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3 **Vegetative Development and Productivity of the**

4 **Watermelon Under Different Irrigation Depths in**

5 **the Northwest Region of Espírito Santo**

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11 **ABSTRACT**

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Brazil is one of the main producers of watermelon crops (*Citrullus lanatus*), which present great water requirement and offer in their irrigated cultivation, when well managed, the possibility of productive gains and fruit quality. The objective of this study was to evaluate the productivity and the vegetative development of the plant and the watermelon fruits of the 'Top Gun' cultivar submitted to different irrigation depths in the Northwestern region of Espírito Santo. The experiment was carried out in the horticulture sector of the Federal Institute of Espírito Santo-Campus Itapina, from September 30, 2017 to December 15, 2017. A completely randomized design was used consisting of six treatments corresponding to 50%, 75%, 100%, 125%, 150% and 175% of the reference evapotranspiration (ET_o) calculated daily, with four repetitions of each treatment. The length of the branches of all the selected plants and the longitudinal and transverse lengths of their fruits were evaluated weekly. In the last analysis, the fruit weight was also collected and the productivity was estimated. Development and differentiated production responses were verified with the different depths applied. Water replacements corresponding to the 125% ET_o leaf gave the best vegetative and productive development of the watermelon 'Top Gun' cultivar, cultivated in the northwestern region of Espírito Santo.

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14 *Keywords: Citrullus lanatus; 'Top Gun' cultivar; yield; irrigation management;*

15 *evapotranspiration; water replenishment.*

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18 **1. INTRODUCTION**

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20 Considered a cosmopolitan culture, watermelon (*Citrullus lanatus*) is cultivated in almost all

21 tropical and subtropical regions of the planet. In Brazil, the Northeast region was historically

22 the largest producer of this vegetable, however, it lost expressiveness because of its

23 irrigated crop, pioneered adopted by the most technologically developed regions of the

24 country. This way of cultivation stands out for the possibility of choosing the time of planting

25 and the control of the water offered to the detriment of the phenological stage of the crop,

26 interfering in the production [1].

27

28 Brazil is one of the main producers of watermelon, producing, in 2013, about 2.16 million

29 tons of fruit, thus occupying the 4th position in the world ranking and, in the same year, the

30 state of Espírito Santo produced 8,107 tons of this fruit [2]. Although still small, such

31 production has been helping and gaining ground in the process of agricultural production

32 diversification in the state of Espírito Santo, which presents coffee production as a

33 production base [3].

34

35 The culture still presents few studies about the factors responsible for the productivity and
36 quality of its fruits, even being one of the most important national vegetables [4]. It is known,
37 however, that it presents a great demand and water application management, and that even
38 small periods of water shortage can lead to a compromise in the productivity [5] and quality
39 of its fruits [6].

40

41 In regions with monthly rainfall less than 100 mm and the ones that undergo summer
42 periods, irrigation becomes a practice of great relevance, allowing gains in productivity and
43 quality. This practice still stands out as making production viable during the off-season,
44 allowing greater profitability to producers, due to the generally higher prices achieved in the
45 commercialization of fruits [7].

46

47 The watermelon culture presents a demand for quantity and frequency of variable irrigation
48 according to its phenological stage, and its response to them is very relevant in irrigation
49 planning, seeking a productive maximum in the face of a good use of available water
50 resources, one of the main limiting factors for its production [8]. The watermelon culture
51 presents a need for efficient water management when seeking productive gains [7].

52

53 Because of the few studies on the physiological and productive responses of the watermelon
54 crop and aiming at assisting farmers in the adoption of adequate irrigation management
55 based on the reference evapotranspiration (ET_o), in order to increase production in the
56 region, this work had as an objective to evaluate the productivity and the vegetative
57 development of the plant and the watermelon fruits of the 'Top Gun' cultivar submitted to
58 different irrigation depths in the northwestern region of Espírito Santo.

59

60 **2. MATERIAL AND METHODS**

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62 This work was carried out at the Federal Institute of Espírito Santo-*Campus* Itapina, located
63 in Colatina-ES, Brazil (19°32'22" South, 40°37'50" West, 62 m altitude), from September
64 30th, 2017 to December 15th, 2017, in the sector of Horticulture. The climate of the region is
65 classified as Tropical Aw [9]. The region is characterized by irregular rainfall and high
66 temperatures. The soil of the experimental area is classified as Dystrophic Red-Yellow
67 Latosol [10].

68

69 The experimental design was completely randomized with six treatments: 50% (T1), 75%
70 (T2), 100% (T3), 125% (T4), 150% (T5) and 175% (T6) of the reference evapotranspiration
71 (ET_o) calculated daily, with four repetitions of each treatment. Each treatment consisted of 4
72 lines of 30.0 m long by 2.0 m wide, where the watermelon plants, double hybrid 'Top Gun',
73 were conducted in spacing 2.0 x 1.5 m, totaling 20 plants per repetition, 80 plants per
74 treatment and 480 plants throughout the experiment.

75

76 Only six central plants of the planting lines were evaluated in each treatment, totaling 24
77 useful plants per treatment, remaining the other ones as border.

78

79 In the experimental area, an automated drip irrigation system, micro spray type, was used,
80 using an emitter per plant, with an average flow rate of 20 l.h⁻¹, at a service pressure of 2.0
81 kgf.cm⁻².

