Embrapa
Portal de Periódicos da Embrapa
International Journal of
Maize&Sorghum
Formerly Revista Brasileira de Milho e Sorgo
ABMS

# TECHNICAL AND ECONOMIC PERFORMANCE OF MAIZE GENOTYPES WITH DIFFERENT GENETIC BASES SUBJECTED TO DIFFERENT LEVELS OF INVESTMENT IN SANTA CATARINA, BRAZIL

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**ABSTRACT –** The state of Santa Catarina has a deficit in maize production to meet the demand for animal feed, due to the reduction in the area cultivated with the cereal, which has been mainly replaced by soybeen crops. This work aimed to evaluate the technical and economic viability of different investment levels and maize genotypes with different genetic bases. The experiments were conducted in Lages-SC, during the 2017/2018 and 2018/2019 growing seasons. The experimental design was a randomized complete block design in split-plots. In the main plot, four investment levels (low, medium, high, and very high) were evaluated, differing in plant population, fertilization, seed treatment, and disease, pest, and weed management. In the subplots, four genotypes were evaluated: SCS155 Catarina (OPV, open-pollinated variety), AG1051 (DH, double hybrid), AG5055 (TH, triple hybrid), and AG9025PRO3 (SH, single hybrid). Agronomic evaluations were conducted, including grain yield and its components, along with economic analysis. The data were analyzed using the F-test and, when significant, the means were compared using Tukey's test at the 5% significance level. The single hybrid AG9025PRO3 showed higher grain yield than the other genotypes, regardless of investment level. The lowest investment level resulted in a higher net margin, regardless of the genotype used. Production systems with higher production costs and yields proved more economically viable when using the single hybrid AG9025PRO3. The economic viability of maize cultivation, at different investment levels, depends on the yield achieved and the price paid for the grain.

**Keywords:** *Zea mays*, profitability, productivity, cultivars, genotypes.

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Maize is of high socioeconomic importance in Santa Catarina, the state being one of the main producers of this crop in the first harvest (Giehl et al., 2021), as it is cultivated in all regions of the state and is the main item in the rations of swine and poultry herds (Eicholz et al., 2020). Historically, demand for maize grains in Santa Catarina has not been met by local production, resulting in a 4.4-million-ton deficit in 2020 (Giehl et al., 2021). The scarcity of maize grains is mainly due to the decrease in cultivated area in recent years. Between the 2012/13 and 2019/20 harvests, the area cultivated with maize for grain production decreased by 125,000 hectares. Furthermore, average productivity decreased from 8.4 t ha$^{-1}$ in the 2018/2019 crop season to approximately 7.0 t ha$^{-1}$ in the 2020/2021 crop season (Giehl et al., 2021).

The low cultivated area is mainly due to the sustained appreciation of soybean prices and the decline in maize prices, which led to the conversion of maize areas to soybean cultivation (Giehl et al., 2021). Considering the cost of production and the returns from cultivation, between 2012 and 2017, except 2016, soybeans were more attractive than maize. In 2016 and between 2018 and 2021, the equivalence between soybeans and maize made maize more competitive than soybeans (EPAGRI, 2021). However, according to EPAGRI (2021), this was not reflected in an increase in cultivated area.

Maize cultivation is water-intensive for its agronomic performance. The period between anthesis and heading is the most critical phase for water deficiency, which can reduce productivity by up to 50% (Sangoi et al., 2010a, 2010b). This characteristic of the crop often interferes with producers' decisions to replace maize with soybeans. Other reasons for the decrease in maize supply in Santa Catarina include the lack of an agricultural policy to stabilize maize prices and the high cost of maize cultivation, driven by the intensification of transgenic seed use. In Brazil, 196 genotypes were made available in the 2019/2020 crop season. Of this total, 131 were transgenic genotypes, which represented 67%. Regarding genetic base variability, 86.4% of the genotypes offered were single hybrids, 5.8% were triple hybrids, 3.9% were double hybrids, and the remaining 3.9% accounted for the remaining genotypes (Pereira Filho & Borghi, 2020).

The deficit of maize grains in Santa Catarina is supplied by interstate imports, mainly from Mato Grosso do Sul and Paraná, and by imports from neighboring countries such as Paraguay and Argentina (Giehl et al., 2021). Given the importance of maize in the feeding of pigs and poultry in the state of Santa Catarina, which represent 44.5% and 37.2% of the total maize demand, respectively (Giehl et al., 2021), the production deficit implies higher costs for the entire production chain.

In the first decade of the 21st century, studies conducted by Sangoi et al. (2003), Sangoi et al. (2006a, 2006b), and Forsthofer et al. (2006) consolidated the concept that as investment in maize farming increased, so did grain productivity and, consequently, the producer's income, provided that cultivation was carried out at the preferred sowing time. In these studies, there was an association between maximum technical efficiency and maximum economic efficiency. Currently, this concept needs to be reviewed to revive maize cultivation in SC.

It is necessary to search for maize production systems that are financially profitable for grain producers. This scenario would make the Santa Catarina production chain more competitive. It is necessary to identify production systems that yield higher financial returns and encourage farmers to produce the cereal, making it competitive with soybean cultivation.

Beyond the economic aspect, increasing the area cultivated with maize is agronomically necessary, as farmers often end up with monocultures with soybeans, resulting in less diversified crops (Volsi et al., 2020). Less diversified production systems are increasingly inefficient and unsustainable due to stagnant productivity and rising costs (Wang et al., 2019). The inclusion of maize in rotation with soybeans is very important because of the benefits this cultural practice provides, thereby increasing the sustainability of agricultural production (Franchini et al., 2011). Among the advantages are: greater inclusion of straw in the system, conservation of organic matter, improved soil conservation, and more efficient control of weeds, pests, and diseases. Therefore, systems with greater crop diversity are more economically viable (Volsi et al., 2020).

The profitability of cultivation aims to conduct the production process to achieve maximum profit or minimum cost (Münch et al., 2014). In this approach, the profitability of production is related to its technical and economic efficiency. Technical efficiency involves physical aspects of production, such as productivity. Economic efficiency involves monetary aspects (Artuzo et al., 2018). Therefore, it is essential to analyze current maize production systems to identify the most financially viable way to cultivate this important cereal.

The objective of this work was: a) to evaluate the technical and economic viability of maize production systems with different genotypes and levels of investment in management; b) to identify production systems that make maize cultivation technically and economically viable in the state of Santa Catarina.

