academicJournals

Vol. 11(21), pp. 1935-1944, 26 May, 2016
DOI: 10.5897/AJAR2016.10909
Article Number: F8D839858719
ISSN 1991-637X

http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

Full Length Research Paper

The management of sowing density on yield and lodging in the main oat biotype grown in Brazil

Marcos Vinicios Romitti[1], José Antonio Gonzalez da Silva[2], Anderson Marolli[1], Emilio Ghisleni Arenhardt[3]*, Ângela Teresinha Woschinski de Mamann[1], Osmar Bruneslau Scremin[1], Osório Antonio Lucchese[2], Cleusa Adriane Menegassi Bianchi Krüger[2], Lorenzo Ghisleni Arenhardt[2] and Luis Michel Bandeira[2]

[1]Department of Physical and Engineering Sciences, Regional University of the Northwest of Rio Grande do Sul, 480 Lulu Ingelfritz Street, Zip code: 98700-000, Ijuí, RS, Brazil.
[2]Department of Agrarian Studies, Regional University of the Northwest of Rio Grande do Sul, 3000 Comércio Street, Zip code: 98700-000, Ijuí, RS, Brazil.
[3]Department of Crop Plants, Federal University of Rio Grande do Sul, 7712 Bento Gonçalves Avenue, Zip code: 91540-000, Porto Alegre, RS, Brazil.

Received 15 February, 2016; Accepted 19 April, 2016

The sowing density management in the main oat biotype cultivated in Brazil can bring yield gains with reduced lodging. The aim of this study was to sow the density adjustment of early cycle oat cultivars and reduced stature to increase biomass and grain yield with reduced lodging, considering high and low N-residual release succession systems in different years. The study was carried out in 2011, 2012 and 2013 in randomized blocks experimental design with four replications in factorial scheme 4 × 2, for sowing density (100, 300, 600 and 900 seeds m^{-2}) and oat cultivars (Brisasul and URS Taura) in the corn/oat and soybean/oat succession systems. In each succession system two experiments were conducted, one to quantify the biomass production rate, and the other, aimed at estimating the grain yield and lodging. Regardless of year and cultivar, the main oat biotype grown in Southern Brazil evidences optimal sowing density around 500 seeds m^{-2} in the biomass and grain expression yield in the corn/oat and soybean/oat succession systems. In the soybean/oat succession system, the use of optimal density can favor the plant lodging, especially in favorable cultivation years. The corn/oat succession system through lower release of N-residual proves to be efficient concerning the grain yield expression and reduced lodging in the use of adjusted density.

Key words: *Avena sativa* L., succession systems, climate change, biomass, regression.

INTRODUCTION

Oats (*Avena sativa* L.) is considered a multi-purpose cereal and its grains have excellent nutritional value for human and animal consumption (Hawerroth et al., 2013). The greatest expression of oat productivity is directly associated with the management techniques, such as the nutrients availability, plant population, phytosanitary control, among others (Benin et al., 2005; Silva et al., 2015). The plant population is an important factor in the potential expression of biomass and grains yield in cereals (Ceccon et al., 2004), its variation is associated with the genotype potential in producing fertile tillers, once the sowing density influences the number of spikes and/or panicles produced by area (Sparkes et al., 2006; Valério et al., 2009). The increase in the number of tillers and/or plants per area acts directly on the vegetal biomass, an important aspect to enhance biological productivity and the relationship between the straw and grain mass (Ozturk et al., 2006; Silveira et al., 2010). It is highlighted that the rapid coverage of vegetal biomass on the soil by the canopy adjustment may favor a better use of light and nutrients for grain yield and a more effective control in the weeds evolution (Fleck et al*.,* 2009; Silva et al., 2012).

The technical specifications of the Brazilian Commission of Oat Research have suggested sowing density in 200 to 300 seeds m^{-2}, a condition adopted since that the cultivation of this species began to have commercial importance in the 90s. However, the continuous oat breeding has modified the plant architecture, among other features, changing the high stature biotype, late cycle and high relation straw/grain, for genotypes with stature lower than one meter, reduced cycle and greater caryopsis volume in relation to husk (Hawerroth et al., 2015; Silva et al., 2015). Therefore, changes that may modify the response of cultivars to plant population, suggest the need for more adjusted recommendations to the actual biotype of white oats grown in the Southern Brazil.

In agricultural systems, the type of biomass on soil influences the dynamics of release and use of N-residual in the expression of the yield components (Mantai et al., 2015). The wheat and oat grown on the soybeans and corn residue show differences in the tillers and canopy development, reflecting directly on biomass and grain yield (Wendling et al., 2007; Mantai et al., 2015). Aside from this, the constant climate changes has also changed the vegetal productivity, demonstrating the necessity of more stressed tolerant plant varieties (Araus et al., 2008) and efficient in the use of light and nutrients (Oliveira et al., 2011; Costa et al., 2013). Therefore, the oat productivity is directly associated to the use of fertilizers, cultivation techniques and soil and edaphoclimatic conditions (Costa et al., 2013; Silva et al., 2015). Although the favorable cultivation conditions may increase vegetal productivity, they tend to promote increased vegetative vigor, making favorable the lodging occurrence, condition that brings serious losses in yield and grains quality (Silva et al., 2012).

