SEEDING DENSITY IN WHEAT GENOTYPES AS A FUNCTION OF TILLERING POTENTIAL

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ABSTRACT: Seeding density adjustments is one of the practices that most influence grain yield, as well as other agronomic traits. Therefore, the objective of this study was to determine the ideal plant stand to achieve the maximum grain yield in genotypes showing differential tillering ability. Also, to establish the associations between the genotypes used with tillering and other agronomically important traits as weight of a thousand grains. Two experiments were conducted in 2005 and 2006 in Capão do Leão, Rio Grande do Sul state, Brazil. Five low (JURITI, BR 18, CEP 29, BR 18 and CD 108) and five high (CD 114, SAFIRA, FIGUEIRA, BRS 177 and UMBU) tillering potential wheat cultivars were tested for two years on a split-plot design. The results indicate the need for recommending cultivars based on more than one year of cultivation, especially when dealing with contrasting genotypes for the trait fertile tillers. Regarding the ideal plant stand, seeding density of low tillering ability genotypes ranges from 417 to 555 seeds m^{-2}, in order to obtain maximum yield and grain weight. On the other hand, for high tillering ability genotypes, the ideal stand ranges from 221 to 422 seeds m^{-2}. These results were year independent. Furthermore, low tillering ability genotypes showed a closer association of number of fertile tillers with grain yield. However, an inverse association was found between number of fertile tillers and weight of a thousand grains.
Key words: *Triticum aestivum* L., grain yield, number of fertile tillers, plant stand

DENSIDADE DE SEMEADURA DE GENÓTIPOS DE TRIGO EM FUNÇÃO DO POTENCIAL DE AFILHAMENTO

RESUMO: O ajuste da densidade de semeadura é uma das técnicas culturais que mais influenciam o rendimento de grãos, bem como outros caracteres agronômicos. O objetivo do trabalho foi determinar o estande ideal de plantas em que se possa obter o máximo rendimento de grãos em genótipos que apresentem diferente capacidade de afilhamento e, estabelecer a relação das constituições genéticas utilizadas com o afilhamento e outros caracteres de interesse agronômico como massa de mil grãos. Dois experimentos foram conduzidos no município de Capão do Leão/RS, nos anos de 2005 e 2006. Foram testadas dez cultivares de trigo inicialmente classificadas como de reduzido e de elevado potencial de afilhamento, sendo conduzidos no delineamento de parcelas subdivididas. Os resultados apontaram a necessidade da recomendação de cultivares testadas em mais de um ano de cultivo, principalmente quando utilizados genótipos contrastantes para o caráter número de afilhos férteis. Com relação ao estande ideal de plantas, independente do ano, a densidade de semeadura dos genótipos com reduzido potencial de afilhamento, relacionada com o ponto máximo de rendimento de grãos, está entre 417 e 555 sementes m^{-2}, proporcionando também maior massa de mil grãos. Por outro lado, o estande ideal dos genótipos com elevado afilhamento, está entre 221 a 422 sementes m^{-2}. Além disso, genótipos com baixo potencial de afilhamento propiciam a melhor relação direta do número de afilhos férteis com o rendimento de grãos da cultura, com efeito inverso na massa de mil grãos.
Palavras-chave: *Triticum aestivum* L., rendimento de grãos, número de afilhos férteis, estande de plantas

INTRODUCTION

Seeding density is a limiting factor for plants to capture environmental resources (Lloveras et al., 2004). It is considered one of the cultivation practices that most influences grain yield and other agronomical characters. Changes in seeding density have special importance in wheat crops since they have a direct effect on grain yield and its components (Ozturk et al., 2006) according to the cultivation environment (Lloveras et al., 2004).

Currently, the density used for the wheat crop can range from 300 to 400 viable seeds per square meter (Comissão Sul-Brasileira de Pesquisa de Trigo, 2005). Such recommendation does not take into account genotype differences, especially concerning tiller production and survival. Furthermore, the ideal should take into account environmental conditions, such as altitude, temperature, soil and seeding time (Klepper et al., 1982; Gade, 1995). Such effects have been observed in favorable and unfavorable conditions, where there is an uniform/disuniform culm population and regularly/irregularly spaced tillers, respectively (Rickman et al., 1983). This last scenario (unfavorable conditions) leads to a lower nutrient use efficiency. Therefore, understanding genotype performance and interaction with the environment is fundamental for the best estimate of number of seeds per square meter. The key factor in this case is the genotype's tillering potential.

Goal of this work was to determine the ideal plant stand in which one can obtain the maximum grain yield in wheat genotypes that present different tillering ability. Also, to establish the association between tillering ability of the tested genotypes and other agronomic traits, such as weight of a thousand grains.

MATERIAL AND METHODS

The experiment was performed in the years 2005 and 2006. It is located in the Capão do Leão - Rio Grande do Sul State, Brazil (31°52' S and 52°21' W, at an altitude of 13.24 m). The climate, according to Köppen, is Cfa, with an average annual pluviometric precipitation of 1280.2 mm (Moreno, 1961). The soil is a clayey-textured Typic Hapludult with waved landscape, having a striking presence of water table close to the surface. The soil chemical analysis was determined, every year, in a 0–20 cm deep sampling. The soil presented the following attributes: clay content was 115 and 130 g kg^{-1}; organic matter content was 12 and 15 g kg^{-1}; the pH in water was 5.5 and 5.7; available P content was 13.0 and 14.3 mg dm^{-3} and available K was 68 and 74 mg dm^{-3}, in 2005 and 2006, respectively.

