Yield components of soybean cultivars under sowing densities

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ABSTRACT

The aim of this study was to assess yield components and grain yield of soybean cultivars in response to sowing densities. For this, two soybean cultivars and five sowing densities were tested, in a two-factor scheme. The following yield components were measured by the end of the cycle: plant height; insertion height of the first pod; number of nodes per plant; number of pods with one, two, three and four grains; number of pods per plant; number of grains per plant; weight of a thousand grains; humidity and grain yield. Sowing densities did not cause significant variations of grain yield (bags ha^{-1}) for any cultivar, however, higher populational densities promoted a reduction in the number of pods with two and three grains, as well as a reduction in the total number of pods and grains per plant for both cultivars. Cultivar NS 5700 IPRO was the most productive, with a higher number of pods with two and three grains and number of pods and grains per plant.

Keywords: *Glycine max;* plant population; plasticity; grain yield

INTRODUCTION

Soybean [*Glycine max* (L.) Merrill] is the most cultivated legume in the world. In Brazil, soybean production has increased significantly over the last few years, with a record production of 120.93 million tons in the 2019/2020 harvest, representing a 5.1% increase compared to the previous growing season (Conab, 2020). This yield increase stems mainly from intense plant breeding programs that result in annual launches of ever more productive and adapted genotypes, as well as from the improvement and development of management techniques that allow the maximum performance of cultivars (Sediyama *et al.*, 2015).

Among soybean management techniques, cultivar choice and sowing density are some of the factors that influence soybean yield components, and consequently, grain yield the most (Mauad *et al.*, 2010). An adequate plant population is determinant for the spatial arrangement of plants, once it interferes with the closing speed of interlines (Balbinot Junior *et al.*, 2016; Masino *et al.*, 2018), which directly affects light, water and nutrient uptake (Procópio *et al.*, 2013), and therefore, plant growth and yield (Lima *et al.*, 2012).

In general, at low densities, soybean plants tend to produce fewer branches and increase the number of pods per plant, thus compensating for the lower number of individual plants per area with higher production per plant. On the other hand, at high densities, there is less branch production, and the production of each plant is smaller and more dependent on the main branch (Ferreira *et al.*, 2016; Werner *et al.*, 2016; Ferreira *et al.*, 2018).

However, this response can be affected by soybean's high plasticity, which consists of the ability to adapt to environmental and management conditions, through morphological changes and yield components, to adapt

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them to the available space and the competition condition imposed by the arrangement of plants, thus maintaining its yield even in face of significant variations in plant density (Lopes & Lima,2015; De Luca *et al.*, 2014; Cruz *et al.*, 2016; Ferreira *et al.*, 2018).

Moreover, genotypes may respond differently to sowing densities, which means a certain cultivar can be more productive in either higher or lower populations (Soares *et al.*, 2015). In this sense, while some authors have verified sowing densities may interfere with soybean yield (Soares *et al.*, 2015; Balbinot Junior *et al.*, 2016), others have found this characteristic did not variate as a function of plant population (Procópio *et al.*, 2013; Ribeiro *et al.*, 2017). Therefore, the aim of this study was to assess yield components and grain yield of soybean cultivars in response to sowing densities.

MATERIAL AND METHODS

The experiment was carried out in farm fields (27º 52' 28" S, 53º 49' 57" W, 491 meters above sea level) located in the municipality of Santo Augusto in the state of Rio Grande do Sul (RS), Brazil, during the 2019/2020 agricultural harvest. In this region, the climate is classified as Cfa (Humid subtropical climate), according to Köppen-Geiger's classification, and the majority of soils from cultivation areas are classified as Latosolic Dystropheric Red Nitosol (Cunha *et al.*, 2004).

Cultivars NS S700 IPRO and NS 6010 IPRO were used in the experiments at five sowing densities (12.20, 13.64, 14.08, 14.92 and 15.46 seeds per meter), in a two-factor scheme and a randomized block design with three repetitions. Seeds were previously treated with Fortenza® Duo (Fortenza 600 FS® + Cruiser® 600 FS + Maxim Advanced®), inoculated with Atmo® (*Bradyrhizobium japonicum*), and co-inoculated with AzzoFix® (*Azospirillum brasilense*, strains AbV5 and AbV6), besides adding micronutrients (SynFlex® and Glutamin CoMo®).

