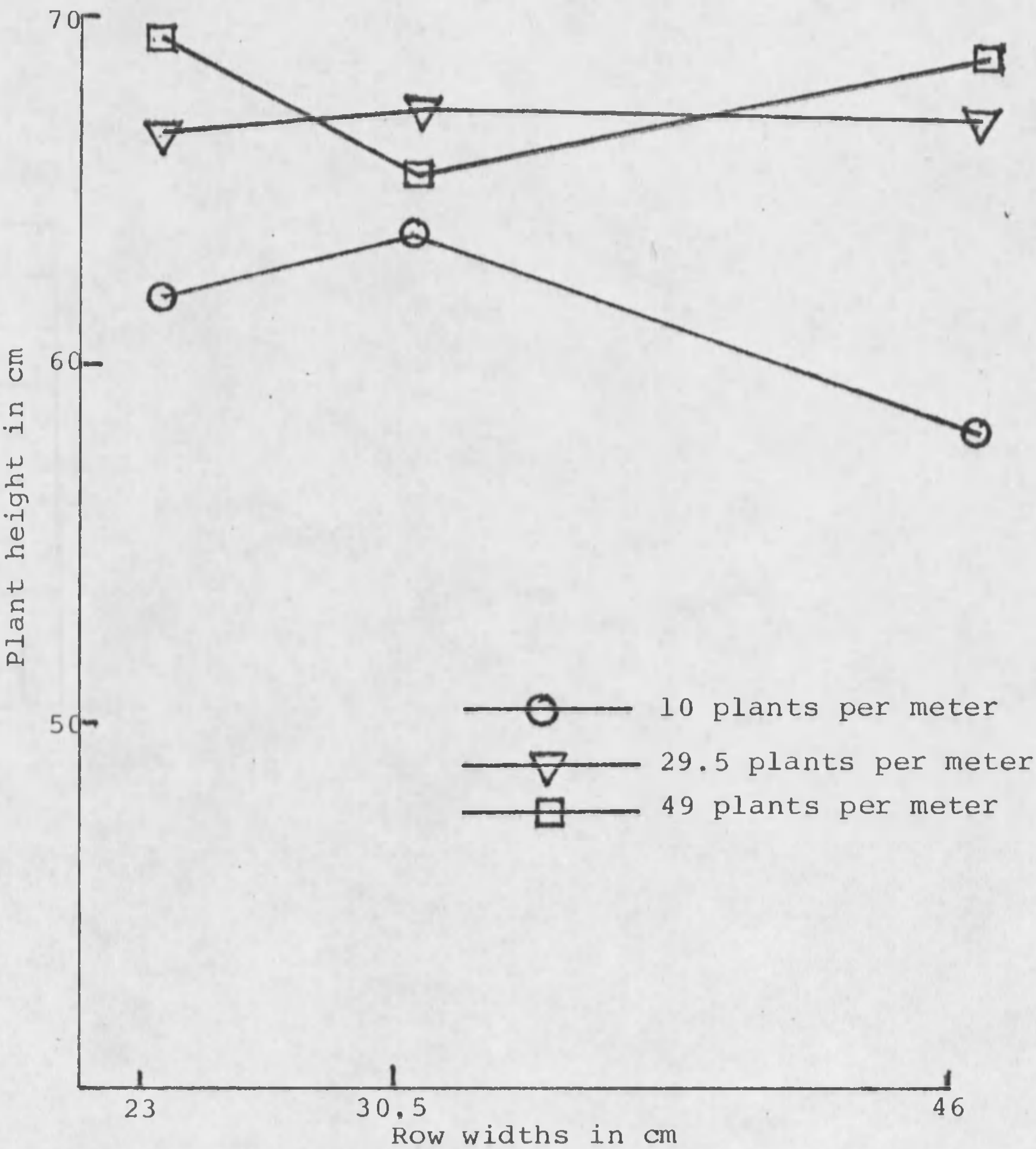

Figure 3. Effect of row width and seedling density on plant height of 74-B-6229-399.

the 30.5 cm rows. For the highest density of 49 plants per meter there was a decrease in plant height when row width was changed from 23 to 30.5 cm. Plant height again increased when row widths were increased to 46 cm. The greatest average plant height was found in the plots of all three row widths with the two highest densities. The smallest plant height was in the plots with the widest rows and smallest plant densities.