82

83 The reference evapotranspiration (ET_o) was estimated daily (Equation 1) by the Penman-
84 Monteith method FAO-56 Standard [11], through data obtained from a complete ONSET®
85 weather station, consisting of air temperature sensors (°C), wind direction (°), wind speed

86 (m.s⁻¹), relative humidity (%) and global solar radiation (W.m⁻²), located near the
 87 experimental area.
 88
 89

$$ET_o = \frac{0.408\Delta(Rn - G) + \gamma \frac{900}{T + 273} u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34 u_2)} \quad (\text{Eq.1})$$

90
 91

92 in which ET_o is the daily reference evapotranspiration (mm.d⁻¹); R_n is the daily radiation
 93 balance (MJ.m⁻².d⁻¹); G is the daily flow of heat in the soil (MJ.m⁻².d⁻¹); T is the daily average
 94 air temperature (°C); u₂ is the daily average wind speed at 2 m in height (m.s⁻¹); e_s is the
 95 saturation pressure of the daily average water vapor (kPa); e_a is the daily average water
 96 vapor pressure (kPa); Δ is the slope of the vapor pressure curve at the point of T (kPa.°C⁻¹)
 97 and γ is the psychrometric coefficient (kPa.°C⁻¹).
 98

99 The daily evapotranspiration estimate of the crop (ET_c) was determined by Equation 2. The
 100 values of the crop coefficients (K_c) used were about the days after transplanting (DAT) for
 101 the crop: 0.4 (1-18 DAT); 0.5 (19-26 DAT); 0.7 (27-30 DAT); 0.8 (31-35 DAT); 0.95 (36-40
 102 DAT); 1.05 (41-50 DAT); 0.9 (51-54 DAT); 0.8 (55-60 DAT) and 0.7 (61-64 DAT) [5].
 103

$$ET_c = ET_o \times K_c \quad (\text{Eq. 2})$$

104
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106 where: ET_c = evapotranspiration of the crop for the day (mm); K_c = crop coefficient of the
 107 day (dimensionless); ET_o = reference evapotranspiration for the day (mm);
 108

109 In order to calculate the volume of water to be applied daily in each treatment (V), Equation
 110 3 was used in which the evapotranspiration of the crop is multiplied by the factor (F),
 111 according to the percentage of each treatment (T₁ = 0.50, T₂ = 0.75, T₃ = 1.0, T₄ = 1.25, T₅
 112 = 1.50 and T₆ = 1.75), by the location coefficient (wet or shaded area, whichever is higher)
 113 and by area of the plant, then, the result was divided by the application efficiency of the
 114 irrigation system adopted.
 115

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$$V = \frac{ET_c \times F \times KI \times A}{Ea} \quad (\text{Eq. 3})$$

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118 where: V = volume of water to be applied daily in each treatment (mm); ET_c =
 119 evapotranspiration of the crop for the day (mm); F = percentage of treatments (decimal); KI =
 120 location coefficient (%); A = area of the plant (3 m²); Ea = efficiency of application of the
 121 irrigation system (90%).
 122

123 Soil preparation was carried out by plowing, sorting and opening of pits 20 days before
 124 planting. Fertilization was done based on soil analysis (Table 1), according to the need of the
 125 watermelon crop, according to Prezotti *et al.* [12], following the manual of recommendation
 126 of liming and fertilization for the state of Espírito Santo, for a productivity of 25 tons per
 127 hectare. 150 g.pit⁻¹ of NPK 08-28-10 (pit fertilization) were applied; 100 kg.ha⁻¹ of N and 100
 128 kg.ha⁻¹ of K₂O, weekly applied by sowing before irrigation (cover fertilization).
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Table 1. Chemical characteristics of the soil in the 0-20 cm layer

pH (water)	O.M. (%)	P -----	K mg dm ³	Na -----	Ca -----	Mg -----	Al -----	SB cmolc dm ³	t -----	CEC -----	V %
6.5	1.84	179.9	244	14	4.60	1.46	0.00	6.74	6.74	7.94	84.9

132 *pH: potential of Hydrogen; OM: organic matter; P: phosphorus; K: potassium; Na: sodium; Ca: calcium;*
133 *Mg: magnesium; Al: aluminum; SB: sum of bases; t: effective cation exchange capacity; CEC: cation*
134 *exchange capacity at pH 7; V: percentage base saturation.*
135

136 The watermelon seeds, 'Top Gun' cultivar Chinese double hybrid, used in the production of
137 seedlings were purchased locally and individually seeded on September 30th, 2017, in
138 polyethylene bags with dimensions of 10 x 20 x 0.5 cm, filled with a conventional substrate
139 composed of 70% of subsoil soil and 30% of sifted and sieved cattle manure. For each 1000
140 kg of this mixture (subsoil soil plus manure) were added 2 kg of dolomitic limestone, 4 kg of
141 single superphosphate and 0.3 kg of potassium chloride [12].
142

143 The seedlings were produced in a greenhouse and transplanted directly into the field on the
144 16th day after sowing (October 15th, 2017), when they presented two well-formed leaves. In
145 the first five days after transplanting (DAT), an irrigation depth corresponding to 100% of the
146 ETo was used for all treatments, thus maintaining the soil in the field capacity in all
147 treatments, providing uniform initial development and adaptation of the seedlings to the
148 planting site. The treatments with the different irrigation depths started at the 6th DAT.
149

