

Original Research Article

Amaranth response to water stress

ABSTRACT

Amaranth is a species that has rapid growth, tolerates drought and produces grains of high food value. In this work the potential for dry season cropping in the Brazilian savannah of two amaranth species (*Amaranthus caudatus* e *Amaranthus cruentus*) was studied, subjecting them to three different periods of water availability at the beginning of the crop. Weekly data were collected on height, dry matter mass of shoot, panicle and roots, and at the end of the cultivation, yield, harvest index, thousand-grain weight, water-productivity. It was also determined the falling plant estimation. In the dry matter production evaluation, it was observed that the water deficit caused the reduction of the shoot, but significant increase of the root. The *A. caudatus* Inca did not show a significant productivity difference between the treatments, with a mean of 1,591.0 kg ha⁻¹ and reached harvest point at 63 days. The *A. cruentus* BRS Alegria had better productivity in the treatment without water restriction, average of 2,008.6 kg ha⁻¹ and reached harvest point at 86 days. Both species have potential for dry season cropping in the Brazilian savannah.

Keywords: *Amaranthus caudatus* Inca; *Amaranthus cruentus* BRS Alegria; dry season cropping; water deficit; Brazilian savannah

1. INTRODUCTION

The use of new plant species is important for crop diversification, since only five species (rice, potato, maize, soy and wheat) form the basis of world food for human. In this context, *Amaranthus* sp. is an alternative, since it has a high protein value with balanced amino acid, close to the ideal for human nutrition [1], being rich in lysine, arginine and histidine [2,3].

Another appeal to the consumption of amaranth is in the gluten-free, and for this reason, amaranth flour has received, in recent years, considerable attention as an interesting source for the formulation of gluten-free products, due to its high nutritional value and free from prolamins, which lead to gluten intolerance, toxic to celiac [4].

From the agronomic point of view, amaranth stands out as an option to diversify grain cultivation in the Brazilian savannah. Although the region has experienced rapid growth in agriculture, it is based mainly on soya, cotton, maize and, to a lesser extent, on beans [5]. Experiments with amaranth demonstrated their potential for cultivation for both soil protection and grain production in the Brazilian savannah [6].

According to Achigan-Dako et al. [7] *Amaranthus* sp was found as a promising food crop, mainly due to its resistance to heat, droughts, diseases and pests, and the high nutritional value of its seeds and leaves. However, although this genus of plant is highly tolerant to adverse environmental conditions, including poor soils, lack of water and severe defoliation, field yields are generally lower than those produced by cereals [8]. Under rainfed conditions in the Uttarakhand hills of India, Shukla et al. [9] recorded yield of 1,117 kg ha⁻¹ of *A. hypochondriacus* grains.

A. caudatus, of Andean origin, possess lower adaptability in regions of tropical climate under high temperatures [10], but has showed high grain yields in the Brazilian savannah of 1,892 kg ha⁻¹ [11]. *A. cruentus* has been adapted to the crop in Brazil, especially to the Brazilian savannah, with favorable agronomic performance, both in biomass production and in grain production [12], with a yield of 1,886 kg ha⁻¹ [11].

39 Faced with the scarcity of information on the effect of water stress on the development of
 40 amaranth crop, the objective of this work was to evaluate the effect of water restriction on the
 41 production of *A. caudatus* Inca and *A. cruentus* BRS Alegria under climatic conditions of the
 42 Cuiabana lowland of Mato Grosso state.

43 2. MATERIAL AND METHODS

44 The work was developed at the Experimental Farm of the Federal University of Mato Grosso,
 45 Brazil, (15°51' S, 56°04' W) at 140 masl. The climate of the region, according to the classification
 46 of Köppen [13], is Aw, with mean monthly temperature between 22.0 °C to 27.2 °C and average
 47 annual rainfall of 1,320 mm.

48 The experimental design was a randomized block design, in a 3 x 2 factorial scheme (three
 49 periods of irrigation x two species of amaranth), making a total of six treatments, with three
 50 replications. The 36.0 m² plots consisted of five rows of plants, twelve meters long, spaced 0.5 m
 51 [12], and 0.2 m between plants in the row. The chemical analysis (0-20 cm depth) of the soil
 52 revealed the following results: pH in CaCl₂=4.9; P=9.2 mg dm⁻³; K=36.00 mg dm⁻³;
 53 Ca²⁺+Mg²⁺=2.5 cmol_cdm⁻³; Al=0.0 cmol_cdm⁻³; H+Al=3.5 cmol_cdm⁻³ and V = 42.9%.

54 Seeding was carried out with a manual seeder on June 26, 2014, using seeds of *A. cruentus* with
 55 BRS Alegria cultivar, developed by EMBRAPA [12] and *A. caudatus* with the Inca variety.
 56 These seeds were stored in a refrigerated chamber (17 ± 2 °C) until sowing, with 94 and 98%
 57 germination, respectively, for *A. cruentus* and *A. caudatus* by Rules for Seed Analysis method
 58 [14]. The irrigations were in the morning by a conventional sprinkler irrigation system, using
 59 sector sprinklers, which allowed irrigation of the plots individually. The evaluation of water
 60 distribution uniformity was performed according to Christiansen [15]. Soil water was maintained
 61 close to field capacity and monitored by soil moisture determination equipment, with probes
 62 permanently installed at 150 mm and 300 mm depth in all plots.