Correlations

Correlation coefficients were determined for all paired combinations of the variables used in this experiment and are listed in Table 23. Most correlations were highly significant. However, many of the correlations involving seed/head or maturity date variables were insignificant.

Grain yield was highly and positively correlated with the number of heads per unit area and weight of 1000 seed. Heads per unit area and weight of 1000 seed were also positively correlated with each other. Plant populations and planting patterns which supported a great number of heads per unit area also supported high seed weight. These correlations contrast with yield component studies involving other barleys and wheats. Welty (1973) also found in his barley hill spacing experiment a high positive correlation between yield and seed weight but a high and negative

Table 23. Correlation coefficients for all simple combinations of variables studied in Experiment III.

	Grain yield	Heads/ unit area	Seed/ head	Weight of 1000 seed	Days to first pollen shed	Duration of pollen shed	Maturity date	Height
Heads/unit area	+.86**							
Seed/head	-.13	-.48**						
Weight of 1000 seed	+.57**	+.26	-.09					
Days to first pollen shed	+.39*	+.41**	-.40**	+.41**				
Duration of pollen shed	-.38*	-.35*	-.43**	-.53**	-.86**			
Maturity date	+.10	-.04	+.24	+.11	-.28	+.42**		
Height	+.55**	+.49**	-.18	+.38*	+.47**	-.37*	+.15	
Days from last pollen shed to maturity	.33	.17	.21	.62**	.32	-.64**	.17	.25

*Correlations are significant at the .05 level.

**Correlations are significant at the .01 level.

correlation between seed weight and the number of heads per unit area. Knott and Talukdar (1971) also found a high and positive correlation between yield and seed weight in the large seeded 'Thatcher' wheat. They found that seed weight was negatively correlated with the number of heads per unit area.

In the present study yield was also positively correlated with the number of days to first pollen shed and negatively correlated with the duration of pollen shed. Heads per unit area and seed weight were also positively correlated with the number of days to first pollen shed and negatively correlated with the duration of pollen shed. There was a trend for the plots which began pollen shed late to pollinate over a relatively short period of time, have a high number of heads per unit area, have a relatively greater seed weight, and to yield well.

The number of seed per head was negatively correlated with the first pollen shed date and positively correlated with the duration of pollen shed. This indicates that the plants which shed pollen early and over a long period of time were able to set the most seed per head. Seed per head, however, was negatively correlated with heads per unit area and with grain yield.

Maturity date was only significantly correlated with the duration of pollen shed. The longer the duration of pollen shed the later was the maturity date. The lack of significant maturity date correlations is possibly due to prolonged cool temperatures between flowering time and maturity.

Discussion

There is evidence of a dynamic trade-off between inter- and intra-plant competition in this experiment. Figure 4 illustrates the relative changes of yield, yield components, and plant tillering with changes in plant population. Low plant populations had little competition between plants, but because of profuse tillering they had significant competition within plants. The low populations were the first to begin pollen shed and the last to end pollen shed as young tillers continued to develop and shed pollen over an extended period of time. Since the plants produced flowers and set seed over a prolonged period of time, grain filling was not uniform and the average seed weight was consequently depressed. The resultant grain yield of the low plant populations was relatively low. As plant populations increased, inter-plant competition also increased and intra-plant competition decreased. Increasing the number of plants per unit area resulted in fewer secondary tillers per plant, a delayed date of first pollen shed, a shortened duration of pollen shed, and a steady increase in seed weight. There was also an increase in plant height as inter-plant competition for light became