## Material and Methods

The experiment was conducted in the district of Santa Terezinha do Salto, municipality of Lages/SC, in the agricultural years 2017/2018 and 2018/2019. The experimental area is located 20 km from the city center of Lages, in the southern plateau of the state of Santa Catarina. The site's geographical coordinates are 27º 50' 35" south latitude, 50º 29' 45" west longitude, and an altitude of 849 meters. The region's climate is Cfb, mesothermal, with mild summers, average temperatures of the warmest month below 22º C, and well-distributed rainfall, according to the Köppen-Geiger classification cited by Kottek et al. (2006). The soil of the experimental area is a Typical Dystrophic Red Nitosol according to the classification proposed by Santos et al. (2018). The results of the soil chemistry analysis performed on samples collected from the arable layer (0 to 20 cm) in August of each agricultural year are described in Table 1.

Black oats (*Avena strigosa*) were cultivated in the winter preceding each agricultural year. Maize was sown using a no-till system with manual seeders on October 17, 2017, and October 22, 2018. Strings marked with distances corresponding to the desired densities for each genotype and investment level were used to position the seeds appropriately in each plant population. Three seeds were sown per hole to ensure the desired stand. When the plants had three expanded leaves, thinning was performed to adjust the population to the desired level.

**Table 1**. Results of soil analysis performed prior to the implementation of the experiments in the 2017/18 and 2018/19 agricultural years. Lages-SC, 2021.

| Agricultural Year | Clay | pH | | OM * | P | K | $Ca^{2+}$ | $Mg^{2+}$ | $Al^{3+}$ |
|---|---|---|---|---|---|---|---|---|---|
| | g $kg^{-1}$ | $H_2O$ | SMP | g $kg^{-1}$ | ---mg $dm^{-3}$ --- | | ------ cmolc $dm^{-3}$ ------ | | |
| 2017/18 | 50 | 5.7 | 5.2 | 6.3 | 18.1 | 205 | 10.1 | 2.5 | 0.1 |
| 2018/19 | 45 | 5.9 | 4.9 | 6.2 | 22.8 | 186 | 9.9 | 2.3 | 0.2 |

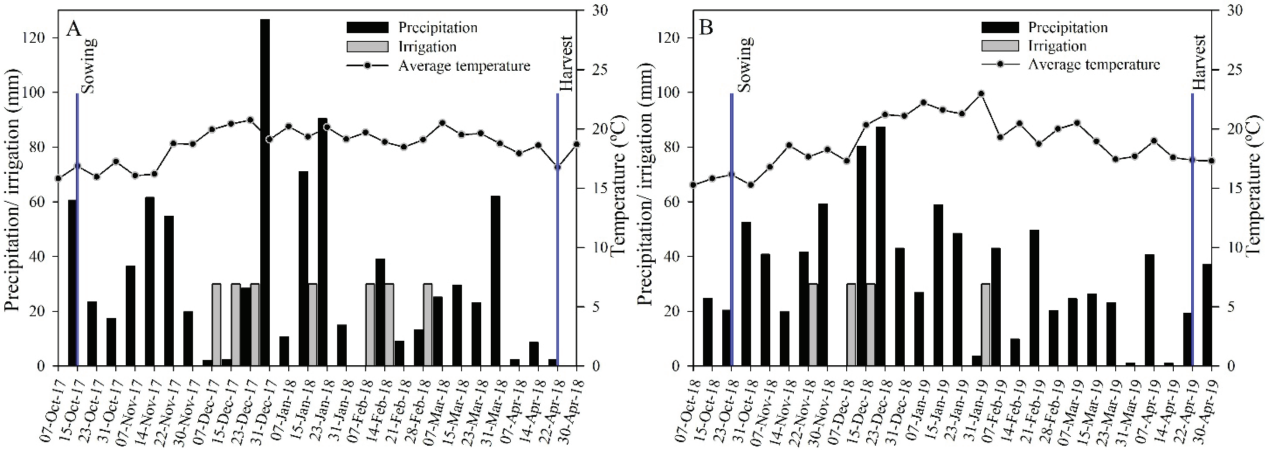
* OM: Organic matter; P and K were extracted by Mehlich-1; $Ca^{2+}$, $Mg^{2+}$, e $Al^{3+}$ were extracted with KCl 1 mol $L^{-1}$.

Source: Prepared by the Authors, 2021.

Information on prevailing meteorological conditions during the growing seasons was collected from the Brazilian Institute of Meteorology (INMET, 2021). The data were obtained from an automatic station located at the geographic coordinates of 27° 48’ 08” South latitude, 50° 20’ 07” West longitude.

The following were determined: Tmed = Average temperature every 4 days; Precipitation = accumulated precipitation every 4 days in the 2017/2018 and 2018/2019 agricultural years (Figures 1A and 1B, respectively). Throughout the maize development cycle, rainfall was irregular in both agricultural years, requiring supplementary irrigation. A sprinkler irrigation system was adjusted to apply a 30 mm layer in each irrigation (Figures 1A and 1B).

The design was a randomized block design with split plots. In the main plot, four management systems with different investment levels were evaluated: low (NB), medium (NM), high (NA), and very high (NMA). In the subplots, four maize genotypes with different genetic bases and productive capacities were tested: the open-pollinated variety SCS155Catarina (OPV), the double hybrid AG1051 (DH), the triple hybrid AG5055 (TH), and the single hybrid AG9025PRO3 (SH). Each genotype subjected



Source: Adapted from INMET (2021).

**Figure 1.** Average temperature, precipitation, and irrigation carried out during the maize devel-opment cycle in the agricultural years 2017/2018 (A) and 2018/2019 (B), Lages – SC.

to different investment levels received different growing conditions regarding plant density and fertilization (Table 2). The subplots consisted of four rows, 70 cm apart, and six meters long. The useful area was the two central rows, excluding 0.5 meters at each end.

The experimental area received maintenance fertilization on the sowing day, according to the recommendations by Silva et al. (2016), taking into account two factors: the results of the soil analysis carried out in August prior to each agricultural year (Table 1) and the expected grain yields per hectare for each investment level, which were 6, 9, 15 and 21 t $ha^{-1}$, for the low, medium, high and very high investment levels, respectively. Different fertilizer doses were applied on the day of sowing, depending on the adopted management system (Table 2). The fertilizers were applied superficially over the sowing lines. The fertilizer sources used were urea (45% N), triple superphosphate (46% P2O5), and potassium chloride (60% K2O). The nitrogen fertilizer dose applied as topdressing also followed the recommendations of Silva et al. (2016) to achieve the desired yields in each management system. Topdressing fertilization was carried out according to the phenological stages of the Ritchie et al. (1993) scale predicted for each treatment (Table 2).

