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The sowing density on oat productivity indicators

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The sowing density adjustment in oatcan maximize the productivity expression.The aim of this study is to define the behavior of productivity expression of biomass, grains, straw andharvest indexthrough increasing sowing density in the main biotype cultivated in Southern Brazil. It proposesthe possibility of indicating higher sowing density to the productivity maximization of biomass and grains.With the densityadjusted to the grain productivity to simulate the reflexes on the biological and straw productivity and harvest index compared to recommendeddensity, considering high and reduced tillering cultivars in different succession systems.The study was carried out in 2013, 2014 and 2015 in randomized blockdesign with four replications in a 4 × 2 factorial scheme, for sowing density (100, 200, 300, 600 and 900 m^{-2}) and oat cultivars (Brisasul and URS Taura), respectively, in the corn/oat and soybean/oat succession system.With the increase in sowing density, the biological and straw productivity evidence alinear behavior and the grain productivity and harvest index ofquadratic behavior, regardless of the cultivar,agricultural year and succession system. It is possible to indicate a higher sowing density to the biomass and grain productivity maximization with sowing density close to 500 seeds m^{-2} in the main succession systems.In high and reduced tillering cultivars, the adjusted density compared tothe recommended increasedthe biological and straw productivity, regardless of agricultural year and succession systems.

Key words: *Avena sativa*, succession system, weather condition, regression.

INTRODUCTION

White oat (*Avenasativa L.*) is acknowledgedas a grain producer withnutritional quality for human and animal feeding (Garcia et al., 2012; Hawerroth et al., 2015). In Southern Brazil, it is an alternative to wheat for the winterfarming, evidencing in recent years accentuated growth in the cultivated area, mainly, due to use of the

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grains for commercialization and production of adequate haystacks for the direct sowing system (Hartwig et al., 2007; Mantai et al., 2015).

The expression of productivity potential of the white oat is associated to management techniques, viz, the plants population, nutrients availability, phytosanitary control and others (Silva et al., 2012; Mantai et al., 2015). The productivity variation by the plants population is associated with the genotype potential to produce fertile tillers as the sowing density directly influences the number of ears and/or panicles produced by area (Valério et al., 2009; Castro et al., 2012). Moreover, the fast coverage of the soil by the canopy adjustment may favor the best use of light and nutrients, providing more effective control inthe evolution of the species considered invaders (Fleck et al., 2009; Lamego et al., 2013). The high variation of productivity is also associated with the large variability of cultivation conditions, the agricultural year being the major contribution factor (Storck et al., 2014; Arenhardt et al., 2015). Therefore, years of favorable and unfavorable weather can change the efficiency of the use of natural resources and management technologies on the vegetable productivity (Mantai et al., 2015; Arenhardtet al., 2015).

The continuous genetic improvement of oats has been significantly modifying the plant architecture, reducing height, cycle, leaf area, among other characteristics (Silva et al., 2012; Romitti et al., 2016). Therefore, they are alterations which may modify the cultivars responseto the plants population, mainly when seeking an increment onthe productivity of oats biomass and grains on the current standard biotype of short-cycle and reduced height cultivated in a commercial scale in Brazil. Studies carried out by Abreu et al. (2005) and Silva et al. (2012) revealed that the increase of the plant population of white oat resulted in an increased crop growth rate and biomass productivity per unitarea. Santi et al. (2016) observed increased productivity of lupine biomass by increasing sowing density. The total biomass productivity also denominated biological productivity is directly linked to the photosynthesis and breathing processes in the vegetative and reproductive phases (Demétrio et al., 2012; Silva et al., 2015). Thus, harvest index (grain productivity divided by biological productivity) is an important parameter in determining the efficiency with which the photo assimilates are converted in straw and grain (Silva et al., 2011, 2015).

The technical recommendations of oat sowing (CBPA, 2006) have been suggesting 200 to 300 viable seeds m^{-2}, indications based on research from a plant biotype with different characteristics of the one which is currently used in production systems. This fact raised the hypothesis that the plant population above the recommended plant population may provide more effective gainson the increment of straw and grain productivity in the main biotype of oat cultivated in Southern Brazil. These conditions maybe better understood when considering cultivars of high and reduced tillering evaluated in different conditions of agricultural year and in succession system with high and reduced residual N release.

The aim of this study was to define the productivity expression behavior of the biomass, grains, straw and harvest index through increasing sowing density in the main biotype grown in Southern Brazil. It proposes the possibility of indicating a higher sowing density to the productivity maximization of the biomass and grains. With the density adjustedto the grain productivity to simulate the reflexes on the biological productivity, straw and harvest index compared to recommended plant density, considering high and reduced tillering in different agricultural years and in different succession systems.