Ten wheat genotypes originating from Brazilian breeding programs were used : IPR 85, FIGUEIRA, CD 108, CD 114, JURITI and CEP 29 supplied by Cooperativa Central de Pesquisa Agrícola - COODETEC; and UMBÚ, BRS 177, SAFIRA and BR 18 supplied by Embrapa Wheat - Centro Nacional de Pesquisa do Trigo. The genotypes were selected for their contrasting abilities fertile tillers (NFT), under the rational that they would have differential response in grain yield to variations in seeding density. The genotypes IPR 85, CD 108, JURITI, CEP 29 and BR 18 were selected for their low and the genotypes CD 114, UMBÚ, BRS 177, SAFIRA and FIGUEIRA for their high tillering ability. These genotypes were evaluated in five different seeding densities: 50, 200, 350, 500 and 650 seeds m^{-2}.

The seeding densities to be used were defined as the standard seed rate (350 seeds m^{-2}) plus or minus two levels of 150 seeds m^{-2} (Comissão Sul-Brasileira de Pesquisa de Trigo, 2005). Fertilization was performed at the base (seeding) as 250 and 200 kg ha^{-1} N-P_2O_5-K_2O (5-20-20), respectively, for 2005 and 2006. A supplement of 40 kg ha^{-1} of nitrogen was applied at the begin of tillering. Control of pests and diseases was performed according to CSBPT-2005 recommendations (Comissão Sul-Brasileira de Pesquisa de Trigo, 2005).

The experimental design used was split-plot with three replications. The genotype was considered as plot and the seeding density as sub-plot. Essays were hand sown on 06/10/2005 and 06/16/2006, using the conventional sowing system. Plant emergence occurred eight days after sowing. The following characters were field evaluated: i) number of fertile tillers (NFT), by counting the number of fertile tillers in one linear meter from each sub-plot. This was performed at the physiological maturation stage of each genotype. In the laboratory: ii) grain yield (GY), by individually threshing each sub-plot, in kg ha^{-1} and iii) weight of a thousand grains (WTG), by counting one of four sub-samples of 250 seeds, expressing the values in grams.

An analysis of variance for the split-plot design was performed considering year as random, and both genotype and density as fixed. The analyses were performed on Winstat software (Winstat, 2006). The effects of interactions between these factors were tested by a regression analysis, verifying the fitting of distinct polynomial orders as a function of different density levels. The regressions are displayed as individual graphs for each genotype.

RESULTS

The results from the joint analysis of variance reveal differences ($p < 0.05$) for the triple interaction among year, genotype and density effects for the three evaluated characters: NFT, GY and WTG. This implies that a partitioning in single effects is needed (Table 1). Thus, the analysis was performed to verify the variations in NFT, GY and WTG for the genotypes at the different seeding density levels. A regression analysis was applied, considering the factors year and genotype as fixed. For the three characters, by applying the linear regression, parameters were obtained up to fourth polynomial order, as can be seen by mean square values in Table 2. The significance of the analyzed polynomial and its fitting to the determination coefficient (R^2) are shown (Tables 3, 4 and 5). Great variation for genotype performance was observed, considering the character NFT and different seeding densities for both evaluation years. The best performance of genotypes was observed in the first year (Figure 1). On the other hand, the genotypes JURITI and BR 18 were the only ones to show similar (positive linear) performance on both years (Table 3).

The selected low NFT genotypes (IPR 85, CD 108, JURITI, CEP 29 and BR 18) did in fact show a lower number of fertile tillers per linear meter in all densities (Figure 1). Only CD 108 showed a quadratic trend for NFT for the different density levels. All the other genotypes showed a positive linear trend, with exception to IPR 85 and CEP 29 in 2006, where they showed a stable performance facing the different density levels, i.e., non-significant response for any of the tested polynomial orders.

Among the genotypes selected by their high NFT values (FIGUEIRA, UMBU, CD 114, BRS 177 and SAFIRA), only FIGUEIRA and BRS 177 showed a linear trend of NFT as a function of the different density levels that was negative in 2006 and positive in 2005 (Figure 1). A similar quadratic trend for both years was observed for the genotype SAFIRA regarding NFT. In this experiment, the point of maximum tiller number was obtained with densities of 544 (2005), 543 (2005), 494 (2006) and 256 (2006) seeds m^{-2}, respectively, for CD 108, SAFIRA, CD 114 and SAFIRA. On these densities, the same genotypes produced 88, 142, 142 and 163 fertile tillers per linear meter, respectively.

A large variation was obtained for GY both within and between years, as can be seen by the significance of the tested polynomials (Table 2). This difference is confirmed by the range of the point of maximum for this character among the tested genotypes, which varied from 2,505 to 3,818 kg ha^{-1} in 2005 and from 3,867 to 5,559 kg ha^{-1} in 2006 (Figure 2). A quadratic trend was observed in both years for CD 114, BRS 177 and SAFIRA, and a linear trend was observed in both years for CEP 29. The remaining genotypes showed significance of at least one polynomial order as a function of density (Table 4).

All genotypes initially selected as low NFT showed in 2005 a linear trend for GY as a function of

Table 1 - Summary of analysis of variance for the split-plot model showing sources of variation year, genotype and densities, evaluated for the characters number of fertile tillers per linear meter (NFT), grain yield (GY) and weight of a thousand grains (WTG).

