Corn hybrids grain yield submitted to different sowing densities in the medium-high Uruguay region of Rio Grande do Sul[1]

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ABSTRACT

The use of corn hybrids adapted to the soil and climate conditions of the cultivation region under adequate optimum plant density is a determining factor for the maximization of grain yield. In this sense, the objective was to evaluate the productivity of corn hybrids under two sowing densities during the 2020/21 crop season in the medium-high Uruguay region of the state of Rio Grande do Sul. The corn hybrids AS1555 PRO3, B2401 PWU, B2418 VYHR, B2612 PWU, BG7061 YHR, DKB235 PRO3, NS45 VIP3, NS73 VIP3, NS80 VIP3, P2501, P3016 VYHR, P3565 PWU and 30F53 VYHR were submitted to densities of 66,667 and 88,889 plants ha^{-1}, in a randomized block design with ten replications. Corn hybrids showed superior grain yield when subjected to the density of 88,889 plants ha^{-1} in the medium-high Uruguay region of Rio Grande do Sul, surpassing in most cases the state and national average yield of harvest 2020/21. Most of the corn hybrids used present potential for cultivation at higher sowing density than their respective recommendations. Considering the superior productivity of hybrids NS80 VIP3, B2401 PWU and NS73 VIP3, their cultivation under conditions similar to those of the study is recommended.

Keywords: cultural management; production potential; *Zea mays*.

INTRODUCTION

Corn (*Zea mays* L.) is considered one of the main cereals grown in the world, being the raw material for the production of various products intended for human and animal feed, mainly by the good carbohydrate, protein and lipid contents of its grains (Szareski *et al.*, 2018). Its economic and nutritional importance is concentrated in agroindustrial chains, where more than half of the world's grain production is destined for the production of animal feed (Erenstein *et al.,* 2022). In addition, the grain has energy potential, being used in the production of fuel ethanol (biofuel additive for gasoline) (Ranum *et al.*, 2014).

The largest commodity-producing countries are the United States, China and Brazil, responsible for approximately 31%, 23% and 11% of the total corn production, respectively (USDA, 2022). The Brazilian production is the result of the cultivation of three annual crops, which together exceed 22.3 million hectares, with average productivity of 5,922 kg ha^{-1} (CONAB, 2022).

The productive potential of corn can be divided into three genotypic components: productivity per plant, response capacity to agricultural inputs, and tolerance to biotic and abiotic stresses (Testa *et al.*, 2016). Aiming to maximize the productive efficiency of the cereal, continuous modifications have been made in plant architecture,

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thus improving the response of corn hybrids to conditions of high intraspecific competition, unfavorable climate and/or low soil fertility (Testa *et al.*, 2016). The changes in leaf angle have provided the increase in leaf area index and photosynthetic efficiency, as well as, the changes in the number of stomata and distance between vascular bundles, which have enabled to increase in the tolerance of plants to water stress (Souza *et al.*, 2013; Li *et al.*, 2015a; Gong *et al.*, 2015). On the other hand, the root system architecture is still considered a limiting factor for further technical advances (water and nutrient efficiency) (Lynch, 2013; Meister *et al.*, 2014; Postma *et al.*, 2014; Saengwilai *et al.*, 2014; Gong *et al.*, 2015; Zhan & Lynch, 2015).

That way, genetic and agronomic advances in the crop have provided the development of corn hybrids with better responses to agricultural inputs and greater tolerance to biotic and abiotic stresses of the growing environment (Ciampitti & Vyn, 2012; 2014; Haarhoff & Swanepoel, 2018; Schwalbert *et al.*, 2018; Szareski *et al.*, 2018). What made it possible to increase the grain yields and the average plant density used in the main producing countries (Assefa *et al.*, 2018). In this sense, high grain yields have often been attributed to the use of higher plant densities. This is because, among the productive components of the crop, plant density, the number of grains and ears per hectare, and grain mass, stand out for exerting a great impact on productivity (Assefa *et al.*, 2012; 2016; Ciampitti & Vyn, 2012; 2014; Testa *et al.*, 2016).