MATERIALS AND METHODS

The experimentwas conducted in the field during 2013, 2014 and 2015 in Augusto Pestana town, 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 and the climate of the region, according to Köppen classification, is Cfa type, witha hot summer without a dry season. In the study, ten days before sowing, a soil analysis was performed at the local and identified the following chemical characteristics: (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 cmolc dm^{-3}, Ca = 6.6 cmolc dm^{-3}, and Mg = 3.4 cmolc 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 cmolc dm^{-3}, Ca = 6.5 cmolc dm^{-3}, and Mg = 2.5 cmolc dm^{-3}).

In all the three years, sowing was done in the second fortnight of May with seeder-fertilizer at a row spacing of 0.20 m. During the experimentation, tebuconazole fungicide (trade name FOLICUR® CE)was applied at the dosage of 0.75 L ha^{-1}.Weed control was carried out with metsulfuron-methyl herbicide (trade name ALLY®at a dose of 4 g ha^{-1}) and additional manual weeding whenever necessary.10 kg ha^{-1}(except in the standard experiment unit), 60 kg P_2O_5 ha^{-1} and 50 kg K_2O ha^{-1} were applied at the time of sowingfor productivity expectancy of 3 t $ha^{-1}$and rest of N to complement an expectancy of 3 t ha^{-1} wasappliedin coverage on the phenological stage of fourth leaf expanded.

The studies were carried out in the main succession systems used in southern Brazil for oats, involving soil coverage with vegetable residue of high and reduced carbon/nitrogen ratio, in corn/oat and soybean/oat succession systems, respectively. In each succession system, two experiments were conducted, one to quantify the biological biomass and the other aiming exclusively at grain productivity estimation. In all experiments, the experimental design was randomized blocks with four repetitions, in a 4×2 factorial scheme to four sowing density (100, 300, 600 and 900 viable seeds m^{-2}) and two oat cultivars (Brisasul and URS Taura). The indicated oat cultivars represent current genotypes with biotype desired in commercial farming in Brazil, with similarity regarding the cycle (early), height (reduced) and lodging (moderately resistant), however, distinguished in the capacity of production tillering (Brisasul = high; URS Taura = reduced).

The grain productivity was obtained by cutting three central rows of each plot at the time of harvesting with grain moisture around 22.0%. The plants were threshed with a stationary harvester and directed to the laboratory for correction grain moisture to 13.0% and weighing to estimate grain productivity (GP, kg ha^{-1}). In experiments aiming to quantify the biological productivity, the harvest of the plant material was done close to the ground from the moment ofphysiological maturity of grains in the collection of a linear meter of the three central rows of each plot. The green biomass samples were directed to forced-air oven at a temperatureof 65°C, until it reached constant weight for the estimation of biological productivity (BP, kg ha^{-1}). Straw productivity (SP, kg ha^{-1}) was determined by subtraction BP – GP and the harvest index (HI, kg kg^{-1}) by the division GP/BP..

In meeting the assumption of homogeneity and normality by Bartlet and Liliefors test was carried out at variance analysis for detection of the main effects and of interaction. The values of the general average of grain production for the intendedexpectancyof 3 t ha^{-1}, according to soil MO and succession system, along with temperature information and rainfall were usedfor ranking the agricultural year asfavorable year (FY), acceptable year (AY) and unfavorable year (UY).The adjustment of second-degree equations ($GP= a \pm bx \pm cx^2$) was performed for the estimation of the sowing ideal density ($D = - b/2c$) directed to maximum grain productivity. Equations that describe the behavior of biological productivity, of straw productivity and harvest index, as a form of simulation of expression these variables from the sowing ideal dose based on the maximum grain productivity were obtained. Genes computational program was used for the determination.

RESULTS AND DISCUSSION

In Figure 1, in the application moment of N-fertilizer in 2014, the averages of maximum temperature were higher (±27°C) as compared to 2015 and 2013. The nitrogen applied in coverage in 2014 was followed by rainfall volume greater than 50 mm, volume also observed close to harvest. These facts justify the smaller productivity obtained in this year (Table 1), due to a loss of nutrients byleaching and losses by excess of rainfall during maturation, characterizing it as an unfavorable year (UY). In 2015, the maximum temperature near to application of N-fertilizer was the lowest (±12°C) as compared to other years. In the fertilizing moment, the soil presented adequate humidity due to the rain accumulation from previous days (Figure 1). The high rain volume during the cycle provided periods of less sunlightwhich reduced the photosyntheticefficiency by the plant. Therefore, the average of grain productivity in Table 1, justifies a reasonable productivity, characterizing 2015 as an acceptable year (AY) of cultivation.In 2013, the maximum temperature obtained in the application moment of N-fertilizer was around 20°C. The nutrient supply occurred under favorable conditions of soil moisture (Figure 1). In this agricultural year, although the total rainfall volume wasthe smallest, the adequate distribution of rainfall during the cycle (Figure 1) was decisive in the highest average productivity of grains (Table 1). It stands out that the established dose of N-Fertilizer exceeded the desired expectation of 3 t ha^{-1} characterizing 2013 as a favorable year (FY) for cultivation.