Before sowing, herbicide (Shadow®) was applied to minimize weed incidence. Sowing was performed on November 20th, 2019, at a 6 km h^{-1} speed, 4 cm depth and 45 cm spacing between lines. Base fertilization was carried out with 270 kg ha^{-1} of a 2-23-23 ($N–P_2O_5–K_2O$) commercial formula in the sowing lines, and 20 days after seedling emergence, 120 kg ha^{-1} KCl (60% K_2O) were applied manually. Sowing plots measured 3.15 m × 20 m, and each plot had seven sowing lines. In order to quantify the final population of emerged plants (Table 1), 20 days after sowing, the number of plants was accounted six times within 10 m in the two central lines of the plot.

Three insecticide and fungicide applications were performed, the first being on January 14th, 2020 (Elatus®, Cypress® 400 EC, Premio® and Agrex'Oil®) when plants were at the R1 stage (beginning of flowering - 50% of plants with one flower). The second application was on February 2nd, 2020 (Nomolt® 150, Batent®, Fox®, Engeo Pleno™ S, Cuprozin Ultra® and Agrex'Oil®) when plants were at the R4 stage (most pods in the upper third with 2 to 4 cm in length), and the third one, on February 22nd, 2020 (Cronnos®, Engeo Pleno™ S, Premio® and Agrex'Oil®) when plants were at the R5.3 stage (most pods between 25 and 50% graination). All products were used following dosage recommendations for soybean crop.

Plots were manually harvested on March 21st, 2020, when plants were at the R8 stage, only from 1 m of the central line of each plot. Next, the following yield components were assessed: plant height (cm); insertion height of the first pod (cm); number of nodes per plant; number of pods with one, two, three and four grains; number of pods per plant; number of grains per plant; weight of a thousand grains (grams); and grain yield (bags ha^{-1}). For statistical analyses, the weight of a thousand grains and grain yield were corrected to 13% humidity.

Table 1: Final population of plants in relation to the sown density

Treatment	Cultivar	Sown density (20/11/2019)		Final Population (10/12/2019)	
		Plants m^{-1}	Plants ha^{-1}	Plants m^{-1}	Plants ha^{-1}
T1	NS 5700 IPRO	12.20	271111	10.47	232593
T2	NS 5700 IPRO	13.64	303111	10.77	239260
T3	NS 5700 IPRO	14.08	312889	11.15	247778
T4	NS 5700 IPRO	14.92	331556	12.13	269630
T5	NS 5700 IPRO	15.46	343556	12.78	284075
T6	NS 6010 IPRO	15.46	343556	12.88	286297
T7	NS 6010 IPRO	14.92	331556	12.75	283334
T8	NS 6010 IPRO	14.08	312889	12.48	277408
T9	NS 6010 IPRO	13.64	303111	11.32	251482
T10	NS 6010 IPRO	12.20	271111	10.72	238149

For each variable, the components of variance were estimated using the following mathematical model:

$$Y_{ijk} = \mu + C_i + P_j + (CP)_{ij} + B_k + \varepsilon_{ijk}$$

where Y_{ijk} is the mean value observed of the response variable in plot *ijk*, *m* is the overall mean, C_i is the fixed effect of level *i* (*i* = 1, 2) of the cultivar factor, P_j is the fixed effect of level *j* (*j* = 271111, 303111, 312889, 331556, 343556) of the population factor, $(CP)_{ij}$ is the interaction effect of level *i* of the cultivar factor with level *j* of the population factor, β_k is the random effect of the block (k = 1, 2 and 3) and ε_{ijk} is the effect of the experimental error, considered normal and independently distributed with a mean of zero and a common variance σ^2 (Storck *et al.*, 2016). From the significance of the factors under study, means were grouped through Scott-Knott test (Scott & Knott, 1974) at 5% probability of error for cultivars and, for the population factor, a regression analysis was performed. All analyses were performed using Microsoft Office Excel and Sisvar software (Ferreira, 2011).

RESULTS AND DISCUSSION

Figure 1 shows the weather conditions recorded during the experimental period, where rainfall up to 430 mm was accumulated, with uneven distribution, and the mean temperature oscillated from 14.30 to 29.25 ºC, which is over soybean basal temperature (Soltani & Sinclair, 2012), indicating adequate thermal conditions for the development of the crop. Also, as expected, the final number of plants per meter did not differ between cultivars and had a linear growing response between plant populations (Figure 2a).

