PLANT POPULATION EFFECT ON YIELD AND YIELD COMPONENTS OF HYBRID AND PURELINE WINTER WHEAT

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CHAPTER I

INTRODUCTION

Wheat is a major food cereal of the world and is a dietary mainstay for millions of people. The importance of wheat as a human and animal food provides incentive for continuing world-wide efforts to improve its productivity. Being a self-pollinated crop, cultivar development has traditionally relied on purelines selected from segregating populations following hybridization. The discovery of an effective biological system in wheat involving cytoplasmic male sterility and pollen fertility restoration has provided the possibility of commercial utilization of F_1 hybrids to achieve new levels of productivity. Future adoption of hybrid wheat will depend primarily on the economic advantage obtained in the grower's field. Interest in hybrid wheat has prompted research on production and management procedures which may be suitable for adoption of wheat hybrids on commercial scale. Any management practice that reduces production costs but maintains the hybrid yield advantage will improve profitability of the grower. Plant population may be one factor which can be modified to improve economics of production. Due to the heterotic expression of emergence, vigor, and tillering capacity, it is postulated that the seeding rate of hybrid wheat cultivars can be reduced to 50% that of current pureline cultivars without reducing yield (Virmani and Edwards, 1983). Little scientific data are available to support this claim. Information is needed which demonstrates superiority of wheat hybrids at lower seeding rates over purelines in commercial plantings. The objectives of this study were to: 1) determine whether there is an interaction between seeding rate and cultivar type (purelines vs. hybrids) for grain yield and components of yield 2) determine the effect of environment (locations) on this interaction, 3) determine the yield component(s) most affected by seeding rate, and 4) determine optimum seeding rate(s) for pureline and hybrid wheat genotypes currently under cultivation.

CHAPTER II

LITERATURE REVIEW

In a three-year evaluation of various seeding rates and dates in Hays, Kansas, Jardine (1916) found that the seeding rate of 33.6 kg/ha produced yield as large as that of 67.2, 100.8, or 134.4, if wheat is planted before the last week in September. After that date, however, greater seeding rates produced significantly higher yields. In a five-year test, Martin (1926) found that when wheat was planted at the optimum time (mid-September through mid-October) highest yields were obtained from a 67.2 kg/ha seeding rate near Lawton, Oklahoma.

Briggle et al. (1963) compared four wheat purelines with their F_1 hybrids at three planting rates: 1, 2, and 4 seeds per hill spaced 2 inches apart. A significant entry x seeding rate interaction was found for grain yield in one cross only. In this case the hybrid produced 41.5 % more grain than its parents at the higher planting rate, whereas at the lower planting rates the parents did not differ from the hybrid. The other hybrid was not better than its parents at any seeding rate.

A comprehensive 3-year study of wheat hybrids and their parents at five seeding rates (27, 54, 108, 216, and 324 seeds m^{-2}) was conducted at Aberdeen, Idaho, by Briggle et al. (1967 a,b). A similar trend, increased yield with increased plant density through 216 seeds m^{-2}, was noticed in parental cultivars and spring and winter wheat hybrids.

Fonseca and Patterson (1968) tested seven pureline parents and 21 F_1 hybrids derived from a diallel cross at six and nine plants per hill in 1962-63, and at 3, 6, 9, and 12 plants per hill in 1963-64. They detected no significant genotype by seeding rate interaction for yield and yield components. Forty five durum spring wheat hybrids and their ten parents were evaluated in North Dakota by Winder and Lebsock (1973). They found that the highest yielding hybrid, `Langdon' x 61-130, exceeded the standard variety `Wells' by 16% when both were sown at 33 kg/ha rates; however, compared to Wells seeded at 67 kg/ha (normal rate), this hybrid showed only a 9% yield advantage. In another cross the highest yielding hybrid, `Wells' x `Langdon', was 22% and 4% higher than the Wells check seeded at 33 and 67 kg/ha, respectively.

In a two year date and rate of seeding study done by Peck and Croy (1973) under irrigated conditions in the Oklahoma Panhandle, seeding rate of 50.5 kg/ha was found to be the optimum. Darwinkel et al. (1977) found that seed rate had a positive influence on the number of spikes, but a negative effect on the number of grains per spike and grain weight. They also noted that grain yield per spike depended on the age of the tiller. Tillers that emerged earlier produced more and heavier spikes. They also noted that the number of grains per spike and grain weight could be related to the rate of development of the spike-bearing shoot. In another study on the effect of plant density on the pattern of tillering and grain production of winter wheat, Darwinkel (1978) found that a 160-fold increase in plant density (5 to 800 plants m^{-2}) resulted in a 3-fold increase in grain yield. Maximum yield was obtained at 100 plants m^{-2}, which corresponded to 430 spikes m^{-2} and to about 19 000 grains m^{-2}. At higher plant density more spikes and more grains were produced, but grain yield remained constant. Tillering per plant was largely favored by low plant densities, and a larger proportion of tillers produced spikes. More tillers were formed per unit area, however, at higher plant densities. Despite a higher mortality, more spikes were produced. The productivity of individual spikes decreased with increasing plant density. Above 400 spikes m^{-2}, grain yield per spike depended solely on grain number, because the weights of grains of the various shoots were similar. England (1983) compared the performance of three wheat hybrids, their parents and a pureline cultivar

(Chisholm) at seeding rates of 33.5 and 67 kg/ha, and found that the genotype by seeding rate interaction was nonsignificant. Quick et al. (1986) conducted seeding rate x genotype studies for seven hard red winter wheats at 10 locations in eastern Colorado under dryland conditions. Two Cargill hybrids, two Rohm & Haas hybrids, one Hybritech hybrid and two purelines, Vona and Sandy, were compared at six seeding rates: 10, 20, 30, 40, 50, 60 lb/acre (11.2, 22.4, 33.6, 44.8, 56, and 67.2 kg/ha). No significant genotype x seeding rate interaction indicated that the response of the genotypes was similar at various seeding rates. They recommended that the 33.6 kg/ha rate (390,000 plants/acre) was adequate for all locations. This is half the seeding rate normally used by farmers in Oklahoma.

Since no work has been done on this problem in Oklahoma, and since there is not a consensus opinion in the literature, a study was designed for Oklahoma to determine whether different seeding rates should be used for wheat hybrids and purelines.

CHAPTER III

MATERIALS AND METHODS

Four hard red winter wheat (Triticum aestivum L) genotypes were included in this study. Two adapted, high yielding pureline cultivars, `Chisholm' and `TAM W-101' released by the Oklahoma and Texas Agricultural Experiment Stations, respectively, were compared with two well adapted Cargill hybrids, `Bounty 122' and `Bounty 205'. Each of these genotypes was planted at the rate of 123, 185, 247, and 371 seeds m^{-2} at Lahoma (Pond Creek silt loam , fine-silty, mixed, thermic Pachic Argiustolls) in 1987-88. The test was repeated in 1988-89 at three locations, Lahoma, Woodward (Carey loam, fine-silty, mixed, thermic Typic Argiustolls) and Chickasha (McLain silt loam, fine, mixed, thermic Pachic Argiustolls), with an additional rate of 309 seeds m^{-2}. Tests were planted in early October each year. The experimental design was a split-plot arrangement of genotypes as main-plots and seeding rates as sub-plots, with six replications. An individual sub-plot consisted of six, 5-m rows spaced 25 cm apart. Seed weight of each genotype was determined and the number of grams for each seeding rate for each genotype was determined prior to seeding. Adjustments were made to account for germination percentage. Plots were planted with a six-row cone planter. Fertilizer was applied preplant according to recommendations based on soil tests and was incorporated into the soil. The foliar fungicide, Tilt, was applied to control foliar diseases.