All seeds received normal industrial treatment. Besides, they were treated with the insecticides Imidacloprid and Thiodicarb one day before sowing. At the very high investment level, a growth regulator was applied as a seed treatment 1 day before sowing (Table 3). This product was also applied post-emergence at the V5 stage. Weed, pest, and disease control was carried out differently across investment levels, varying in the number of applications, products

**Table 2**. Characterization of maize crop management systems in the 2017/2018 and 2018/2019 agricultural years, Lages-SC.

| Investments | Cultivar* | Plant density PDha$^{-1}$ | Base fertilization (kgha$^{-1}$) | | | Topdressing Nitrogen fertilization (kgha$^{-1}$) [(2)] | | |
|---|---|---|---|---|---|---|---|---|
| | | | N | $P_2O_5$ | $K_2O$ | V4 | V8 | V12 |
| Low | SCS155Catarina | 40.000 | 30 | 130 | 60 | 40 | - | - |
| | AG1051 | 40.000 | 30 | 130 | 60 | 40 | - | - |
| | AG5055 | 40.000 | 30 | 130 | 60 | 40 | - | - |
| | AG9025PRO3 | 40.000 | 30 | 130 | 60 | 40 | - | - |
| Average | SCS155Catarina | 50.000 | 30 | 175 | 90 | 85 | - | - |
| | AG1051 | 50.000 | 30 | 175 | 90 | 85 | - | - |
| | AG5055 | 55.000 | 30 | 175 | 90 | 85 | - | - |
| | AG9025PRO3 | 60.000 | 30 | 175 | 90 | 85 | - | - |
| High | SCS155Catarina | 60.000 | 30 | 265 | 150 | 87.5 | 87.5 | - |
| | AG1051 | 60.000 | 30 | 265 | 150 | 87.5 | 87.5 | - |
| | AG5055 | 65.000 | 30 | 265 | 150 | 87.5 | 87.5 | - |
| | AG9025PRO3 | 75.000 | 30 | 265 | 150 | 97.5 | 97.5 | - |
| Very high | SCS155Catarina | 60.000 | 30 | 355 | 210 | 88.3 | 88.3 | 88.3 |
| | AG1051 | 60.000 | 30 | 355 | 210 | 88.3 | 88.3 | 88.3 |
| | AG5055 | 65.000 | 30 | 355 | 210 | 88.3 | 88.3 | 88.3 |
| | AG9025PRO3 | 90.000 | 30 | 355 | 210 | 105 | 105 | 105 |

*SCS155Catarina: Open-pollinated variety; AG1051: Triple hybrid; AG5055: Dual hybrid; AG9025PRO3: Simple Hybrid. [(2)] Nitrogen topdressing applied at the phenological stages of maize cultivation according to the scale of Ritchie et al. (1993).

used, and application timing, as described in Table 4.

Herbicide, insecticide, and fungicide sprays were applied with a constant-pressure sprayer at 30 lb in$^{-2}$, pressurized with CO2. XR 110-015 flat fan nozzles were used, calibrated for a spray volume of 200 L ha$^{-1}$. During application, the spray was directed onto the plant's upper leaves.

The harvest took place on April 20, 2018, and April 24, 2019, for the 2017/2018 and 2018/2019 crop seasons, respectively. The maize ears were harvested manually and threshed in a stationary thresher. The grain weight of each subplot was determined. Subsequently, a sample of approximately 0.5 kg was separated to determine moisture content and other productivity components in the Field Plant Laboratory of the Center for Agricultural and Veterinary Sciences of the State University of Santa Catarina (CAV/UDESC). Four hundred grains were counted and weighed, and then conditioned in an oven under ventilation and a temperature of approximately 65 ºC until they reached a constant mass.

The wet grain weights from the usable area were converted to one hectare and expressed

**Table 3**. Characterization of the products (a.i. $ha^{-1}$) used as seed treatment in the 2017/2018 and 2018/2019 growing seasons. Lages - SC.

| | |
|---|---|
| Fungicides[1/] | Metalaxil-M (0.016g) + Fludioxonil (0.12 g) + Thiabendazole (0.02 g) |
| Inseticides | Deltamethrin (0.002g) + Pirimiphos-methyl (0.008g) + Imidacloprid (0.003g) + Thiodicarb (0.008g) |
| Growth Regulator[2/] | Kinetin (0.001g) + Gibberellic acid (0.0007g) + 4-indole-3ylbutyric acid (0.0007g) |

[1/] The SCS155Catarina cultivar did not receive the fungicide Thiabendazole in either of the growing seasons.
[2/] The growth regulator was applied to the seeds only at the very high investment level, one day before sowing.
Source: Prepared by the Author, 2021.

at a standard grain moisture content of 13% to estimate grain productivity. After determining the dry mass of 1,000 grains, it was converted to account for 13% moisture and used to express the mass of 1,000 grains (MMG).

The financial analysis was based on the work of Kay et al. (2020). To determine the costs, all stages of the production process were considered: desiccation, sowing, applications, harvesting, transportation, technical assistance, financial costs, and marketing costs. Production costs, productivity obtained, and marketing prices were considered to determine gross revenue (GR), total cost (TC), net margin (NM), gross margin (GM), and profitability index (PI), as described in Table 5.

To determine variable costs, the prices of inputs used were obtained through the average market prices, consulted among agricultural stores and cooperatives in the region, in the period preceding the planting of the 2017/2018 and 2018/2019 crops. Costs related to labor, mechanical services, general expenses, technical assistance, production insurance, financial costs, and marketing expenses in each agricultural year were obtained based on data provided by EPAGRI (2017) and EPAGRI (2018a). Fixed costs were based on CONAB (2017) and CONAB (2018), including the following items: depreciation of improvements and installations; depreciation of implements; depreciation of machinery; maintenance of improvements and installations; social charges; and capital insurance. Real values were converted to dollars (US$) at the exchange rate for April 2018 (US$ 1 = R$ 3.407) and April 2018 (US$ 1 = R$ 3.896) published by the Brazilian Central Bank (BCB, 2026).

The price paid per 60 kg bag was determined according to spreadsheets containing average price data for maize grains paid to producers in Santa Catarina, provided by EPAGRI (2018b) and EPAGRI (2019). The average prices paid in the harvest month of the experiments (April 2018 and 2019) were used. According to this criterion, the prices were US$ 10.86 (US$ 0.18 $kg^{-1}$) in the 2017/2018 agricultural year, and US$ 8,47 (US$ 0.14 $kg^{-1}$) in the 2018/2019 agricultural year.

In addition to the economic analysis, the data obtained were statistically evaluated using

**Table 4**. Characterization of the use of herbicides, growth regulators, insecticides and fungicides in maize cultivation, according to each investment level and phenological stage of application, in the agricultural years 2017/2018 and 2018/2019, Lages – SC.

