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Prohexadione-Calcium and Nitrogen Topdressing Fertilisation on Productive Performance of Maize with Late Sowing

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Authors' contributions

This work was carried out in collaboration between all authors. All authors read and approved the final manuscript.

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ABSTRACT

Background: The growing use of nitrogen topdressing fertilisation, combined with late sowing of maize crops, causes greater sensitivity to lodging and breaking of plant stems, and poses risks to yield and grain quality. Thus, plant growth retardants are currently an option to mitigate losses resulting from adverse effects.

Aims: The objective of this work was to evaluate the influence of using the plant growth retardant prohexadione-calcium (Pro.Ca) in response to application of different nitrogen levels on morphometric and productive characteristics of maize after late sowing.

Study Design: The experiment used a randomized block design (RBD) with four replications.

Place and Duration of Study: The field research was conducted at Lages, Santa Catarina State, Brazil, in Santa Catarina State University farm (27° 52'S; 50° 18'E and 930 m elevation), from February to June of 2017.

Methodology: The treatments were composed of two levels of nitrogen: 135 and 270 kg N ha^{-1}, and three doses of the plant growth retardant Pro.Ca: 0, 100 and 200 g a.i. ha^{-1}.

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Results: The results showed that the tested nitrogen levels significantly affected (P = .05) ear height and plant height while number of grains per spike, stem diameter, thousand-grain weight and final yield were not affected (P > .05). The 135 kg of N ha^{-1} (100% level) show better results for agronomic traits of maize. The plant growth retardant Pro.Ca applied on maize plants at V12 stage at a 100 g a.i. ha^{-1} lead to a decrease in 8.9% and 5.3% in plant and ear height, respectively, which point to its use with high level of nitrogen topdressing fertilisation associated with Pro.Ca to avoid excessive vegetative growth in plant and ear height, maintaining the yield component number of grains per ear and final yield.

Conclusion: The recommended dose of nitrogen (135 kg ha^{-1}) topdressing a V4 stage are adequately for achieve higher grain yield and plant height at late sowing; but Pro.Ca (100 g a.i. ha^{-1}, applied at V12 stage) can effectively retard maize plant growth, which results in shorter plants with lower ear height, without affecting grain yield; which helps to minimise the occurrence of breaking and lodging of the stem.

Keywords: Growth retardant; Nitrogen fertilisation; Zea mays.

1. INTRODUCTION

Maize (*Zea mays* L.) is the cereal with the greatest geographical coverage in the world, whose development cycle ranges from 90 to 205 days. It has wide genetic variability to possibility adapts to different soil and climate conditions. It is grown from sea level up to 4,000 meters of altitude and in semi-arid regions with rainfall of 400 mm per year, up to tropical regions with more than 1,500 mm per year [1]. In the 2017/2018 growing season, world production was estimated at 1.03 billion tonnes. Brazil is the third largest world producer, with total production of 83.5 million tons and average production of 4.96 tons ha^{-1} [2].

Under field conditions, maize plants are exposed to adverse situations and may be influenced by factors such as seed quality, temperature, rainfall, strong winds, low soil fertility and damage caused by wild plants, pests and diseases. Therefore, there can be losses in grain yield if accurately management is not performed [3]. Nitrogen (N) fertilisation is often used to achieve high grain yield. Nitrogen is the nutrient that most crops require in greater amount, hence it plays an important role in biochemical processes [4].

Many Brazilian soils are ineffective in providing all the N required by plants; thus, nitrogen topdressing application is required to meet the need for this nutrient in periods of greater demands by crops [5]. Benefits provided by nitrogen fertilisation include an increase in plant height and ear height. However, excess growth poses risks to yield and grain quality [6]; moreover, because late sowing leads to lesser intensity of solar radiation at the end of the cycle, thus reducing the reproductive period and increasing the incidence of foliar diseases. Therefore, plants are more prone to lodging and breaking of its stems [7].