150 Weekly evaluations of the length of all branches of the plants, selected in each treatment,
151 and of the longitudinal and transverse length of all fruits were carried out using a measuring
152 tape graduated in centimeters. Through the sum of the length of all the branches of the
153 selected ones, starting from their base, the average length of the branches was calculated
154 for each treatment.
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156 The experiment was finalized on December 15th, 2017, when the fruits were submitted to the
157 last measurement and weighed in a digital scale with an accuracy of 0.05 grams, with the
158 average weight of the fruits per treatment, the production was then estimated per the
159 corresponding hectare.
160

161 The data of the components, length of branches, length and transverse length circumference
162 of the fruits, fruit weight and yield were submitted to analysis of variance of the regression by
163 the F test ($P < 0.05$), using R software [13]. When significant, regression models were
164 adjusted to better explain the effect of treatments, higher coefficient of determination (R^2).
165 The maximum points were determined through the first derivative of the regression
166 equations.
167

168 3. RESULTS AND DISCUSSION

169
170 The relative humidity during the field cultivation period presented a maximum value of 99.2%
171 and a minimum of 29.7%, making an average value of 76.5%. The average values recorded
172 for the maximum and minimum air relative humidity were 88.0% and 27.9%, respectively,
173 with an average of 56.2% (Figure 1). Relative humidity is considered to be one of the factors
174 that most affect the growth and productivity of the watermelon crop, with the range of 60 to
175 80% suggested for most vegetables [14]. High relative air humidity indexes may compromise
176 fruit quality, favoring the incidence of foliar diseases, while low moisture favors the
177 production of sweeter fruits [15].
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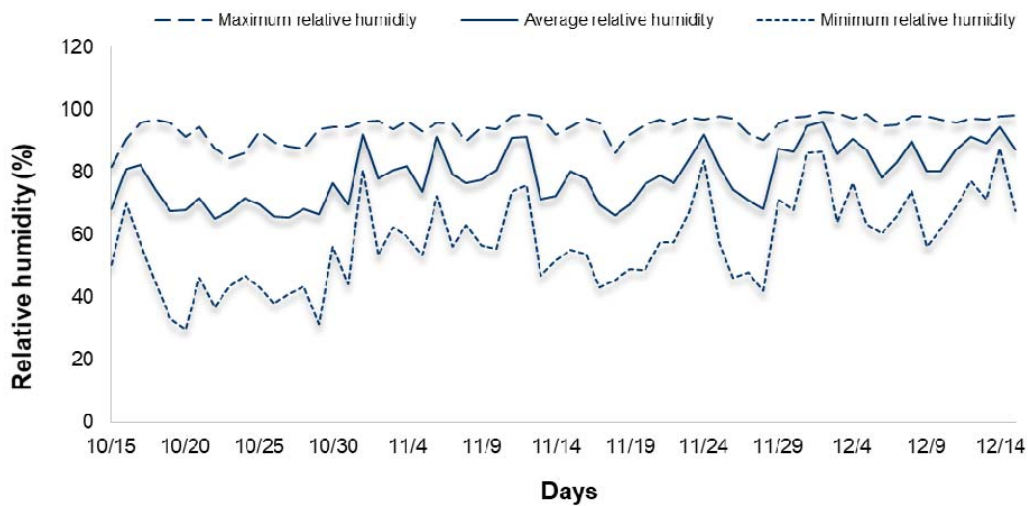


Fig. 1. Daily variations of maximum, minimum and average relative humidity during the growing season (10/15/2017 to 12/15/2017) of the watermelon crop, Top Gun cultivar

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During the experimental period of watermelon cultivation, the maximum temperature recorded was 40.2°C (14th DAT) and the minimum temperature recorded was 16.8°C (4th DAT), with an average value of 25.3°C (Figure 2). These climatic conditions, observed during the experiment, fit the ideal conditions of production of the crop, which consists of hot and mild climate, long days and low relative humidity, optimum temperature range of 23 to 28°C [16].