Sources of variation	DF	Mean Squares		
		NFT	GY	WTG
Year	1	50362.56*	115197272.7*	1521.90*
Genotype	9	27627.54*	10800391.9*	911.60*
Repetition	2	1287.60	412872.10	12.43
Density	4	7232.19^{ns}	13851591.6*	58.10^{ns}
Year × Genotype	9	1074.57^{ns}	1569175.0*	36.94^{ns}
Year × Repetition	2	1462.32	453094.1	40.01
Year × Density	4	2761.40*	1963514.3*	44.16^{ns}
Genotype × Repetition	18	427.48	429772.5	32.60
Genotype × Density	36	487.90^{ns}	760959.5*	27.79^{ns}
Year × Genotype × Repetition	18	318.68	392494.3	26.15
Year × Genotype × Density	36	610.71*	341477.1*	32.51*
Residue	160	192.65	169737.3	19.50
Coefficient of Variation (%)		13.63	13.17	13.41

*Significant at 5% and ^{ns}Non- significant at 5% (F test). DF = degree of freedom.

Table 2 - Summary of analysis of variance for the regression model for wheat genotypes (IPR 85, FIGUEIRA, CD 108, UMBU, CD 114, BRS 177, JURITI, SAFIRA, CEP 29 and BR 18) evaluated for the characters number of fertile tillers per linear meter (NFT), grain yield (GY) and weight of a thousand grains (WTG) in five seeding densities (50, 200, 350, 500 and 650 seeds m^{-2}).

Year	PO+	Genotype / Mean Square									
		IPF 85	FIGUEIRA	CD 108	UMBU	CD 114	BRS 177	JURITI	SAFIRA	CEP 29	BR 18
		Number of tillers per linear meter (NFT)									
2005	1º	1657*	8333*	2050*	2066*	7022*	7744*	2236*	1293*	2430*	2017*
	2º	2.88	378*	427*	40	61.9	152	57.1	272*	11.5	34
	3º	32.03	40.83	14.7	546*	425*	19.2	61.6	136	20.8	0.3
	4º	50.51	0.23	16.6	20.7	92	7.61	52.5	68.5	97.3	10.5
2006	1º	100.8	4563*	8433*	907	5713*	61.6	1717*	1936*	76.8	2764*
	2º	148	13.7	632	421	2171*	408	924	2072*	0.38	0.85
	3º	7.5	700	760	163	353	264	22.5	625	472	145
	4º	58.6	20.1	60.8	373	547	267	998	117	200	292
		Grain yield in kg (GY)									
2005	1º	1446285*	3234083*	671404*	15732	402520	176486	761613*	1157188*	4396075*	2645082*
	2º	262	377152	555450*	1253214*	734714*	1637472*	25357	2398126*	2817	4041
	3º	27664	111020	238699	259052	116333	496	392163	189871	331380	167851
	4º	20031	167508	26656	283360	341604	197125	20129	569669	100542	57536
2006	1º	6357203*	374083	3843488*	4712	1060696*	62837	7367589*	5217504*	8039363*	598688
	2º	1187424*	6346149*	39498	7065120*	5749060*	4903600*	2595313*	7894468*	5259	1051650*
	3º	54613	1002840*	138176	1602216*	60032	597623	134804	804585	388740	36820
	4º	128267	300414	83440	761409	502427	991315	237821	15274	127231	162574
		Weight of a thousand grains (WTG)									
2005	1º	31.01*	0.49	2.46	13.94	30.8*	111.16*	51.09*	12.41	28.13*	147.6*
	2º	7.37	26*	4.66	3.51	6.72	35.2*	0.23	0.88	0.76	2.85
	3º	0.53	16	2.02	2.76	2.83	3	0.09	1.36	4.72	4.72
	4º	0.13	11	0.52	4.63	1.13	1.31	1.57	0.04	4.06	4.63
2006	1º	407*	15.33	0.39	184.5*	21.16	18.56	9.35	115.2	16.35	2.64
	2º	0.68	8.22	48.5	15.24	0.17	1.92	65.1	41	0.31	108
	3º	5.94	2.18	64.97	3.13	55.62	0.003	67.9	37.6	103.4	127
	4º	0.83	25.23	121.8	15.09	0.76	25.53	127.2	6.84	0.27	124

*significant at 5% (F test). +Polynomial order: (1º = first order. 2º = second order. 3º = third order and 4º fourth order)

density (Figure 2), except for CD 108. In 2006, the genotypes IPR 85, JURITI and BR 18 showed a quadratic trend with a point of maximum for GY of 3,867, 4,140 and 3,648 kg ha^{-1}, respectively. These yields were achieved with seeding densities of 555, 516 and 417 seeds m^{-2}. For the genotypes CD 108 and CEP 29 in 2006, a linear trend was observed as a function of seeding densities.

Among the genotypes selected by their high NFT, the genotypes CD 114, BRS 177 and SAFIRA showed a similar quadratic trend for GY as a function of density. On the other hand, when individually evaluated for GY, different points of maximum were detected. Genotype BRS 177 had the highest yield, presenting 3,818 and 5,560 kg ha^{-1}, as a function of 221 and 340 seeds m^{-2} in 2005 and 2006, respectively. Nevertheless, CD 114 presented 2,878 and 5,205 kg ha^{-1}, at densities of 415 and 388 seeds m^{-2}, respectively, in 2005 and 2006. The genotype SAFIRA presented 3,478 and 5,337 kg ha^{-1} yields at densities of 410 and 422 seeds m^{-2}, respectively, in 2005 and 2006. Finally genotypes FIGUEIRA and UMBU presented a great variation for GY in their performance between the years. Thus, only in 2006 a similar trend could be observed, showing a third order polynomial as a function of seeding density.

A differential performance was observed for the genotypes regarding the character WTG (Figure 3) as a function of density. In the year 2006, most genotypes had similar performances without differences between the density levels, except IPR 85 and UMBU. All genotypes designated as low NFT a nega-

Table 3 - Fitting of regression equations for wheat genotypes (IPR 85, FIGUEIRA, CD 108, UMBU, CD 114, BRS 177, JURITI, SAFIRA, CEP 29 and BR 18), evaluated for the character number of fertile tillers per linear meter (NFT), in five seeding densities (50, 200, 350, 500 and 650 seeds m^{-2}).