The use of plant growth retardants is an option to mitigate the adverse effects that may reduce crop yield. Through hormone control, they alter plant metabolism, thereby controlling and regulating the growth of various plant organs through chemical signalling [8]. The growth retardant prohexadione-calcium (Pro.Ca) (3-oxide-4-propionyl-5-oxo-3-cyclohexene-carboxylate) inhibits gibberellin biosynthesis and can effectively control growth of branches and increase yield in fruit trees; recently, it was released in Brazil for use in wheat, oats, barley, rye and triticale [9]. The use of these gibberellin inhibitors may increase grain yield not only by reducing lodging, but also by increasing absorption of solar radiation, altering the stems diameter, increasing leaf dimensions (length and width), and stimulating more vigorous root growth [10].

However, there is a lack of scientific information on the effects of such substances on the management of maize plant height. Therefore, application of Pro.Ca in maize could enable the use of high doses of nitrogen, thus maximising the productive potential of maize crops without causing losses as a result of lodging of plants and breaking of stems. For the above-mentioned reasons, the objective of this study was to evaluate the influence of using prohexadione-calcium (Pro.Ca) on production of shorter maize plants and on the response to application of different doses of nitrogen in topdressing fertilisation on the morphometric and productive characteristics of late-sown maize.

2. MATERIALS AND METHODS

2.1 Description of the Study Site

The experiment was conducted in the experimental farm of Santa Catarina State University - Agroveterinary Sciences Center (UDESC - CAV), from February to June 2018, in the municipality of Lages, located in the Southern Plateau of Santa Catarina State. Geographical coordinates are 27°52'30" south latitude and 50°18'20" west longitude, and average altitude of 930 m. The climate in the region, according to the Köppen classification, is Cfb (mesothermal, with mild summers). Average temperatures of the hottest month are below 22°C, and rains are well-distributed throughout the year [11].

Data on weather were collected in the Company of Agricultural Research and Rural Extension of Santa Catarina (EPAGRI; Lages-SC). Fig. 1 shows information on maximum, minimum and average temperature and rainfall during the experiment.

The soil of the experimental area is classified as Aluminic Humic Cambisol [12]. Table 1 shows the chemical properties of soil in the 0-20 cm layer, according to a soil analysis performed in November, 2017. Fertilisation at sowing consisted of application of 25.25 kg ha^{-1} of N, 150 kg ha^{-1} of P_2O_5 and 100 kg ha^{-1} of K_2O, performed in agreement with the Soil Chemistry and Fertility Commission - RS/SC [13] aiming at an expected grain yield of 10 tons ha^{-1}.

2.2 Experimental Lay Out and Treatments

The experiment used a randomized block design (RBD) in a 2 x 3 factorial arrangement with four replications. The first factor consisted of two doses of nitrogen was applied in a single dose at stage V4 as 135 kg N ha^{-1} and two stages, V4 and V10 as 270 kg N ha^{-1} (equally divided into each stage of the scale of Ritchie; Hanway & Benson) [14], equivalent to once and twice as much, respectively, the recommended dose, aiming at an expected grain yield of 10 tons ha^{-1}. The second factor consisted of three doses of the growth retardant prohexadione-calcium (Pro.Ca), namely: 0 (without application, only water); 100 and 200 g a.i. ha^{-1}, applied in a single dose at phenological stage V12 by means of a CO_2-pressurised backpack sprayer with an equivalent spray volume of 200 $L.ha^{-1}$.

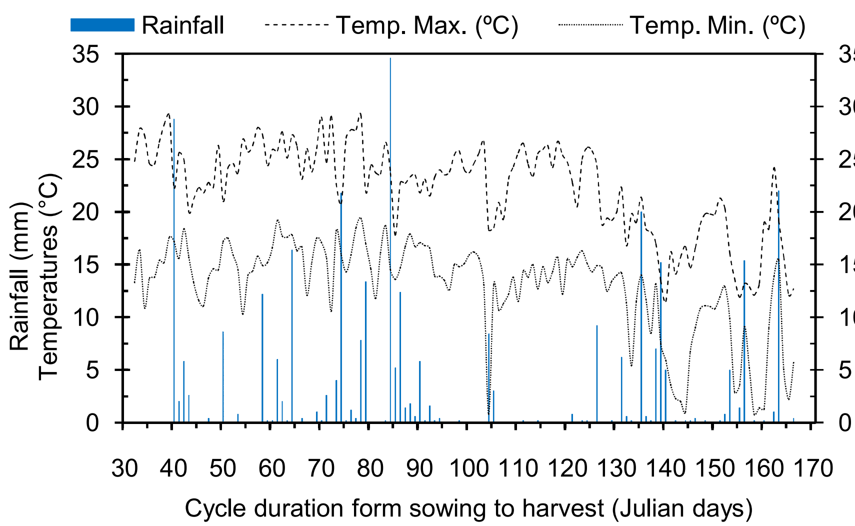

Fig. 1. Daily precipitation and maximum and minimum temperatures during the experiment (seeding at Feb, 1th; harvest at June, 15th)