The occurrence of rains, winds and soil condition with a higher nitrogen content, may increase the occurrence of plant lodging, whose conditions are common variables along the crops cultivation (Berry et al., 2003). In this context, the use of sustainable technologies and low cost, such as vegetation cover management, the use of the N-residual and the density cultivation adjustment on the main oat biotype grown in the Southern Brazil, can bring benefits to maximize the biomass and grain yield with lodging reduction.

The aim of this study is the sowing density adjustment of early cycle's oat cultivars and reduced stature to increase biomass and grain yield with reduced lodging, considering high and low N-residual release succession systems in different years.

MATERIALS AND METHODS

The study was developed in the field during the years 2011, 2012 and 2013 in Augusto Pestana city, RS state, Brazil (28°26'30'' South latitude and 54°00'58'' West longitude). The soil of the experimental area is classified as Distrofic Red Latosol Typical, which its U.S. equivalent is Rhodic Hapludox (USDA, 2014), and the climate of the region, according to Köppen classification, is 'Cfa type', with hot summer without a dry season. In the study, ten days before sowing, soil analysis was performed and it was identified in the following chemical characteristics of the local: i) corn/oat system (pH = 6.5, P = 34.4 mg dm^{-3}, K = 262 mg dm^{-3}, Organic matter = 3.5%, Al = 0.0 $cmol_c$ dm^{-3}, Ca = 6.6 $cmol_c$ dm^{-3} and Mg = 3.4 $cmol_c$ dm^{-3}) and ii) soybean/oat system (pH = 6.2, P = 33.9 mg dm^{-3}, K = 200 mg dm^{-3}, Organic matter = 3.4%, Al = 0.0 $cmol_c$ dm^{-3}, Ca = 6.5 $cmol_c$ dm^{-3} and Mg = 2.5 $cmol_c$ dm^{-3}). During the three years, sowing was performed in the second fortnight of May with seeder-fertilizer for composition of 5 rows of 5 m in length and row spacing of 0.20 m, forming the experimental unit of 5 m^2. During the study execution, tebuconazole fungicide applications were made at the dosage of 0.75 L ha^{-1}. Moreover, the weeds control was carried out with metsulfuron-methyl herbicide at a dose of 4 g ha^{-1} and additional weeding whenever necessary. At the oats sowing time 80 and 60 kg ha^{-1} of P_2O_5 and K_2O, were applied, respectively, based on levels of P and K in the soil and nitrogen base with 10 kg ha^{-1} and rest of N applied in topdressing on the phenological stage of fourth leaf expanded, expecting thus grain yield about 3 t ha^{-1}.

The studies were carried out considering the two main succession systems used in southern Brazil for oats, involving soil coverage with vegetable residue of high and reduced carbon/nitrogen ratio in the corn/oat and soybean/oat succession systems, respectively. In each succession system two experiments were conducted, one to quantify the biomass production rate by the cuts made every 30 days until the harvesting point, and the other, for analysis of plant lodging and grain harvest to estimate yield.

Therefore, in all four experiments, the experimental design was randomized blocks with four repetitions, following factorial scheme 4 × 2 to oat cultivars (Brisasul and URS Taura) and sowing density (100, 300, 600 and 900 seeds m^{-2}), respectively. The oat

*Corresponding author. E-mail: emilio.arenhardt@yahoo.com.br.

cultivars used represent current genotypes with biotype desired in southern Brazil, with similarity to the cycle (early), height (reduced) and lodging (moderately resistant), however, distinguished in production tillering capacity (Brisasul = high; URS Taura = reduced).

Grain yield was obtained by cutting three central rows of each plot in the moment defined as the last cut in the experiment directed to analysis of biomass production rate (120 days), stage near the harvesting point, with grain moisture around 15%. The plants were threshed with a stationary harvester and directed the laboratory to correct grain moisture to 13%, and weighing to estimate grain yield (GY, kg ha^{-1}). In experiments aiming to quantify the biomass production rate in each succession system, the harvest of the plant material was held close to the ground at the 30, 60, 90 and 120 days after the emergency, totaling four cuts through collection of a linear meter of three central rows of each plot. The green biomass samples were directed to forced-air oven at a temperature 65°C, until it reached constant weight to estimation of total dry matter produced (TDM, kg ha^{-1}).

The lodging index was estimated visually and expressed in percentage, having considered the angle formed in the vertical position of the plants culm in relation to the ground and the area of lodged plants. For this estimate it was used the methodology suggested by Moes and Stobbe (1991), modified, with the lodging index (LODG-I) defined by the equation: LODG-I% = I × LODG × 2; where (I) reflects the plants inclination degree, ranging from 0 to 5 (0, absence of inclination and 5, all plants completely lodged); LODG represents the area with lodged plants in the plot, which ranges from 0 to 10, where 0 corresponds to the absence of lodged plants in the plot and 10 to lodged plants over the whole plot, regardless of their inclination. Therefore, this equation considered the incidence and severity of plants lodging, for example, when there is I = 5 and LODG = 10, LODG-I%= 5×10×2 = 100%, which corresponds to the existence of lodged plants close to the ground in the total area of plot.