Plants were counted at the one-leaf stage on 1 m sections of two interior rows of each plot to evaluate stand. Fall tiller count was taken at one site (Lahoma) in 1988 from 12.5 cm sections of the ends of four interior rows in each plot. The plants from these sections were dug with a spade on December 23, 1988, and number of tillers was counted for each sample.

The number of tillers producing spikes per 1 m sections of two interior rows of each plot was counted prior to harvest. The 1 m sections were chosen from each row at random.

To estimate kernels per spike and kernel weight, 25 spikes were harvested from one interior row in each plot at random. The seeds from each sample were counted and the average number of kernels per spike was calculated by dividing the total number of kernels from the sample by 25. Kernel weight was determined by dividing the weight of kernels obtained from the 25 selected spikes by the number of kernels.

The four interior rows of each plot were harvested with a plot combine for determination of grain yield. The two outer rows and ends of the interior rows served as border. The harvested area was 4.5 m^2. Grain yield was expressed as kilograms per hectare.

All data were analyzed statistically to determine genotypic, seeding rate, and interaction effects. Environments were assumed to be random in the model. Grain yield and yield components of genotypes were evaluated with orthogonal comparison procedures while data regarding the effect of seeding rate on yield and yield components were analysed with regression techniques.

CHAPTER IV

RESULTS AND DISCUSSION

The combined analyses of variance across environments (year-location) indicated that genotype x seeding rate and environment x genotype x seeding rate interactions were not significant for grain yield and yield components, showing that the genotypes, relative to each other, responded similarly to seeding rates across all environments tested (Table 1). Genotype and seeding rate effects on grain yield and yield components were confounded by significant environment by seeding rate interaction. The linear component of environment by seeding rate interaction was not significant for kernel spike^{-1} or weight kernel^{-1} but it was significant for grain yield and spikes m^{-2}. The quadratic component of environment by seeding rate interaction was not significant for grain yield or yield components while residual portion was significant for spikes m^{-2} only. Due to significant environment by genotype and environment by seeding rate interactions, each environment will be discussed separately.

Before discussing the grain yield and yield components, the number of seedlings emerged will be discussed to demonstrate that different seeding rates resulted in different population densities.

Plant Density After Emergence

Plant density was clearly influenced by seeding rate (Fig. 1). Increasing the seeding rate resulted in a corresponding increase in number of plants. There was no significant difference in the plant stand of purelines and hybrids in any environment (Table 2). Within purelines, Chisholm had more plants per unit area than TAM W-101 in all environments except at Lahoma in 1987-88 (Table 3). Within hybrids Bounty 205, had more plants per unit area than Bounty 122 in all environments.

Grain Yield

No significant genotype x seeding rate interaction occurred for grain yield in any of the four environments tested (Table 4). These results agree with findings of Fonseca and Patterson (1968), England (1983) and Quick et al. (1986). Partitioning the total genotype x seeding rate interaction into hybrid vs. pureline x seeding rate, within hybrids x seeding rate, and within purelines x seeding rate, still did not show any significant interactions. Therefore the data were averaged over genotypes and over seeding rates in each of the four environments to draw conclusions about main effects.

Differences among seeding rates were not significant for grain yield at Lahoma in 1987-88 or at Chickasha in 1988-89 (Table 4). The reason for lack of response of grain yield to a wide range of seeding rates (123 to 371 seeds m^{-2}) at Lahoma in 1987-88 was due to favorable weather condition during the growing season, which allowed the lower seeding rates to produce a high number of spikes per unit area, thus neutralizing the plant stand advantage of higher seeding rates. Lower seeding rates tended to produce numerically more kernels per spike and heavier kernels. Johnson et al. (1988) also reported grain yield unaffected by seeding rates in a favorable growing season in Georgia. At Chickasha, yields were relatively low for all treatments probably due to drought stress during grain filling.

At Woodward grain yield increased linearly with increasing seeding rate (Fig. 2). Regression analysis showed predicted yield (Y) to fit the linear equation, $Y = 4173 + 298SR$ ($R^2 = 0.83$). The average yield at this location was 4473 kg ha^{-1}, which is 1.84 times higher than Oklahoma state wheat yield average of 2425 kg ha^{-1} for the year, 1988 (Oklahoma Agricultural Statistics, 1988). The high yields at Woodward are probably due to the sub-irrigated nature of the test plot area. At Lahoma (1988-89) the linear effect of seeding rate on grain yield was also significant. Average yield at Lahoma (1988-89) was 3438 kg ha^{-1}. Regression analysis showed predicted yield (Y) to fit the linear equation, $Y = 3110 + 328SR$ ($R^2 = 0.67$). Lack of similar responses of grain yield to seeding rate at the same location in different years can be explained by the different weather conditions between the two years. While the 1987-88 growing season was excellent for wheat growth in all respects, 1988-89 was not so good because of low temperatures, the effects of which will be discussed later.

Purelines and hybrids did not differ significantly for grain yield in three environments, (Lahoma 1987-88, Lahoma 1988-89 and Woodward 1988-89), (Table 5). At Chickasha (1988-89) purelines significantly outyielded the hybrids because the high yielding hybrid (Bounty 122) could not maintain its superiority due to drought stress during grain filling while the higher yielding pureline (Chisholm) still maintained its better performance. Within purelines, Chisholm was consistently higher yielding than TAM W-101 in all environments in 1988-89. The lower yields of TAM W-101 in 1988-89 are partly explained by its relatively more sensitivity to cold injury and partly due to its lower emergence in comparison to Chisholm; at Lahoma in 1987-88, no significant difference was detected between purelines. Within hybrids, Bounty 122 significantly outyielded Bounty 205 in three environments (Lahoma 1987-88, and 1988-89, and Woodward 1988-89), whereas at Chickasha Bounty 205 yielded significantly higher than Bounty 122.

Fall Tillers

Analysis of variance showed that genotype x seeding rate interaction was not significant for fall tillers (Table 6). The interactions, hybrid vs. pureline x seeding rate, within hybrids x seeding rate, and within purelines x seeding rate, were also not significant. However, differences among seeding rates and among genotypes were highly significant.

Fall tillers (Y) showed a quadratic response to seeding rate (SR), $Y = 79.5 + 535SR - 181SR^2$, $R^2 = 0.99$ (Fig. 3). Only a proportion of fall tillers produced spikes. This proportion increased as plant density decreased. The survival percentage of fall tillers was 52, 42, 39, 39 and 38% for the lowest to highest seeding rate, respectively.