Year	Genotype	Regression equation fitting(*)	$R^{2(+)}$
2005	IPR 85	y = 33.52222 + 0.049555x	0.95
	FIGUEIRA	y = 57.97777 + 0.20444x - 0.00013333x^2	0.99
	CD 108	y = 46.321693 + 0.15437x - 0.00014179x^2	0.98
	UMBU	y = 114.83222 - 0.22086x + 0.00106x^2 - 0.0000010534x^3	0.99
	CD 114	y = 100.8562 - 0.20642x + 0.0010305x^2 - 0.00000093004x^3	0.92
	BRS 177	y = 75.17777 + 0.10711x	0.97
	JURITI	y = 29.18888 + 0.057555x	0.92
	SAFIRA	y = 109.23598 + 0.12303x - 0.00011322x^2	0.88
	CEP 29	y = 38.53333 + 0.06x	0.94
	BR 18	y = 41.73333 + 0.054666x	0.98
	Genotype	Regression equation fitting(*)	$R^{2(+)}$
2006	IPR 85	y = 80.06	-
	FIGUEIRA	y = 159.44444 - 0.082222x	0.86
	CD 108	y = 80.011111 + 0.11177x	0.85
	UMBU	y = 162.33	-
	CD 114	y = 64.29947 + 0.31570x - 0.00031957x^2	0.89
	BRS 177	y = 129.86	-
	JURITI	y = 60.87777 + 0.05044x	0.46
	SAFIRA	y = 142.01799 + 0.16496x - 0.00032117x^2	0.84
	CEP 29	y = 91.33	-
	BR 18	y = 64.46666 + 0.064x	0.86

(*)Significant at 5% (F test); (+)R^2 – determination coefficient.

tive linear trend as a function of seeding density, except for CD 108 that showed no variation. For the genotypes with high NFT, a quadratic trend was observed for FIGUEIRA and BRS 177 in 2005, with a point of maximum for the character WTG as 30.8 and 37.6 grams at densities of 338 and 193 seeds m^{-2}, respectively.

DISCUSSION

Wheat cultivars present low tiller survival rate, and consequently, low NFT (Galli, 1996). This behavior can be a reflex of the physiological fitness in which the tillers are produced, prioritizing nutrition for the main culm instead tillers (Frank & Bauer, 1982). Regarding the production of first tillers, Fletcher & Dale (1974), attributed the low frequency of emergence to their overall position, since they are located at an anatomically low vascular region. For wheat and barley, McCall (1934) and Fletcher & Dale (1974) also suggested that vascular connection failures between the tiller and the whole plant would be the main reason for its retarded growth. For field conditions, i.e., plant competition, the understanding of the mechanisms controlling tiller formation and survival could help to obtain a better plant performance.

The great influence of seeding density on the evaluated characters (NFT, GY and WTG) highlights the importance wheat crops of establishing an ideal plant stand at germination. The recommendations should be based on more than one year of testing, especially when one is evaluating contrasting phenotypes for tillering ability. Thus, one can identify the genotype with best use of environmental resources and a density that will fit to a better yield response. This will be achieved with the ideal interaction with the environment, through plant competition for light, water and nutrients (Darwinkel, 1978).

The effect of year on the GY of the evaluated genotypes was a major cause for the response to different density levels. A dry winter followed by high temperatures in 2005, especially from June to August, with an absolute maximum temperature above 30ºC and reduced rain (Embrapa Clima Temperado, 2007) had a large effect on NFT and WTG. Several authors point high temperatures as major causes for tillering reduction (Cannell, 1969; Thorne & Wood, 1987; Hucl

Table 4 - Fitting of regression equations for wheat genotypes (IPR 85, FIGUEIRA, CD 108, UMBU, CD 114, BRS 177, JURITI, SAFIRA, CEP 29 and BR 18) evaluated for the character grain yield (GY) in five seeding densities (50, 200, 350, 500 and 650 seeds m^{-2}).

Year	Genotype	Regression equation fitting(*)	$R^{2(+)}$
2005	IPR 85	$y = 1267.41111 + 1.46377x$	0.96
	FIGUEIRA	$y = 1747.1556 + 2.18888x$	0.83
	CD 108	$y = 1481.0889 + 4.57511x - 0.0051111x^2$	0.82
	UMBU	$y = 2520.2466 + 5.52674x - 0.0076772x^2$	0.70
	CD 114	$y = 1862.1534 + 4.88703x - 0.0058783x^2$	0.71
	BRS 177	$y = 2914.4529 + 5.63163x - 0.0087756x^2$	0.90
	JURITI	$y = 1722.6222 + 1.062222x$	0.63
	SAFIRA	$y = 1643.6085 + 8.74341x - 0.01065021x^2$	0.82
	CEP 29	$y = 1541.8 + 2.552x$	0.91
	BR 18	$y = 1230.22222 + 1.97955x$	0.92
	Genotype	Regression equation fitting (*)	$R^{2(+)}$
2006	IPR 85	$y = 1563.0635 + 8.3x - 0.0074730x^2$	0.97
	FIGUEIRA	$y = 588.05409 + 25.97469x - 0.064677x2 + 0.00045144x^3$	0.96
	CD 108	$y = 1869.0889 + 2.38622x$	0.93
	UMBU	$y = 1947.0141 + 29.44852x - 0.078143x2 + 0.000057061x^3$	0.91
	CD 114	$y = 2728.0931 + 12.76392x - 0.016443x^2$	0.92
	BRS 177	$y = 3804.255 + 10.325259x - 0.0151862x^2$	0.75
	JURITI	$y = 1492.5365 + 10.25265x - 0.0099269x^2$	0.96
	SAFIRA	$y = 1902.9915 + 16.26837x - 0.019268x^2$	0.94
	CEP 29	$y = 2708.1778 + 3.45111x$	0.94
	BR 18	$y = 2425.8021 + 5.86474x - 0.0070328x^2$	0.89

(*)Significant at 5% (F test); (+) R^2 – determination coefficient.