The relationship between sowing density and grain productivity cannot be assessed in isolation, as the impact of sowing density on grain yield depends on complex interactions between various factors, such as genotype, maturity group and sowing date, soil type, water and nutritional availability (Assefa *et al.*, 2016; Bernhard & Below, 2020). In this scenario, there is a constant search for equations and curves capable of fully explaining the behavior of grain yield as a function of sowing density. In general, the models proposed are asymptotic (Overman & Scholtz, 2011) or quadratic (Van Roekel & Coulter, 2011).

Most cultivated cereals respond to the availability of nutrients by changing the number of productive tillers, so that grain yield shows little variation because of changes in sowing density (Assefa *et al.*, 2016). However, modern maize hybrids do not demonstrate this behavior, having limited tillering capacity and generally producing only one ear per plant (Tokatlidis, 2013). This makes grain yield highly dependent on sowing density (Van Roekel & Coulter, 2011; Tokatlidis *et al.*, 2011; Assefa *et al.*, 2016).

Taking into account the importance of plant density on grain yield, it was aimed to evaluate the grain yield of corn hybrids subjected to two sowing densities during the 2020/21 crop in the medium-high Uruguay region of the state of Rio Grande do Sul.

MATERIAL AND METHODS

Experimental area

The experiment was conducted in the experimental area of the Federal University of Santa Maria Campus Frederico Westphalen (27º 23' 50" S, 53º 25' 37" W) during the 2020/21 harvest. According to Köppen-Geiger's climate classification, the region's climate is characterized as Cfa (Humid Subtropical Climate), and the soil is classified as Latosolic Red Dystropheric Typical (Santos *et al.*, 2018).

Previous to sowing the experiment, a chemical analysis of the soil in the experimental area was carried out at a depth of 0-20 cm, which showed the following values: Clay = 75.5%; pH (H_2O) = 5.7; P = 8.1 mg dm^{-3} (Mehlich^{-1}); K = 80.5 mg dm^{-3}; Calcium (Ca^{2+}) = 8.6 cmolc dm^{-3}; Magnesium (Mg^{2+}) = 4.6 cmolc dm^{-3}; and, Organic matter = 3.1%.

Pre-seeding management

As pre-seeding management, two herbicide applications were made in the area to control weeds, the first on September 4th, 2020, with glyphosate and diquat, and the second on September 18th, 2020, with glyphosate.

Sowing corn hybrids and fertilizer management

Sowing was performed manually on September 20th, 2020. The fertilizer management was performed according to soil analysis and recommendations for the crop, with estimated grain yields exceeding 12,000 kg ha^{-1} (CQFS, 2016). Were used 585 kg ha^{-1} of fertilizer with formulation 5-20-20 (N-P_2O_5-K_2O) in the base fertilization and 238 kg ha^{-1} of nitrogen in three applications in cover fertilization, performed in the phenological stages V3 (30% of the total dose of N), V7 (40% of the total dose of N) and V9 (30% of the total dose of N), respectively.

Cultural tracts, phytosanitary management and irrigation

To minimize yield losses due to competition with weeds, the herbicide atrazine was applied between the sowing rows when the plants were in the V4 phenological stage. In addition, pests and diseases were monitored and when necessary, their control was performed by applying insecticides and fungicides recommended for the crop. The application dates, targets, commercial products and doses used were: Application of Engeo Pleno™ s (Active ingredients: Tiametoxam + Lambda-Cialotrina) at a dose of 250 mL ha^{-1}, on October 25th, 2020 to control *Spodoptera frugiperda* in susceptible hybrids, at which time most of the plants were at phenological stage V6; Application of Aproach® Prima (Active ingredients: Picoxistrobina + Ciproconazol) at a dose of 400 mL ha^{-1}, on November 4th, 2020 for the control of *Cercospora zeae-maydis* and *Phaeosphaeria maydis*, at which time most of the plants were at phenological stage V8; Application of Connect® (Active ingredients: Imidacloprido + Beta-Ciflutrina) at a dose of 800 mL ha^{-1}, on November 4th, 2020 for the control of *Dalbulus maidis*.