To meet the homogeneity and normality assumptions via *Bartlett* tests, analysis of variance were performed for the detection of the main effects and interaction. Based on this information, it was proceeded the linear equation adjustment $(TDM = b_0 \pm \mathrm{b}_1\mathrm{x})$ in estimating the biomass production day^{-1} ha^{-1} rate and the averages comparison by Scott and Knott (1974) at the analysis of points of density considered on grain yield and lodging. Afterwards, with the equation adjustment of degree two $(GY = b_0 \pm \mathrm{b}_1\mathrm{x} \pm \mathrm{b}_2\mathrm{x}^2)$ for grain yield (GY), it was obtained the optimal sowing density (X) by the equation $(\mathrm{X} = -\frac{\mathrm{b}_1}{2\mathrm{b}_2})$. It was carried out regression equation adjustment (linear or quadratic) that describes the behavior expression of percentage of oat plant lodging by increasing the cultivation density. In these equations, oat lodging estimate was performed in distinct cultivation conditions using optimal sowing density (X) at maximum grain yield. For all the determinations employed, computational program GENES (Cruz, 2013) was used. It is highlighted that the average grain yield values per crop year along with the temperature and rainfall information were used to classify the years as favorable and unfavorable.

RESULTS AND DISCUSSION

In this study, significant differences were detected between the main effects and interaction between cultivars, years and sowing densities. Therefore, the results are presented in order to unfold the effects of this interaction. In Table 1, about the soybean/oat succession system, the highest rate of biomass production day^{-1} was obtained at a density of 900 seeds m^{-2}, regardless of the years and cultivars evaluated. The increase of sowing density in oat indicates the biomass rate fostering; however, the most expressive average values of grain yield were obtained at the points of 300 and/or 600 seed m^{-2}. In these two densities, the 600 seeds m^{-2} provided in most cases, greater plant lodging. However, the highest biomass day^{-1} rate for rapid ground cover in the use of light and weed control with grain yield, is more efficient at the point of 600 seeds m^{-2}. Although this density facilitates greater plant lodging in this system in relation to 300 seeds m^{-2}, the tendency of increased lodging can be circumvented by the use of growth reducers, strategy that has been adopted for oats and other cereals (Hawerroth et al., 2015).

In Table 1, the rapid N-residual release soybean/oat system, the biomass production day^{-1} rate and grain yield indicated in general terms, cultivar URS-Taura is larger than Brisasul and with greater stability of the grain yield and lodging in different densities tested, regardless of cultivation year. It is highlighted, in this condition, that the most favorable years to increase of grain yield were also those that provided greater plant lodging. The years 2011 and 2013 indicated the most expressive average values (Table 3) as a result of climate conditions temperature and more favorable rainfall for the cultivation, mainly in 2013, with mild temperatures and adequate rain distribution during the crop cycle (Figure 1). It is verified that in a condition that high biomass and grain yield are searched by means of combined use of N-fertilizer and N-residual, the possibility of plant lodging becomes stronger on condition of favorable cultivation year.

In Table 2, corn/oat system, the equations obtained also indicated higher biomass production day^{-1} rate in higher density, justifying the fact that they are positively related. In this condition, the highest yields were found at 300 and 600 seeds m^{-2}. In the analysis of the biomass production day^{-1} rate with grain yield, regardless of year and cultivar, the point of 600 seeds m^{-2} also appears as more indicated. In this condition of high C/N ratio (corn/oat system), the low N-residual release rate seems to influence on sowing density when compared to soybean/oat system, because in most situations, the maximum grain yield was obtained at the point of 600 seeds m^{-2}. The year 2011 stands out when the cultivar URS Taura also indicated maximum yields with 900 seeds m^{-2}. In this way, differences between cultivars were detected, with cultivar URS Taura showing in 2011 and 2012 the greatest grain yield, but in 2013, the most expressive results were

Table 1. Regression equation of total dry matter and grain yield averages and lodging oat cultivars in sowing densities on soybean/oat system.

Cultivar	Density (seeds m^{-2})	Equation $TDM=b_0 \pm b_1 x$	R²	P (b_{1x})	GY (kg ha^{-1})	LODG (%)
Year 2011						
Brisasul	100	1142 + 59x	0.93	*	2672[c]	3.5[d]
	300	1762 + 71x	0.95	*	3142[b]	17.5[c]
	600	1773 + 78x	0.95	*	3627[a]	58.7[b]
	900	2656 + 98x	0.90	*	2887[c]	85.0[a]
URS-Taura	100	1729 + 64x	0.94	*	2712[c]	4.7[c]
	300	1542 + 68x	0.98	*	3841[a]	8.7[c]
	600	1420 + 75x	0.89	*	3833[a]	30.0[b]
	900	1282 + 78x	0.90	*	3470[b]	52.5[a]
Year 2012						
Brisasul	100	2444 + 77x	0.98	*	2221[b]	1.2[b]
	300	2129 + 84x	0.95	*	2923[a]	6.2 [b]
	600	2476 + 98x	0.97	*	2851[a]	10.0[b]
	900	2533 + 102x	0.99	*	2315[b]	45.0[a]
URS-Taura	100	2680 + 88x	0.94	*	2463[b]	2.7[b]
	300	2334 + 92x	0.89	*	3101[a]	3.2[b]
	600	3052 + 104x	0.93	*	3326[a]	4.5[b]
	900	2796 + 108x	0.98	*	2473[b]	20.0[a]
Year 2013						
Brisasul	100	2975+86x	0.93	*	3629[b]	0.0 [d]
	300	2519+96x	0.93	*	4100[a]	10.2[c]
	600	2855+108x	0.94	*	3790[b]	83.7[b]
	900	3106+112x	0.97	*	3191[c]	96.2[a]
URS-Taura	100	3192+96x	0.86	*	3133[a]	6.7[c]
	300	3302+103x	0.88	*	3329[a]	11.7[c]
	600	3289+112x	0.90	*	3182[a]	56.7[b]
	900	3702+115x	0.95	*	2835[b]	80.0[a]