Hybrids produced significantly more tillers than purelines (Table 7). However, the mean number of productive spikes per unit area was the same for both hybrids and purelines, which shows that hybrids could not carry the superiority of fall tillers over purelines to productive stage. Within hybrids, Bounty 205 produced significantly more tillers than Bounty 122. Within purelines Chisholm had significantly higher number of tillers than TAM W-101.

Number of Spikes per Unit Area

Analyses of variance for number of spikes per unit area showed that genotype x seeding rate interaction was not significant in any environment (Table 8). When the total sum of squares of genotype x seeding rate interaction for spikes per unit area was partitioned into pureline vs. hybrid, within hybrids, and within purelines interactions with seeding rate, these were still nonsignificant. Differences among seeding rates and among genotypes were, however, significant.

The number of spikes per unit area increased linearly with increasing seeding rates at Woodward and Lahoma (1988-89), whereas this relationship was quadratic at Chickasha (Table 8 & Fig. 4). At Lahoma (1987-88) both quadratic and residual effects of seeding rate were significant for spikes per unit area. At Woodward lower seeding rates could not produce as many spikes as higher seeding rates probably due to cold injury on February 4, 1989 when the temperatures fell to -20°C at this location. These low temperatures might have killed more late developing tillers, thus placing lower seeding rates at a disadvantage because of their heavy reliance on secondary and tertiary tillers in comparison to higher seeding rates. Ciha (1983) showed that greater seeding rates may increase yield when environmental factors cause a reduction in tillering. At Lahoma (1988-89) also the low temperature of -29°C on February 4, 1989 might have done more damage to secondary and tertiary tillers than main shoots thus giving an advantage to higher seeding rates in comparison to lower seeding rates in 1988-89. This may also be the cause of significant differences among seeding rates for grain yield in 1988-89. Johnson et al. (1988) and Roth et al. (1984) reported that yield responses to seeding rate were influenced by environment. They found that high seeding rate produced the greatest yield response with late planting or severe winters.

In three of the four environments, there was no significant difference between the number of spikes produced by hybrids or purelines. However, hybrids produced significantly more spikes per unit area than purelines at Woodward (Table 9). Within hybrids, Bounty 205 produced significantly more spikes per unit area than Bounty 122 in all environments. Within purelines Chisholm was significantly better than TAM W-101 at all the three locations used in 1988-89 but TAM W-101 produced more spikes than Chisholm at Lahoma in 1987-88. The difference in performance of purelines for this trait during the two years may be explained by the cold injury to TAM W-101 in 1988-89.

Number of Kernels per Spike

Analyses of variance for number of kernels per spike indicated that genotype x seeding rate interaction was not significant in any environment (Table 10). The individual interactions of pureline vs. hybrid, within hybrids, and within purelines with seeding rate were also not significant. At Lahoma (1987-88), differences among seeding rates were not significant for kernels per spike while in the other three environments, (Lahoma 1988-89, Woodward, and Chickasha) seeding rate had a significant effect on this trait. In these three environments, number of kernels per spike decreased linearly with increasing seeding rate (Fig. 5). The mean number of kernels per spike of hybrids was significantly higher than that of purelines at Lahoma (1987-88 and 1988-89), less than purelines at Chickasha, and similar to purelines at Woodward (Table 11). Hybrids did not differ significantly for this character in any environment. Within purelines Chisholm had significantly higher number of kernels per spike than TAM W-101 in all environments.

Weight per Kernel

Analyses of variance for weight per kernel indicated that genotype x seeding rate interaction was not significant in any environment even if the total sum of squares for this interaction was further partitioned into 1) pureline vs. hybrid, 2) within hybrids, and 3) within purelines interactions with seeding rate (Table 12). Kernel weight was not significantly affected by seeding rate.

Mean weight per kernel for purelines was significantly higher than that for hybrids at Lahoma in 1987-88 and at Chickasha, whereas it was similar at Lahoma in 1988-89 (Table 13). At Woodward, mean kernel weight of hybrids was higher than that of purelines. Within hybrids, Bounty 122 had significantly heavier kernels than Bounty 205 in all environments. Purelines did not differ for kernel weight at Lahoma (1988-89) and Chickasha whereas at Lahoma (1987-88) and Woodward TAM W-101 had significantly heavier kernels than Chisholm.

CHAPTER V

SUMMARY AND CONCLUSIONS

Combined analyses of variance across different environments did not show significant genotype by seeding rate or environment by genotype by seeding rate interactions for grain yield and yield components, indicating that the response of the genotypes to seeding rate, relative to each other, was similar across the four environments used in this study.

Mean grain yields of the hybrids and purelines did not differ significantly in three (Lahoma 87-88, Lahoma 88-89, and Woodward) out of the four environments. At Chickasha, however, purelines significantly outyielded the hybrids. Grain yield was not affected significantly by seeding rates at Lahoma (1987-88) and Chickasha; at Woodward and Lahoma (1988-89) it showed a linear response to increasing seeding rates. Number of spikes per unit area and number of kernels per spike varied to a greater extent than weight per kernel with varying seeding rate.

The conclusions drawn from this study may be summarized as follows: 1) In view of nonsignificant pureline vs. hybrid by seeding rate and environment by genotype by seeding rate interactions for grain yield and its components, it can be concluded that purelines and hybrids responded similarly to seeding rate and that this response was consistent across all environments tested. 2) Number of spikes per unit area generally increased while number of kernels per spike generally decreased with increase in seeding rate and compensated for each other while weight per kernel was affected little; 3) Recommendations of optimum seeding rates are complicated by significant environment by seeding rate interaction. Seed cost also plays an important role in the recommendation of seeding rate. For Chickasha and Lahoma (1987-88), the lowest seeding rate (123 seeds m^{-2}) will, obviously, be the optimum seeding rate for both purelines and hybrids due to lower seed cost. For Woodward and Lahoma (1988-89), although the highest seeding rate maximized grain yields, the total return minus seed cost was not statistically higher than lower seeding rates (Table 14). After deducting the seed cost from total return, the optimum (economical) seeding rate for both hybrids and purelines was again 123 seeds m^{-2}. Therefore, a seeding rate of 123 seeds m^{-2} will be sufficient for both hybrids and purelines for grain yield provided they are sown at optimum planting time.

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APPENDIXES

APPENDIX A - TABLES

Table 1. Combined analyses of variance for plant density, grain yield and yield components of four wheat genotypes at four seeding rates across four environments.