The insertion height of the first pod differed between cultivars, in which cultivar NS 6010 IPRO obtained the highest value (23.30 cm), and also between populations, in which higher populations promoted higher heights (Figure 2b). Similarly, some authors (Mauad *et al.*, 2010; Cruz *et al.*, 2016; Ribeiro *et al.*, 2017) have observed increases in the insertion height of the first pod as sowing density was elevated. An explanation for this is high sowing density may harm sunlight uptake, resulting in plant etiolation (Mauad *et al.*, 2010; Cruz *et al.*, 2016). This characteristic is extremely important since great increases in the insertion height of the first pod may be disadvantageous, once this leads to the formation of plants with low stem exploration, decreasing the productive potential of the crop (Ribeiro *et al.*, 2017). However, if too low, there might be great harvest losses as well, considering the height of the harvester cutting bar (Mauad *et al.*, 2010; Cruz *et al.*, 2016).

As the majority of pods from both cultivars had three grains, the number of pods with one and four grains was low in all conditions tested, in which there was no effect of any source of variation (Table 2) and no model adjusted to the testing populations (Figures 2c and 3c). Nevertheless, the occurrence of pods with two and three grains differed only between cultivars, with higher means obtained for cultivar NS 5700 IPRO, of 10.39 and 38.95, respectively (Table 2). Accordingly, this cultivar also presented a higher number of pods and number of grains per plant. However, although no significant differences were observed between populations for those variables through the analysis of variance, linear decreasing models were significant, suggesting population increase tends to reduce the number of pods with two and three grains, the total number of pods per plant, and consequently, the number of grains per plant (Figures 3a and b).

Also, the number of nodes on the main stem differed between cultivars and populations (Table 2), in which cultivar NS 5700 IPRO presented a higher mean (18,35) and, in general, population increase reduced the number of nodes (Figure 4b). Possibly, these results reflect the increase in inter and intraspecific competition for soil resources, such as water and nutrients, caused by high sowing densities, which reduced the number of ramifications where reproductive gems develop, hence reducing the number of pods per plant, and therefore, the number of grains (Mauad *et al.*, 2010; Ramos Junior *et al.*, 2019). Another issue that should be taken into account is that population density increase can result in alterations in the microclimate inside the canopy (Masino *et al.*, 2018), which might increase the incidence of pests and diseases (Farias *et al.*, 2019). This could also affect yield components, especially considering the elevated accumulated rainfall amount observed on some days during the cycle (Figure 1).

On the other hand, the weight of a thousand grains was higher for cultivar NS 6010 IPRO and was not significantly influenced by plant population (Table 2 and

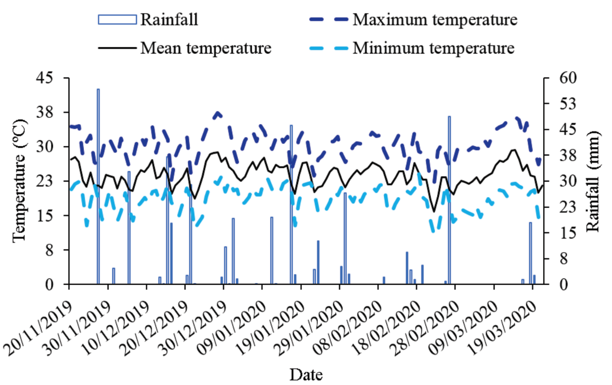

Figure 1: Maximum, mean and minimum air temperatures and rainfall regime corresponding to the experimental period, in Santo Augusto, RS, Brazil.

Figure 5b). Such a result represents intrinsic genetic characteristics of the cultivar, such as its higher resistance to hydric stress, compared with cultivar NS 5700 IPRO. Also, another characteristic that should be considered is the maturity group (MG) of both cultivars, since cultivar NS 5700 IPRO has an MG of 5.7, whereas the MG of cultivar NS 6010 IPRO is 6.0. Thus, cultivars with longer cycles, such as NS 6010 IPRO, in this case, tend to accumulate a