& Baker, 1990). Under ideal temperature conditions, around 15 to 20ºC, plants would respond in an efficient manner to tillering (Mota, 1989), i.e., each genotype would have expressed its full potential for this character. Similar results are found in the literature, highlighting the lower GY of cultivars grown in dry winters, showing reduced tillering and reduced ear numbers (Lloveras et al., 2004). In 2006, a better year regarding both such climatic conditions as temperature and rain (Embrapa Clima Temperado, 2007), higher NFT, GY and WTG values were observed for all genotypes.

The higher tillering potential verified for FIGUEIRA, UMBU, CD 114, SAFIRA and BRS 177, in different seeding densities, indicates the best performance of these genotypes in reduced densities, likely due to a better water and nitrogen use (Masle, 1985). According to Skinner & Nelson (1994), light acts as an early signal in cell division and causes a higher leaf growth which is correlated with new leaf and tiller formation. Also, it provides an increase in green area for the plant, leading to an improvement in capturing radiation (Whaley et al., 2000).

The higher genetic potential for tillering, when subjected to low density, can be the mechanism by which wheat can produce a canopy with large radiation absorption levels, keeping a high grain yield (Whaley et al., 2000). Thus, in reduced densities, the genotype SAFIRA was superior, with a maximum NFT (163) at a density of 256 seeds m^{-2}, and GY of 4,805 kg ha^{-1} (2006). This result confirms the high performance of genotypes with high NFT in reduced seeding densities. Similar results have been found with 250 seeds m^{-2}, with higher GY as compared to higher densities (Wood et al., 2003). The same authors justify the result as a function of higher number of grains per ear and higher grain weight.

The genotype SAFIRA did not show a similar association between point of maximum at NFT and GY and seeding density, in 2006. As can be seen in the present work, the point of maximum GY was achieved with a density higher than the one needed to obtain maximum NFT. An abrupt fall in NFT values was observed after this point, i.e., suggesting a lack of association between these characters. Therefore, for genotypes with high tillering potential, the optimum density level for GY does not mean the maximum NFT.

Table 5 - Fitting of regression equations for wheat genotypes (IPR 85, FIGUEIRA, CD 108, UMBU, CD 114, BRS 177, JURITI, SAFIRA, CEP 29, BR 18), evaluated for the character weight of a thousand grains (WTG) in five seeding densities (50, 200, 350, 500 and 650 seeds m^{-2}).

Year	Genotype	Regression equation fitting(*)	$R^{2(+)}$
2005	IPR 85	y = 43.73555 + -0.0067777x	0.79
	FIGUEIRA	$y = 26.83899 + 0.023625x - 0.000034973x^2$	0.83
	CD 108	y = 32.21	-
	UMBU	y = 32.09	-
	CD 114	y = 35.09111 + -0.0067555x	0.74
	BRS 177	$y = 36.081693 + 0.015648148x - 0.000040687x^2$	0.97
	JURITI	y = 39.315 - 0.0087x	0.96
	SAFIRA	y = 31.11	-
	CEP 29	y = 38.38944 - 0.0064555x	0.74
	BR 18	y = 51.006111 - 0.014788x	0.92
	Genotype	Regression equation fitting (*)	$R^{2(+)}$
2006	IPR 85	y = 48.29833 - 0.024566x	0.98
	FIGUEIRA	y = 24.70	-
	CD 108	y = 29.49	-
	UMBU	y = 32.816667 - 0.016533333x	0.84
	CD 114	y = 27.95	-
	BRS 177	y = 25.33	-
	JURITI	y = 33.93	-
	SAFIRA	y = 25.97	-
	CEP 29	y = 30.12	-
	BR 18	y = 42.44	-

(*) Significant at 5% (F test); (+)R^2 – determination coefficient.

The low NFT genotypes presented higher yields at higher densities because there was a direct association with increase in NFT, which is not valid for high NFT genotypes. Thus, it is important for the breeder to use low NFT type genotypes, not only because of the direct association between NFT and GY which saves energy otherwise spent on lagging tillers, but also because they are less affected by changes in the environment, which often results in yield losses. The biggest concern should be on the density adjustment, resulting in increase of nutrient absorption and translocation, without the risk of losses due to higher tiller senescence during development, leading to an improved yield.

As observed for the majority of genotypes with low tillering potential, the increase in density was vital for increases in NFT and GY. For the genotypes with linear performance of GY as a function of different densities, the increase in the character was outstanding, showing 36, 65, 89 and 92% superior values , respectively, for JURITI, IPR 85, BR 18 and CEP 29. Similar results were found by other investigations, reaching 33% (Geleta et al., 2002) and 49.3% (Ozturk et al., 2006) of increase in GY as a function of increase in density. However, genotypes with low tillering ability which showed (in one environment) the maximum point for GY, always reached this point at densities above 417 seeds m^{-2}, a considered high value according to current average densities recommended for wheat in Brazil. Thus, the low NFT genotypes have a better performance at high seeding densities.