		Mean Square				
Source	df	Plants M^{-2}	Spikes M^{-2}	Kernel $Spike^{-1}$	Weight $Kernel^{-1}$	Grain Yield
		--- x 10^3 ---				x 10^3
Environment (E)	3	15**	292**	508**	3473**	100538**
Rep (E)	20	1.5	7.9	10.2	10.9	1292
Genotype (G)	3	390**	225*	283	614*	4952
Prl vs. Hyb	1	2.7	0.6	147	216	830
Within Hyb	1	103**	652**	0.2	1350**	3377
Within Prl	1	11.6	23	702*	276	10648*
E x G	9	10**	37**	94**	115**	1656**
G x Rep (E)	60	1.1	7	7.8	11	288
Seeding Rate (SR)	3+	666**	236**	110**	8	377
SR_L	1	2000**	646**	314**	14	596
SR_Q	1	0.1	55*	8	10	7
SR_{Res}	1	0.1	5.4	6.8	0.6	529
E x SR	9	1.1	18**	8.8	4.6	407*
E x SR_L	3	1.4	26.8**	23	4.7	1052**
E x SR_Q	3	0.8	10.5	0.3	5.5	39
E x SR_{Res}	3	1.1	17*	8.4	3.5	129
G x SR	9	0.8	2.4	7.8	5.7	77
(Hyb vs. Prl)x SR	3	0.1	0.5	2.2	1.9	30

Table 1. (Continued)

Source	df	Plants M^{-2}	Spikes M^{-2}	Kernel Spike^{-1}	Weight Kernel^{-1}	Grain Yield
		Mean Square				
		--- x 10^3 ---				x 10^3
Within Hyb x SR	3	3.9	1.3	8.9	1.9	130
Within Prl x SR	3	2.3	5.3	12	13	70
E x G x SR	27	0.8	2.9	7	9.4	95
Residual	240	0.8	5.5	6.0	7.9	123

*, ** Significant at 0.05 and 0.01 probability levels, respectively.
+ Seeding rate of 309 seeds m^{-2} was excluded for carrying out the analyses of variance.
Hyb = hybrid   Prl = Pureline

Table 2. Analyses of variance for plant density of four winter wheat genotypes in each of the four environments.

	Location and Year					
	Lahoma 1988		Lahoma 1989	Woodward 1989	Chickasha 1989	
Source	df	MS	df	MS		
Replication	5	4029	5	561	578	1369
Genotype (G)	3	14135**	3	36160**	19472**	20876**
Hyb vs. Prl+	1	5310	1	1116	2150	4392
Within Hyb	1	8480**	1	62210**	48963**	31099**
Within Prl	1	28616**	1	45155**	7304*	27136**
Error (a)	15	1431	15	546	1153	1204
Seeding rate (SR)	3	17046**	4	128589**	159776**	137669**
G x SR	9	1117	12	1113*	793	1347
Error (b)	60	1711	80	557	596	894

*,** Significant at 0.05 and 0.01 levels of probability, respectively, according to orthogonal contrasts.

\+ Hyb = hybrid Prl = pureline

Table 3. Plant density of four winter wheat genotypes, averaged over seeding rates, in each of the four environments.

	Location and Year			
Genotype	Lahoma 1988	Lahoma 1989	Woodward 1989	Chickasha 1989
	------------ Plants m^{-2} -----------			
Bounty 122	188	165	175	163
Bounty 205	215	229	229	209
Hybrid Mean	202	197	202	186
Chisholm	162	218	223	195
TAM W-101	211	163	201	152
Pureline Mean	187	191	212	174

Table 4. Analyses of variance for grain yield of four winter wheat genotypes at various seeding rates in each of the four environments.

	Location and Year					
	Lahoma 1988			Lahoma 1989	Woodward 1989	Chickasha 1989
Source	df	-- MS --	df	MS		
		$x10^6$		$x10^6$		
Replication	5	2.9	5	0.42	1.83	0.48
Genotype (G)	3	1.0	3	2.28**	4.65**	3**
Hyb vs. Prl+	1	0.5	1	0.22	2.27	3.38**
Within Hyb	1	2.2*	1	1.44*	3.5*	0.75*
Within Prl	1	0.3	1	5.17**	8.19**	4.89**
Error (a)	15	0.42	15	0.28	0.56	0.12
Seeding rate (SR)	3	0.10	4	0.60**	0.34*	0.22
SR_L	1	0.17	1	1.62**	1.28**	0.48
SR_Q	1	0.002	1	0.003	0.0001	0.08
SR_{Res}	1	0.14	2	0.38	0.05	0.17
G x SR	9	0.09	12	0.11	0.06	0.16
(Hyb vs. Prl) x SR	3	0.11	4	0.12	0.03	0.03
Within Hyb x SR	3	0.10	4	0.05	0.11	0.04
Within Prl x SR	3	0.06	4	0.15	0.03	0.04
Error (b)	60	0.12	80	0.17	0.10	0.13
C.V. % Main plot		8.8		7.00	7.50	7.70
C.V. % Subplot		9.5		12.00	7.20	18.0

*, ** Significant at 0.05 and 0.01 levels of probability, respectively.

\+ Hyb = Hybrid Prl = Pureline

Table 5. Grain yield of individual genotype and hybrid vs. pureline, averaged over seeding rates in each of the four environments.

Genotype	Location and Year			
	Lahoma 1988	Lahoma 1989	Woodward 1989	Chickasha 1989
	------------	Kg ha^{-1}	--------------	
Bounty 122	3803	3537	4852	1711
Bounty 205	3374	3227	4369	1934
Hybrid Mean	3588	3382	4610	1822
Chisholm	3654	3762	4705	2444
TAM W-101	3813	3175	3966	1873
Pureline Mean	3733	3468	4335	2158

Table 6. Analysis of variance for number of fall tillers m^{-2} of four wheat genotypes at five seeding rates at Lahoma in 1988-89.

Source	df		Mean Square
			X 10^3
Replication	5		19.7
Genotype (G)	3		187**
Prl vs. Hyb+		1	284.9**
Within purelines		1	49.0*
Within Hybrids		1	162.2**
Error (a)	15		6.6
Seeding Rate (SR)	4		123**
SR_L		1	444.2**
SR_Q		1	43.2**
SR_{Res}		2	2.2
G x SR	12		4.9
(Hyb vs. Prl) x SR		4	3.4
Within Hyb x SR		4	5.4
Within Prl x SR		4	5.8
Error (b)	80		3.3
C.V.% Main plot			8.9
C.V.% Subplot			14.0

*, ** Significant at 0.01 and 0.05 levels of probability, respectively.
\+ Prl = Pureline Hyb = Hybrid

Table 7. Number of fall tillers, productive spikes, and % fall tiller converted to productive spikes of four winter wheat genotypes at Lahoma in 1989, averaged over seeding rates.

Genotype	Fall Tillers M^{-2}	Productive Spikes M^{-2}	% Fall Tillers converted to Productive spikes
Bounty 122	1648	624	38
Bounty 205	2064	738	36
Hybrid Mean	1856	681	37
Chisholm	1540	717	47
TAM W-101	1312	634	48
Pureline Mean	1426	675	47.5

Table 8. Analyses of variance for spike density of four winter wheat genotypes at various seeding rates in each of the four environments.