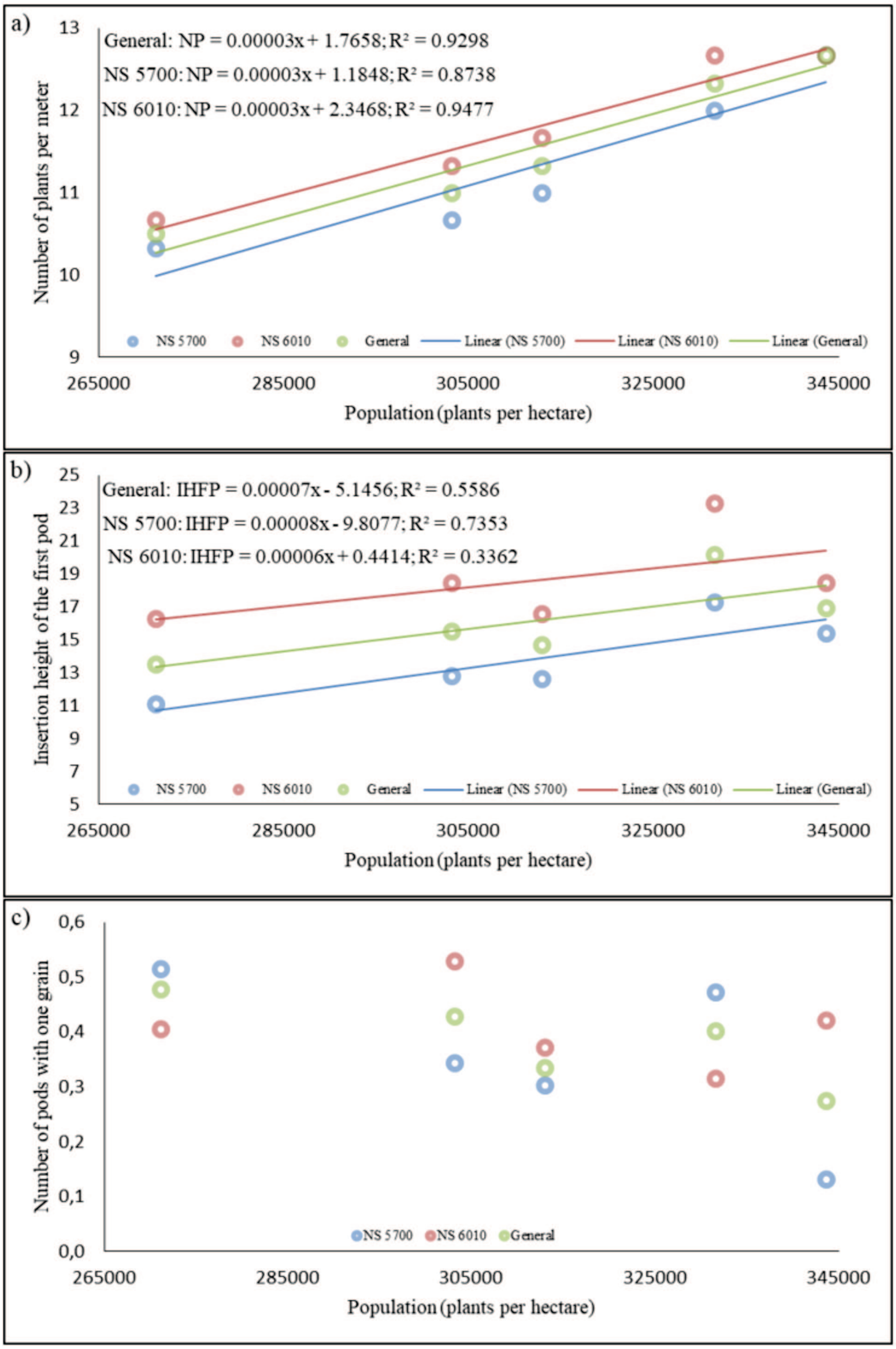

Figure 2: Effect of soybean cultivars and plant populations on: a) number of plants per meter, in units; b) insertion height of the first pod, in centimeters; and, c) number of pods with one grain, in units per plant, in Santo Augusto, RS, Brazil, during the 2019/2020 harvest.

Table 2: Abstract of the analysis of variance with the sources of variation (SV), degrees of freedom (DF) and the mean squares of the analysis of variance with the respective significance, coefficient of experimental variation (CV, in %) and the means of the variables evaluated for two soybean cultivars and five sowing populations during the 2019/2020 harvest in Santo Augusto, RS, Brazil