Table 1. Chemical analysis of the soil of the experimental plots

Sample depth	Clay	V	OM	pH (H_2O)	P Mehlich-1	K	Ca	Mg	H^++Al^{+3}	CEC (pH 7)
	----------%---------				---$mg.dm^{-3}$---		---------$cmol_c.dm^{-3}$-----------			
0 – 20 cm	47	79	2.7	5.8	20.2	1.8	7.7	5.7	3.5	17.3

V = base saturation; OM = organic matter; P Mehlich-1= South Brazilian official soil P extraction; CEC cation exchange concentration

Each experimental unit consisted of four rows of five meters in length, with inter-row spacing of 50 cm. The two central rows were selected as usable area, in a total of 5 m^2, while the two external rows were discarded. Soil was prepared in a conventional manner (plowing and harrowing). Late-season sowing was performed mechanically on February 1st, 2018 with a density of 80,000 plants ha^{-1}, using hybrid P30F53YH with early-cycle transgenic events Yieldgard and Herculex, characterised by stability in cultivation environments and tolerance to lodging.

2.3 Agronomic Practices and Management

Weed control was carried out at post-emergence when the plants were at stages V4 and V6, using a product based on atrazine (Primóleo®; 6 $L.ha^{-1}$). One insecticide application was also performed, with active ingredients Thiamethoxan and Lambda-Cyhalothrin (Engeo Pleno®; 200 $mL.ha^{-1}$) for control of corn rootworm (*Diabrotica speciosa*) and fall armyworm (*Spodoptera frugiperda*) when the plants were at stage V6.

2.4 Parameters Collected and their Determination

At phenological stage R2, the following characters were determined in five subsequent plants in the usable area of each plot: plant height (distance measured from the soil surface to the end of the tassel; ear height (distance measured from the soil surface to the main ear) and stem diameter (measured from the middle third of the second internode, from the base of the plant, in the sense of the smallest and the largest diameter, respectively).

At crop maturity, lodged or broken stems within the usable area of the plot were counted to determine the percentage of lodging or breaking plants, calculated by dividing the number of lodged or broken plants by the total number of plants in the usable area multiplied by 100. A plant was considered to be broken when its stem was broken below the main ear. A plant was considered to be lodged when its angle between the lower internodes of the stem and the soil was lower than 45°.

Harvesting was performed mechanically on 15 June 2018 by collecting all the ears contained in the usable area and by evaluating productive performance, based on the following characteristics: final population of plants and number of ears per plant. Then, grain yield components were determined through handled harvesting of five ears of the usable area of the plot to determine number of grains per ear and 1000-grain weight. For determination of grain yield in tonnes per hectare, the grains were stored in kraft paper bags and oven-dried, under ventilation and temperature of approximately 60ºC to constant mass. The weights obtained from the dry weight grains harvested in the usable area of the plots were converted to one hectare and corrected, based on 13% moisture content.

2.5 Data Analysis

The data were tabulated and then underwent analysis of homogeneity and normality and, subsequently, analysis of variance by the F-test. When significant variances were detected, the averages were submitted to Tukey's probability test (P = .05), and regression analysis was performed separately for the doses of the plant growth retardant.

3. RESULTS

There was no lodging of plants in the treatments applied, because there were no favorable climatic conditions, e.g., excess rainfall associated with strong winds, because it rained about 330 mm and average wind speed was less than 5 $km.h^{-1}$ (Fig. 1).