	Location and Year					
	Lahoma 1988			Lahoma 1989	Woodward 1989	Chickasha 1989
Model	df	MS	df	MS		
		x10^3		x10^3		
Replication	5	9.3	5	10.4	17.9	1.6
Genotype (G)	3	107**	3	98.6**	96.0**	108.9**
Hyb vs. Prl+	1	11.6	1	0.8	44.2*	27.3
Within Hyb	1	182**	1	193**	167**	252**
Within Prl	1	128**	1	102**	77**	48.2*
Error (a)	15	8.6		6.4	7.4	8.1
Rate (SR)	3	49.8*	4	49.3**	68.2**	89.4**
SR_L	1	30.7	1	193.2**	269.5**	335.1**
SR_Q	1	67.4*	1	2.5	1.7	13.5*
SR_{Res}	1	51.2*	2	0.8	0.7	4.5
G x SR	9	3.8	12	2.6	2.2	2.4
(Hyb vs. Prl) x SR	3	4.5	4	0.9	1.6	2.8
Within Hyb x SR	3	0.4	4	1.4	2.7	0.3
Within Prl x SR	3	6.4	4	5.2	2.3	3.9
Error (b)	60	10.3	80	4.6	3.8	3.3
C.V. % Main plot		6.3		5.3	5.6	6.6
C.V. % Subplot		13.8		10.0	9.0	9.5

*, ** Significant at 0.05 and 0.01 levels of probability, respectively.
\+ Hyb = hybrid Prl = Pureline

Table 9. Number of spikes m^{-2} of four winter wheat genotypes, averaged over seeding rates, in each of the four environments.

	Location and Year			
Genotype	Lahoma 1988	Lahoma 1989	Woodward 1989	Chickasha 1989
	--------------	Spikes M^{-2}	--------------	
Bounty 122	664	624	654	531
Bounty 205	787	738	760	661
Hybrid Mean	725	681	707	596
Chisholm	696	717	705	655
TAM W-101	799	634	633	598
Pureline Mean	747	675	669	626

Table 10. Analyses of variance for number of kernels per spike of four winter wheat genotypes at various seeding rates in each of the four environments.

	Location and Year					
	Lahoma 1988			Lahoma 1989	Woodward 1989	Chickasha 1989
Model	df	-- MS --	df	MS		
Replication	5	11.5	5	8.8	7.7	12.5
Genotype (G)	3	398**	3	71**	35.4	106**
Hyb vs. Prl+	1	688**	1	48**	17.4	99**
Within Hyb	1	18.8	1	17	10.0	7.5
Within Prl	1	487**	1	149**	78.9*	211**
Error (a)	15	6.4	15	4.3	12.2	8.3
Rate (SR)	3	8.1	4	54.3*	112**	30.9**
SR_L	1	12.0	1	207**	445**	123.7**
SR_Q	1	3.3	1	7.9	0.8	0.6
SR_{Res}	1	8.9	2	1.2	1.6	0.2
G x SR	9	7.3	12	3.2	2.3	8.4
(Hyb vs. Prl) x SR	3	4.4	4	5.3	2.6	8.1
Within Hyb x SR	3	1.6	4	1.9	2.6	7.4
Within Prl x SR	3	15.8	4	2.3	1.8	1.3
Error (b)	60	8.3	80	3.0	2.7	7.4
C. V. % Main plot		4.9		4.3	7.7	6.0
C. V. % Subplot		11.2		9.7	10.0	12.7

*, ** Significant at 0.05 and 0.01 levels of probability, respectively.

Table 11. Number of kernels per spike of four winter wheat genotypes, averaged over seeding rates, in each of the four environments.

	Location and Year			
Genotype	Lahoma 1988	Lahoma 1989	Woodward 1989	Chickasha 1989
	------------ Kernels Spike^{-1}			-----------
Bounty 122	28.0	22.7	21.2	20.2
Bounty 205	29.0	21.7	20.4	20.9
Hybrid Mean	28.5	22.2	21.1	20.6
Chisholm	26.0	22.5	21.2	24.2
TAM W-101	20.0	19.4	18.9	20.5
Pureline Mean	23.0	20.9	20.1	22.4

Table 12. Analyses of variance for weight per kernel of four winter wheat genotypes, at various seeding rates, in each of the four environments.

	Location and Year					
	Lahoma 1988		Lahoma 1989	Woodward 1989	Chickasha 1989	
Source	df	-- MS --	df	------------ MS ------------		
Replication	5	16.7	5	5.9	5.1	6.0
Genotype (G)	3	380**	3	172**	371**	137**
Hyb vs. Prl+	1	221**	1	38.5	83**	244**
Within Hyb	1	187**	1	416**	1012**	152**
Within Prl	1	732**	1	77*	19.5*	14
Error (a)	15	10.4	15	23	2.9	12.4
Rate (SR)	3	10.2	4	1.2	5.8	4.4
SR_L	1	3.9	1	0.2	12.6	1.9
SR_Q	1	19.8	1	0.01	3.8	0.9
SR_{Res}	1	7.1	1	3.1	3.4	7.5
G x SR	9	3.6	12	14.3	5.3	9.1
(Hyb vs. Prl) x SR	3	4.9	4	8.1	2.6	1.7
Within Hyb x SR	3	1.5	4	20.2	4.9	7.8
Within Prl x SR	3	4.2	4	15.9	8.3	17.6
Error (b)	60	7.0	80	12.5	6.0	6.6
C. V. % Mainplot		5.8		7.2	2.0	7.0
C. V. % Subplot		9.6		11.9	6.6	11.6

*, ** Significant at 0.05 and 0.01 levels of probability, respectively.
\+ Hyb = Hybrid Prl = Pureline

Table 13. Weight per kernel of four winter wheat genotypes, averaged over seeding rates, in each of the four environments.

	Location and Year			
Genotype	Lahoma 1988	Lahoma 1989	Woodward 1989	Chickasha 1989
	--------- Weight $Kernel^{-1}$ (mg) ---------			
Bounty 122	28.2	31.8	41.8	22.3
Bounty 205	24.2	26.5	33.6	19.1
Hybrid Mean	22.2	29.2	37.7	20.7
Chisholm	25.3	29.0	35.4	24.1
TAM W-101	33.1	31.3	36.6	23.1
Pureline Mean	29.2	30.2	36.0	23.6

Table 14. Return per hectare from grain yield of hybrid and pureline wheat at each of the five seeding rates at Woodward and Lahoma in 1988-89.