SV	DF	NP(1)	IHFP	P1G	P2G	P3G	P4G
		Mean Square					
Block	2	0.23 ns	183.45*	0.15 ns	10.88 ns	254.95*	0.07 ns
Cultivar	1	1.63 ns	189.25*	0.02 ns	18.99*	1078.48*	0.04 ns
Population	4	4.97*	39.09*	0.04 ns	9.24 ns	92.17 ns	0.03 ns
Interaction	4	0.13 ns	2.82 ns	0.07 ns	2.62 ns	17.76 ns	0.05 ns
Error	18	0.71	7.97	0.10	3.75	41.64	0.03
CV	%	7.31	17.47	83.94	20.18	16.55	107.49
Cultivar	**Population**	Mean					
NS 5700 IPRO	271111	10.33	11.10	0.52	11.03	51.13	0.23
NS 5700 IPRO	303111	10.67	12.82	0.34	12.00	45.78	0.00
NS 5700 IPRO	312889	11.00	12.66	0.30	11.48	44.09	0.06
NS 5700 IPRO	331556	12.00	17.31	0.47	8.81	42.53	0.25
NS 5700 IPRO	343556	12.67	15.39	0.13	8.08	38.95	0.05
Mean NS 5700 IPRO		11,33a	13.65b	0.36a	10.39a	44.99a	0.12a
NS 6010 IPRO	271111	10.67	16.28	0.41	9.72	37.63	0.16
NS 6010 IPRO	303111	11.33	18.47	0.53	10.00	33.50	0.12
NS 6010 IPRO	312889	11.67	16.59	0.37	8.09	33.86	0.40
NS 6010 IPRO	331556	12.67	23.30	0.32	7.87	28.11	0.16
NS 6010 IPRO	343556	12.67	18.47	0.42	8.32	32.08	0.18
Mean NS 6010 IPRO		11.80a	18.68a	0.41a	8.80b	33.00b	0.20a
Overall Mean		11.57	16.17	0.38	9.59	38.99	0.16

SV	DF	PH	NN	PP	GP	MTG	GY
		Mean Square					
Block	2	284.26*	8.13*	371.67*	2136.91*	523.90 ns	116.45 ns
Cultivar	1	661.81*	5.41*	1344.62*	8632.57*	1865.19*	670.85*
Population	4	8.22 ns	4.59*	156.75 ns	841.03 ns	365.28 ns	46.02 ns
Interaction	4	2.27 ns	0.44 ns	26.49 ns	164.66 ns	287.36 ns	15.65 ns
Error	18	21.97	0.94	69.24	496.73	293.33	115.99
CV	%	4.85	5.41	16.92	18.38	11.58	14.42
Cultivar	**Population**	Mean					
NS 5700 IPRO	271111	94.41	18.97	62.90	152.19	142.75	82.98
NS 5700 IPRO	303111	90.36	18.66	58.13	141.91	143.69	80.43
NS 5700 IPRO	312889	90.91	18.82	55.94	143.33	133.59	77.84
NS 5700 IPRO	331556	92.24	17.61	52.06	129.53	136.53	77.49
NS 5700 IPRO	343556	91.98	17.26	47.21	116.71	143.49	78.30
Mean NS 5700 IPRO		91,89b	18.35a	55.86a	138.21a	140.01b	79.41a
NS 6010 IPRO	271111	101.87	18.13	48.19	117.16	156.08	71.97
NS 6010 IPRO	303111	99.73	17.91	44.15	108.74	163.10	73.99
NS 6010 IPRO	312889	101.33	18.54	42.71	107.74	137.70	63.66
NS 6010 IPRO	331556	101.33	16.08	36.45	87.97	174.21	70.82
NS 6010 IPRO	343556	101.62	16.89	41.00	100.58	147.82	69.30
Mean NS 6010 IPRO		101.28a	17.50b	42.48b	104.28b	155.78a	69.95b
Overall Mean		96.58	17.92	49.17	121.25	147.90	74.68

(1) NP: number of plants per meter at harvest, in units; IHFP: insertion height of the first pod, in centimeters; P1G: pods with one grain, in units per plant; P2G: pods with two grains, in units per plant; P3G: pods with three grains, in units per plant; P4G: pods with four grains, in units per plant; PH: plant height, in centimeters; NN: number of nodes on the main rod, in units; PP: pods per plant, in units; GP: grains per plant, in units; MTG: mass of a thousand grains, in grams; GY: grain yield, in bags per hectare. (2) Cultivars with general averages of the variable not followed by the same lowercase letter in the column differ from each other by the Scott-Knott test, at 5% probability of error. * Significant effect by F test at 5% probability of error. ns Not significant.

higher amount of photoassimilates in the grain, resulting in a higher grain weight as observed by Silva (2016).