**Herbicides** (g de a.i. ha$^{-1}$)

| Management System | Phenological Stage of Development* | | |
|---|---|---|---|
| | Semeadura | V5 | V9 |
| Low | - | Atrazine (1750 g) +<br>Simazine (1750 g) | - |
| Medium | - | Atrazine (1750 g) +<br>Simazine (1750 g) +<br>Tembotrione (84 g) | - |
| High | Atrazine (1750) +<br>Simazine (1750) | Atrazine (1750 g) +<br>Tembotrione (84 g) | Atrazine (1750 g) +<br>Mesotrione (144 g) |
| Very High | Atrazine (1750)<br>Simazine (1750) | Atrazine (1750 g) +<br>Tembotrione (84 g) | Atrazine (1750 g) +<br>Mesotrione (144 g) |

**Insecticides** (g de a.i. ha$^{-1}$)

| Management System | Phenological Stage of Development | | |
|---|---|---|---|
| | V3 | V5 | V8 |
| Low | - | - | - |
| Medium | Methomyl (129 g) | - | - |
| High | Methomyl (129 g) | Chlorantraniliprole (24 g) | Espinoteran (9 g) |
| Very High | Methomyl (129 g) | Chlorantraniliprole (24 g) | Espinoteran (9 g) |

**Fungicides** (g de a.i. ha$^{-1}$)

| Management System | Phenological Stage of Development | | |
|---|---|---|---|
| | V10 | VT | R2 |
| Low | - | - | - |
| Medium | Azoxystrobin (60 g) +<br>Cipocronazole (24 g) +<br>Propiconazole (100 g) | - | - |
| High | Azoxystrobin (60 g) +<br>Cipocronazole (24 g) +<br>Propiconazole (100 g) | Pyraclostrobin (91 g) +<br>Epoxiconazole (56 g) +<br>Mancozeb (1125 g) | - |
| Very High | Azoxystrobin (60 g) +<br>Cipocronazole (24 g) +<br>Propiconazole (100 g) | Pyraclostrobin (91 g) +<br>Epoxiconazole (56 g) +<br>Mancozeb (1125 g) | Pyraclostrobin (91 g) +<br>Epoxiconazole (56 g) +<br>Mancozeb (1125 g) +<br>Carbendazim (250 g) |

**Growth Regulator** (g de a.i. ha$^{-1}$)

| Management System | Phenological Stage of Development |
|---|---|
| | V4 |
| Very High | Kinetin (0,018 g de a.i. ha$^{-1}$) + Gibberellic Acid (0,01g) + 4-Indole-3-Ilbutyric acid (0,01 g) |

* Weed control performed on the day of sowing, and at stages V5 and V9 on the scale of Ritchie et al. (1993).

**Table 5**. Economic parameters, equations and description.

| Parameters | Unit | Equation | Description |
|---|---|---|---|
| Gross Revenue (GR) | ($\text{R\$ ha}^{-1}$) | GR = PG x PP | Produced Grain (PG); PP: Average price (PP) |
| Total Cost (TC) | ($\text{R\$ ha}^{-1}$) | TC = VC + FC | Variable costs (VC): Fixed cost (FC) |
| Net Profit Margin (NPM) | ($\text{R\$ ha}^{-1}$) | NPM = GR - TC | Gross revenue (GR); Total cost (TC) |
| Gross Margin (GM) | (%) | GM = (NPM/TC).100 | Net profit margin (NPM); Total cost (TC) |
| Profitability Index (PI) | (%) | PI = (NPM/GR).100 | Net profit margin (NPM); Gross revenue (GR) |

Source: Adapted from Kay et al. (2020) and EPAGRI (2017, 2018a).

analysis of variance and the F-test. The F-values for the main effects and interactions were considered significant at the 5% significance level ($P < 0.05$). The means were compared using Tukey's test at the 5% significance level.

## Results and Discussion

The number of ears per $m^2$ was influenced by the interaction of management levels and genotypes in the agricultural years (Table 6). In general, it increased as the investment level rose from low to very high. Similar behavior was found by Sangoi et al. (2006a), who, regardless of the genotype used, observed a greater number of ears per $m^2$ with increasing investment levels. Forsthofer et al. (2006) also detected a greater number of ears per $m^2$ with increasing investment levels, regardless of the sowing season. This behavior is due to the increase in density and fertilization rate, depending on the genotypes and investment levels used.

**Table 6.** Ears per square meter (number) of maize genotypes subjected to management systems with different investment levels in the agricultural years 2017/2018 and 2018/2019. Lages/SC.

| Investment Level | Genotypes | | | | Average | CV (%) |
|---|---|---|---|---|---|---|
| | SCS155 Catarina | AG1051 | AG5055 | AG9025PRO3 | | |
| | | | **Year 2017/2018** | | | |
| Low | 4.91 cB* | 4.61 bB | 6.16 bA | 6.16 bA | 5.46 | 6.63 |
| Medium | 5.27 bcB | 5.24 bB | 6.70 abA | 6.76 bA | 5.99 | |
| High | 6.31 aB | 6.31 aB | 6.93 abB | 7.95 aA | 6.87 | |
| Very high | 6.04 abC | 6.70 aBC | 7.38 aB | 8.69 aA | 7.20 | |
| Average | 5.63 | 5.71 | 6.79 | 7.39 | | |
| CV (%) | | | 6.79 | | | |
| | | | **Year 2018/2019** | | | |
| Low | 4.79 bBC | 4.43 bC | 5.80 bcA | 5.36 bAB | 5.10 | 11.38 |
| Medium | 5.15 abA | 5.15 abA | 5.51 cA | 5.98 bA | 5.45 | |
| High | 5.86 aC | 6.04 aBC | 6.76 abAB | 7.38 aA | 6.51 | |
| Very high | 5.95 aC | 5.86 aC | 6.90 aB | 8.15 aA | 6.72 | |
| Average | 5.44 | 5.37 | 6.24 | 6.72 | | |
| CV (%) | | | 7.86 | | | |

*Means followed by the same lowercase letter in the column and uppercase letters in the row do not differ from each other by Tukey's test ($p<0.05$)- source: prepared by the Author, 2021.

The SH AG9025PRO3 genotype had the highest number of ears per square meter (Table 6). It was statistically superior to the other genotypes at the high and very high levels. This result is mainly due to the higher plant population and greater fertilization used in this cultivar (Table 2). The increase in plant density results in more ears per unit area in well-managed crops (Shao et al., 2018). This characteristic is more pronounced in single hybrids, which exhibit less morphological and phenological variability, reducing intraspecific competition (Sangoi et al., 2009).