Battisti et al. (2013) asserted that the rainfall is the meteorological variable that mostly affects the productivity in relation to the temperature, sunshine and solar radiation. Arenhardt et al. (2015) emphasized that the condition of the cultivation year of wheat is predominantly defined by distribution and volume of rainfall. The temperature, sunlight and solar radiation also influence the productivity (Souza et al., 2013). The temperature acts as a catalyst of the biological process, reason why the plants require the minimum and maximum temperature for normality of the physiological activity (Tonin et al., 2014). In oat, the favorable weather is described as that with milder temperatures and quality of solar radiation in favoring the tillering and grain filling. Besides, without occurrence of rain in high amount and intensity, but which favors adequate soil moisture (Castro et al., 2012).

In Table 2, regardless of oat cultivar, agricultural year and succession system, the increment of sowing density in relation to the grain productivity presented quadratic behavior. The parameters of inclination (cx^2) were effective in validating these equation in the estimated of adjusted density. Therefore, in conditions of unfavorable year (2014) and acceptable year to the cultivation in soybean/oats system, the adjusted sowing to the higher production expression of grains was between 500 and 570 seeds m^{-2}, regardless of oat cultivar.It is highlighted that in these years, the adjusted density of seeds provided increment in the grain productivity in relation the recommended density (250 seeds m^{-2}). In the favorable year of cultivation (2013), the adjusted density was close to 410 and 420 seeds m^{-2}. In these conditions, the differences between adjusted and recommended density did not present change in grain productivity (Table 2). In general, in the soybean/oats system, independently of year and oat cultivar, the optimal density of sowing was 500 seeds m^{-2}, increasing the elaboration of grains in comparison to the density of recommendation in more than 260 kg ha^{-1}. The results presented in soybean/oats system revealed that in unfavorable and acceptable year to cultivation, the use of more elevated seed sowing promotes effective benefits in the grain productivity. In the year 2013 (FY), although the amount of seeds in the adjusted sowing is lower than values obtained in 2014 (UY) and 2015 (AY), in 2013there was necessity of superior amount of seeds than the recommendation, however, not evidencing differences in grain productivity expression.Possibly, the favoring of agricultural year had contributed in the larger productivity and development of fertile tillers compensating the use of smaller amount of seeds.

In the corn/oats (Table 2), regardless of agricultural year condition and cultivar, the adjusted density of seeds presented values higher than 500 seeds m^{-2}. The use of adjusted density also presented increment of grain productivity higher than the recommendation. Results obtained in acceptable year to the oat cultivation (2015)stand out, when the adjusted density increased the grain productivity in more of 485 and 600 kg ha^{-1} in the URS-Taura and Brisasul cultivars, respectively in comparison with recommended sowing density. In general, regardless of year and cultivar, the adjusted density in corn/oats system was of 550 seeds m^{-2}, increasing the grainproductivity in more than 300 kg ha^{-1} in relation to the recommended sowing density. In this growing conditions, lower release of N-residual (corn/oats system), the use of