As for plant height, cultivar NS 6010 IPRO produced the highest plants, with mean values of 101.28 cm (Table 2). However, plant population did not interfere with this characteristic (Figure 4a). Similar results were obtained by Procópio *et al.* (2013), Balbinot Junior *et al.* (2016) and Ribeiro *et al.* (2017), where plant height was not influenced

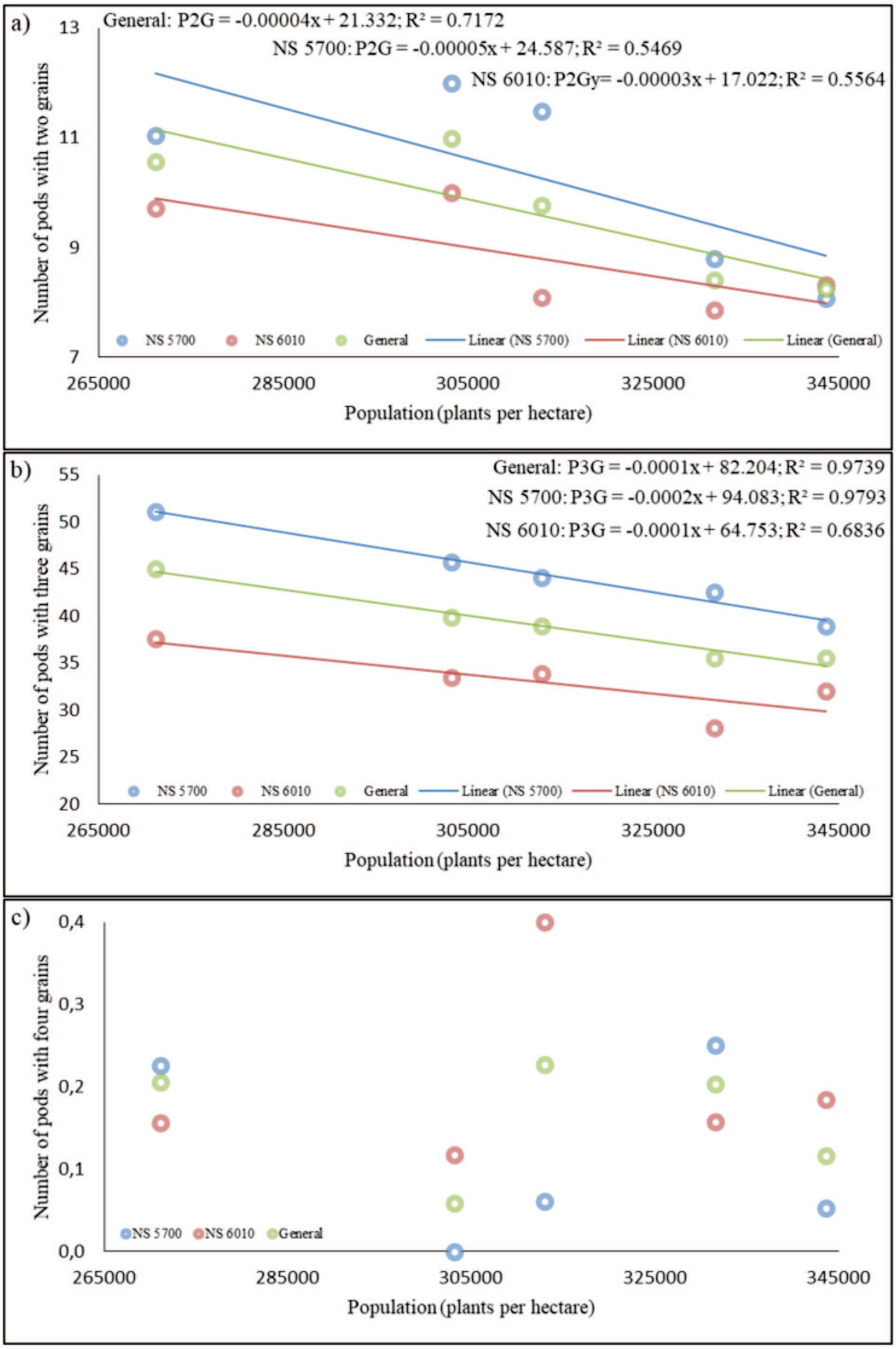

Figure 3: Effect of soybean cultivars and plant populations on: a) number of pods with two grains; b) number of pods with three grains; and, c) number of pods with four grains, in units per plant, in Santo Augusto, RS, Brazil, during the 2019/2020 harvest.

by variations in sowing densities. As highlighted by these authors, this may be a consequence of soybean's high phenotypic plasticity, which, as previously mentioned, attributes to plants a high capacity of changing their morphology and, also, grain yield according to plant density, promoting the maintenance of grain yield in high plant populations (De Luca *et al.*, 2014; Lopes & Lima, 2015; Cruz *et al.*, 2016; Ferreira *et al.*, 2018). In this sense, this