The lower NFT and GY values as a function of increase in density was observed for high NFT genotypes. In high densities there is higher competition for water in the soil after the anthesis, leading to a reduction in the grain filling stage and, consequently, to GY reductions (Darwinkel et al., 1977). High tillering ability genotypes, when subjected to high densities, have their development more affected by the stronger competition between plants than do low tillering ability genotypes. They also decrease their nutrient use efficiency and are more prone to lodging and disease, taking its tow on GY (Ozturk et al., 2006).

The reduction of NFT values can be attributed to the available light quality and to a lesser extent to its intensity. In winter wheat, tiller death beginning is associated to far-red light incidence at the canopy base.

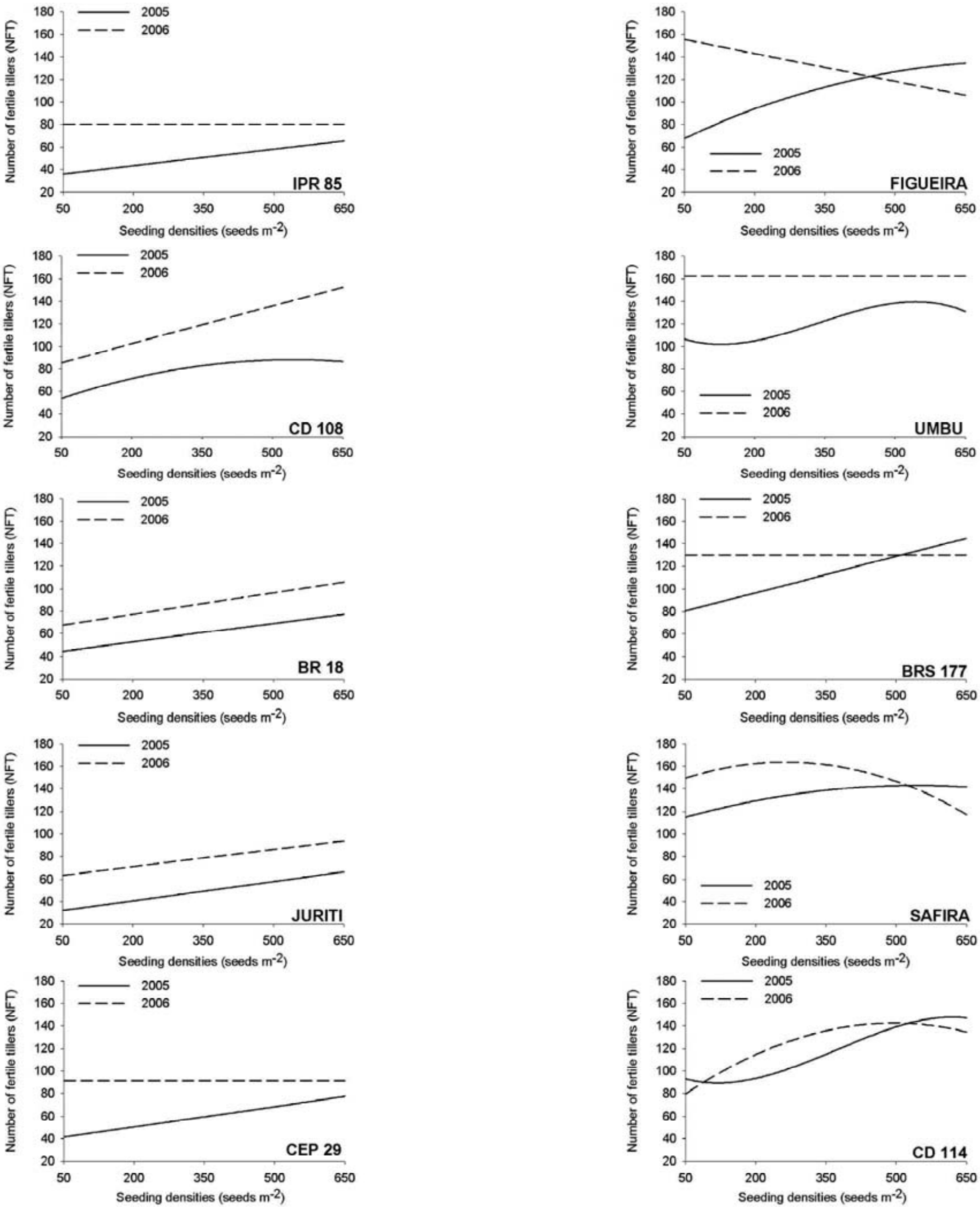

Figure 1 - Display of regression analysis for number of fertile tillers per linear meter (NFT) of wheat genotypes (IPR 85, FIGUEIRA, CD 108, UMBU, CD 114, BRS 177, JURITI, SAFIRA, CEP 29 and BR 18) tested in two years and five different seeding densities. FAEM/UFPel. 2007.

In highly populated conditions, there is a better closing of the canopy which absorbs red light in its upper part and allows far-red light to penetrate the inferior layers, shutting down tiller growth (Sparkes et al., 2006). The increase in NFT and GY for the low tillering ability genotypes (JURITI, IPR 85, BR 18 and CEP 29), observed in the first year of evaluation, is similar to the results reported by other groups (Ozturk et al., 2006). The number of ears per square meter was shown to be the most important yield component in wheat (Ozturk et al., 2006), bringing importance to the low NFT genotypes, since high NFT genotypes not always showed a direct association between ears per square meter and yield.