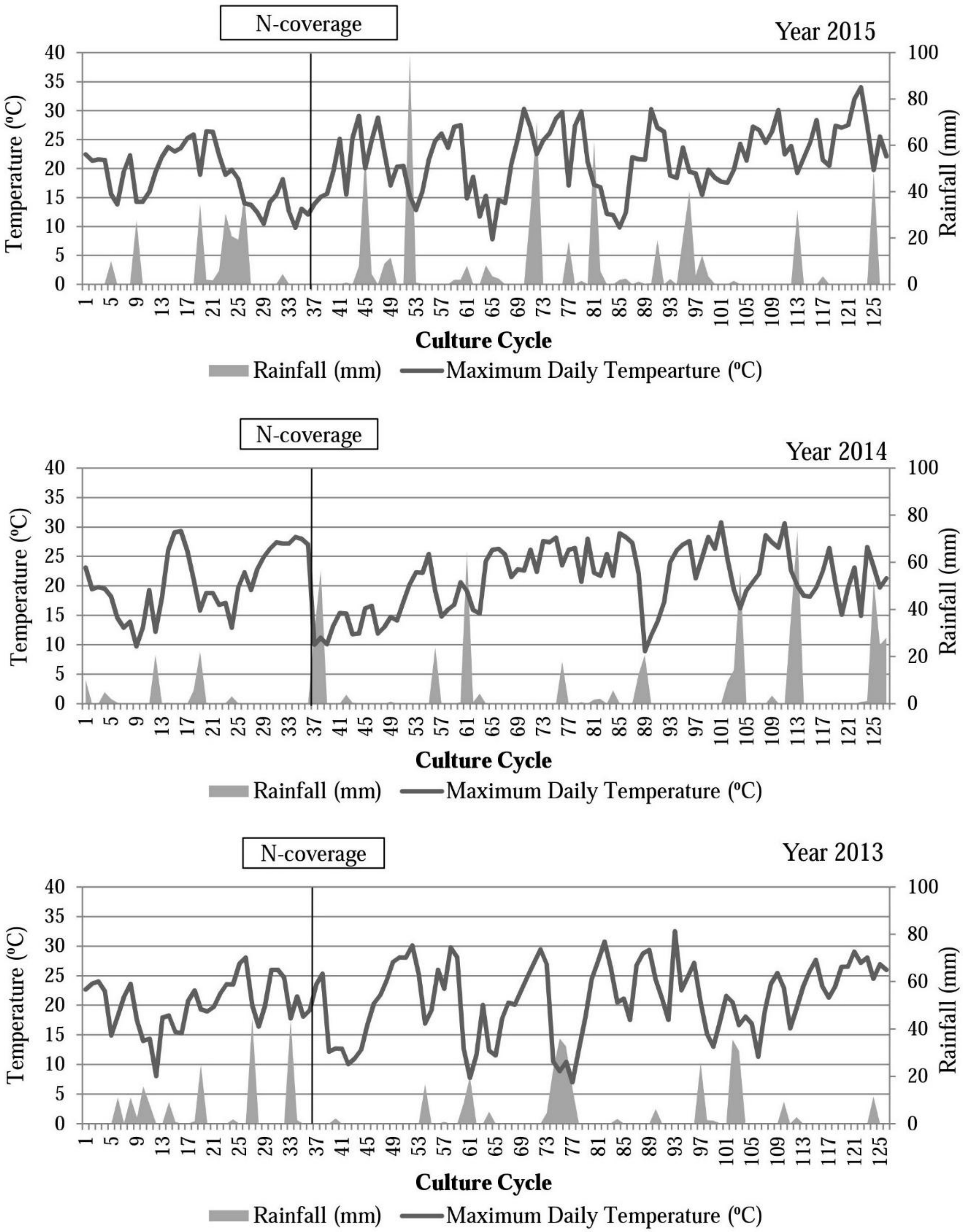

Figure 1. Rainfall and maximum temperature in the cycle of oat cultivation.

higher densities was found to be more effective on grain productivity when compared with the soybean/oats system. Therefore, the type of residual coverage indicates interference in the adjustment of sowing density

Table 1. Temperature and rainfall in cultivation months and means of grain productivity.

Month	Temperature (°C)			Rainfall (mm)		$GP_{\bar{x}}$ (kg ha^{-1})	Class
	Minimum	Maximum	Average	Average 25 years*	Occurred		
2015							
May	10,5	22.7	16.6	149.7	100.5		
June	7.9	18.4	13.1	162.5	191		
July	8.3	19.2	13.7	135.1	200.8		
August	9.3	20.4	14.8	138.2	223.8	2983^{b}	AY
September	9.5	23.7	16.6	167.4	46.5		
October	12.2	25.1	18.6	156.5	211.3		
Total	-	-	-	909.4	973.9		
2014							
May	11.1	24.5	17.8	149.7	20.3		
June	9.3	19.7	14.5	162.5	59.4		
July	7.4	17.5	12.4	135.1	176.6		
August	12.9	23.4	18.1	138.2	61.4	2516^{c}	UY
September	12	23	17.5	167.4	194.6		
October	15	25.5	20.2	156.5	286.6		
Total	-	-	-	909.4	798.9		
2013							
May	10	22.6	16.3	149.7	108.5		
June	8.9	20	14.5	162.5	86		
July	7	20.6	13.8	135.1	97		
August	6.6	19.8	13.2	138.2	1603	3400^{a}	FY
September	9.6	21	15.3	167.4	119.7		
October	13.2	27.1	20.2	156.5	138.8		
Total	-	-	-	909.4	712.0		

*Means rainfall from May to October from 1991 to 2015; FY: Favorable year; UY: unfavorable year; AY: acceptable year; $GP_{\bar{x}}$: mean grain productivity. Means followed by the same lowercase letter in the column do not differ statistically from one another by the Skott & Knott model at a 5% error probability.

in oat, mainly in favorable year of cultivation.

The adjustment of optimal sowing density in different cultivation conditions may benefit the change of the grain productivity plateau. The positive answersin use of higher densities were also observed in cultures as soybean, corn and wheat (Lima et al., 2008; Strieder et al., 2008; Silveira et al. 2010). In wheat, Zagonel et al. (2002) showed that higher density of plants may favor the increase of grainproductivity, to the point of identifying genotypes that were responsive to the increase of the population. Almeida et al. (2003)have already observed, in oat obsolete cultivars of middle and late cycle, amplitude of seeds density adjustedfrom 50 to 500 plants m^{-2}. The increment of the sowing density inearly cycle wheat cultivars, mainly of lower expression of tillering, presented benefits in the increase of sowing density on grain productivity (Silveira et al., 2010). Valério et al. (2008) had already been reporting that the wheat of early genotypes with reduced potential of tillering are more dependents of the correct adjustment of sowing density, suggesting values higher than those of recommendation to increase grain productivity. Silva et al. (2015) highlighted the need of changes in the recommendation of sowing density of oat seeds in the main biotype of early cycle and reduced height cultivated in Southern Brazil to increase the productivity provided, there is nolodging. The same authors highlight the benefits in farming management by greater plant coverage, bothin the more effective control of invasive species, as in the maintenance of soil moisture and erosion control, qualifying the direct sowing system to thesummer species. The use of an adequate density allows a species to develop more quickly and covers the soil more efficiently, causing less interference of the weeds (Fleck et al., 2009). In studies with oats cultivars of reduced height and cycle, it was also observed an adjusted density higher than the recommendation of 550 seeds m^{-2} (Silva et al., 2012).