During the initial period of the study, irrigation was carried out using a sprinkler system to minimize plant losses due to the high temperatures and low rainfall recorded during the months of October and November of 2020 (Figure 1a and 1b). The temperature and rainfall data were obtained from an INMET automatic meteorological station located approximately 300 meters from the experimental area (27° 23' 44" S, 53° 25' 46" W). Irrigation volumes were calculated based on sprinkler flow and irrigation time.

Experimental design and statistical analysis

Thirteen corn hybrids (Table 1) and two sowing densities were used 66,667 and 88,889 plants ha^{-1} (0.33 and 0.25 m between plants in the row, respectively), in a of the two-factor scheme with 26 treatments (13 corn hybrids × 2 sowing densities), in the design of block randomized with ten replications. The replications consisted in plots of 6.75 m^2 (3.0 m length × 2.25 m width), composed of five sowing lines spaced at 0.45 m. No borders were used between the plots, as the useful evaluation area consisted of the entire plot. However, 4.5 m wide borders (10 sowing lines spaced 0.45 m apart) were used around the experimental area.

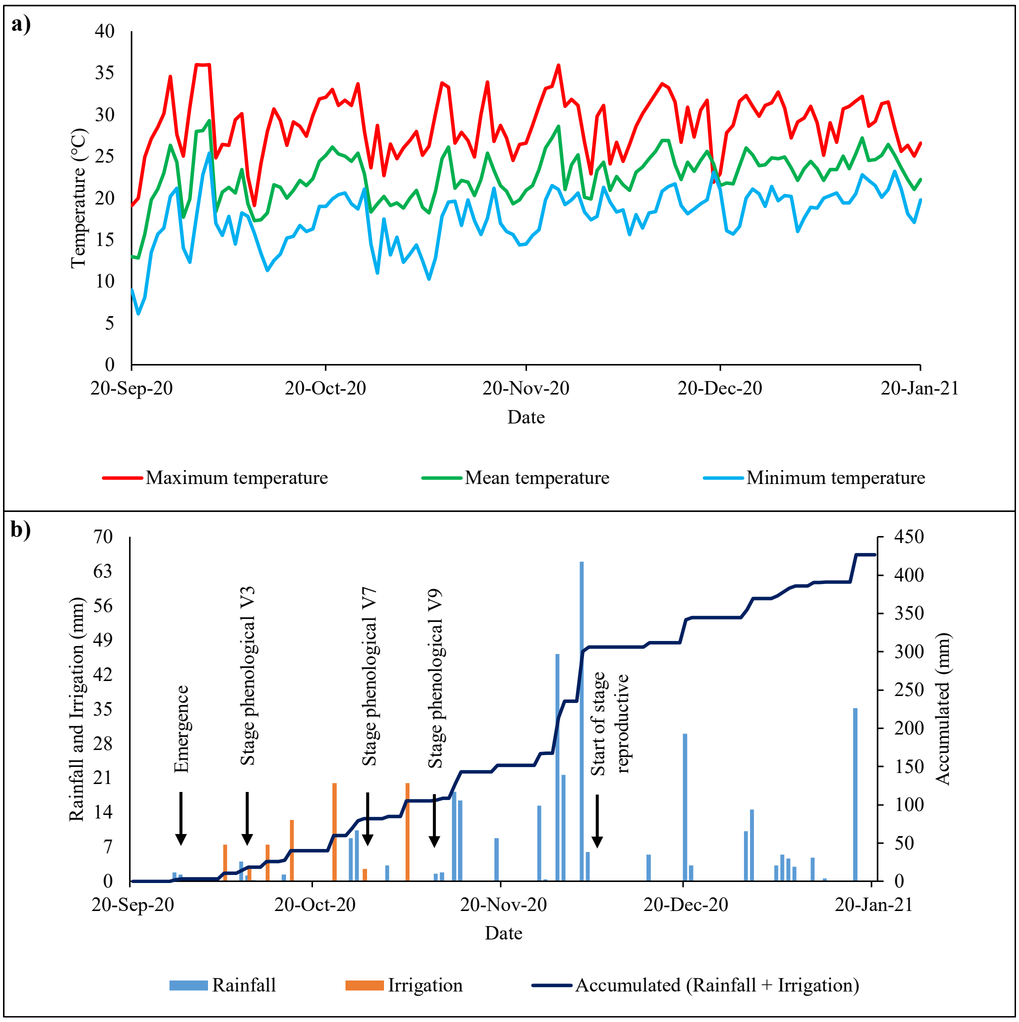

Figure 1: Climatic conditions registered during the experimental period in Frederico Westphalen, RS, Brazil: a) Temperature maximum, mean and minimum of air, in ºC; b) Rainfall, irrigation and accumulated, in mm.

Table 1: Description of the corn hybrids used in the experiment regarding maturity cycle and plant density recommended for the experimental period

Corn Hybrid	Maturity cycle	Recommended Density (in 1,000 plants ha^{-1})	Company holding the hybrid
AS1555 PRO3	Early	60 – 65	Agroeste®
B2401 PWU	Super-Early	60 – 65	Brevant®
B2418 VYHR	Super-Early	70 – 80	Brevant®
B2612 PWU	Early	65 – 70	Brevant®
BG7061 YHR	Super-Early	55 – 65	BioGene®
DKB235 PRO3	Super-Early	75 – 85	Dekalb®
NS45 VIP3	Super-Early	75 – 80	Nidera®
NS73 VIP3	Early	70 – 75	Nidera®
NS80 VIP3	Early	75 – 80	Nidera®
P2501	Super-Early	60 – 75	Pioneer®
P3016 VYHR	Early	60 – 70	Pioneer®
P3565 PWU	Early	65 – 70	Pioneer®
30F53 VYH	Early	70 – 80	Pioneer®