Ear height was individually affected by the nitrogen factor (Table 2). When one single nitrogen topdressing application was performed, at V4 plant growth stage, there was an increase of 20% in this variable. The ears were inserted, on average, 22 cm above than other when N were splited at V4 plus V10 stages (Fig. 2). Similarly, the taller plant heights were obtained with the single application of nitrogen applied on plant at V4 stage than split N at V4 plus V10 (Fig. 2). For this variable, although their difference of 23 cm, this difference is equivalent to a 12% increase, which suggests that, in this situation, total plant height was less influenced by this factor when compared to ear height.

Although there were significant variances by the F-test (P = .05) for application of Pro.Ca, plant height decreased by 0.19 cm when increasing the dose of this growth retardant (Fig. 3). For ear height, a lower slope of the trend line was found. Plant height is influenced by the internodes above ear height (Fig. 3). Stem diameter was not influenced by any of the study factors (Table 2); this variable - for the hybrid in question and under the conditions of this study - is apparently unresponsive when exposed to nitrogen topdressing fertilisation and application of Pro.Ca.

Number of grains per ear showed a significant effect (*P* = .05) in the nitrogen factor analysed individually (Table 2). Application of N on plants at stage V4 resulted in more grains when compared to the double amount of the recommended fertilisation rate. The difference between the averages was 321 grains, which is equivalent to a 17% increase. This was not the behavior for thousand-grain weight, which suggests that ear size may have been influenced. This fact can also be evidenced by the total number of grains in the treatments with application of N at V4 and application at V4 plus V10, in which the plots with a single application had 321 more grains when compared with the plots with twice as much they recommend amount (Table 2). Grain yield was not significantly affected. However, the increase in the number of grains in the treatment with a single application of N had a direct effect on grain yield; there was an increase of 4.5% in plots with a higher number of grains.

Although the variances in the number of grains per ear between the averages of the treatments with Pro.Ca have not resulted in a statistically significant difference (*P* > .05) (Table 2), the dose of 200 g a.i. ha^{-1} of the plant growth retardant led to an increase of 7% when compared to the control. This increase, on average, was equivalent to 128 grains when compared to the control. The same factor resulted in a decrease in thousand-grain weight, because the highest dose, compared to the average of the control, resulted in a decrease by 6%. The same tendency was observed to grain yield when compared to the control, resulting in a decrease by 6 and 10% in GY due 100 and 200 g a.i. ha^{-1} of Pro.Ca, respectively.

4. DISCUSSION

Lodging and breaking of plants may be due to a variety of factors. One of them is that taller plants with larger ear heights have a higher center of gravity, which results in lodging [15]. These characteristics can offer advantages in mechanised harvesting [16]; together with these morphological characteristics, climatic conditions such as high rainfall and strong winds lead to lodging. The increase in plant height may be due to late sowing, which stimulates the vegetative growth of the crop. In the case of this study, there were no wind storms nor prolonged rainfall, especially in the reproductive stages. Rainfall during cultivation was 330 mm (Fig. 1). In another work with hybrid P30F53 and SCS Fortuna an open pollinated variety, both treated with plant growth retardant trinexapac-ethyl was not observed plant lodging and neither stem breaking [17].

Ear height (EH) can be influenced by several factors; although, as a rule, an increase in nitrogen fertilisation leads to an increase in EH, several authors have reported that EH depends on other factors. Kappes et al. [18] reported that increases up to 90 kg of urea in topdressing fertilisation and increases up to 12 % of foliar urea did not affect EH. Souza et al. [19], working with second crop maize, showed that this variable is dependent on the source of nitrogen applied in topdressing fertilisation. However, the same authors reported that EH, when submitted to urea application, shows a smaller variation after an increase in the dose when compared to other sources of N. According to Forsthofer et al. [20], EH may be influenced by interactions between nitrogen doses and time of sowing, which varies according to crop year. The same author suggests that late sowing causes variations in EH after an increase in nitrogen dose, which is smaller when sowing occurs at the preferred time. In this perspective, the greatest EH found in this study, when submitted to a lower dose of N, in this case urea, suggests that it is due to the late sowing which had been performed. However, the behavior may be unfavourable because minors EH are associated with a lower risk of lodging in crops [21, 22]. The plant of lodging, plant height, leaf chlorophyll, grain yield and nitrogen into grains were not affected by fertiliser N sidedressing above the ideal level combined with the use of trinexapac-ethyl [23]. Nitrogen is the nutrient that has the greatest influence on grain yield in maize, however, the excess of this nutrient increases the plant sensitivity to lodging; but lodging occurrence can be minimised due use of a mixture of the plant growth regulators ethephon and diethyl aminoethyl hexanoate (DA-6), called EDAH [24].