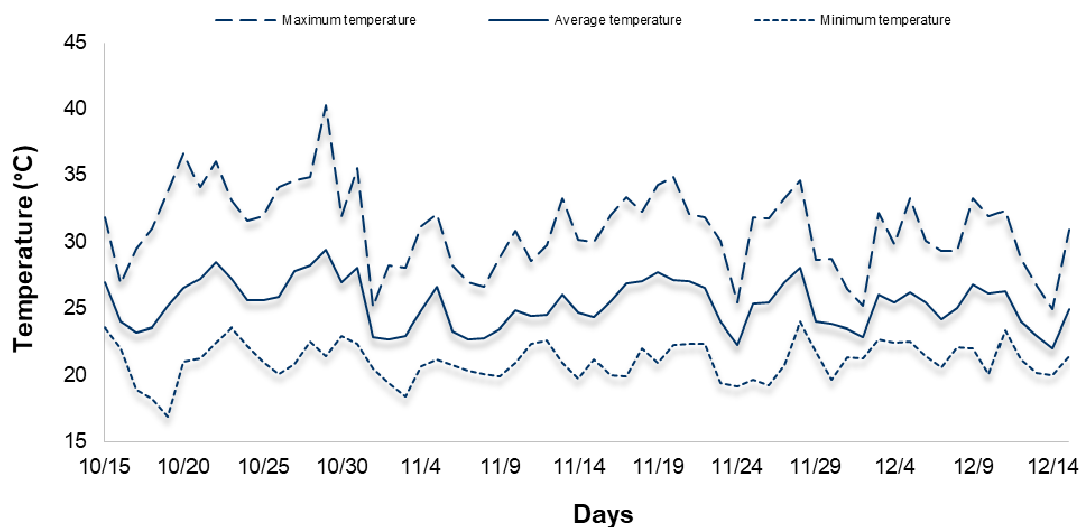


Fig. 2. Daily variations of the maximum, minimum and average temperature during the growing period (10/15/2017 to 12/15/2017) of the watermelon crop, Top Gun cultivar

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The development of watermelon in the experiment period occurred in an environment with climatic conditions satisfactory to the crop. Being a typically tropical, its development is

190 paralyzed under temperatures below 13°C and, below 15°C, its germination is not favored.
191 However, under very high air temperatures there is a larger production of male flowers
192 (above 35°C), which is not desirable and, above 39°C, pollination carried out mainly by bees
193 is damaged because it affects the insects [14].
194

195 During the growing period, the cumulative volume of rainfall was 270.6 mm, whose
196 distribution can be observed in Figure 3. The reference evapotranspiration (ET_o) reached a
197 maximum value of 6.63 mm.d⁻¹ and a minimum of 1.34 mm.d⁻¹, presenting an average value
198 during the field experiment of 3.55 mm.d⁻¹ in the growing period.
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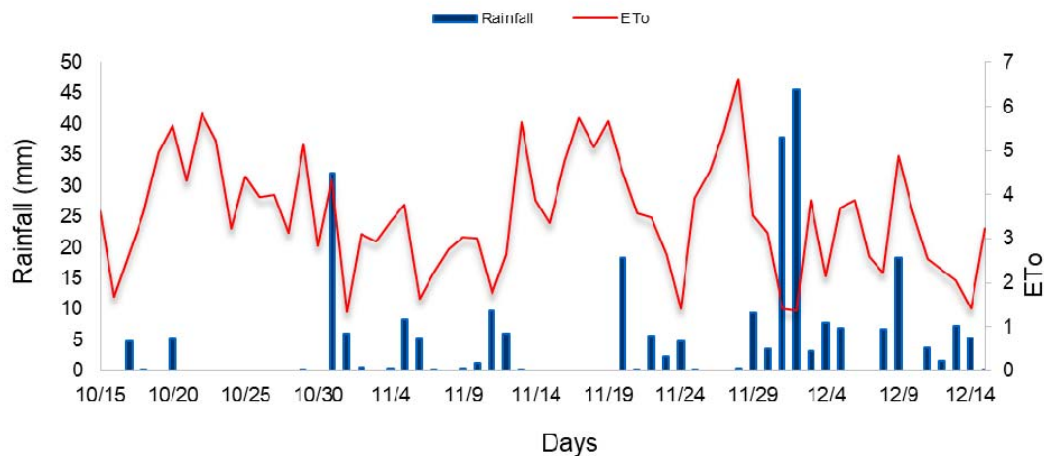


Fig. 3. Daily variations of reference evapotranspiration (ET_o) and rainfall, during the growing season (10/15/2017 to 12/15/2017) of the watermelon crop, Top Gun cultivar

200 The applied depths had their volume calculated based on the percentage of ET_o (50; 75;
201 100; 125; 150 and 175%), estimated daily. The total volume applied (effective rainfall plus
202 volume of the calculated depth corresponding to each treatment) was 598.26 mm; 628.79
203 mm; 659.69 mm; 690.91 mm; 722.79 mm and 755.79 mm for the treatments T1, T2, T3, T4,
204 T5 and T6, respectively (Figure 4).
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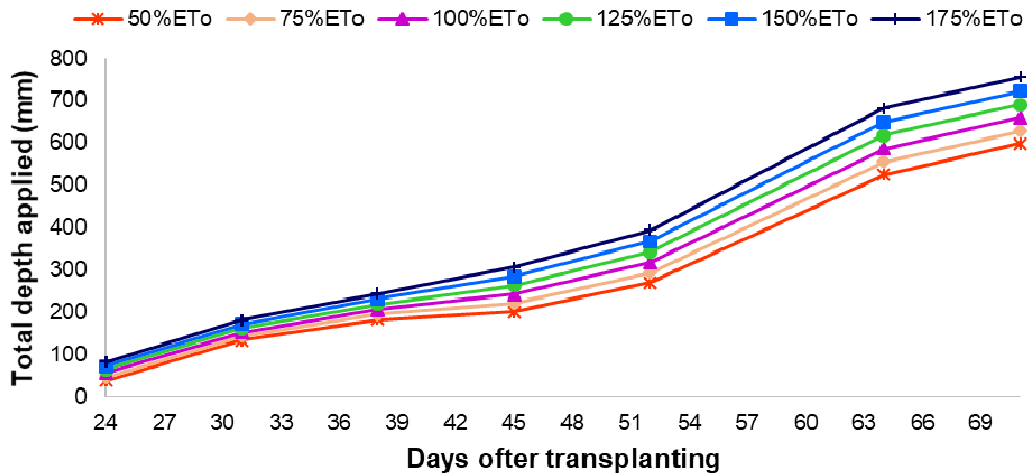