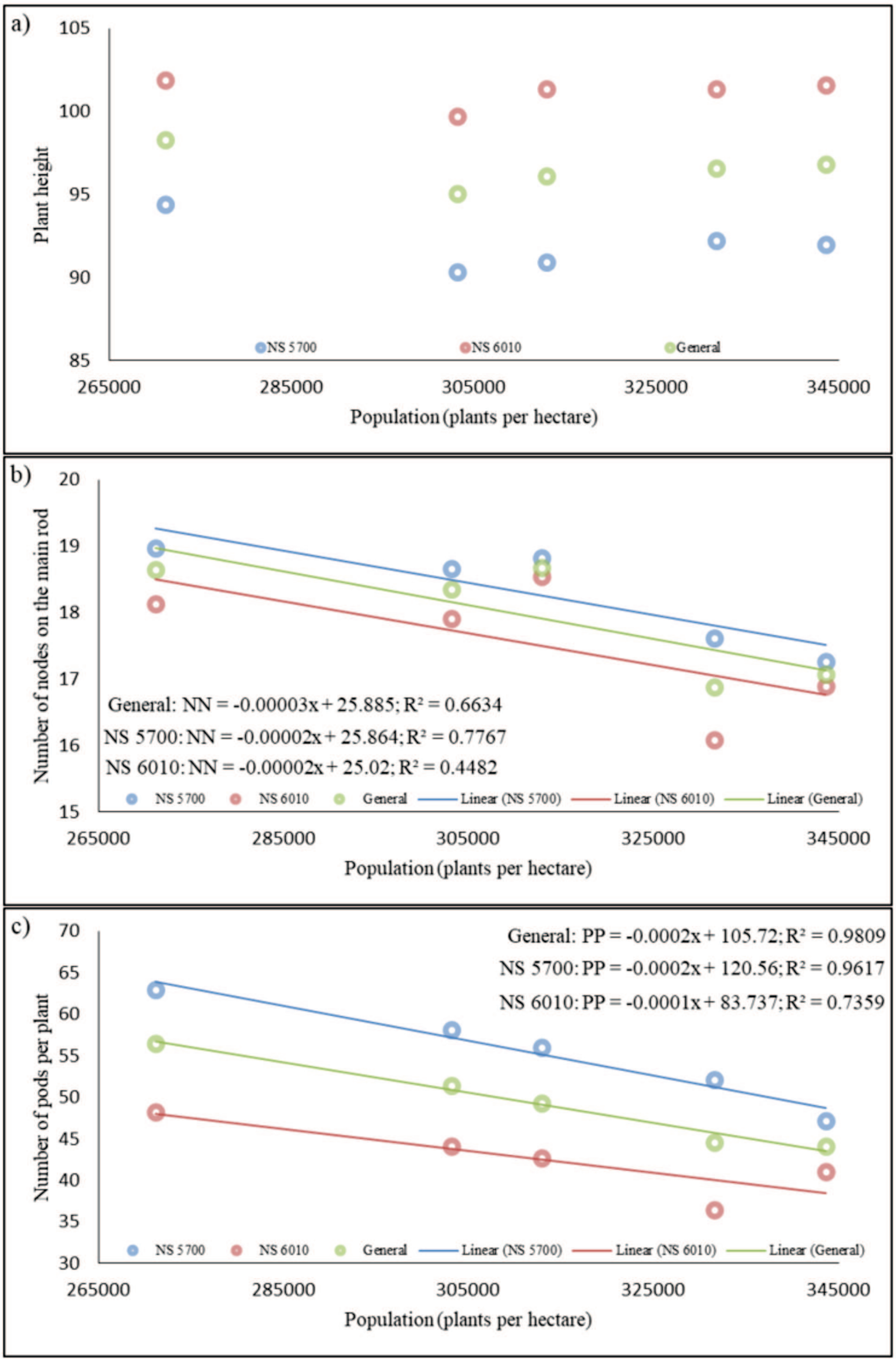

Figure 4: Effect of soybean cultivars and plant populations on: a) plant height, in centimeters; b) number of nodes on the main rod, in units; and, c) number of pods per plant, in units, in Santo Augusto, RS, Brazil, during the 2019/2020 harvest in Santo Augusto – RS.

fact may also explain why grain yield differed only between cultivars but did not variate between populations (Figure 5c), which also indicates the higher number of plants at high densities compensated for the lower production of pods and grains per plant. As for cultivars, the highest grain yield was observed for NS 5700 IPRO, since it had the highest number of pods with two and three grains, and the highest number of pods and grains per plant (Table 2).