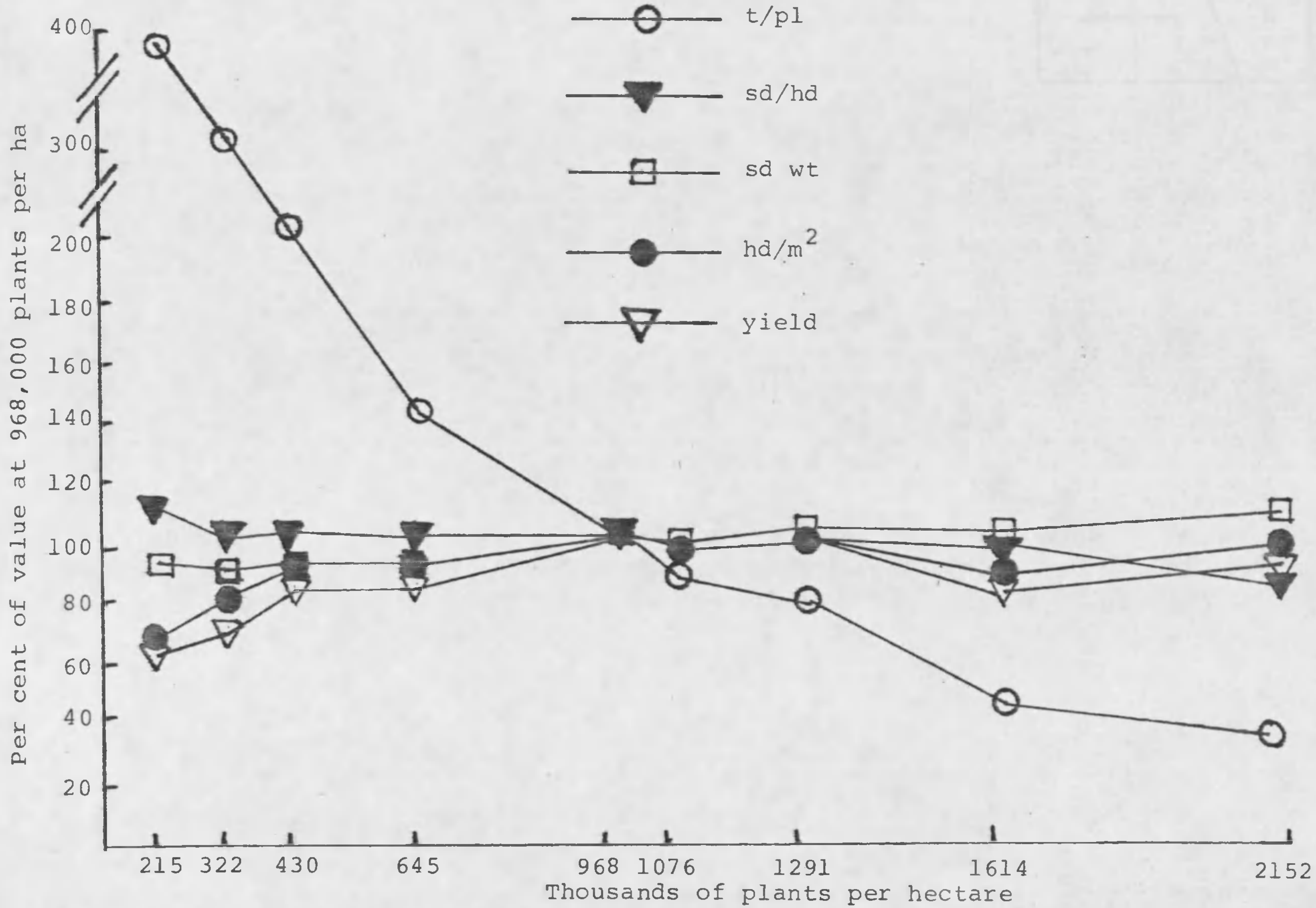

Figure 4. Effect of plant population on number of tillers per plant, grain yield, heads per meter^2, seed weight and number of seed per head, 74-B-6229-399.

more severe. The net yield was enhanced as relaxed intra-plant competition resulted in higher seed weight and the increased plant populations resulted in higher head numbers. However, as plant populations became very large (over 1,000,000 plants per ha), inter-plant competition resulted in such reduced tillering that the total number of heads per unit area remained unchanged even as plant number per unit area increased. The increased seed weight at very high populations was offset by a slight decrease in number of seed per head and of heads per unit area and the net yield slightly declined. It is apparent, then, that there is an optimal plant population range which minimizes both the seed weight depression of intra-plant competition and the tillering depression of inter-plant competition. That range for the barley entry in this study is between approximately 900,000 and 1,300,000 plants per hectare.

Blum (1970) found a very similar response to changing populations in a sorghum study. Seed weight and grain yield were highly and positively correlated for all the hybrids in the study. One early hybrid had highest yields and greatest seed weight at high populations. Panicles per plant and grains per panicle decreased sharply as grain weight increased when plant density was increased from 20 to 28 plants per m^2. He concluded that the number of panicles per plant and grains per panicle were affected mainly by inter-plant competition while the weight of 1000 seed was affected mainly by intra-plant competition.