Table 2. Regression equation and its parameters in estimated of grains productivity by the recommended and adjusted sowing density to the grain productivity (Y_E) in oats.

Cultivar	Equation ($GP=a \pm bx \pm cx^2$)	R^2	P (cx^2)	Density (s m^{-2})		Y_E	
				RC	AJ	RC	AJ
	Soybean/Oats system						
	2015 (AY)						
Brisasul	$2145 + 5.1881x – 4.81 \times 10^{-3}x^2$	0.94	*	250	540	3141^B	3544^A
URS-Taura	$2243 + 6.2308x – 5.48 \times 10^{-3}x^2$	0.89	*	250	570	3458^B	4014^A
	2014 (UY)						
Brisasul	$1874 + 4.4343x – 4.42 \times 10^{-3}x^2$	0.93	*	250	500	2706^B	2986^A
URS-Taura	$1947 + 5.6068x – 5.57 \times 10^{-3}x^2$	0.99	*	250	505	3001^B	3358^A
	2013 (FY)						
Brisasul	$3431 + 2.885x – 3.54 \times 10^{-3}x^2$	0.93	*	250	410	3931^A	4019^A
URS-Taura	$3031 + 1.38642x – 1.65 \times 10^{-3}x^2$	0.97	*	250	420	3274^A	3322^A
General	$2445 + 4.2886x – 4.305 \times 10^{-3}x^2$	-	*	250	500	3248^B	3513^A
	Corn/Oats system						
	2015 (AY)						
Brisasul	$1294 + 6.65352x – 5.82 \times 10^{-3}x^2$	0.99	*	250	570	2594^B	3196^A
URS-Taura	$1683 + 4.42860x – 3.68 \times 10^{-3}x^2$	0.97	*	250	600	2566^B	3051^A
	2014 (UY)						
Brisasul	$2402 + 2.96546x – 2.85 \times 10^{-3}x^2$	0.97	*	250	520	2965^B	3173^A
URS-Taura	$2135 + 3.21667x – 3.14 \times 10^{-3}x^2$	0.99	*	250	510	2743^B	2959^A
	2013 (FY)						
Brisasul	$2529 + 2.89005x – 2.76 \times 10^{-3}x^2$	0.90	*	250	525	3079^B	3286^A
URS-Taura	$2769 + 3.12254x – 2.71 \times 10^{-3}x^2$	0.99	*	250	575	3380^B	3668^A
General	$2135 + 3.87947x – 3.54 \times 10^{-3}x^2$	-	-	250	550	2884^B	3201^A

R^2: Determination coefficient; P(cx^2): angular parameter that measure the significance in 5% level of error probability; GP: grain productivity; (Y_E):value of grain productivity estimated by the regression model; RC: recommended; AJ: adjusted; FY: favorable year; AY: acceptable year; UY: unfavorable year. Means followed by same capital letter in the line do not differ statistically from one another by the Skott& Knott model in 5% level of error probability.

In Table 3 (biological productivity or total biomass), a linear behavior was also observed with the positive parameter of inclination and significant through the increment of the sowing density, regardless of oat cultivar, agricultural year and succession system. In the soybean/oats system, the use of the optimal density of sowing by the grain productivity in the model of linear regression of biological productivity, the favorable year to the farming (2013) evidenced the highest expression of total biomass. Also, in the general model, in soybean/oats, the density of 500 seeds m^{-2} adjusted to the higher productivity of grainsindicated an expectancy of biomass productivity of 8033 kg ha^{-1} higher than the biomass produced in comparison with the density of recommendation.

In the corn/oats system (Table 3), linear behavior was also observed.Besides that, the use of optimal density to grain productivity (Table 2) in the linear model of expression of biological productivity (Table 3) provided high values of total biomass mainly in the favorable year of farming (2013) with values higher than 9200 kg ha^{-1}.In corn/oats system, the density with 550 seeds m^{-2} adjusted to the highest grain productivity indicated an expectancy of biomass productivity of 8266 kg ha^{-1}, significantly higher than the recommended density. The increase of sowing density showed positive increment on the biological productivity, although the grain productivity evidenced quadratic behavior in defining an optimal sowing density to recommendation (Table 2). This fact raised the hypothesis that the tendency linearity obtained in the biological productivity possibly is due to the higher expression of the productivity directed to the elaboration of straw.