At the low investment level, the VPA SCS155Catarina and DH AG1051 had the lowest ears per m$^2$, even though all genotypes used the same plant population and fertilization (Table 6). According to Sangoi et al. (2009), VPAs and DHs exhibit greater phenological variability in plant development. This results in a greater number of sterile plants (Liu et al., 2004).

The variable grains per m$^2$ was influenced by the main effects of investment levels and genotypes, in both agricultural years (Table 7). The AG9025PRO3 and AG5055 genotypes produced more grains per m$^2$ than the SCS155Catarina and AG1051 genotypes. The very high investment level yielded the highest

**Table 7**. Grains per square meter (G.m²) as a function of investment levels, on average across genotypes, in the 2017/2018 and 2018/2019 growing seasons.

| Source of Variation | Number of grains per square meter (G.m²)) | |
|---|---|---|
| | **Year 2017/2018** | **Year 2018/2019** |
| Investment Levels (IL) | | |
| Low | 2134 b * | 2103 b |
| Medium | 2426 b | 2204 b |
| High | 2579 ab | 2348 ab |
| Very high | 2898 a | 2517 a |
| Average | 2509 | 2209 |
| CV (%) | 16.10 | 10.75 |

* Means followed by the same lowercase letter in the column do not differ significantly by Tukey's test at a 5% probability level ($P < 0.05$); Source: prepared by the Author, 2021.

**Table 8**. Grains per square meter (G.m²) as a function of genotype, on average at investment levels, in the 2017/2018 and 2018/2019 growing seasons.

| Source of Variation | G.m$^{-2}$ (n°) | |
|---|---|---|
| Genotypes (G) | **Year 2017/2018** | **Year 2018/2019** |
| VPA SCS155Catarina | 2111 b* | 1952 b |
| DH AG1051 | 2283 b | 1965 b |
| TH AG5055 | 2945 a | 2656 a |
| SH AG9025PRO3 | 2698 a | 2598 a |
| Average | 2509 | 2294 |
| CV (%) | 11.05 | 10.37 |

* Means followed by the same lowercase letter in the column do not differ significantly by Tukey's test at a 5% probability level ($P < 0.05$)- source: prepared by the Author, 2021.

grain yield $m^{-2}$, not differing from the high level and superior to the medium and low levels in both agricultural years. The higher investment level, combined with higher plant populations and fertilization rates, allowed for a greater number of grains per $m^2$. Sangoi et al. (2006b) found similar results. The single-cross hybrid used by the authors showed the highest grain number per $m^2$, and this variable contributed most to the higher yields. Forsthofer et al. (2006) used single-cross hybrids at high investment levels and obtained higher grain yields per $m^2$. The number of grains produced per area is the component that most impacts maize grain productivity (Coelho et al., 2022).

In both agricultural years, there was a significant interaction between investment levels and genotypes on grain yield (Table 9). It ranged from 7,847 to 15,882 kg $ha^{-1}$ in the first agricultural year, and between 7,885 and 14,524 kg $ha^{-1}$ in the second agricultural year. In general, grain yield increased with increasing investment level, especially when a single hybrid was used. In both agricultural years, all genotypes showed higher grain yields at the very high investment level, with no significant differences among the genotypes SCS155Catarina and AG9025PRO3 in the first agricultural year and AG5055 in the second agricultural year at the high level. In the second agricultural year, the cultivar AG1051 showed no difference between the very high, high, and medium levels.

Sangoi et al. (2003, 2006a, 2006b), Von Pinho et al. (2009), and Forsthofer et al. (2006) also observed that productivity increased as the level of management improved, with the single-cross hybrid standing out as the most productive and responsive to increased technology use. Higher investment levels resulted in considerable increases in base and topdressing fertilization, and higher plant density (Table 2). Furthermore, in the present study, increasing amounts of herbicide, insecticide, and fungicide applications were used (Tables 3 and 4). This procedure protected the genotypes from biotic stresses caused by weeds, pests, and diseases, thereby increasing their capacity to achieve higher productivity.

The single hybrid AG9025PRO3 showed the highest yields at all investment levels in both agricultural years, with no statistical difference only in the first agricultural year, compared to the AG5055 cultivar at the medium investment level (Table 9). The highest yield of AG9025PRO3 in the 2017/2018 agricultural year was 15,882 kg $ha^{-1}$ at a very high level, with no difference from the yield at the high level of 14,507 kg $ha^{-1}$. In the 2018/2019 agricultural year, yield was very high at 14,524 kg $ha^{-1}$ and was statistically higher than at the high level. In both agricultural years, all genotypes showed an increase in yield when comparing the lowest to the highest investment level (Table 9). This increase was greater in the SH genotype, which had productivity levels of 5,743 kg and 4,079 kg higher than NB at the MA level in the 2017/2018 and 2018/2019 harvests, representing increases of 56.64% and 39.05%, respectively. The other genotypes showed

**Table 9**. Grain productivity (kg $ha^{-1}$) of maize genotypes subjected to management systems with different levels of investment, in the agricultural years 2017/2018 and 2018/2019. Lages/SC.

| Investment Level | Genotypes | | | | Average | VC (%) |
|---|---|---|---|---|---|---|
| | SCS155 Catarina | AG1051 | AG5055 | AG9025PRO3 | | |
| **2017/2018** | | | | | | |
| Low | 8.050 bB* | 7.847 bB | 8.889 cB | 10.139 cA | 8.731 | 12.01 |
| Medium | 8.697 bC | 8.407 bC | 10.079 bcB | 12.633 bA | 9.954 | |
| High | 10.540 aB | 9.082 bC | 11.127 bB | 14.507 aA | 11.314 | |
| Very high | 10.803 aC | 11.010 aC | 12.915 aB | 15.882 aA | 12.675 | |
| Average | 9.522 | 9.109 | 10.752 | 13.291 | | |
| CV (%) | 5,76 | | | | | |
| **2018/2019** | | | | | | |
| Low | 7.889 bC | 7.885 bB | 9.098 cB | 10.445 cA | 8.829 | 6.66 |
| Medium | 8.163 bB | 8.237 abB | 10.043 bcA | 11.006 cA | 9.362 | |
| High | 8.536 bC | 8.878 abC | 11.303 aB | 13.341 bA | 10.515 | |
| Very high | 10.105 aBC | 9.100 aC | 10.860 abB | 14.524 aA | 11.147 | |
| Average | 8.672 | 8.525 | 10.326 | 12.329 | | |
| CV (%) | 7,52 | | | | | |

* Means followed by the same lowercase letter in the column and uppercase letters in the row do not differ from each other by Tukey's test. ($p<0.05$).

lower capacity for increased productivity. In the 2017/2018 harvest, VPA, TH, and DH showed increases of 2,753 (34%), 3,163 (40%), and 4,026 (45%), respectively. In the 2017/2018 harvest, VPA, TH, and DH increased by 2,753 (34%), 3,163 (40%), and 4,026 (45%), respectively. In the 2018/2019 harvest, VPA, SH, and DH showed increases of 2,216 (28%), 1,215 (15%), and 1,762 (19%). This result corroborates one of the work's hypotheses: differences in productivity between genotypes with different genetic variabilities are influenced by the production system adopted.