Greater plant heights may be associated with the risk of lodging or breaking of plants [25]. According to Favarato et al. [26] during vegetative stages the plant send its reserves and photoassimilates to growth of stem, particularly to internodes length, and longer internodes make plant sensitive to lodging or breaking. Changes in plant development are dependent on climate change arising from sowing time; the cycle of maize hybrids suggests that they are associated with the relevance of such changes [27]. Dartora et al. [28] reported that plant height varies widely when subjected to increasing doses of N,

Table 2. Analysis results of ANOVA and the effects of nitrogen (N) and plant growth retardant (Pro.Ca) on the characteristics lodging (LOD), ear height (EH), plant height (PH), stem diameter (SD), number of grains per ear (NGE), thousand-grain weight (TGW) and grain yield (GY) of corn hybrid P30F53YH in the 2018 growing season

SOV	DF	Traits						
		LOD	EH	PH	SD	NGE	TGW	GY
Bloco	3	0.01	0.02	0.03	0.87	180032.5	76.17	0.30
N	1	0.05	0.27**	0.31**	7.49	616962.7*	3.18	0.00
Pro.Ca	2	0.02	0.11*	0.08*	2.97	35434.6	741.04	0.03
N×Pro.Ca	2	0.03	0.02	0.00	3.11	37527.0	13.76	0.43
Error	15	0.01	0.02	0.06	3.03	119484.0	233.5	0.21
CV%		26.0	17.1	14.3	8.1	20.6	7.1	24,4
N Doses ($kg.ha^{-1}$)		**Single effects of N levels**						
		LOD (%)	**EH (m)**	**PH (m)**	**SD (cm)**	**NGE (n°)**	**TGW (g)**	**GY ($ton.ha^{-1}$)**
135		0.01	1.07	1.90	2.20	1837.1	215.1	3.72
270		0.03	0.86	1.68	2.09	1516.4	214.7	3.90
Pro.Ca ($g\ a.i.\ ha^{-1}$)		**Single effects of Pro.Ca levels**						
0		0.03	1.02	1.91	2.18	1622.1	225.6	4.01
100		0.01	0.93	1.74	2.07	1657.3	206.8	3.77
200		0.01	0.95	1.71	2.19	1750.9	212.7	3.62

*** and * = differ statistically by the F-test at P = .01 and P = .05, respectively; SOV = sources of variation; DF= degrees of freedom; CV% = coefficient of variation*

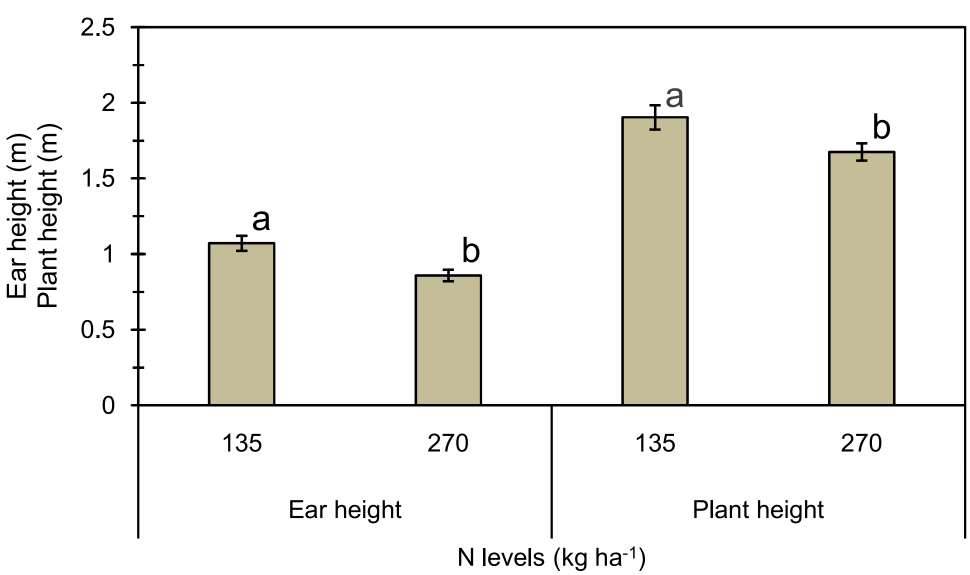

Fig. 2. Ear height and plant height of maize hybrid P30F53YH after nitrogen application at V4 plus V10 phenological stage