At the end of the crop cycle, the plots were harvested by hand and the respective grain yields (kg ha^{-1}) and humidity levels were quantified, for later standardization of the grain yields at 13% humidity.

The data were subjected to analysis of variance according to the following model:

$$Yijk = \mu + Hi + Dj + (HD)ij + \beta k + \varepsilon ijk$$

Where, Y_{ijk} is the observed mean value of the response variable in plot *ijk*, μ is the overall mean, H_i is the fixed effect of level *i* (*i* = AS1555 PRO3, B2401 PWU, B2418 VYHR, B2612 PWU, BG7061 YHR, DKB235 PRO3, NS45 VIP3, NS73 VIP3, NS80 VIP3, P2501, P3016 VYHR, P3565 PWU, 30F53 VYHR) of the corn hybrid factor, D_j is the fixed effect of level *j* (*j* = 66,667 and 88,889 plants ha^{-1}) of the sowing density factor, $(HD)_{ij}$ is the effect of the interaction of level *i* of the corn hybrid factor with level *j* of the sowing density factor, β_k is the random effect of the block (*k* = 1, 2, 3, 4, 5, 6, 7, 8, 9, 10), and ε_{ijk} is the effect of the experimental error, considered normal and independently distributed with zero mean and common variance σ^2 (Storck *et al.*, 2016). Subsequently, the experimental precision was calculated and the grouping of means was performed using the Scott-Knott test, which was performed if there was a significant interaction ($p \leq 0.05$) between corn hybrids and sowing densities, so that the unfolding of the corn hybrid factor within each sowing density was evaluated, and vice versa. In all analyses, a 5% significance level was established, and these were performed with the software Microsoft Office Excel and SISVAR (Ferreira, 2019).

RESULTS AND DISCUSSION

According to the classification proposed by Pimentel-Gomes (2009), grain yield showed precision experimental average ($CV_{exp.}$ = 14.56%), with significant effects for corn hybrids and sowing densities, as well as for the interaction between them (Table 2). After a meticulous verification of the coefficients of variation experimental of the grain yield of 205 experiments conducted with the maize crop, Storck *et al.* (2016) achieved an average value of 14.7%, so the experimental coefficient of variation obtained can be considered normal for the grain yield variable in maize hybrids.