Recent investigations in wheat under different seeding densities report no differences in grain pro-

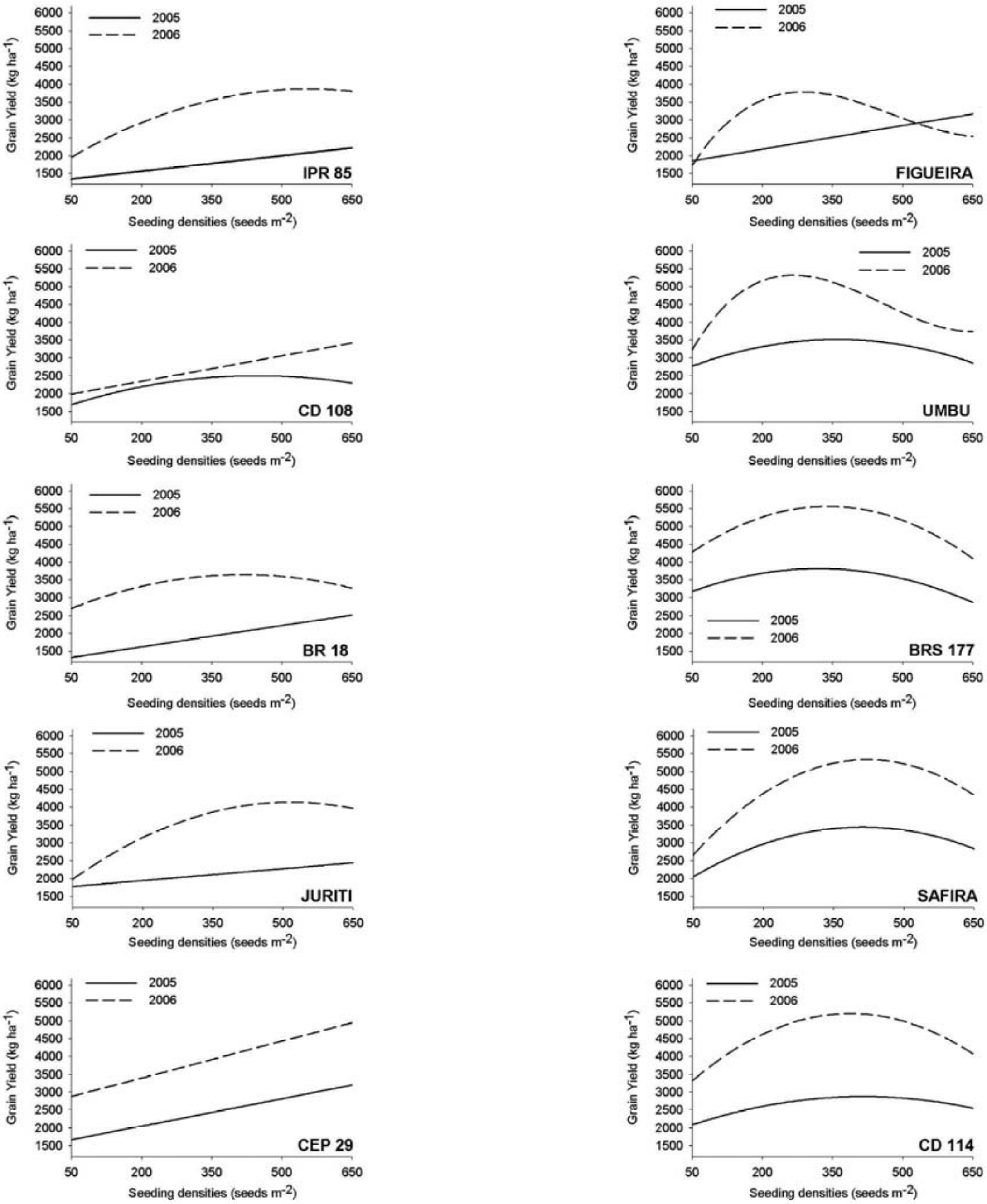

Figure 2 - Display of regression analysis for grain yield (GY) of wheat genotypes (IPR 85, FIGUEIRA, CD 108, UMBU, CD 114, BRS 177, JURITI, SAFIRA, CEP 29 and BR 18) tested in two years and five different seeding densities. FAEM/UFPel. 2007.

tein (Ozturk et al., 2006). Also, in durum wheat (*Triticum durum* Desf.), the density in which the maximum yield was reached, a slight increase in grain nitrogen was observed, without any changes in the overall grain nutrition value (Arduini et al., 2006). Thus, based on the current available information, it is possible to infer that changes in seeding density will not affect genotype industrial quality.

The large variability of Brazilian wheat genotypes used in this work regarding the character NFT is denoted by different points of maximum GY. The higher yields were obtained with lower seeding densities for high tillering ability genotypes and vice-versa. Likewise, different results are also found in other studies. A maximum GY was obtained with densities of 371–508 seeds m^{-2} (Lloveras et al., 2004), but also with