The density of plants per unit area is a decisive factor

Table 3. Regression equation and its parameters in estimative of biological productivity by the recommended and adjusted sowing density to the grain productivity (Y_E) in oats.

Cultivar	Equation (BP=a±bx)	R²	P (bx)	Density (s m^{-2})		Y_E	
				RC	AJ	RC	AJ
Soybean/Oats system							
2015 (AY)							
Brisasul	5339 + 2.72x	0.98	*	250	540	6019[B]	6808[a]
URS-Taura	5636 + 1.98x	0.88	*	250	570	6132[B]	6766[a]
2014 (UY)							
Brisasul	6286 + 3.99x	0.99	*	250	500	7283[B]	8279[A]
URS-Taura	6540 + 4.13x	0.99	*	250	505	7573[B]	8627[A]
2013 (FY)							
Brisasul	7098 + 3.71x	0.99	*	250	410	8025[B]	8618[A]
URS-Taura	7655 + 2.78x	0.99	*	250	420	8351[B]	8823[A]
General	6425 + 3.22x			250	500	7229[B]	8033[A]
Corn/Oats system							
2015 (AY)							
Brisasul	4196 +4.14x	0.99	*	250	570	5231[B]	6556[A]
URS-Taura	5404 + 4.05x	0.88	*	250	600	6417[B]	7835[A]
2014 (UY)							
Brisasul	6497 + 3.2x	0.97	*	250	520	7308[B]	8184[A]
URS-Taura	6661 + 2.89x	0.96	*	250	510	7383[B]	8133[A]
2013 (FY)							
Brisasul	7739 + 2.81x	0.95	*	250	525	8442[B]	9214[A]
URS-Taura	8749 + 1.66x	0.89	*	250	575	9163[B]	9702[A]
General	6541 + 3.14x	-	-	250	550	7325[B]	8266[A]

R^2: Determination coefficient; P(bx): angular parameter that measure the significance in 5% level of error probability; BP: biological productivity; Y_E: value of biological productivity estimated by the regression model; RC: recommended; AJ: adjusted; FY: favorable year; AY: acceptable year; UY: unfavorable year. Means followed by same capital letter in the line do not differ statistically from one another by the Skott& Knott in 5% level of error probability.

in the development of a speciesseeking the maximization of the production. Therefore, besides providing a higher grain productivity, it may potentialize the biomass area^{-1} (Valério et al., 2008). Abreu et al. (2006) noted that the seed sowing periods and the cycle of oat cultivars presented significant effect in the biomass production, directly interacting in the best adjustment of population density. Fleck et al. (2009) considered that in early stages of plant development the high population favors the fast soil coverage with benefits in the protection against erosion and weed reduction. In this context, Schuch et al. (2000) discussed the importance of the fast biomass accumulation in oat, conditionstrengthened by the biomass production rate and uniformity of emergency, and the latter, directly related to the vigor of the seeds. The increment of the tiller number and/or plants per unit area indicated a strong participation in the biomass production, important aspect to increase the biological productivity (Silveira et al., 2010; Silva et al., 2015). The productivity of total biomass, also denominated biological productivity, is directly linked to the photosynthesis and respiration process in the vegetative and reproductive phases (Demétrio et al., 2012; Silva et al., 2015). Harvest index is an important parameter to determinethe efficiency with which thephoto-assimilates are converted in straw and grains (Silva et al., 2012, 2015). The increase in the plant population of white oats resulted in elevation of the growing rate of the oat and of biomass productivity per area (Abreu et al., 2006; Romitti et al., 2016). In the soybean/oats succession system, Silva et al. (2012) observed most evident increases of expression of the biological and grains productivity in relation to the corn/oats system, favored by the higher N-residual availability.

Table 4. Regression equation and its parameters in estimated of straw productivity by the recommended and adjusted sowing density to the grain productivity Y_E in oats.

Cultivar	Equation (SP=a±bx)	R²	P (bx)	Density (s m^{-2})		Y_E	
				RC	AJ	RC	AJ
Soybean/Oats system 2015(AY)							
Brisasul	$2397+2.332x$	0.97	*	250	540	2980^B	3656^A
URS-Taura	$2586+1.162x$	0.82	*	250	570	2877^A	3248^A
2014 (UY)							
Brisasul	$3703+3.997x$	0.92	*	250	500	4702^B	5702^A
URS-Taura	$3698+4.134x$	0.93	*	250	505	4732^B	5786^A
2013 (FY)							
URS-Taura	$4354+3.163x$	0.97	*	250	420	5145^B	5682^A
General	$3355+3.124x$			250	500	4136^B	4917^A
Corn/Oats system 2015(AY)							
Brisasul	$1968+3.339x$	0.90	*	250	570	2803^B	3871^A
URS-Taura	$3211+2.814x$	0.94	*	250	600	3915^B	4899^A
2014 (UY)							
Brisasul	$3858+3.184x$	0.92	*	250	520	4654^B	5514^A
URS-Taura	$3737+3.190x$	0.90	*	250	510	4535^B	5364^A
2013 (FY)							
Brisasul	$4410+2.411x$	0.93	*	250	525	5013^B	5676^A
URS-Taura	$5760+1.649x$	0.99	*	250	575	6172^B	6708^A
General	$3824+2.764x$	-	-	250	550	4515^B	5344^A