The overall mean of the grain yield was high (9,630.74 kg ha^{-1}) when compared to the average yield of Rio Grande do Sul (5,476 kg ha^{-1}) and Brazil (4,367 kg ha^{-1}) during the 2020/21 crop (CONAB, 2022). The hybrids NS80 VIP3, B2401 PWU, NS73 VIP3, P3565 PWU, P3016 VYHR, DKB235 PRO3 and AS1555 PRO3 resulted in grain yields higher than the overall mean of the experiment (Figure 2), and besides these, hybrids B2612 PWU, BG7061YHR and NS45 VIP3 also exceeded the state and national means (Table 2).

Table 2: Analysis of variance of the grain yield of thirteen corn hybrids subjected to two sowing densities during the 2020/21 harvest in Frederico Westphalen, Rio Grande do Sul, Brazil

Sources of variation	**Degrees of freedom**	**Mean squares of grain yield**
Blocks	9	5,263,496.029*
Corn hybrid (C)	12	272,417,471.334*
Sowing density (D)	1	38,389,218.643*
Interaction C×D	12	4,023,605.683*
Error	225	1,966,128.648
$CV_{exp.}$ = 14.56%	Overall mean = 9,630.74 kg ha^{-1}	

Hybrid	Grain yield (kg ha^{-1}) (1)		
	66,667 plants ha^{-1}	88,889 plants ha^{-1}	General/Hybrid
NS80 VIP3	12,570.30 aB	14,247.23 aA	13,408.77
B2401 PWU	12,377.17 aB	14,030.31 aA	13,203.74
NS73 VIP3	11,963.31 aB	13,889.04 aA	12,926.18
P3565 PWU	12,351.11 aA	13,073.88 bA	12,712.49
P3016 VYHR	11,899.94 aA	13,034.39 bA	12,467.17
DKB235 PRO3	11,058.39 aB	12,492.12 bA	11,775.25
AS1555 PRO3	10,483.03 bB	11,963.39 bA	11,223.03
B2612 PWU	9,193.07 cA	8,984.54 cA	9,088.80
BG7061 YHR	8,548.01 cA	9,209.67 cA	8,878.84
NS45 VIP3	6,832.47 dA	7,672.77 dA	7,252.62
B2418 VYHR	5,443.49 dA	4,699.02 eA	5,071.26
P2501	4,226.58 eA	4,171.59 eA	4,199.09
30F53 VYHR	3,257.46 eA	2,727.31 fA	2,992.39
General/Density	9,246.49	10,014.99	9,630.74

* Effect significant by the test F at 5% of error probability. $CV_{exp.}$ = Coefficient of variation experimental (in %). (1) Means of grain yield of corn hybrids not followed by the same lower case letter in the column and means of sowing density not followed by the same upper case letter in the row differ by the Scott-Knott test, at 5% of probability of error.

The grain yield of the crop is highly influenced by plant density, and this, in turn, is influenced by both the soil and climate conditions of the growing region and by the intrinsic characteristics of the genotype. In this sense, in an ideal growing environment and with unlimited availability of resources, the relationship between density and productivity should present a positive linear behavior; however, limiting factors linked to the growing environment (incident solar radiation rate, water and nutritional availability) and the hybrid (productive potential and tolerance to intra-specific competition), make this relationship typically quadratic, with an optimal plant density for each combination of hybrid and growing environment, in which grain yield is maximized (Van Roekel & Coulter, 2012; Robles *et al.,* 2012; Hernández *et al.,* 2014; Gambin *et al.,* 2016; Assefa *et al.,* 2018). Thus, the large variation in grain yield observed (2,727.31 kg ha^{-1} ≤ grain yield ≤ 14,247.23 kg ha^{-1}) may be related to the adaptability of corn hybrids to the growing environment to which they were submitted, since these, representing a random sample of the genotypes currently available for cultivation in the Southern Region of Brazil.