Genotype		Seeding rate (seeds m^{-2}) 123	185	247	309	371
Woodward						
Hybrid	Grain yield (Kg ha^{-1})	4558	4583	4606	4689	4745
	Total return ($)	501.46	504.19	506.66	515.83	521.95
	Seed cost ($)	31.00	46.50	62.00	77.50	93.00
	Total return - seed cost ($)	470.46	457.69	444.66	438.33	428.95
Pureline	Grain yield (Kg ha^{-1})	4185	4291	4361	4304	4535
	Total return ($)	460.47	472.01	479.71	473.44	498.88
	Seed cost ($)	4.93	7.39	9.86	12.32	14.82
	Total return - seed cost	455.49	464.62	469.85	461.12	484.06
LSD (0.05) for total return - seed cost = 32.58						
Lahoma 1988-89						
Hybrid	Grain yield (Kg ha^{-1})	3155	3185	3611	3378	3579
	Total return	347.00	350.39	397.21	371.61	393.71
	Seed cost ($)	31.00	46.50	62.00	77.50	93.00
	Total return - seed cost	316.00	303.89	335.21	294.11	300.71
	LSD (0.05) for total return - seed cost = 46.60					
Pureline	Grain yield (Kg ha^{-1})	3413	3386	3535	3340	3669
	Total return ($)	375.43	372.40	388.85	367.40	403.59
	Seed cost ($)	4.93	7.39	9.86	12.32	14.82
	Total return - seed cost	370.50	365.01	378.99	355.08	388.77
LSD (0.05) for total return - seed cost = 25.27						

Hybrid seed cost per kg = $0.62
Pureline seed cost per kg = $0.14
Grain sale price of wheat per kg = $0.11

APPENDIX B - FIGURES

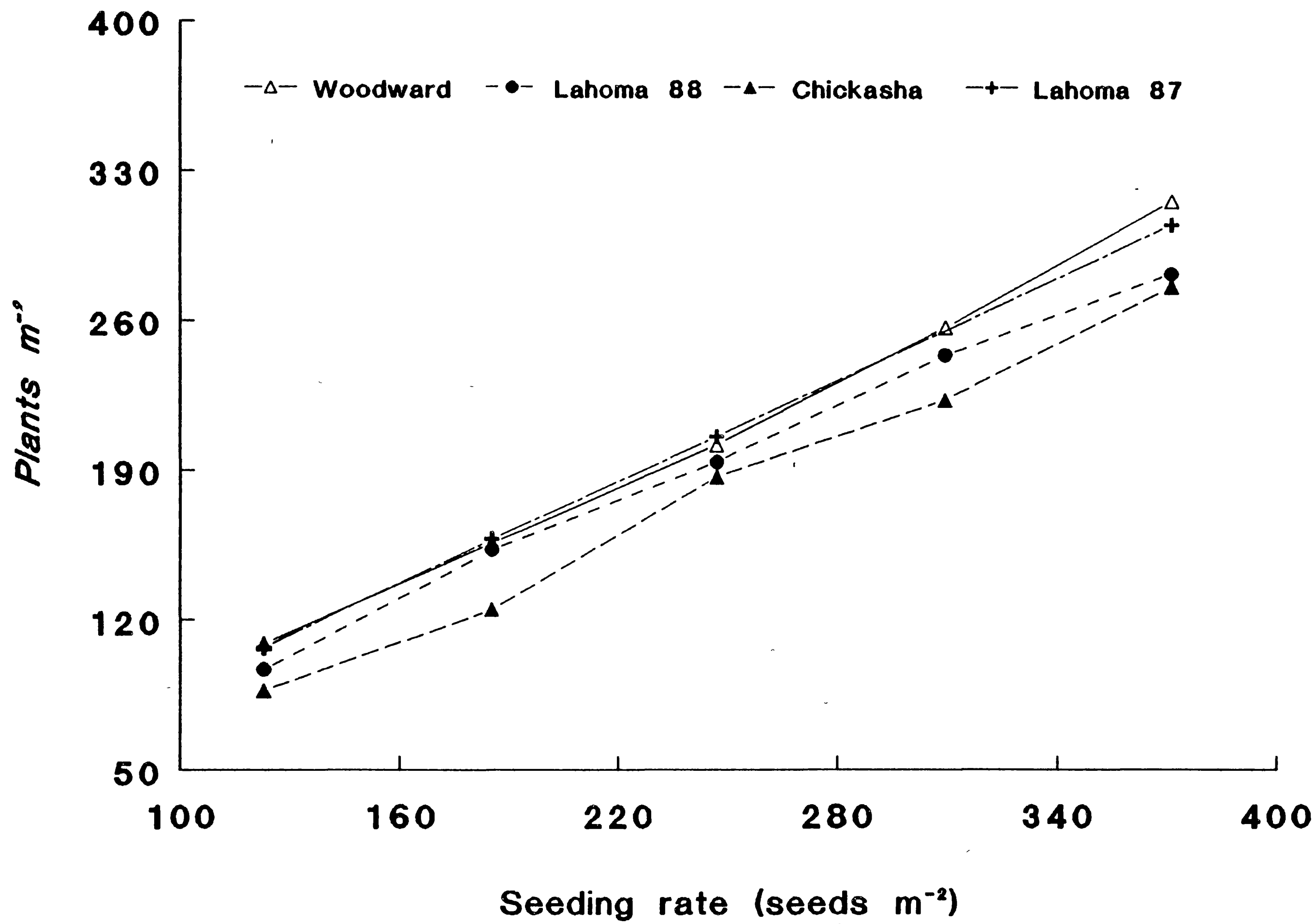

Fig. 1. Effect of seeding rate on plant density in four environments.