R^2: Determination coefficient; P(bx): angular parameters that measure the significance in 5% level of error probability; SP: straw productivity;Y_E: value of straw productivity estimated by de regression model; RC: recommended; AJ: adjusted; FY: favorable year; AY: acceptable year; UY: unfavorable year. Means followed by same capital letter in the line do not differ statistically from one another by the Skott & Knott model in 5% level of error probability.

Table 4 showed a linear behavior with positive parameter of inclination through the increment of the seeds density. In the use of the optimal density of sowing to the grain productivity in the linear regression model of the straw productivity, the use of the adjusted density showed favorability to the straw elaboration in the increment of seeds density, except in the URS Taura cultivar in acceptable year of cultivation (2015), which did not show any changes. In the general model in soybean/oat system, regardless of agricultural year and oat cultivar, the density of 500 seeds m^{-2} adjusted to the highest grain productivity, it indicated an expectancy of straw productivity of 4917 kg ha^{-1}, higher than the recommended sowing density with 4136 kg ha^{-1}, increase in almost 800 kg ha^{-1} of straw directed to the soil.

In the corn/oats system (Table 4), the favorability of expression of the straw productivity through the adjusted density was also statistically different to the recommended sowing density in all the conditions. In the general model in corn/oats system, regardless of agricultural year and oat cultivar, the density of 550 seeds m^{-2} adjusted to the highest grain productivity indicated an expectancy of straw productivity of 5344 kg ha^{-1}, higher than the density of recommendation with 4515 kg ha^{-1}, increasing in morethan 800 kg ha^{-1} of straw directed to the soil. It is possible to highlight the favorability of expression of the straw productivity in the corn/oats in comparison to the soybean/oats system, suggesting that the system of higher N-residual release (soybean/oats) promotesmore pronounced effects on grains elaboration than straw, unlikethe corn/oats system.

Studies carried out with different winter's species showed the elevated performance of the white oat in the straw productivity seeking the soil protection. The straw productivity is essential as organic residue to the succession cultures, promotes improvement of the physical and chemical quality of the soils,erosion control and soil resistance to compaction (Marchãoet al., 2007; Silva et al., 2015). The use of the black oat straw on the soil coverage reduced the infestation of invasive plants, benefitting the productivity of soybean (Fleck et al., 2009).

The elevated performance of the white oat in the straw production seeking the soil protection qualities, direct sowing system, which is directly dependent of the volume and quality of the biomass (Silva et al., 2008). Oliveira et al. (2011) commentedon the importance of detecting the genetic differences among the oat cultivars in the straw and grains production. The growth and the biomass production in the oat are stronglylinked to the nitrogen availability, index of leaf area, photoperiod, temperature, sun radiation and hydric availability (Almeida et al., 2011; Mantai et al., 2016). Therefore, the use of sustainable and low cost technologies such as the management of vegetation cover, the use of N-residual and the adjustment of the sowing density in oat may favor the straw productivity which returns to the soil on the erosion control, moisture maintenance and protection of the culture in early stage (Silva et al., 2012; Romitti et al., 2016).

In Table 5, regardless of oat cultivar, agricultural year and succession system, the increment of the sowing density on the harvest index presented quadratic behavior. In the soybean/oats system, the use of the optimal sowing density to the grain productivity in the quadratic regression model to the predictability of the harvest index indicated absence of differences between the recommended and adjusted density. However, in acceptable year of cultivation (2015), the URS Tauracultivar presented the highest expression of the harvest index with the adjusted density. In the general model, in soybean/oats system, regardless of agricultural year and oat cultivar, the adjusted and recommended seeds density did not differ on the expression of the harvest index, with an estimated value of 0.44. In the general model, in corn/oats system, no differences were observed; however, there wasa reduction of expression of this variablein this cultivation condition, with harvest index of 0.40. The results obtained suggested that the increase of the adjusted density, besides presenting the highest expression to the grain productivity (Table 2), also favored the straw productivity (Table 4) in the same proportion. Therefore, not changing the relation between straw and grains, and consequently, maintaining the expression of the harvest index between recommended and adjusted seed density. The results obtained on the harvest index, reasserted what was mentioned about the corn/oats system, through a higher expression of straw productivity than in the soybean/oats system. Therefore, a higher straw production directly decreases the expression of harvest index.