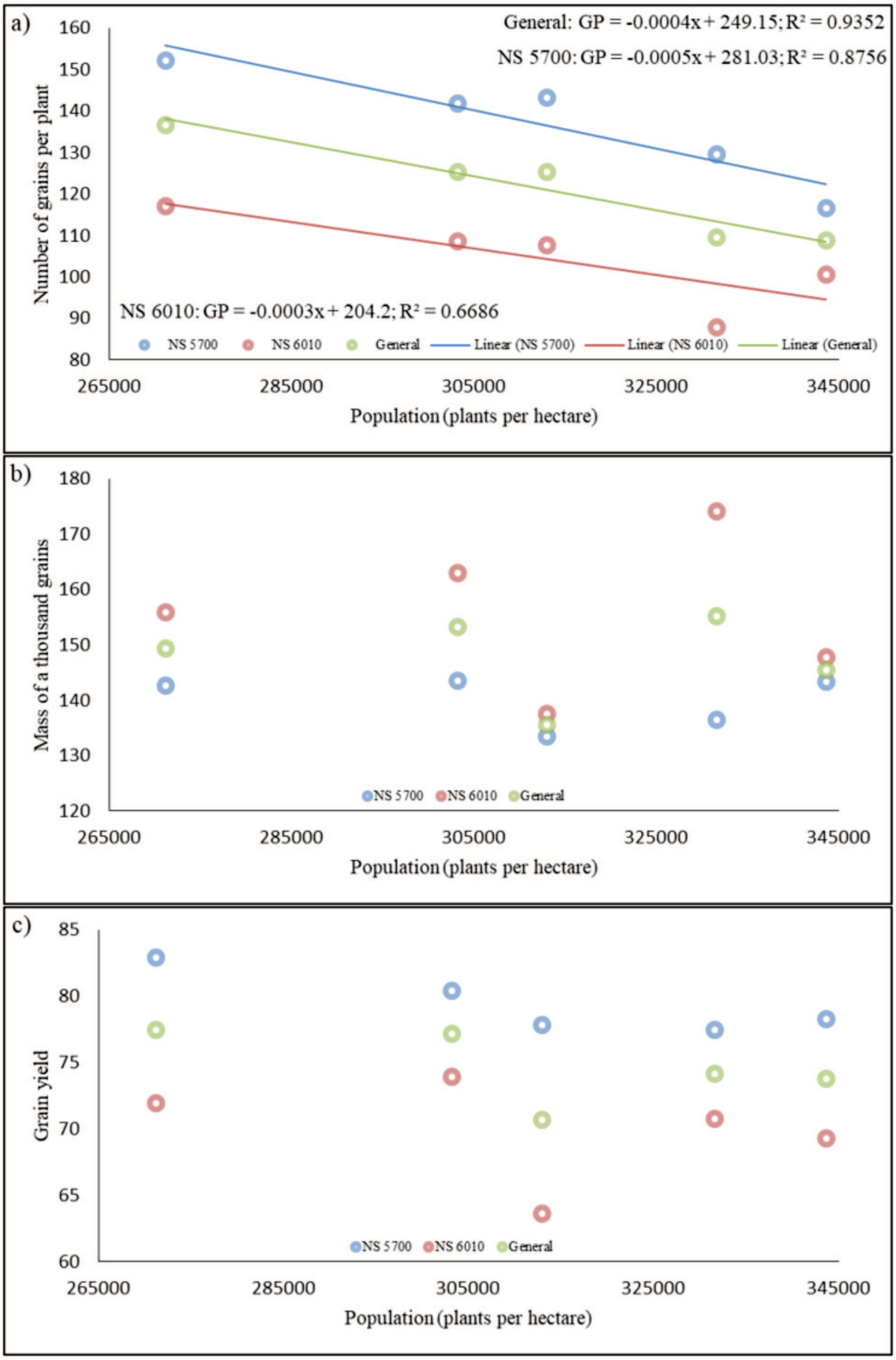

Figure 5: Effect of soybean cultivars and populations on: a) number of grains per plant, in units; b) mass of a thousand grains, in grams; and c) grain yield, in bags per hectare, in Santo Augusto, RS, Brazil, during the 2019/2020 harvest in Santo Augusto – RS.

CONCLUSION

Although cultivar NS 5700 IPRO was more productive than cultivar NS 6010 IPRO, both proved to be more productive when submitted to lower sowing densities, making densities between 271111 and 303111 plants ha^{-1} the most indicated for their cultivation in the conditions under study.

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