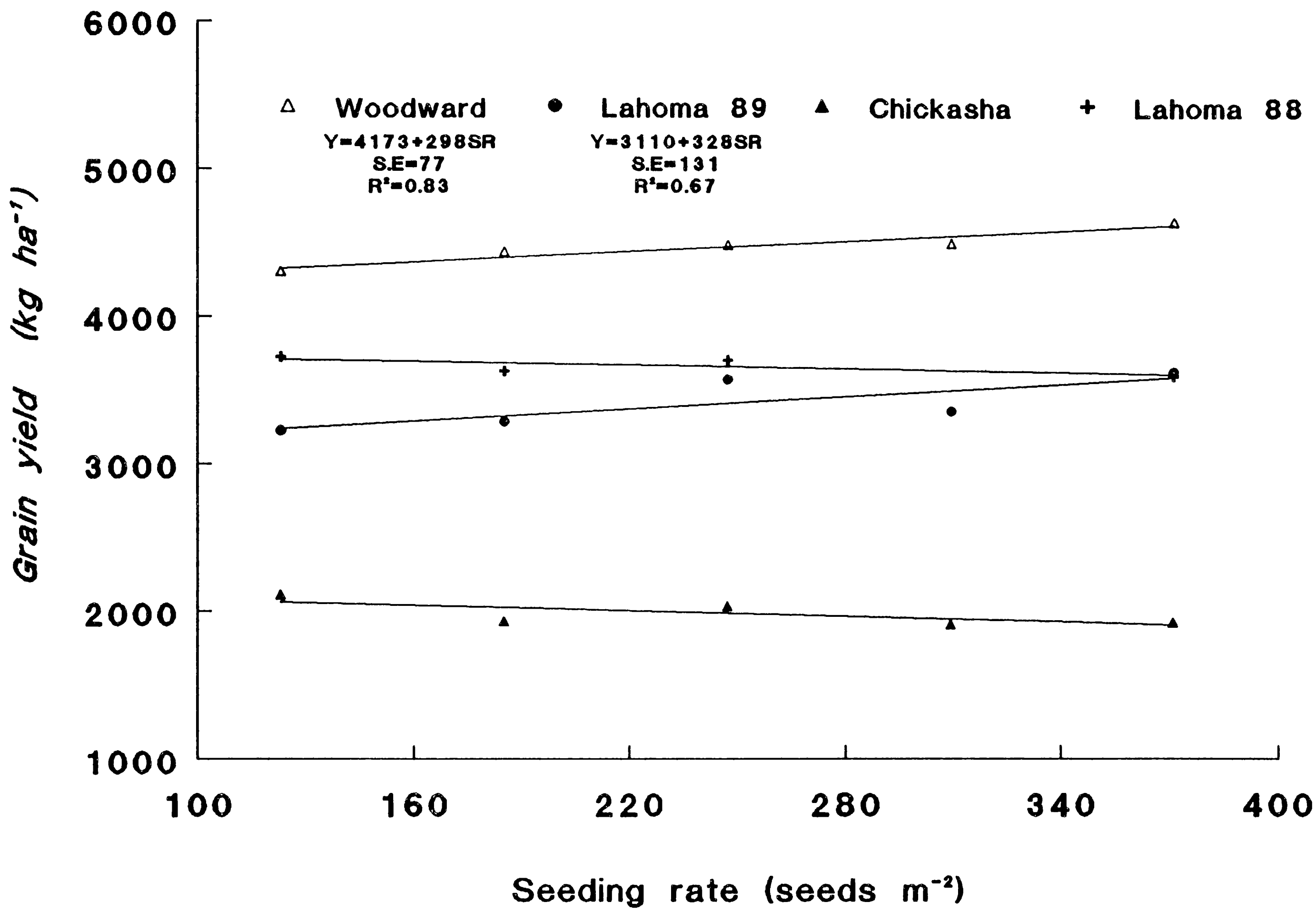

Fig. 2. Relationship between seeding rate and grain yield averaged over genotypes in four environments.

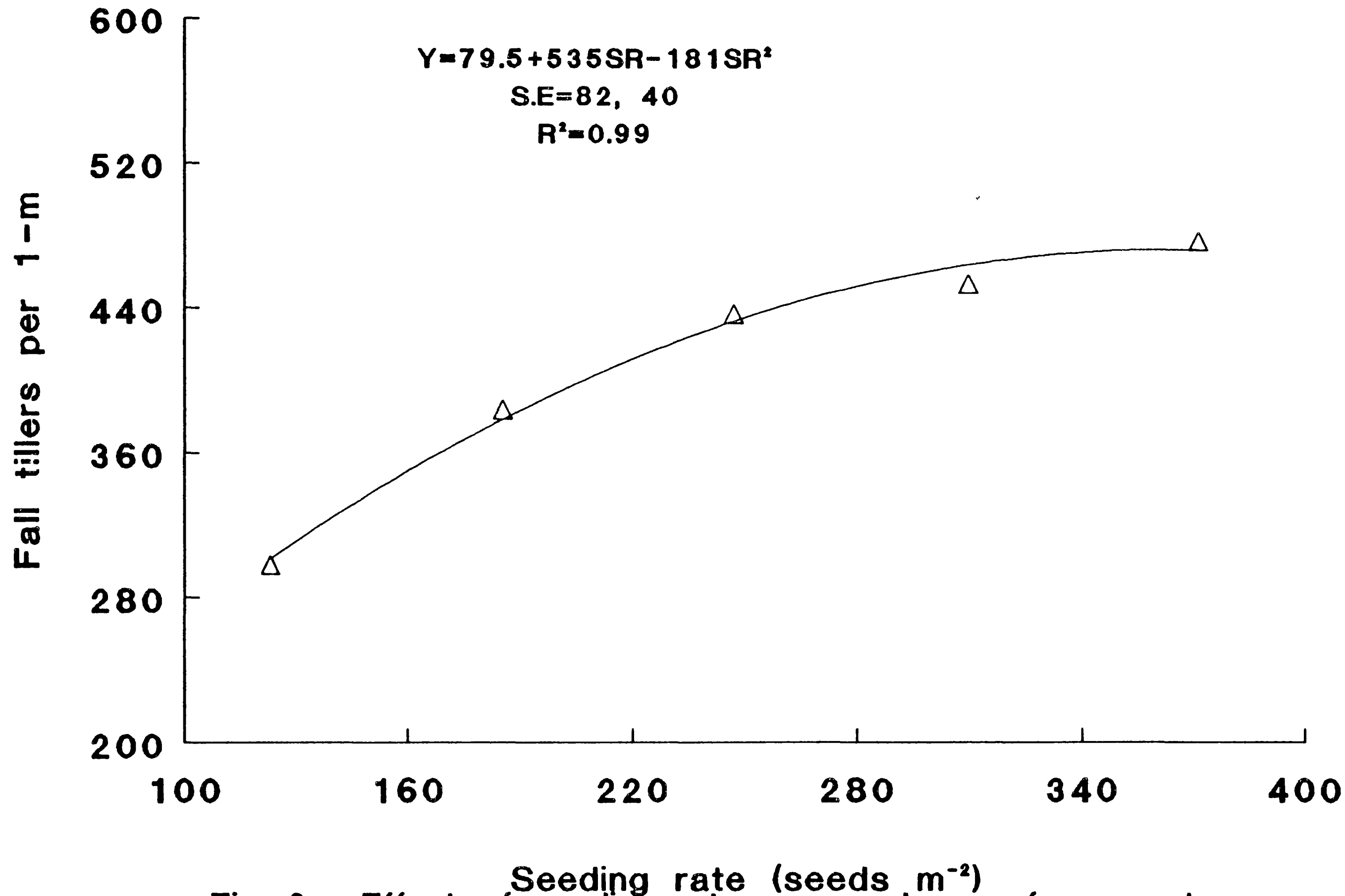

Fig. 3. Effect of seeding rate averaged over four genotypes on fall tillers.