Fig. 4. Total water applied for treatment (effective rainfall plus depth of each treatment) provided in each treatment during the growing period (10/15/2017 to 12/15/2017) of the watermelon crop, Top Gun cultivar

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The behaviors presented by the average growth of the watermelon branches in each treatment (Figure 5) show different responses of the development of the plants to the treatments used. Good developmental responses were observed in the treatments corresponding to 75%, 100%, 125% and 150% of ETo. The treatment of 175% of the ETo showed an initial average growth of the branches similar to the treatments of 75% to 150%, but, from the 45 DAT, it was not able to provide the same average growth rate of the branches, probably due to the effect of the higher volume of water applied. The treatment corresponding to 50% of the ETo gave the lowest development during the whole cycle, reaching 0.8 m at the end of it.

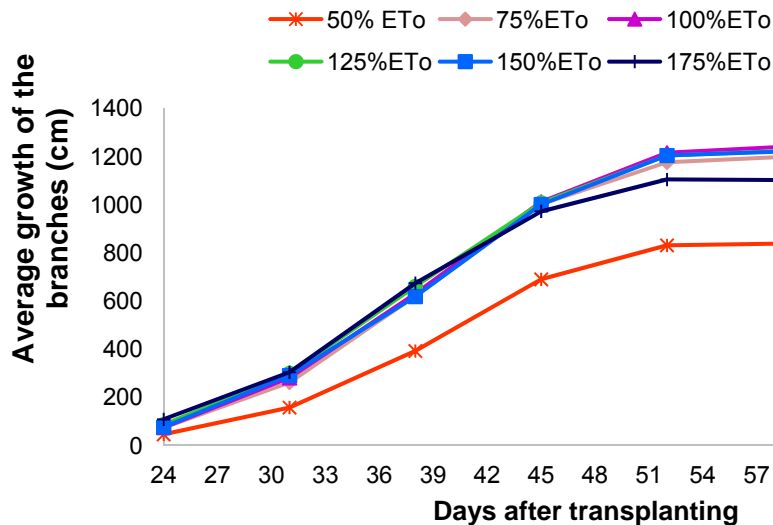


Fig. 5. Average accumulated growth of the branches of the watermelon plant under different irrigation depths

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219 These responses indicate that volumes below and above the water supply range of 75% to
220 150% of ETo are detrimental to the average development of the branches in the watermelon
221 crop, evidencing in the case of higher volumes, a later loss. According to Pereira [17], water
222 stress acts by causing a reduction in the rate of evapotranspiration in plants and in the
223 physiological functions that are related to it, such as nutrient assimilation, photosynthesis
224 and respiration.

225
226 Under favorable conditions of soil characteristics, the excess irrigation applied to the
227 watermelon crop suffers percolation, which results in damage to the irrigant [18]. This
228 damage is not exclusively linked to the costs of this unnecessary volume of irrigation, but
229 also to the leaching of nutrients that such percolation favors, even affecting the development
230 of the crop.

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232 Under unfavorable conditions of soils with reduced drainage, excess water compromises the
233 respiration of the roots, causing the yellowing of the plants, which may lead to their death,
234 due to the low tolerance to low aeration of the soil [7].