TDM: Total dry matter (kg ha-1); GY: grain yield (kg ha^{-1}); LODG: lodging (%); R²: determination coefficient; P (b_{ix}^{n}): equation inclination parameter; *Significant at 5% error probability by the *t* test. Averages followed by different letters are statistically different group by Scott & Knott test at 5% error probability.

obtained with the cultivar Brisasul. A relevant fact was the reduced lodging observed in all conditions tested, reporting that the corn/oat system proves efficient in reducing plant lodging (Table 2). Although in this system, the N-residual rate release is reduced, benefits in the tissues structure was obtained, possibly by increasing lignin content, generating greater culm resistance. Concerning the oats aimed at human food, this condition shows relevant, because the value of the product for the industry is reflected in high mass of grains and the hectoliter, strongly damaged traits in occurrence of lodging.

The determination of the biomass production rate is decisive in determining the sowing density adjustment, and it allows the establishment that will favor better use of light and nutrients in association with natural weeds control (Fleck et al., 2009; Silva et al., 2012). However, the use of very elevated densities may reduce the grain yield through strong intraspecific competition and encourage plant lodging (Krüger et al., 2011; Hawerroth et al., 2015). Pinthus (1973) defined the lodging as a permanent modification state of the culm position in relation to its original position, resulting in curved plants or broken culms. The breaking and/or lodging are

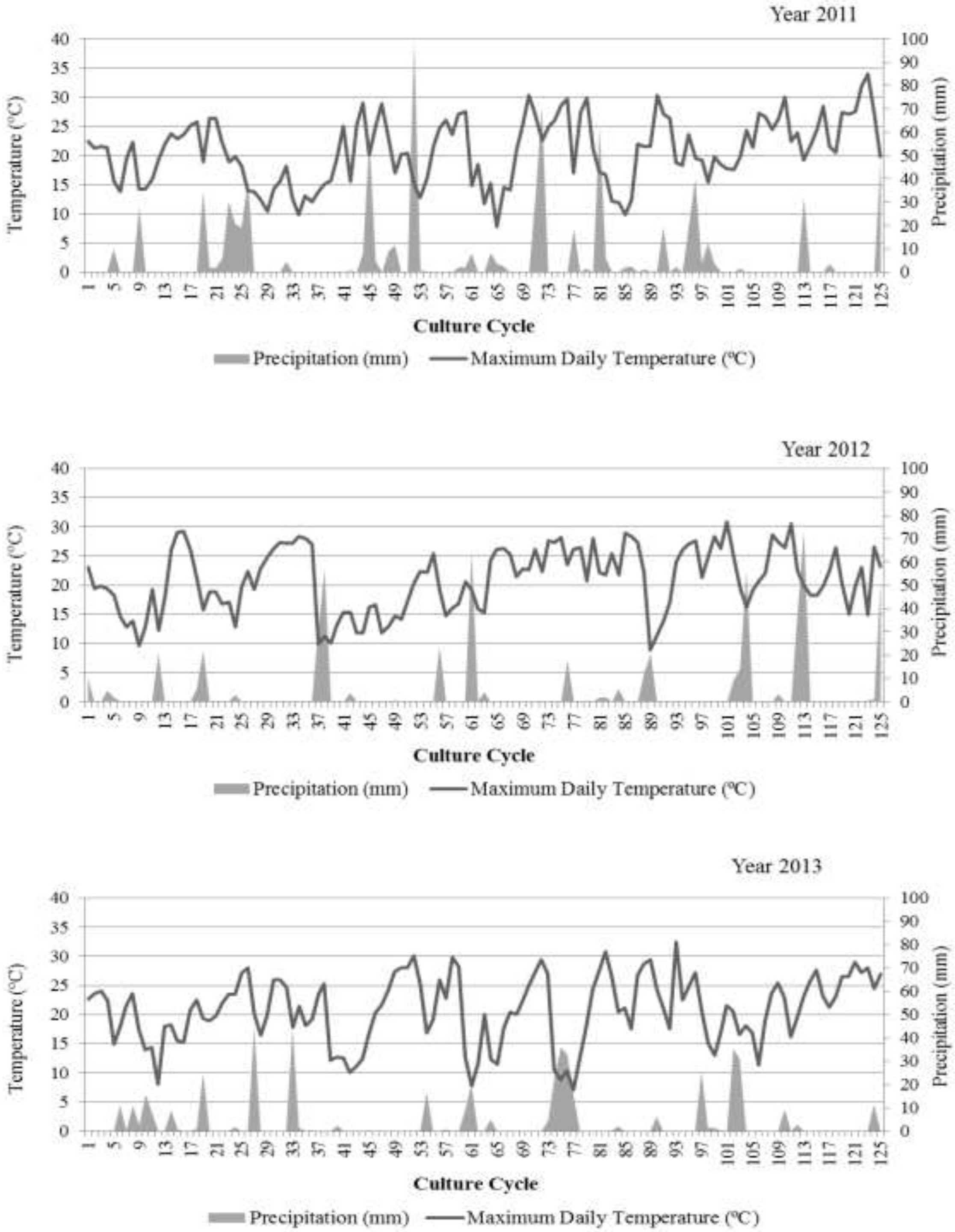

Figure 1. Different years of study climatological data.