SUMMARY AND CONCLUSIONS

Plant competition studies involving 11 short barley selections, Arivat barley, and two short wheat cultivars, Siete Cerros and A5525-8, indicate a wide range of variable response to row widths, intrarow plant densities, and plant population densities. There were significant response differences between entries, between treatments within entries, and for some variables, between directions of entry responses.

The wheats were planted in 9 seeding patterns with plant populations ranging from about 200,000 to 2,000,000 plants per ha. First pollen shed date, duration of pollen shed, maturity date, and plant heights were only slightly affected by the tenfold change in population density. Compared to the short barleys the short wheats shed pollen later and over a much shorter period of time, matured slightly earlier, and had greater plant heights. The average pollen shed duration was 10 days. One remarkable characteristic observed in the two wheats was the 2 to 3 week period between head extrusion and pollen shed which allowed pre-pollination head development and uniform pollen shed and seed set over a wide range of plant population densities.

The first pollen shed date, duration of pollen shed, maturity date, and plant height of Arivat were also generally unaffected by a fivefold increase in plant population from about 300,000 to over 1,500,000 plants per ha. Compared to the wheats and short barleys Arivat began pollen shed very early and over a short period of time, matured very early, and was tall. The average pollen shed duration was 19 days. The plant heights of Arivat and Siete Cerros were not significantly different.

The short barley selections were generally very responsive to the fivefold change in plant population. When the plant population was increased from 300,000 to 1,500,000 plants per ha there were several significant variable responses. The days to first pollen shed increased in one entry, the duration of pollen shed decreased in 8 entries, and the number of days from last pollen shed to maturity decreased in one entry. The number of days from planting to maturity decreased in one entry and plant height increased in two entries.

The short barleys also displayed considerable differences between entries. They began pollen shed over a range of 23 days, shed pollen from 22 to 31 days, and matured over a range of 10 days. The short barleys were all significantly shorter than the wheats. Plant heights ranged from 52 to 68 cm compared to 102 and 91 cm for Siete Cerros and A5525-8 wheats.

There were significant entry x plant population interactions when the short barleys, Arivat, and the two wheats were grown at 300,000 and 1,500,000 plants per ha. The interaction for the date of first pollen shed was significant at the 10% level and the pollen shed duration interaction was significant at the 5% level. Those significant interactions suggest that there are indeed differential responses of entries to changes in plant population.

Plant internode lengths were measured and compared for all entries at the two population densities. None of the six plant internodes of the wheats changed significantly when plant population increased from 300,000 to 1,500,000 plants per ha. However, when plant population increased the peduncle length of Arivat decreased while the lengths of three lower internodes increased. At the higher plant population the peduncle length of one short barley selection decreased, lower internodes of 8 short barleys increased, and the internodes of 2 short barleys remained unchanged. Arivat and 10 short barley selections had 7 plant internodes while one short barley and the two wheats had 6 plant internodes.

One short barley, 74-B-6229-399, was grown in 3 row widths and 3 intrarow plant densities representing plant populations ranging from 200,000 to over 2,000,000 plants per ha. Yield and yield component data were obtained. The highest grain yields were obtained in plots planted in 23 or 30.5 cm row widths with an intrarow plant density of 29.5 plants per meter and plant populations ranging from about 900,000 to 1,300,000 plants per ha. Grain yield was significantly and positively correlated with the number of heads per unit area, weight of 1000 seed, date of first pollen shed, and maturity date. There was a significant and negative correlation between grain yield and the duration of pollen shed. Increasing the number of plants per unit area resulted in fewer secondary tillers per plant but more heads per unit area, a delayed date of first pollen shed, a shortened duration of pollen shed, and a steady increase in seed weight and grain yield. Grain yield increased steadily until the plant population reached about 1,000,000 plants per ha when the increase in heads per unit area was offset by severe reductions in plant tillering.

In these studies pollen shed duration proved to be a very useful variable. It was not only negatively correlated with yield in one barley selection, but its response varied significantly from barley to barley with the change in plant population density. These results suggest the usefulness of comparing pollen shed duration of similar barley selections under various plant population densities.

The results of these studies indicate that there exists tremendous variability in the population from which the short barleys were selected. They also indicate the usefulness of evaluating future barleys from similar populations under contrasting seeding patterns and plant population densities.

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