The increase in productivity with higher investment levels is due to increased plant density, base and topdressing fertilization, and applied phytosanitary management (Tables 2 and 4). This result indicates that single hybrids with higher productive capacity achieve higher grain yields. Single hybrids have superior productivity compared to both double and triple hybrids (Emygdio et al., 2007) and to VPA (Sangoi et al., 2006a). Modern single hybrids have a greater capacity to adapt to higher-density conditions, due to lower female sterility, greater synchrony between female and male flowering, and fewer lodged and broken plants (Sangoi et al., 2002). The higher productivity of single hybrids in dense environments is due to their early characteristics. They require less thermal sum to reach flowering, have a smaller leaf area, and need a larger plant population to achieve a leaf area index capable of efficiently intercepting solar radiation to reach their productivity ceilings (Sangoi et al., 2010a, 2010b).

The highest investment levels to achieve higher productivity are characterized by management practices that involve higher doses of base and topdressing fertilizers, higher plant density, and phytosanitary treatments (Table 2). In addition, the presence of transgenic genes in SH AG9025PRO3 supports full plant development and high productivity.

TH AG5055 showed intermediate productivity compared to VPA and DH (Table 6). At the average investment level of the two agricultural years, this cultivar and SH achieved the desired productivity. In general, TH was more productive than VPA and DH at the average investment level, and less productive than HS. Similar behavior was observed by Emygdio et al. (2007). The VPA (SCS155Catarina) and DH (AG1051) showed the lowest productivities, as their lower heterosis and greater morphological and phenological variability between plants increase intraspecific competition and make it difficult to achieve high productivities (Tokatlidis & Koutroubas, 2004). The present work shows that TH can be used in production systems with intermediate productivity, while VPA and DH can be used in systems with lower productivity expectations. This data differs from the data reported by Sangoi et al. (2006a). These authors observed that double hybrids can be viable at intermediate productivities and are superior to VPA. The present work shows that TH can replace this behavior.

TH AG5055 showed intermediate productivity between HS, DH, and VPA. At the medium investment level, this cultivar and HS reached the desired productivity of 9 t $ha^{-1}$. In general, TH was more productive than VPA and DH at the medium investment level, and less productive than HS. At the high and very high investment levels, TH productivity was also lower than HS, but higher than VPA and DH. This result corroborates the observations of Emygdio et al. (2007), who found that THs are less productive than HS and more productive than DH and VPA. Aiming for greater productive efficiency, this cultivar may be worth considering to achieve intermediate productivities, which explains why, according to Pereira Filho and Borghi (2020), TH is the second most expressive genotype, accounting for 5.8% of the genotypes commercialized in Brazil.

The VPA (SCS155Catarina) and DH (AG1051) genotypes showed the lowest productivities, and similar productivities to each other within the low, medium, and very high investment levels in the 2017/2018 crop season, and in the medium, high, and very high levels in the 2018/2019 crop season. Due to their broader genetic base, VPAs exhibit greater morphological and phenological variability, characteristics that increase intraspecific competition and are unfavorable to obtaining high productivities (Tokatlidis & Koutroubas, 2004). However, VPAs have greater productive stability and a lower probability of presenting lower-than-expected productivity under scenarios of climatic variability (Lana et al., 2017). Furthermore, this cultivar type has the lowest seed cost, implying lower financial risk and the potential for viability in low-investment production systems, even if it does not achieve the highest productivities (Sangoi et al., 2006b). However, the genotypes SCS155Catarina and AG1051, at the medium level, and all genotypes submitted at the high and very high levels did not reach the desired productivities of 15 t ha$^{-1}$ at the high level and 21 t ha$^{-1}$ at the very high level.

The limitation to high productivity observed in the present work may be related to the intrinsic characteristics of the experimental area. Possible reasons for this may be: a) chemical limitation of the soil, since the soil pH was below the ideal range for maize cultivation (Table 1), which according to Silva et al. (2016) is 6.0; b) inadequate plant population arrangement, the spacing between rows in the present work was 0.7m, and according to Sangoi et al. (2019) the use of 0.40 m row spacing is more efficient than 0.8 m to optimize productivity under high plant density conditions; c) lack of crop rotation in the experimental area and possible subsurface soil compaction.

Another important point is that HS was more productive than the other genotypes under the low-investment management system. This behavior confirmed the data obtained by Sangoi et al. (2003, 2006a, 2006b), showing that the greater genetic variability of VPAS and DHs does not confer greater tolerance to biotic and abiotic stresses than HS. The greater heterosis and greater morphological and phenological uniformity of the single hybrids result in better agronomic performance than the other genotypes, regardless of the producer's investment capacity in management.

Gross revenue and total cost increased with increasing investment for all genotypes (Tables 10 and 11). However, net margin and other economic parameters (gross margin and profitability index) did not show the same pattern, decreasing as investment levels increased in both agricultural years. The genotypes showed a higher net margin at the lowest level in both agricultural years, except for genotype AG9025PRO3, which in the first agricultural year had a higher net margin at the medium investment level (Table 10).

The highest net profit margins for each agricultural year were observed when using HS AG9025PRO3, at the medium level in the first agricultural year (US$ 1,098.59) (Table 10) and at the low level in the second agricultural year (US$ 679.45) (Table 11). The other genotypes showed higher net profit margins at the low investment level in both agricultural years, indicating that this level provided the highest profitability, except for HS in the 2017/2018 crop season. This situation occurred because, at the low investment level, the genotypes showed productivity higher than the target productivity of 6 t ha$^{-1}$, with productivity between 7.847 (AG1051) and 10.139 kg ha$^{-1}$ (AG9025PRO3) in the 2017/2018 crop season and between 7.885 (AG1051) and 10.445 kg ha$^{-1}$ (AG9025PRO3) in the 2018/2019 crop season (Table 11).