complex phenomena, and their expression depends on genetic factors interrelated with the climate, soil and management practices (Fontoura et al., 2006). Among the main agents that promote the plant lodging, the wind and rain stand out (Easson et al., 1993; Silva et al., 2006). In favoring conditions to lodging, the use of plant

Table 2. Regression equation of total dry matter and grain yield averages and lodging oat cultivars in sowing densities in corn/oat system.

Cultivar	Density (seeds m^{-2})	Equation: TDM= $b_0 \pm b_1x$	R^2	P (b_{1x})	GY (kg ha^{-1})	LODG (%)
Year 2011						
Brisasul	100	1837 + 54x	0.95	*	1918^c	1.0^c
	300	1689 + 63x	0.91	*	2731^b	4.0^c
	600	2126 + 72x	0.98	*	3221^a	6.7^b
	900	3029 + 91x	0.97	*	2562^b	15.0^a
URS-Taura	100	2158 + 68x	0.92	*	2045^c	0.5^b
	300	2422 + 71x	0.98	*	2836^b	1.3^b
	600	2772 + 98x	0.92	*	3111^a	3.0^b
	900	3533 + 102x	0.97	*	3127^a	6.2^a
Year 2012						
Brisasul	100	2966 + 84x	0.91	*	2427^b	1.2^b
	300	2881 + 90x	0.91	*	2816^a	1.7^b
	600	2703 + 93x	0.87	*	2938^a	4.0^b
	900	2742 + 110x	0.97	*	2489^b	10.0^a
URS-Taura	100	2838 + 82x	0.95	*	2641^b	1.2^c
	300	2933 + 90x	0.94	*	3056^a	1.7^c
	600	2761 + 94x	0.97	*	2967^a	3.7^b
	900	3472 + 111x	0.93	*	2453^b	6.2^a
Year 2013						
Brisasul	100	1797 + 83x	0.94	*	3065^c	1.0^a
	300	2228 + 101x	0.92	*	3441^b	1.5^a
	600	3488 + 104x	0.93	*	3687^a	1.7^a
	900	4045 + 118x	0.91	*	3381^b	2.7^a
URS-Taura	100	3649 + 105x	0.86	*	2748^b	0.7^a
	300	3862 + 111x	0.92	*	3231^a	0.7^a
	600	3812 + 112x	0.93	*	3157^a	1.0^a
	900	4055 + 122x	0.87	*	2833^b	2.7^a

TDM: Total dry matter (kg ha-1); GY: grain yield (kg ha^{-1}); LODG: lodging (%); R^2: determination coefficient; P (b_{ix}^n): equation inclination parameter; *Significant at 5% error probability by the *t* test. Averages followed by different letters are statistically different group by Scott & Knott test at 5% error probability.

growth regulator has been used as an efficient solution, including allowing the use of higher sowing densities and larger doses of nitrogen in increasing yield (Matysiak, 2006; Schwerz et al., 2015). Rademacher (2000) defines plant growth regulator as a synthetic compound capable of reducing undesirable longitudinal growth of the aerial part of plants, with no decrease in grain yield.

In the definition of the optimal sowing density in oats and their reflexes about the plant lodging, in Tables 3 and 4 equations presented that the grain yield behavior and the lodging, validated by the analysis of variance of regression (not displayed) and test on the inclination parameter (b_{ix}^n) that were significant. In Table 3, in the soybean/oat system, regardless of year and cultivar, the grain yield showed quadratic trend and the lodging linear adjustment at the sowing densities increase, except in 2012, because the cultivars showed quadratic behavior in plant lodging. In the years 2011 and 2012 in soybean/oat system Table 3), independent of the cultivars tested, the optimal density cultivation for grain yield was obtained

Table 3. Regression equation to estimate the optimal density on grain yield and reflections on the plant lodging in soybean/oat system.