235
236 Analyzing the results of the final average length of the branches in the accumulated volumes
237 of water applied in each treatment (Figure 6), we can observe that these values present a
238 regression with quadratic behavior and coefficient of determination of 0.87. The highest
239 estimated average length for the branches, 1321.64 cm, was attributed to the total depth of
240 687.36 mm, only 3.51 mm less than the accumulated value attributed to that one studied
241 corresponding to 125% of the ETo. Higher yields of watermelon production were observed
242 by Eltz *et al.* [19], in plants that presented the highest branch lengths, attributing such
243 occurrence, probably to a larger leaf area for photosynthesis and higher speed of soil cover.
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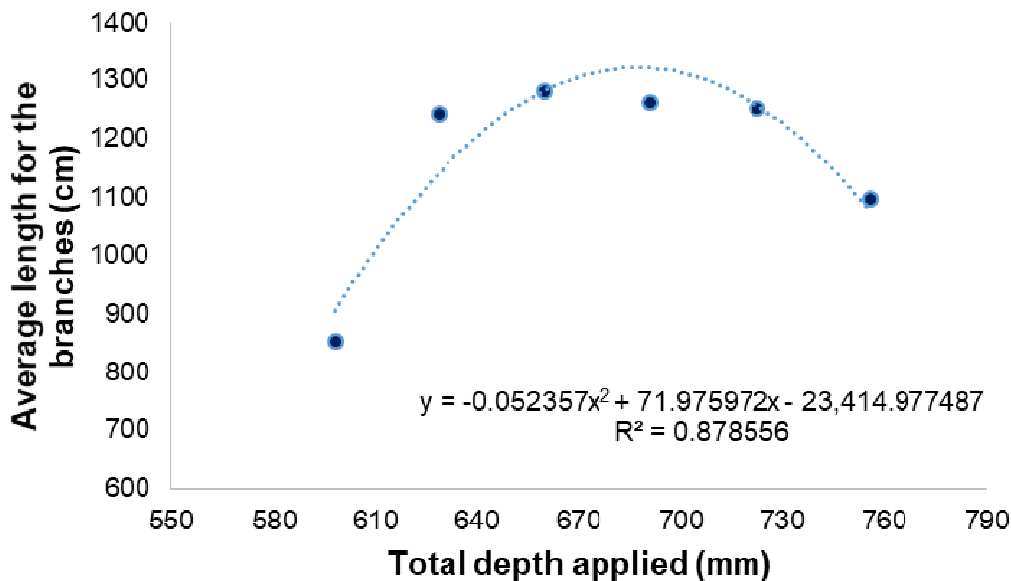
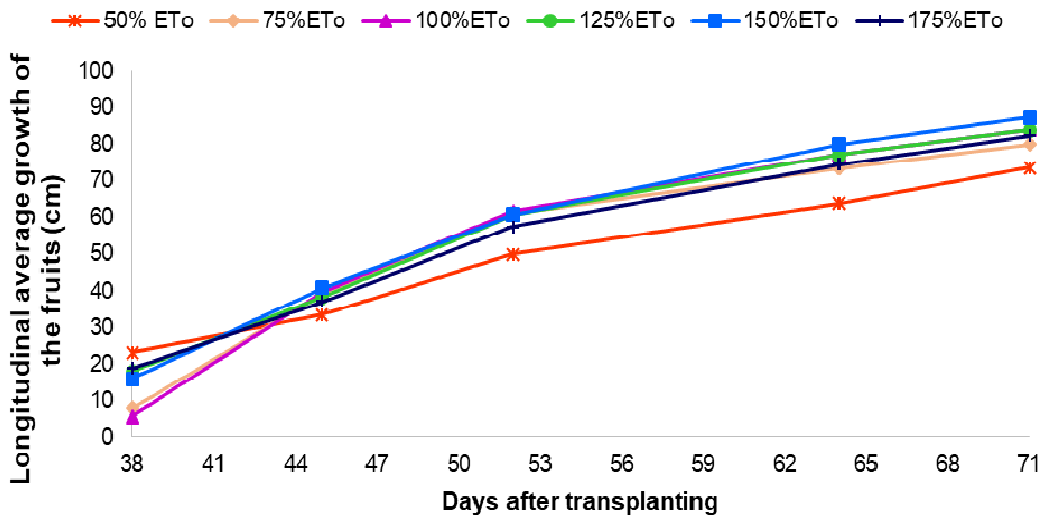
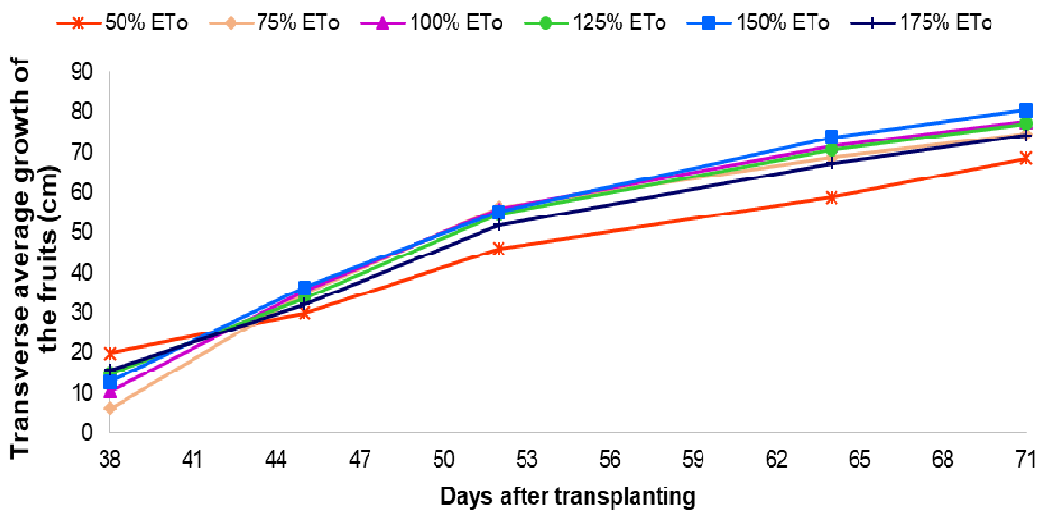


Fig. 6. Final average length of the watermelon branches, Top Gun cultivar, submitted to different irrigation depths

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246 By the behavior of the fruit growth, both in the longitudinal (Fig. 7A) and transverse (Fig. 7B)
247 directions, it is possible to verify that from the 45th DAT, in the treatment corresponding to
248 50% of the ETo, that the water deficiency compromised the development of the fruits,
249 directly reflecting on their productivity.