The grain yield ranged between 3,257.46 and 12,570.30 kg ha^{-1}, when using the density 66,667 plants ha^{-1}, with hybrids NS80 VIP3, B2401 PWU, NS73 VIP3, P3565 PWU, P3016 VYHR and DKB235 PRO3 the most productive. At the density of 88,889 plants ha^{-1}, the grain yield ranged between 2,727.31 and 14,247.23 kg ha^{-1}, with hybrids NS80 VIP3, B2401 PWU and NS73 VIP standing out from the others (Table 2).

In general, the corn hybrids responded positively to the highest sowing density (88,889 plants ha^{-1}), showing an average increase in grain yield of around 770 kg ha^{-1} when compared to the density of 66,667 plants ha^{-1} (Table 2), indicating that the productive potential of these hybrids is limited to the plant density recommended for the South Region of Brazil (Table 1). Therefore, knowledge about the appropriate plant density for specific hybrids

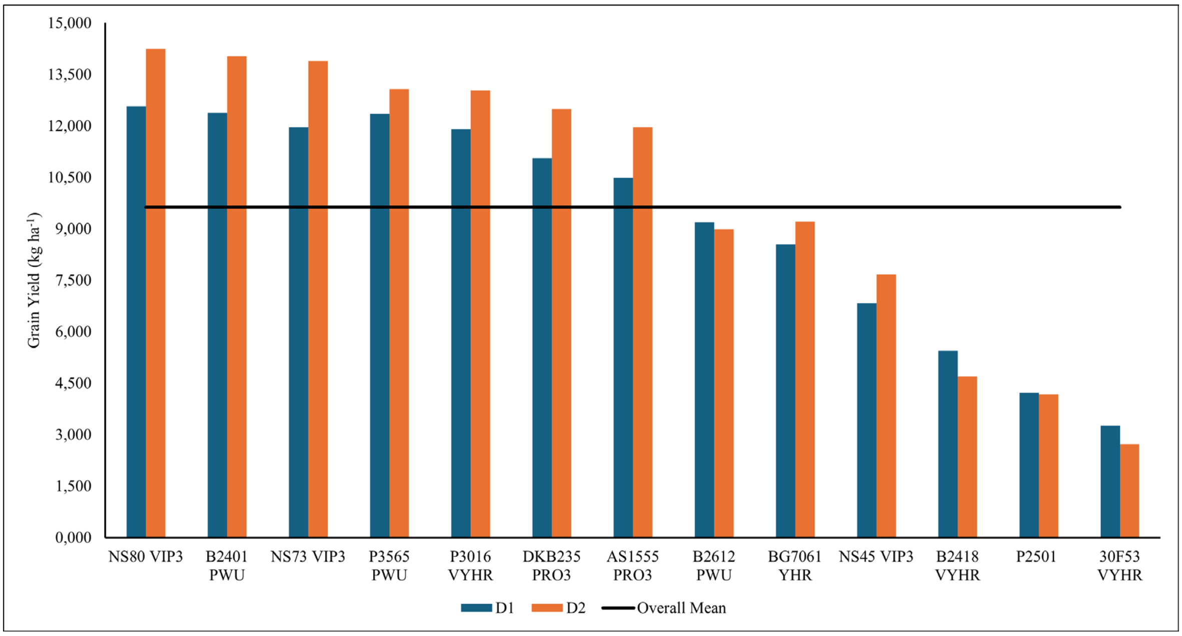

Figure 2: Comparative of grain yield of thirteen corn hybrids under two sowing densities and their respective means. *D1 and D2 = 66,667 and 88,889 plants ha^{-1}, respectively.

and growing regions can help to increase the technical efficiency of the crop (Van Roekel & Coulter, 2012; Robles *et al.*, 2012; Reeves & Cox, 2013; Hernández *et al.*, 2014) in the medium-high Uruguay Region of Rio Grande do Sul. In the literature, there are reports of the positive effect of corn plant stand on grain yield in multi-environment trials (23 growing environments × 9 corn hybrids), with a mean increment of 1,000 kg ha^{-1} being observed when increasing the density by 10,000 plants ha^{-1} (Gambin *et al.*, 2016). Thus, Buso *et al.* (2016) suggest that the yield increase is related to the improved spatial distribution of plants at densities of around 80,000 plants ha^{-1}.