Cultivar	Equation: $y= a \pm b_{1x} \pm b^2_{2x}$	R^2	P (b_{ix}^n)	Density (seeds m^{-2})	Y_E
	Year 2011				
Brisasul	$GY= 2145 + 5.1881x - 4.81.\ 10^{-3}x^2$	0.94	*	539	3543
	$LODG= - 9.34 + 0.1064x$	0.98	*	(539)	48
URS-Taura	$GY= 2243 + 6.2308x - 5.48.\ 10^{-3}x^2$	0.89	*	568	4014
	$LODG= - 5.40 + 0.0619x$	0.97	*	(568)	30
	Year 2012				
Brisasul	$GY= 1874 + 4.4343x - 4.42.\ 10^{-3}x^2$	0.93	*	502	3006
	$LODG= 7 - 0.04874x + 7.99.\ 10^{-5}x^2$	0.96	*	(502)	3
URS-Taura	$GY= 1947 + 5.6068x - 5.57.10^{-3}x^2$	0.99	*	503	3357
	$LODG= 6 - 0.03081x + 5.08.\ 10^{-5}x^2$	0.97	*	(503)	5
	Year 2013				
Brisasul	$GY= 3431 + 2.8854x - 3.54.\ 10^{-3}x^2$	0.93	*	408	4018
	$LODG = - 16.52 + 0.1336x$	0.91	*	(408)	38
URS-Taura	$GY= 3031 + 1.38642x - 1.65.\ 10^{-3}x^2$	0.97	*	420	3322
	$LODG= - 8.37 + 0.0993x$	0.95	*	(420)	33
General model	$GY= 2445 + 4.28886x - 4.24.\ 10^{-3}x^2$	-	*	505	3529
	$LODG= - 9.91 + 0.1003x$	-	*	(505)	40

GY: Grain yield (kg ha^{-1}); LODG: lodging (%); R^2: determination coefficient; P (b_{ix}^n): equation inclination parameter; *Significant at 5% error probability by the *t* test.

with values greater than 500 seeds m^{-2}. On the other hand, in 2013, the adjusted density results indicated values below 500 seeds m^{-2}, but higher than the recommendation of the species which is 200 to 300 seeds m^{-2}.

The equations obtained with the use of optimal sowing density indicated grain yield estimates of more than 3 t ha^{-1} at the soybean/oat system, in some situations, surpassing 4 t ha^{-1} (Table 3). In this way, the optimal sowing density for maximum grain yield to be included in the model that describes the lodging in oats, allowed estimation of lodged plants by using the optimal density. Therefore, in favorable cultivation years (2011 and 2013), the lodging was estimated between 30 and 48%, indicating that the adjusted density in soybean/oat system can bring losses by the plants falling and compromising the grain quality. It is highlighted that the genotypes tested besides showing cycle and reduced height are also described as moderately resistant to plant lodging (Silva et al., 2015). In unfavorable cultivation year (2012), the plant lodging was almost non-existent, however, with the lowest grain yield (Table 3). The favorable cultivation conditions defined by temperature and rainfall (Figure 1) were decisive on the plant lodging. Therefore, the improvement of investments with fertilization in favorable years can step up lodging, especially with the use of higher sowing density seeking maximum yield. The general analysis (Table 3), regardless of the cultivars and cultivation years, the density adjusted to maximum yield in the soybean/oat system was around 500 seeds m^{-2} (x = 506), with 40% of lodging.

In Table 4, corn/oats succession system, behavior similar to soybean/oat system were observed, with adjustment of quadratic functions in the estimation of grain yield and linearity on the plant lodging in the increased density of sowing, regardless of year and cultivar. In this system, the adjusted densities for maximum grain yield was higher than 500 seeds m^{-2}, however, situations such as in 2011, which showed optimal density around 600 seeds m^{-2} (x = 618) on the cultivar URS Taura. This condition reinforces the hypothesis of dependence of the sowing density adjustment by succession system and cultivar, mainly

Table 4. Regression equation to estimate the optimal density on grain yield and reflections on the plant lodging in corn/oat system.

Cultivar	Equation: $y= a \pm b_{1x} \pm b^2_{2x}$	R^2	P (b_{ix}^n)	Density (seeds m^{-2})	Y_E
	Year 2011				
Brisasul	$GY= 1294 + 6.65352x - 5.82.10^{-3}x^2$	0.99	*	573	3195
	$LODG= - 1.08 + 0.0174x$	0.99	*	(573)	5
URS-Taura	$GY= 1683 + 4.42860x - 3.58.\ 10^{-3}x^2$	0.97	*	618	3053
	$LODG= - 0.64 + 0.0071x$	0.96	*	(618)	4
	Year 2012				
Brisasul	$GY= 2135 + 3.21667x - 3.14.\ 10^{-3}x^2$	0.99	*	512	3000
	$LODG= - 0.88 + 0.0108x$	0.99	*	(512)	4
URS-Taura	$GY= 2402 + 2.96546x - 3.25.\ 10^{-3}x^2$	0.97	*	456	3078
	$LODG= 0.21 + 0.0063x$	0.97	*	(456)	3
	Year 2013				
Brisasul	$GY= 2769 + 3.12254x - 2.71.10^{-3}x^2$	0.99	*	576	3668
	$LODG= 0.78 + 0.0020x$	0.94	*	(576)	2
URS-Taura	$GY= 2529 + 2.89005x - 2.86.10^{-3}x^2$	0.90	*	505	3259
	$LODG= 1 - 0.00588x + 7.89.\ 10^{-3}x^2$	0.97	*	(505)	1
General model	$GY= 2135 + 3.8794x - 3.56.\ 10^{-3}x^2$	-	*	545	3191
	$LODG= 0.322 + 0.00872x$	-	*	(545)	5

GY: Grain yield (kg ha^{-1}); LODG: lodging (%); R^2: determination coefficient; P (b_{ix}^n): equation inclination parameter; *Significant at 5% error probability by the *t* test.