**Table 10**. Estimates of gross revenue, total cost, net margin, and gross margin for four maize genotypes at four investment levels, 2017/2018 crop year.

| Investment levels | Genotypes | Gross Revenue (US$ ha$^{-1}$) | Total Cost (US$ ha$^{-1}$) | Net Profit Margin (US$ ha$^{-1}$) | Gross Margin (%) | Profitability Index (%) | Balanced Productivity (kg ha$^{-1}$) | Equilibrium Price (US$ sc$^{-1}$) |
|---|---|---|---|---|---|---|---|---|
| Low | SCS155 | 1,456.66 | 706.17 | 750.49 | 106% | 51% | 3,903.00 | 5.27 |
| | AG1051 | 1,420.27 | 750.49 | 669.48 | 89% | 46% | 4,148.00 | 5.74 |
| | AG5055 | 1,608.70 | 779.26 | 829.15 | 106% | 51% | 4,306.00 | 5.26 |
| | AG9025PRO3 | 1,834.99 | 874.64 | 960.05 | 109% | 52% | 4,834.00 | 5.18 |
| Average | SSC155 | 1,574.07 | 915.73 | 658.33 | 71% | 41% | 5,060.00 | 6.32 |
| | AG1051 | 1,521.53 | 970.62 | 550.91 | 56% | 35% | 5,363.00 | 6.93 |
| | AG5055 | 1,824.13 | 1,023.45 | 800.39 | 78% | 43% | 5,656.00 | 6.09 |
| | AG9025PRO3 | 2,286.40 | 1,187.81 | 1,098.59 | 92% | 47% | 6,563.00 | 5.64 |
| High | SCS155 | 1,907.49 | 1,420.86 | 486.63 | 34% | 25% | 7,851.00 | 8.09 |
| | AG1051 | 1,643.63 | 1,471.93 | 171.41 | 11% | 9% | 8,134.00 | 9.73 |
| | AG5055 | 2,013.74 | 1,533.56 | 479.88 | 31% | 23% | 8,475.00 | 8.27 |
| | AG9025PRO3 | 2,625.69 | 1,762.20 | 863.20 | 48% | 32% | 9,737.00 | 7.29 |
| Very high | SCS155 | 1,955.04 | 1,664.17 | 290.86 | 17% | 14% | 9,196.00 | 9.24 |
| | AG1051 | 2,008.75 | 1,737.25 | 271.49 | 15% | 13% | 9,598.00 | 9.39 |
| | AG5055 | 2,337.47 | 1,796.84 | 540.34 | 30% | 22% | 9,929.00 | 8.35 |
| | AG9025PRO3 | 2,874.59 | 2,104.14 | 770.16 | 36% | 26% | 11,626.00 | 7.95 |

Source: prepared by the Author, 2021.

**Table 11**. Estimates of gross revenue, total cost, net margin and gross margin of four maize genotypes at four investment levels, agricultural year 2018/2019.

| Investment levels | Genotypes | Gross Revenue (US$ ha$^{-1}$) | Total Cost (US$ ha$^{-1}$) | Net Profit Margin (US$ ha$^{-1}$) | Gross Margin (%) | Profitability Index (%) | Balanced Productivity (kgha$^{-1}$) | Equilibrium Price (US$ sc$^{-1}$) |
|---|---|---|---|---|---|---|---|---|
| Low | SCS155 | 1,113.51 | 642.23 | 471.28 | 73% | 42% | 4,549.00 | 4.88 |
| | AG1051 | 1,112.99 | 683.30 | 429.69 | 63% | 39% | 4,840.00 | 5.20 |
| | AG5055 | 1,284.20 | 710.25 | 573.95 | 81% | 45% | 5,032.00 | 4.68 |
| | AG9025PRO3 | 1,474.41 | 794.70 | 679.45 | 85% | 46% | 5,631.00 | 4.57 |
| Average | SSC155 | 1,152.27 | 826.53 | 325.74 | 39% | 28% | 5,855.00 | 6.08 |
| | AG1051 | 1,162.79 | 878.64 | 284.15 | 32% | 24% | 6,224.00 | 6.40 |
| | AG5055 | 1,417.68 | 926.38 | 491.04 | 53% | 35% | 6,563.00 | 5.54 |
| | AG9025PRO3 | 1,553.72 | 1,051.90 | 501.57 | 48% | 32% | 7,452.00 | 5.73 |
| High | SCS155 | 1,204.89 | 1,297.81 | -92.92 | -7% | -8% | 9,194.00 | 9.13 |
| | AG1051 | 1,253.14 | 1,363.26 | -109.86 | -8% | -9% | 9,657.00 | 9.21 |
| | AG5055 | 1,595.56 | 1,421.53 | 174.03 | 12% | 11% | 10,069.00 | 7.55 |
| | AG9025PRO3 | 1,883.31 | 1,605.58 | 277.73 | 17% | 15% | 11,374.00 | 7.22 |
| Very high | SCS155 | 1,426.41 | 1,516.76 | -90.10 | -6% | -6% | 10,744.00 | 9.01 |
| | AG1051 | 1,284.72 | 1,566.56 | -281.84 | -18% | -22% | 11,098.00 | 10.33 |
| | AG5055 | 1,533.19 | 1,617.38 | -84.19 | -5% | -5% | 11,457.00 | 8.94 |
| | AG9025PRO3 | 2,050.41 | 1,892.55 | 157.61 | 8% | 8% | 13,407.00 | 7.82 |

Source: prepared by the Author, 2021.

In an experiment using three genotypes, four investment levels, and two locations, Sangoi et al. (2006b) found that, provided the farmer has the financial means, it is possible to associate maximum technical and economic efficiency with high productivity ceilings. Thus, the authors found that greater investment in management practices and inputs increased grain productivity and the profitability of maize cultivation, regardless of the cultivar used. In the present work, this was not confirmed, as the genotypes showed higher ML values at a low investment level. With the increase in investment level, only HS proved viable, although the higher level decreased the ML values.

Across the genotypes used at each investment level in both agricultural years, HS AG9025PRO3 was the most profitable, with the highest ML. At the very high level of the 2018/2019 crop, HS was the only cultivar that did not show a loss (Table 11). This result is mainly because this cultivar showed the best agronomic performance at each investment level in both agricultural years (Tables 10 and 11).

Higher investments in agriculture, particularly in inputs and technologies, including genetically modified seeds, can increase production costs. On the other hand, it can also generate higher revenues (Volsi et al., 2020). This scenario arises because higher investments in production can improve plant development, increasing productivity and, consequently, profitability (Artuzo et al., 2018). The present work showed that the highest investment levels with higher productivities did not necessarily yield better economic indices, mainly because they entail higher production costs and do not achieve the desired productivities. HS AG9025PRO3 was the cultivar that came closest to the desired productivity. In this sense, 493 and 5,118 kg of grains were lacking to reach the desired productivity at the high and very high levels in the 2017/2018 agricultural year, and 1,659 and 6,476 kg in the 2018/2019 agricultural year. Therefore, achieving the desired productivity at higher investment levels is essential to the financial viability of maize cultivation.