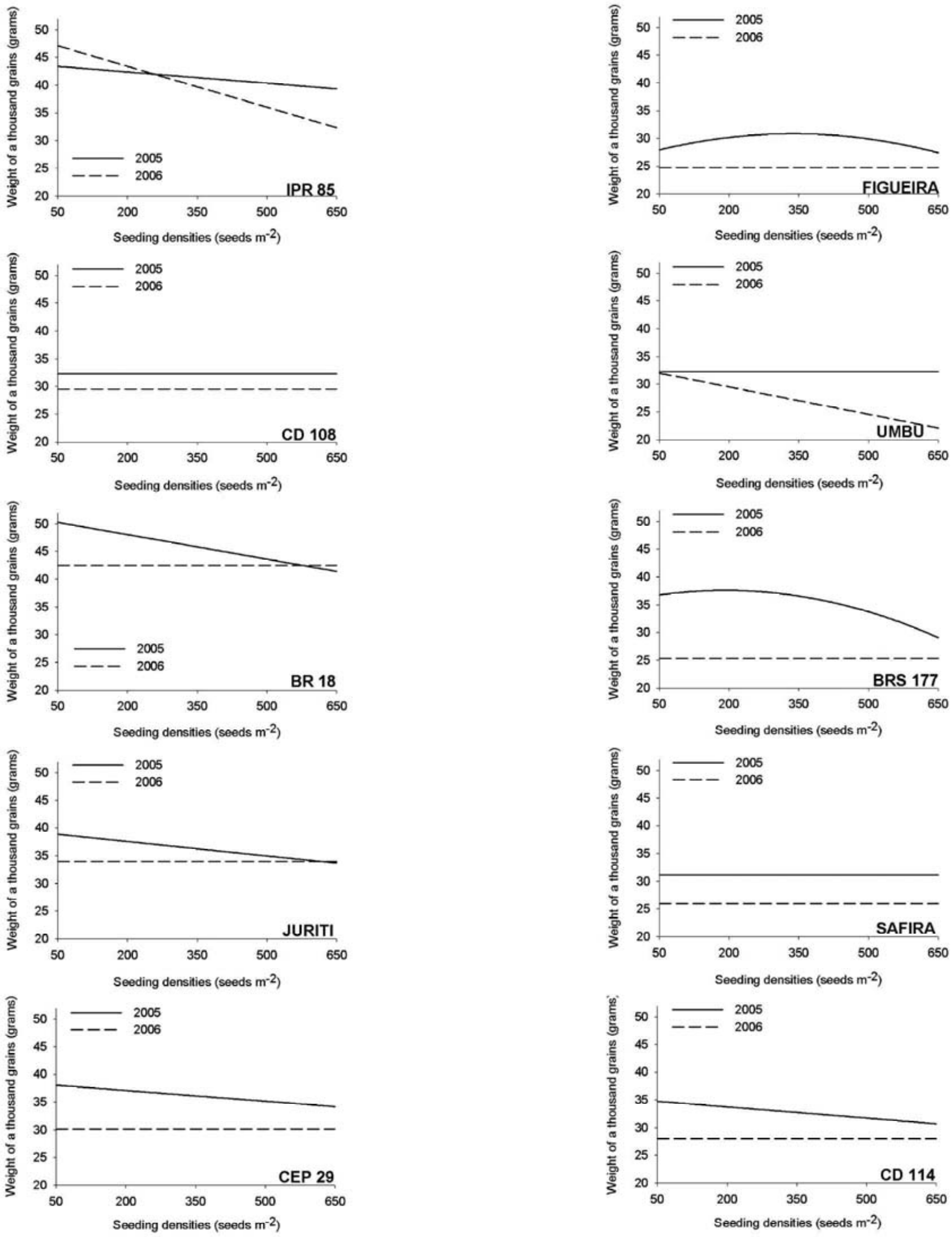

Figure 3 - Display of regression analysis for weight of a thousand grains (WTG), of wheat genotypes (IPR 85, FIGUEIRA, CD 108, UMBU, CD 114, BRS 177, JURITI, SAFIRA, CEP 29 and BR 18) tested in two years and five different seeding densities. FAEM/UFPel. 2007.

200-280 seeds m^{-2} (Ellen, 1990; Lock, 1993) and with 400 seeds m^{-2} (Joseph et al., 1985). This implies that different environmental conditions affect the ideal seeding density and there is not a 'one fits all' rule.

One can highlight from this study a smaller range for GY occurring for high tillering potential genotypes, since they reached high yields with lower seeding densities. However, the bigger range for GY occurring in low tillering potential genotypes can be explained by the need of increasing the density in order to compensate the reduced number of tillers formed by these genotypes and then achieve higher yields. This compensatory effect has special importance when related to yield (Freeze & Bacon, 1990).

The performance of genotypes UMBU and SAFIRA with 26 and 20% range in GY (2005) and JURITI and IPR 85 with 110 and 97% range in GY (2006), before reaching the point of maximum GY is a good example of this compensatory effect.

The high grain yields observed in the present work are considerably above the grain yields of available wheat genotypes in Brazil. The genotype BRS 177 with 5,560 kg ha^{-1} in 2006, at a density of 340 seeds^{-2} and the genotype JURITI which, despite its low tillering potential, showed high yield, with 4,140 kg ha^{-1} at a density of 516 seeds m^{-2}, in 2006.

The genotypes showing the highest values for WTG were among the low tillering potential genotypes. Again, a compensatory mechanism must have acted here to maximize GY. Also, a negative linear trend can illustrate the behavior of these genotypes, since a stronger competition with the increase in NFT causes a lower rate of photo assimilate translocation towards grain filling. The genotypes showed higher values for the character WTG in 2005 and a lower average for NFT. Thus, it supports the idea of a compensatory effect between yield components in order to stabilize yield (Freeze & Bacon, 1990). Distinct reports are found in the literature, where the character WTG appears to be the less affected by seeding density in wheat (Donaldson et al., 2001; Lloveras et al., 2004; Hiltbrunner et al., 2005 and Ozturk et al., 2006) and also in rice (Souza & Azevedo, 1994). On the other hand, this character is highly influenced by the seeding time, which results in longer or shorter periods for grain filling (Ozturk et al., 2006).

The ideal plant stand independs from cultivation year and is achieved differentially by low and high tillering ability genotypes. Low NFT genotypes reach a maximum yield at a seeding density between 417 and 555 seeds m^{-2}, showing also higher WTG. On the other hand, high NFT genotypes reach a maximum yield at a seeding density between 221 and 422 seeds m^{-2}. Also, low NFT genotypes provide a direct association between NFT and GY, showing an inverse effect on WTG, both in unfavorable (2005) and favorable (2006) environments.

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