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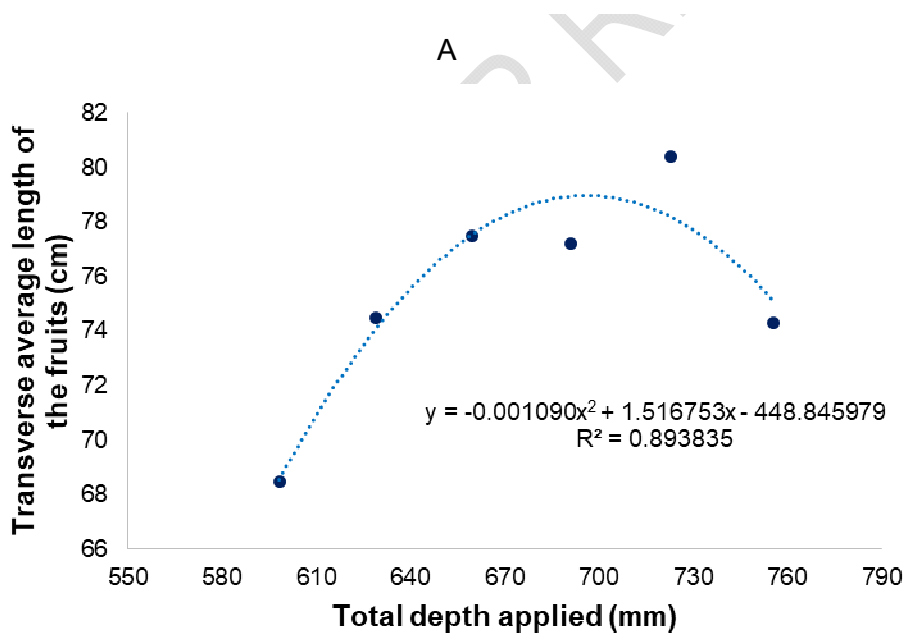
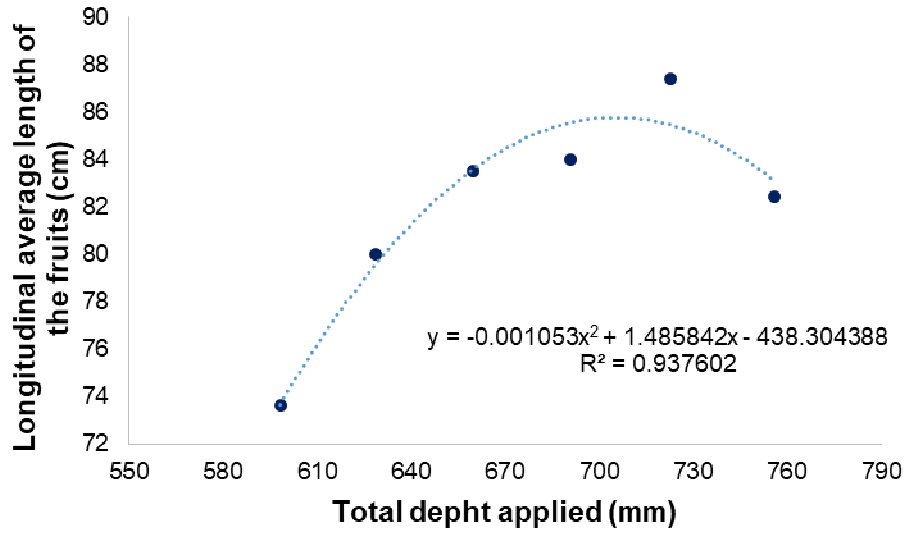
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Fig. 7. Average accumulated growth of the longitudinal (A) and transverse (B) circumference of the watermelon fruits, Top Gun cultivar

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The values corresponding to the final length of the fruits, longitudinal and transverse, obtained by the treatments of irrigation depths presented a quadratic regression model, with determination coefficients of 0.94 and 0.89 respectively (Figure 8). The maximum development in the longitudinal length of the watermelon fruit, 85.84 cm, was reached in the total depth of 705.52 mm, with only 0.21 cm more than that estimated for the studied depth of 125% of the ET₀, while the maximum development in the transversal length of the fruit,

259 78.80 cm, occurred in the that one of 695.75 mm, with approximately 0.02 cm less than that
 260 estimated for the studied depth corresponding to 125% of ETo.
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B

Fig. 8. Final, longitudinal (A) and transverse (B) average length of the watermelon fruits, Top Gun cultivar, submitted to different irrigation depths

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The average weight of the watermelon fruit (Figure 9) presented a quadratic behavior, with a determination coefficient (R^2) of 0.868, reaching its maximum on a 698.96 mm depth (only 8.05 mm more than the accumulated volume in the 125% of the ETo), with an average weight of 9.006 kg, a value higher than the 5.45 kg found for Top Gun cultivar by Cardoso et