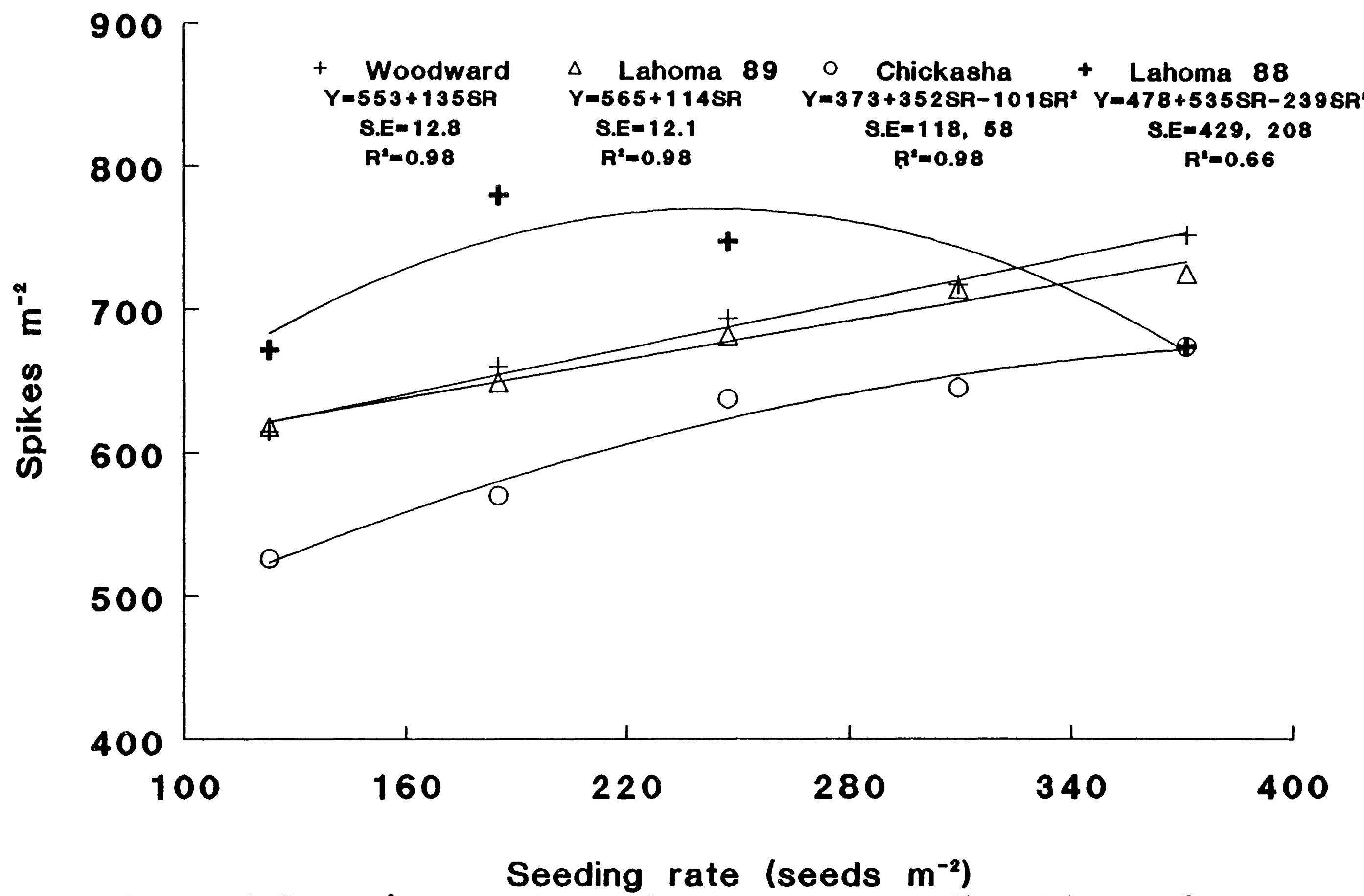

Fig. 4. Spikes m^{-2} averaged over four genotypes as affected by seeding rate in four environments.

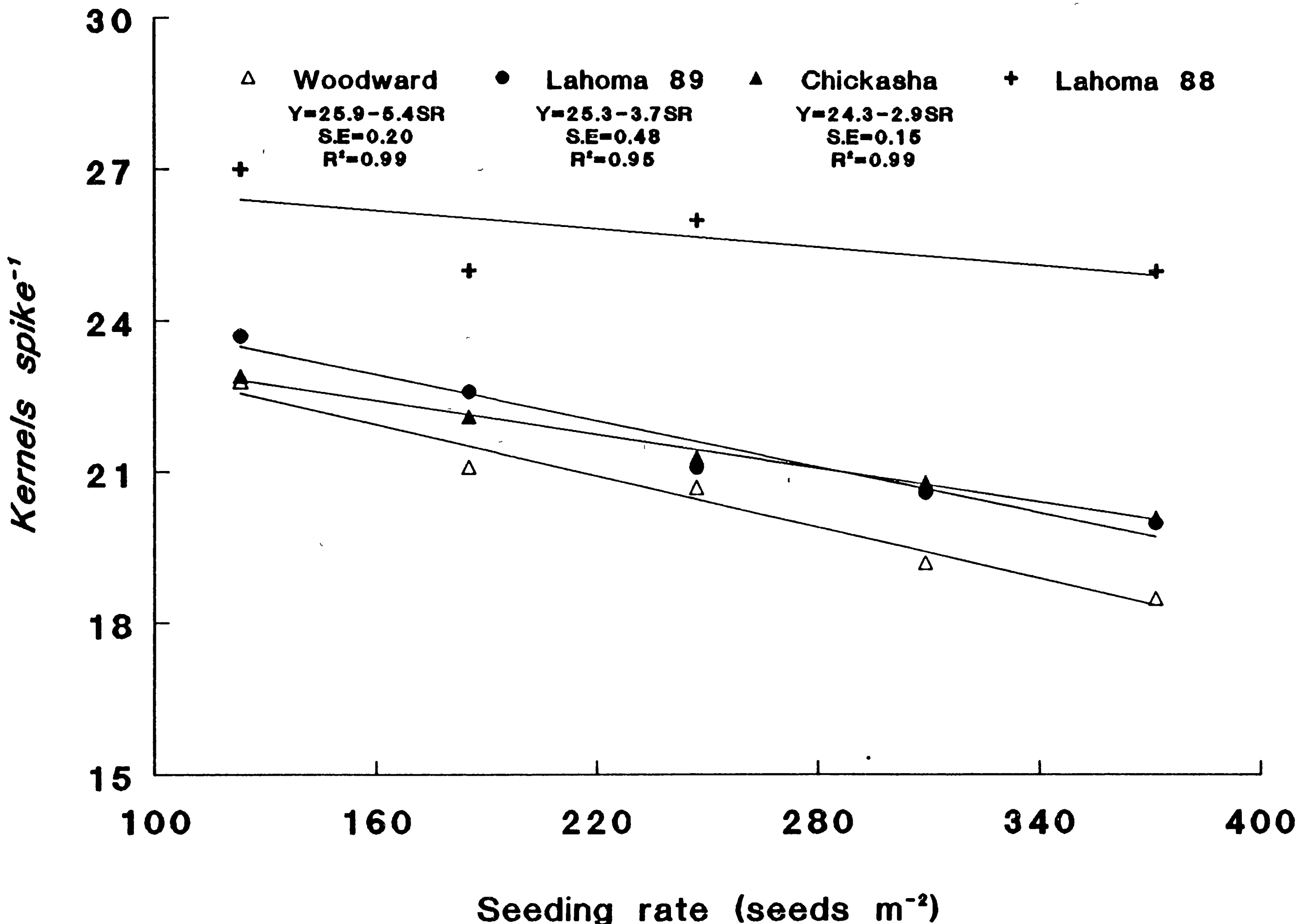

Fig. 5. Kernels per spike averaged over four genotypes as affected by seeding rate in four environments.

2

VITA

Nasir-Ud-Din

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Master of Science

Thesis: PLANT POPULATION EFFECT ON YIELD AND YIELD COMPONENTS OF HYBRID AND PURELINE WINTER WHEAT

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