Reinforcing the idea that grain yield maximization of corn hybrids has been high under density ≥ 80,000 plants ha^{-1}, Robles *et al.* (2012), reported higher grain yield at density of 81,000 plants ha^{-1} for three corn hybrids in various growing environments during 2009 and 2010. Van Roekel & Coulter (2012), suggested that grain yield maximization of mid-season and late-season corn hybrids tends to occur at densities between 80,450 and 108,700 plants ha^{-1}. Similar results were observed by Reeves & Cox (2013), with grain yield maximization suggested at plant density between 86,450 and 103,740 plants ha^{-1}. Hernández *et al.* (2014), observed that the optimal plant density ranged from 73,000 to 119,000 plants ha^{-1}, depending on the corn hybrid used during the 2011/12 and 2012/13 crops. When testing a broader spectrum of sowing densities for corn hybrids, Li *et al.* (2015b) observed that grain weight per plant decreased from 565.86 to 95.66 g, as plant density increased from 15 to 180 thousand plants ha^{-1}, respectively. In this scenario, the authors adjusted a logarithmic equation to explain the relationship between plant density and grain weight per plant. On the other hand, grain yield per area showed quadratic behavior. In this scenario, grain yield increased until reaching the maximum yield (19,310 kg ha^{-1}) at a density of 105.7 thousand plants ha^{-1}, but when the density exceeded 132.6 thousand plants ha^{-1} grain yield decreased.

Hörbe *et al.* (2013), on the other hand, reported the soil conditions of the growing environment as a limiting factor to the increase in corn plant density, since growing in soil considered of low performance (lower organic matter content and water storage capacity) generated a linear reduction in grain yield as the plant density increased. On the other hand, there was a maximization of grain yield at a density of up to 81,576 plants ha^{-1}, when the cultivation occurred in soil considered of high performance (high organic matter content and water storage capacity of the soil).

In the same way, after compiling a meta-database of plant density trials with corn hybrids between 2000 and 2014, Assefa *et al.* (2016) observed variations in density and maximum grain yield depending on the characteristics of the growing environment. In this scenario, the maximum grain yield (± 6,200 kg ha^{-1}) was achieved at a density of 60 thousand plants ha^{-1} in environments considered low-yield, with reductions in grain yield being observed at densities higher than this. For medium-yield environments, the maximum grain yield (± 9,000 kg ha^{-1}) was observed at a density of thousand plants ha^{-1}, with grain yields stabilizing at higher densities. In high-yield environments, grain yield increased sharply with increases in plant density from 45 to 75 thousand plants ha^{-1}, with the maximum grain yield (± 11,500 kg ha^{-1}) being reached at a density of 100 thousand plants ha^{-1}. In very high-yield environments (> 13,000 kg ha^{-1}), grain yield continued to increase even at a density of 100 thousand plants ha^{-1}, suggesting that the factor limiting grain yield in this scenario is linked to the genetic potential of the genotypes, especially in terms of prolificacy, number of grains per ear and grain weight (Ciampitti & Vyn, 2012; Egli, 2015). In addition, the ability to use solar radiation has been identified as a determining factor in increasing yield potential (Liu *et al.*, 2021), especially under high plant densities (Testa *et al.*, 2016).

CONCLUSIONS

The corn hybrids presented higher grain yields when subjected to a density of 88,889 plants ha^{-1} in the medium-high Uruguay region of Rio Grande do Sul, surpassing in most cases the state and national mean productivity of the 2020/21 harvest.

Most of the corn hybrids used present potential for cultivation at plant densities higher than their respective recommendations.

Given the superior productivity of hybrids NS80 VIP3, B2401 PWU and NS73 VIP3, their cultivation under conditions similar to those of the study is recommended.

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