influenced by genetic differences of the lowest production rate and development of tillers observed in cultivar URS Taura, and intensified on condition of lower N-residual availability. In this system, grain yield above 3 t ha^{-1} were also obtained, highlighting the cultivar Brisasul in more favorable cultivation year (2013) with 3.6 t ha^{-1}. In the behavior linear equation of plant lodging, the inclusion of the optimal density for grain yield showed lodging estimates totally different from those obtained in the soybean/oat system. The use of optimal sowing density on this system, independent of favorable and unfavorable year of cultivation and genetic differences between cultivars, allowed efficient reduction in plant lodging. Therefore, management condition evidenced the increase in grain yield with the use of optimal density without lodging. This fact reports the possibility of greater ease of harvest and maintenance of the physical and chemical qualities of the grain, characteristic strongly required by industry.

Valério et al. (2008) observed that wheat genotypes with reduced tillering are more dependent on the sowing density increase. The genotypes of high tillering submitted to high densities, suffer greater competition for water, light and nutrients, reducing the grain yield and favoring the plant lodging (Ozturk et al., 2006). Therefore, the identification of a stable sowing density and responsive to cultivation improvements can foster greater grain yield in the ideal balance of development of yield components and with less risk in the plants fall (Silva et al., 2012). In wheat, it was observed that the equidistant distribution of seeds at density of 350 to 500 seeds m^{-2}, promoted greater grain yield in the cultivars evaluated (Silveira et al., 2010). They also observed that the sowing density adjustment was changed by genotype and cultivation year, with yield increase with stability in higher density. Mantai et al. (2015) observed that the type of vegetal residue by the succession system in oat significantly alters the expression of biomass and grain yield. According to these authors, the N-fertilizer, although being used in less proportion in the soybean/oat system, brings greater plant lodging risks, especially in favorable.

On the other hand, increased doses of N-fertilizer did not promote plant lodging in the corn/oat system, which cultivation conditions reinforces the results obtained in this study, by the contribution of this system in reducing plants fall. Abreu et al. (2005) by studying delayed cycle oat genotypes observed linear increase in biomass and grain yield by increasing the population from 100 to 400 plants m^{-2}. Silva et al. (2015) highlight that the proposal of recommendation of seeds higher than the techniques currently used in oats can increase grain yield provided that there is no lodging, and with benefits in the management of the crop by the greater vegetation cover, be through a more effective weeds control or through moisture maintenance and soil erosion control, qualifying the direct sowing system for the summer species.

Conclusions

Regardless of year and cultivar, the main oat biotype grown in Southern Brazil shows optimal sowing density around 500 seeds m^{-2} in the biomass and grain yield expression in the corn/oat and soybean/oat succession systems.

In the soybean/oat succession system, the use of optimal density can promote the plant lodging, mainly in favorable cultivation years.

The corn/oat succession system although be of lower N-residual release, proves efficient the grain yield expression and reduced lodging in the use of adjusted density.

Conflict of Interests

The authors have not declared any conflict of interests.

ACKNOWLEDGEMENTS

To CNPq, FAPERGS, CAPES and UNIJUÍ for the contribution of resources for the development of this research and for the Scholarship for Scientific and Technological Initiation and Research Productivity.

REFERENCES

Abreu GT, Schuch LO, Maia MS, Rosenthal MS, Bacchi S, Pereira E, Cantarelli LD (2005). Produção de biomassa em consórcio de aveia branca (*Avena sativa* L.) e leguminosas forrageiras. Rev. Bras. Agrociênc. 11(1):19-24.

Araus JL, Slafer GA, Royo C, Serret MD (2008). Breeding for yield potential and stress adaptation in cereals. Crit. Rev. Plant Sci. 27(1):377-412.

Benin G, Carvalho FIF, Oliveira AC, Lorencetti C, Vieira EA, Coimbra JLM, Valério IP, Floss EL, Bertan I, Silva GO (2005). Adaptabilidade e estabilidade em aveia em ambientes estratificados. Cienc. Rural 35(2):295-302.

Berry PM, Spink JH, Gay AP, Craigon J (2003). A comparison of root and stem lodging risks among winter wheat cultivars. J. Agric. Sci. 141:191-202.

Ceccon G, Grassi Filho H, Bicudo SJ (2004). Rendimento de grãos de aveia branca (*Avena sativa* L.) em densidades de plantas e doses de nitrogênio. Cienc. Rural 34(6):1723-1729.

Costa L, Zucareli C, Riede CR (2013). Parcelamento da adubação nitrogenada no desempenho produtivo de genótipos de trigo. Rev. Ciênc. Agron. 44(2):215-224.

Cruz CD (2013). GENES - a software package for analysis in experimental statistics and quantitative genetics. Acta sci. 35(3):271-276.

Easson DL, White EM, Pickles SJ (1993). The effects of weather, seed rate and cultivar on lodging and yield in winter wheat. J. Agric. Sci. 121:145-156.

Fleck NG, Schaedler CE, Agostinetto D, Rigoli RP, Dal Magro T, Tironi SP (2009). Associação de características de planta em cultivares de aveia com habilidade competitiva. Planta Daninha 27(2):211-220.