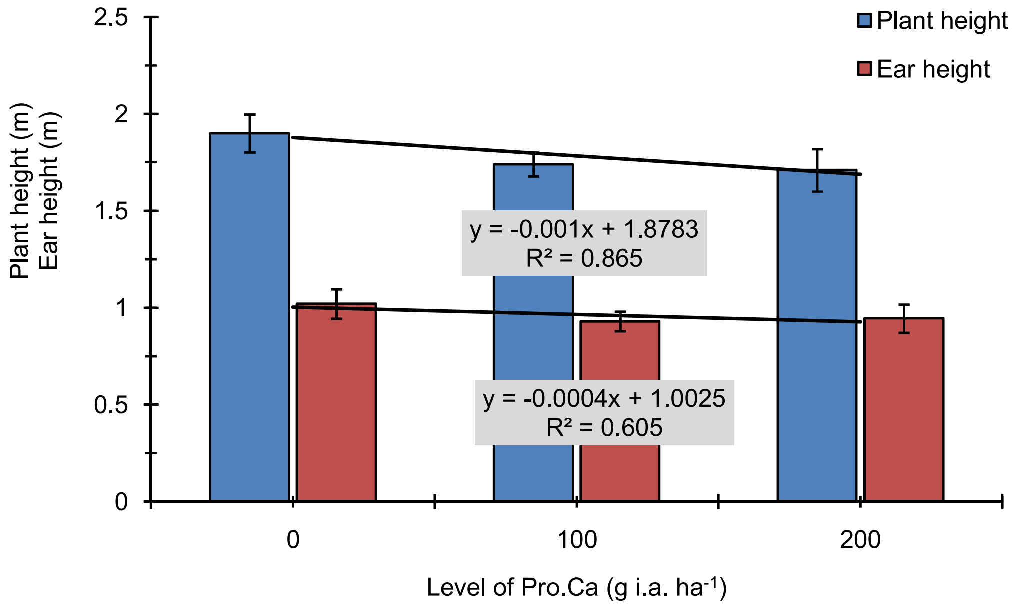

Fig. 3. Reduction of plant and ear height of maize hybrid P30F53YH as a function of application of the plant growth retardant prohexadione-calcium

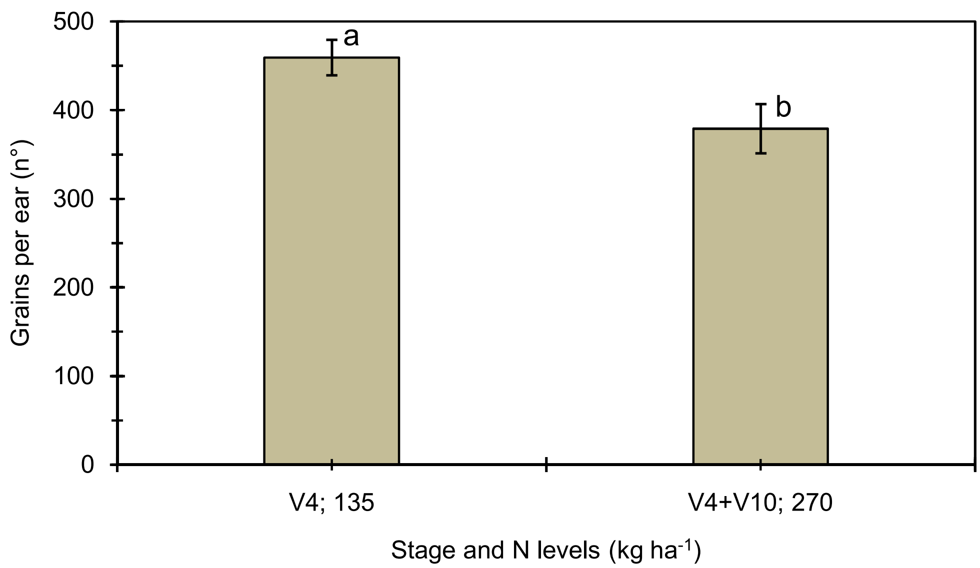

Fig. 4. Grains per ear for the maize hybrid P30F53YH after nitrogen topdressing application at stages V4 and V4 plus V10