Duarte et al. (2013) considered the harvest index an identification component of peanut genotypes tolerant to water stress. In corn cultivation, the harvest index was used in the identification of agronomic performance to different climate scenarios in Central-West of Brazil (Minuzzi and Lopes, 2015). Fageria et al. (2007) commentedon the necessity of analysis of the harvest index in studies with rice, because it is closely associated with the increase of the grain productivity.Ludwig et al. (2010)used the analysis of the productivity and the harvest indexin the definition of soybean cultivars better adjusted to the period and the sowing density.Silva et al. (2015)observed a higher increment of expression of the harvest index in oat cultivation on the soybean/oats system in comparison to the corn/oats through the higher expression of the productivity directed to grains. The same authors also observed a strong plasticity of the oat cultivars to the increase of the sowing density, condition that may favor higher stability of the harvest index by the maintenance of the relation between straw and grains, condition also observed in this study.The isolated analysis of the harvest index does not allow identification of efficient managements,because, the grain productivity is also dependent on the minimum adequate expression of leaves and stems in the biomass composition (Silva et al., 2015). Schaedler et al. (2009) studying white oat cultivars of mid and late cycle obtained harvest index varying from 0.33 to 0.48.

Conclusion

In the increment of the sowing density in oats, the biological and straw productivity evidenced linear behavior and the grains productivity and the harvestindex evidenced quadratic behavior, regardless of cultivar, agricultural year and succession systems.

It is possible to indicate higher sowing density to the maximization of the biomass and grains productivity, withdensity adjusted around 500 seeds m^{-2} in the main succession systems.

In cultivars of high and reduced tillering, the adjusted density in relation to the recommended sowing density enhanced the biological and straw productivity, regardless of agricultural year and succession system.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

Table 5. Regression equation and its parameters in estimative of harvest index by the recommended and adjusted sowing density to the grain productivity (Y_E) in oats.

Cultivar	Equation ($HI = a \pm bx \pm cx^2$)	R²	P (cx^2)	Density (s m^{-2})		Y_E	
				RC	AJ	RC	AJ
Soybean/Oats system							
2015 (AY)							
Brisasul	$0.42 + 5.50.10^{-4}x - 6.6 \times 10^{-7}x^2$	0.95	*	250	540	0.52^A	0.52^A
URS-Taura	$0.39 + 8.39.10^{-4}x - 8.5 \times 10^{-7}x^2$	0.99	*	250	570	0.55^B	0.59^A
2014 (UY)							
Brisasul	$0.30 + 3.59.10^{-4}x - 5.0 \times 10^{-7}x^2$	0.89	*	250	500	0.36^A	0.35^A
URS-Taura	$0.32 + 4.03.10^{-4}x - 5.5 \times 10^{-7}x^2$	0.99	*	250	505	0.39^A	0.38^A
2013 (FY)							
Brisasul	$0.42 + 2.55.10^{-4}x - 4.4 \times 10^{-7}x^2$	0.91	*	250	410	0.46^A	0.45^A
URS-Taura	$0.38 + 5.61.10^{-5}x - 2.0 \times 10^{-7}x^2$	0.89	*	250	420	0.38^A	0.37^A
General	$0.37 + 4.10.10^{-4}x - 5.3 \times 10^{-7}x^2$		*	250	500	0.44^A	0.44^A
Corn/Oats system							
2015 (AY)							
Brisasul	$0.35 + 7.03.10^{-4}x - 8.2 \times 10^{-7}x^2$	0.99	*	250	570	0.47^A	0.48^A
URS-Taura	$0.33 + 3.84.10^{-4}x - 4.2 \times 10^{-7}x^2$	0.99	*	250	600	0.40^A	0.41^A
2014 (UY)							
Brisasul	$0.29 + 4.79.10^{-4}x - 5.8 \times 10^{-7}x^2$	0.94	*	250	520	0.37^A	0.38^A
URS-Taura	$0.35 + 3.07.10^{-4}x - 4.6 \times 10^{-7}x^2$	0.99	*	250	510	0.40^A	0.39^A
2013 (FY)							
Brisasul	$0.36 + 2.24.10^{-4}x - 2.9 \times 10^{-7}x^2$	0.91	*	250	525	0.40^A	0.40^A
URS-Taura	$0.30 + 1.81.10^{-4}x - 2.3 \times 10^{-7}x^2$	0.98	*	250	575	0.33^A	0.33^A
General	$0.33 + 3.79.10^{-4}x - 4.6 \times 10^{-7}x^2$		*	250	550	0.40^A	0.40^A

R^2: Determination coefficient; P(cx^2): angular parameter that measure the significance in 5% level of error probability; HI: harvest index; $\mathbf{Y_E}$: value of harvest index estimated by the regression model;RC: recommended; AJ: adjusted; FY: favorable year; AY: acceptable year; UY: unfavorable year. Means followed by same capital letter in the line donot differ statistically from one another by the Skott& Knott model in 5% level of error probability.

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