Fontoura D, Stangarlin JR, Trautmann RR, Sschirmer R, Schwantes DO, Andreotti M (2006). Influência da população de plantas na incidência de doenças de colmo em híbridos de milho na safrinha. Acta Sci. Agron. 28:545-551.

Hawerroth MC, Silva JAG, Souza CA, Oliveira AC, Luche HS, Zimmer CM, Hawerroth FJ, Schiavo J, Sponchiado JC (2015). Redução do acamamento em aveia‑branca com uso do regulador de crescimento etil‑trinexapac. Pesqui. Agropecu. Bras. 50(2):115-125.

Hawerroth MC, Carvalho FIF, Oliveira AC, Silva JAG, Gutkoski LC, Sartori JF, Woyann LG, Barbieri RL, Hawerroth FJ (2013). Adaptability and stability of white oat cultivars to chemical composition of the caryopsis. Pesqui. Agropecu. Bras. 48(1):42-50.

Krüger CAMB, Silva JAG, Medeiros SLP, Dalmago GA, Sartori CO, Schiavo J (2011). Arranjo de plantas na expressão dos componentes da produtividade de grãos de canola. Pesqui. Agropecu. Bras. 46(11):1448-1453.

Mantai RD, Silva JAG, Sausen ATZR, Costa JSP, Fernandes SBV, Ubessi CA (2015). A eficiência na produção de biomassa e grãos de aveia pelo uso do nitrogênio. Rev. Bras. Eng. Agric. Ambient. 19(4):343-349.

Matysiak K (2006). Influence of trinexapac-ethyl on growth and development of winter wheat. J. Plant Prot. Res. 46(2):133-143.

Moes J, Stobbe EH (1991). Barley treated with ethephon: I. yield components and net grain yield. Agron. J. 83(1):86-90.

Oliveira AC, Crestani M, Carvalho FIF, Silva JAG, Valério IP, Hartwig I, Benin G, Schmidt DAM, Bertan I (2011). Brisasul: a new high-yielding white oat cultivar with reduced lodging. Crop Breed. Appl. Biotechnol. 11:370-374.

Ozturk A, Caglar O, Bulut S (2006). Growth and yield response of facultative wheat to winter sowing, freezing sowing and spring sowing at different seeding rates. J. Agron. Crop Sci. 192(1):10-16.

Pinthus MJ (1973). Lodging in wheat, barley, and oats: the phenomenon, its causes, and preventive measures. Adv. Agron. 25(1):208-263.

Rademacher W (2000). Growth retardants: effects on gibberellin biosynthesis and other metabolic pathways. Ann. Rev. Plant Physiol. 51:501-531.

Scott AJ, Knott M (1974). A cluster analysis method for grouping means in the analysis of variance. Biometrics 30:507-512.

Schwerz F, Caron BO, Schimidt D, Oliveira DM, Elli EF, Eloy E, Rockenbach AP (2015). Growth retardant and nitrogen levels in wheat agronomic characteristics. Científica 43(2):93-100.

Silva EC, Muraoka T, Buzetti S, Trivelin PCO (2006). Manejo de nitrogênio no milho sob plantio direto com diferentes plantas de cobertura, em latossolo vermelho. Pesqui. Agropecu. Bras. 41:477-486.

Silva JAG, Fontaniva C, Costa JSP, Krüger CAMB, Ubessi C, Pinto FB, Arenhardt EG, Gewehr E (2012). Uma proposta na densidade de semeadura de um biotipo atual de cultivares de aveia. Rev. Bras. Agrociênc. 18(3):253-263.

Silva JAG, Mantai RD, Oliveira, AC, Fontaniva C, Arenhardt EG, Olegário MB, Sberse VL (2015) Sowing density on oat production physiological parameters. Científica 43(3):181-189.

Silveira G, Carvalho FIF, Oliveira AC, Valério IP, Benin G, Ribeiro G, Crestani M, Luche HS, Silva JAG (2010). Efeito da densidade de semeadura e potencial de afilhamento sobre a adaptabilidade e estabilidade em trigo. Bragantia 69:63-70.

Spakes DL, Holme SJ, Gaju O (2006). Does light quality initiate tiller death in wheat? Eur. J. Agron. 24(3):212-217.

USDA (2014) Soil Survey Staff. 2014. Keys to Soil Taxonomy, 12th ed. USDA-Natural Resources Conservation Service, Washington, DC.

Valério IP, Carvalho FIF, Oliveira AC, Machado AA, Benin G, Scheeren PL, Souza VQ, Hartwig I (2008). Desenvolvimento de afilhos e componentes do rendimento em genótipos de trigo sob diferentes densidades de semeadura. Pesqui. Agropecu. Bras. 43:319-326.

Valério IP, Carvalho FIF, Oliveira AC, Benin G, Maia LC, Silva JAG, Schmidt DM, Silveira G (2009). Fatores relacionados à produção e desenvolvimento de afilhos em trigo. Semina: Cienc. Agron. 30(1):1207-1218.

Wendling A, Eltz FLF, Cubilla MM, Amado TJC, Mielniczuk J, Lovato T (2007) Recomendação de adubação nitrogenada para trigo em sucessão ao milho e soja sob sistema de plantio direto no Paraguai. Rev. Bras. Cienc. Solo 31:985-994.