268 *al.* [20], when evaluating watermelon cultivars in Manaus region in the state of Amazonas
 269 and 6.028 kg found by Pinho *et al.* [21], for Top Gun watermelon fruits when evaluating the
 270 production and quality of watermelon under daily irrigation equivalent to 100% replacement
 271 of the ETo by dripping in Teresina region in the state of Piauí.
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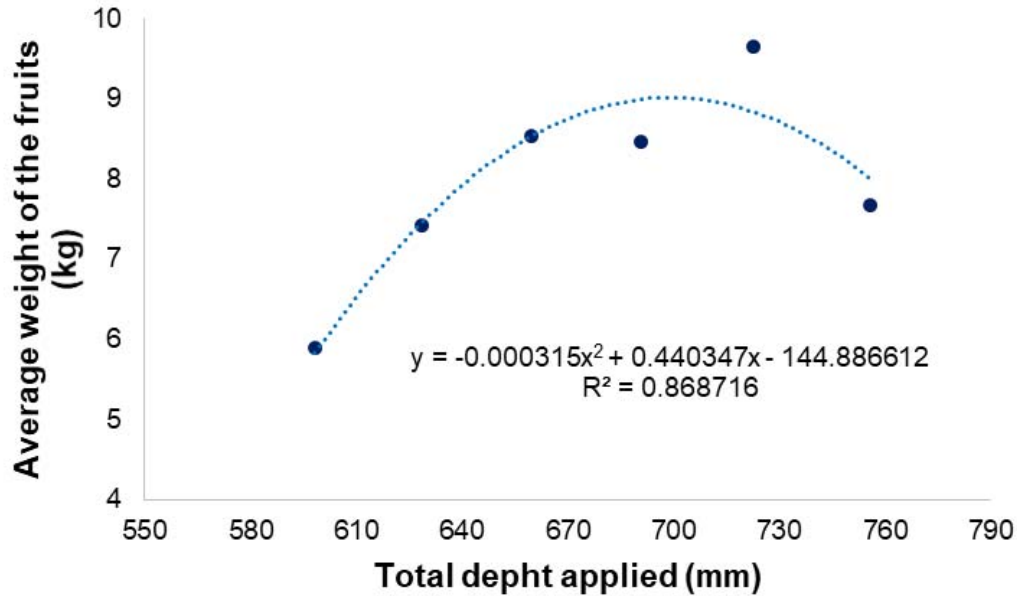


Fig. 9. Average final weight of the watermelon fruits, Top Gun cultivar, submitted to different irrigation depths

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The productivity of watermelon also showed a quadratic behavior, with a determination coefficient (R^2) of 0.868 and maximum estimated yield, 29.97 $\text{ton}\cdot\text{ha}^{-1}$, being reached in the accumulated depth of 699.01 mm, only 0.08 tons more than the estimated for the studied one corresponding to 125% of ETo (Figure 10). This estimated maximum production is about 4.13 tons lower than that found by Pinho *et al.* [21] for Top Gun cultivar under drip irrigation in Teresina, adopting a smaller spacing of 2.0 meters between rows by 1.0 meter between plants.

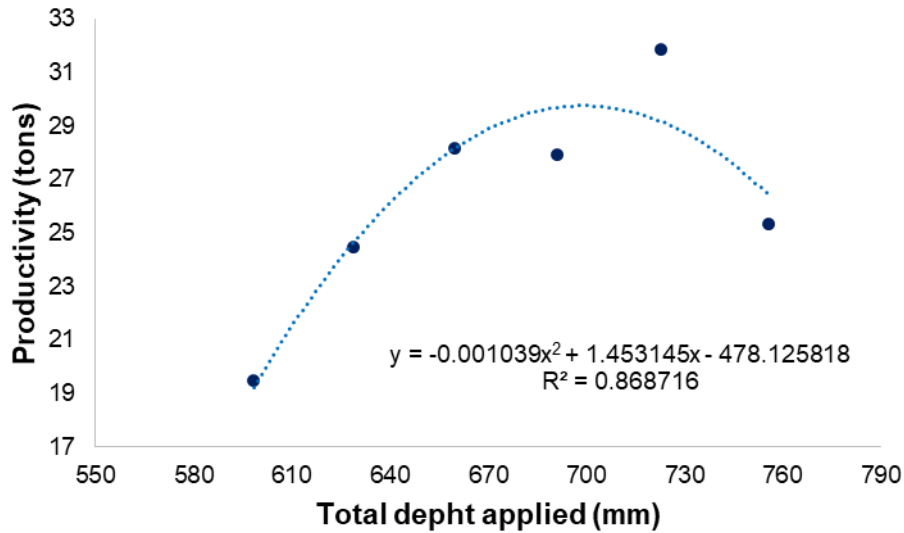


Fig. 10. Average productivity of the watermelon, Top Gun cultivar, submitted to different irrigation depths

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285 The water deficit, especially in the more critical stages of flowering and fruiting, promotes a
 286 considerable reduction in fruit quality and production as a whole [7]. Excess water, especially
 287 in poorly drained soils and irrigation systems that promote leaf wetting, contributes to the
 288 recurrent occurrence of soil diseases. When this excess occurs in the maturation stage, the
 289 damage caused is more harmful than when there is the deficit, leading to a reduction of
 290 sugar in the fruits and, in some situations, cracking [22].

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292 All the evaluated parameters evidenced the occurrence of developmental responses and
 293 differentiated production of the watermelon crop, related to the irrigation depths used. The
 294 125% ETo (T4) depth provided the best vegetative growth response, fruit size and
 295 productivity, and it (125% of ETo) should be considered in irrigation management for the
 296 producers from the Northwestern region of Espírito Santo.

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4. CONCLUSION

Irrigation management performed with water replacements equivalent to the irrigation depth of 125% of the ETo presented the best development in the average length of the branches, fruit growth, higher average weight of the fruit, as well as the higher productivity of the watermelon Top Gun cultivar, cultivated in the Northwestern region of Espírito Santo

307 **COMPETING INTERESTS**

308

309 Authors have declared that no competing interests exist.

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