Gross margin is an indicator of the crop's entrepreneurial capacity, showing how much of the invested capital (total cost) was covered. The higher the gross margin, the lower the risk of the agricultural business (Garbelini et al., 2020). The highest gross margin values for each genotype were observed at the low investment level, with values of 106% (VPA), 89% (DH), 106% (TH), and 110% (HS) in the 2017/2018 growing season (Table 10) and 73% (VPA), 63% (DH), 81% (TH), and 85% (HS) in the 2018/2019 growing season (Table 11). The lowest margin values for each genotype were observed at the very high investment level, with values of 17% (VPA), 16% (DH), 30% (TH), and 37% (HS) in the 2017/2018 growing season, and -6% (VPA), -18% (DH), -5% (TH), and 8% (HS) in the 2018/2019 growing season. This result shows that as investment levels increased, so did the farmer's financial risk. Among genotypes within each investment level, HS AG9025PRO3 proved to be the safest cultivar to grow, with higher gross margins at all investment levels in both growing seasons.

The profitability index is another important indicator of crop profitability, which shows the activity's available revenue rate after all costs are paid (Garcia et al., 2012). Low investment levels yielded the highest profitability indices. The higher the investment level, the lower the profitability index (Table 11), with values ranging from 47 to 52% at the low investment level and from 14 to 27% at the very high investment level in the 2017/2018 agricultural year. In the 2018/2019 agricultural year, the values ranged from a low level (39-46%) to a very high level (-22% to 8%) The increase in costs with investment levels, the value received per bag of maize, and the yields obtained were determining factors in the decrease of the profitability index with the increase in the investment level, showing that after paying all costs, the proportion of ML in relation to gross revenue is higher at lower investment levels.

Based on breakeven productivity, productivity above breakeven productivity is indicative of profitability. The HS AG9025PRO3 required higher breakeven productivities than the other genotypes at each investment level (Tables 10 and 11). This situation is due to the higher cultivation costs of this cultivar, requiring higher productivity to offset them. VPA SCS155Catarina, on the other hand, has the lowest breakeven productivities at each investment level, mainly due to lower seed costs.

Within each investment level, the single hybrid AG9025PRO3 had a lower breakeven price because of its higher productivity. In the second agricultural year, the genotypes SCS155Catarina and AG1051 at the high and very high levels, and the cultivar AG5055 at the very high level, showed higher breakeven productivity and breakeven price values, indicating that the productivities obtained were not sufficient to achieve minimum profitability. This result shows that these genotypes should not be used at higher investment levels due to their limited productivity.

The price paid per bag of maize was crucial for crop profitability. In the first agricultural year, the genotypes at all investment levels were more profitable than in the second agricultural year. This situation was mainly due to the higher prices practiced in the 2017/2018 crop year (US$ 10.86) than in 2018/2019 (US$ 8.47). The SCS155Catarina and AG1051 genotypes showed losses in the second agricultural year at the high and very high levels (Table 11), with equilibrium prices higher than the price stipulated for the 2018/2019 crop year (US$ 8.47). In this sense, their equilibrium prices were, respectively, US$ 9.13 and US$ 9.21 at the high level, and US$ 9.01 and US$ 10.33 at the very high level (Table 11).

This work identifies four key factors that drive the economic returns of maize cultivation. The first is to adapt the cultivar type to the genotype's productive capacity and the rural producer's investment capacity. The second is that even at low investment levels, the use of HS proved more profitable than other genotypes with greater genetic variability. The third is that to obtain satisfactory profitability at high investment levels, it is necessary to use genotypes that reach high productive ceilings, mainly single hybrids. Moreover, the fourth is that at higher investment levels, it is essential to achieve high productivity for the crop to be financially competitive.

At all investment levels, in both agricultural years, the single hybrid AG9025PRO3 showed the best economic performance compared to the other genotypes. The single hybrid showed higher net margins, gross margins, and profitability rates. It is worth noting that economic parameters indicate that increasing investment levels is not a guarantee of greater profitability, even when using HS that enable high productivity.

In experiments conducted in the early 21st century, Sangoi et al. (2003) found that the productivity achieved at the highest investment levels was sufficient to make those levels financially viable, with economic indices superior to those at lower investment levels with lower productivity expectations. This scenario indicated that higher crop productivity is associated with greater economic efficiency. Forsthofer et al. (2006), in experiments conducted in the 2001/2002 and 2002/2003 growing seasons in the state of Rio Grande do Sul, found that, provided it was cultivated at the appropriate time, it was possible to combine maximum technical efficiency with economic efficiency, reinforcing that the pursuit of high productivity was financially viable.

This study aimed to identify maize production systems with preferred planting times in isolation. However, maize cultivation should be included in a crop rotation and diversification production system, because, according to Volsi et al. (2020), crop diversification that includes maize and soybeans presents higher production costs but is also more profitable.

The ML, MB, and IL values in this study corroborate the hypothesis that greater financial investment in management practices does not necessarily lead to higher gross margins for maize producers. Another hypothesis addressed in this work is that the use of conventional genotypes, with lower seed costs, is an alternative that makes maize cultivation technically and economically viable for producers with limited financial capacity to invest in management practices. The data obtained in the two years of conducting the trial showed that, provided the farmer has the financial means to purchase the seeds, all the genotypes studied are financially viable at the low investment level.

It is important to highlight that the yields achieved by HS AG9025PRO3 at the high and very high levels in this study were below the targeted yields of 15 and 21 t ha$^{-1}$ (Table 6). This result indicates that HS did not achieve greater economic viability with increased investment. In the work by Sangoi et al. (2006a), yields achieved with HS at the high (>6 t ha$^{-1}$) and potential (>9 t ha$^{-1}$) levels were similar to the targeted yields.

With this, the authors affirmed that greater investment in management practices and inputs increased grain productivity and the gross margin of maize cultivation, regardless of cultivar type. The results of this study did not confirm the authors' findings, as the yields obtained were insufficient to translate the increased investment level into higher profitability. Furthermore, only the single-cross hybrid was technically and financially viable with increased investment.

## Conclusions

The AG9025PRO3 single hybrid exhibits higher grain productivity than other genotypes, regardless of the level of investment used in the crop.

Low investment levels in maize cultivation result in a higher net margin, regardless of the genotype used.

Production systems focused on high maize productivity, with higher production costs, are more financially viable when using the AG9025PRO3 single hybrid.

The HS AG9025PRO3 has the highest productive capacity, followed by the TH AG5055 with intermediate capacity, and the DH AG1051 and VPA SCS155Catarina with the lowest.

The HS AG9025PRO3 has the highest production capacity, followed by the TH AG5055 with intermediate capacity, and the DH AG1051 and VPA SCS155Catarina with the lowest.

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