and that the behavior of growth curves varies according to the stage of the crop. When at the vegetative stage, these curves stabilise at around 120 kg N ha^{-1}, while at the reproductive stage, this curve is linear and increasing. Mendes Fagherazzi et al. [17] reported that the plant growth stage also influences the effect of growth regulators on plant height; the highest sensitivities to the product are found around stage V7. In the case of this study, the absence of a response from height can be due to late application of the plant growth regulator. As a rule, plant height increases as nitrogen fertilisation increases. The greatest height found in the recommended fertilisation dose suggests that it is associated with intrinsic factors of the hybrid and climatic conditions resulting from late sowing.

Pro.Ca is a class of growth inhibitors which act particularly on gibberellins GA20 and GA1 - plant hormones that stimulate cell elongation. Reduction in plant growth can be advantageous for application of other agrochemicals, because plant shoot more compact increasing the effectiveness of application on the all plant shoot. The effectiveness of such products is dependent on several factors, namely, cultivar, species, phenological stage, canopy architecture and climate conditions, which are dependent on sowing time [29]. Although Pro.Ca has retarded the height of maize plants in this study, this decrease was not statistically significant, which corroborates the results found by Spitzer et al. [30] on their study on plant growth retardants. They found no significant difference for maize plant height in all treatments with Pro.Ca. However, it should be noted that the authors used doses of 63 g a.i. ha^{-1}, i.e., 27 and 127 g less than the doses used in this study. Also, the application was performed at previous stages, which suggests that dose and plant growth stage of application are also crucial factors to produce smaller plants by using this plant growth retardant. Finoto et al. [29] found significant differences in height reduction only with doses above 220 g ha^{-1}. They found the highest grain yield with this dose; however, in their study, the authors worked with a dicotyledon (*Arachis hypogaea*), which suggests that species is also a relevant factor for effectiveness of Pro.Ca. Zagonel and Ferreira [31] reported that application times of the plant growth retardant trinexapac-ethyl on two different hybrids did not cause substantial effects on agronomic and productive traits. An effect was only found for the doses, which indicates that not only the species factor but also the response of the hybrid itself is variable.

There is a major play role about of the compensatory effect of yield components of a crop to higher grain yield and its maximisation depends on the technical indications for the maize crop management recommendations [10]. Based on observations of the variable grains per ear, there was a negative relationship on number of grains per spike with a decrease in thousand-grain weight, particularly from plots treated with Pro.Ca. Moreover, there was no significant difference between the averages of the same treatments on grain yield. This behaviour can also be found in other crops. Fioreze and Rodrigues [32], when evaluating tillering in wheat crops, reported that the increase in the number of grains led to a decrease in grain weight, which resulted in a balance in grain yield. However, the reduction in thousand-grain weight by the effect of growth regulators was also found in other trials. Leolato et al. [33] found a decrease of thousand-grain weight when treated maize plants with trinexapac-ethyl and evaluated its morphometric characteristics; similarly, the plant growth retardant did not affect grain yield, probably because of the compensatory effect.

5. CONCLUSION

Supra-optimal nitrogen topdressing fertilisation, applied on plants at stage V10, did not increase the productive potential of the maize crop as compared to optimal fertilisation supplied to plants at stage V4.

The plant growth retardant Pro.Ca, applied at V12 plant stage, independent of N levels, resulted in little decrease effect on maize plant height and ear height, without affecting final grain yield. There were no lodged or broken plants due to management practices including N and Pro.Ca levels in a late sowing.

The recommended dose of nitrogen (135 kg ha^{-1}) topdressing a V4 stage are adequately for achieve higher grain yield and plant height at late sowing; but Pro.Ca (100 g a.i. ha^{-1}, applied at V12 stage) can effectively retard maize plant growth, which results in shorter plants with lower ear height, without affecting grain yield; which helps to minimise the occurrence of breaking and lodging of the stem.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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