63 The plants emerged five days after sowing and, weekly, were evaluated: plant height, dry mass of
 64 plants, panicles and roots, and stem diameter at 50 mm height. At the end of the cultivation, grain
 65 yield, water-productivity, thousand-grain weight [14] and harvest index were evaluated [16].
 66 Harvesting was manually, when the panicles were mature, in the two central lines of each plot,
 67 covering an area of 1.5 m².

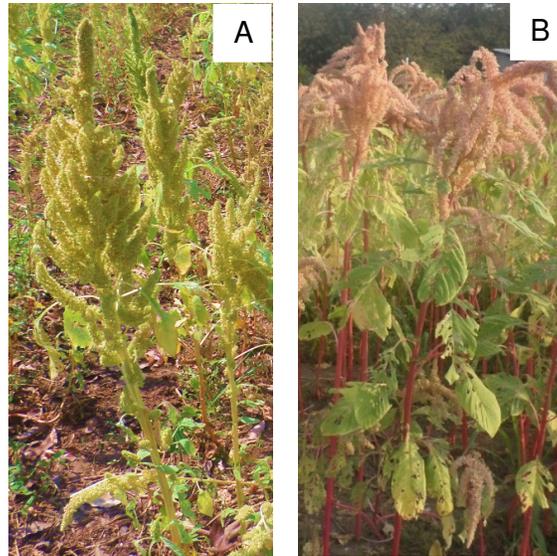
68 Characteristics such as thin and flexible stem facilitate the tipping of plants, especially in plants
 69 with longer cycles [17], mainly in environments with higher frequency and intensity winds. Thus,
 70 for the amaranth, a formula was developed to estimate the risk of plant falling, considering as
 71 flexion-promoting magnitudes the bending moment, defined by plant height (h) and panicle mass
 72 (PM) and, such as magnitudes of flexion-resistance, the stem diameter of the plant (d) and the
 73 shoot mass (SM), with values from 0 to 100, in which the closer to 100 the greater the possibility
 74 of falling and the near to zero the lowest chance of occurrence of falling, according to Expression
 75 1:

$$76 \quad FPE = \frac{h \cdot PM}{d \cdot SM} \quad (\text{Expression 1})$$

77 Where,

78 FPE = Falling Plant Estimation (dimensionless);
 79 h = plant height (mm);
 80 PM = panicle mass (g);
 81 d = stem diameter of the plant (mm); and
 82 SM = shoot mass without the panicle (g).

83 In addition, this formula was developed due to the conformation of plants with dominant panicles,
 84 located at the apex, with relatively large masses in relation to the rest of the plants (Figure 1) and
 85 which may facilitate plant falling, an undesirable characteristic because it makes harvesting
 86 difficult and reduces crop yields.



87 **Figure 1. *Amaranthus caudatus* Inca (A) and *Amaranthus cruentus* BRS Alegria (B) plants in**
 88 **the harvest point, evidencing the panicles.**

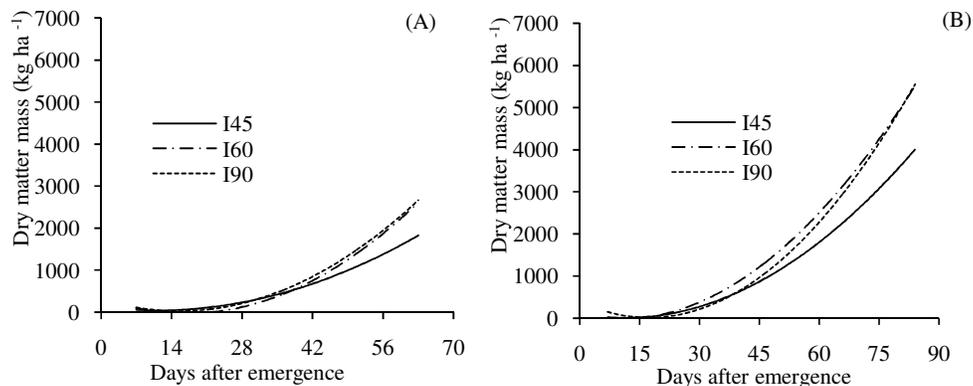
89 3. RESULTS AND DISCUSSION

90 Because *A. caudatus* showed a smaller cycle among the species studied, 63 days did not show
 91 variation in most of the evaluated agronomic attributes. In contrast, the species *A. cruentus*
 92 presented a different behavior, being more demanding about the availability of water during the
 93 productive cycle.

94 The applied water stress caused reductions in the dry matter accumulation in both species studied,
 95 being the lowest for irrigated treatment up to 45 DAE (days after emergence) (Figure 2). This is
 96 due to the fact that plants stressed due to lack of water tend to perform a lower rate of cell
 97 division, thus reducing leaf production, providing a lower accumulation of dry matter at the end
 98 of the cycle [18,19].

99 The dry matter accumulation for *A. cruentus* in irrigated treatments up to 60 DAE, about 5,492 kg
 100 ha⁻¹, was similar to the 6,120 kg ha⁻¹ obtained by the plants that did not undergo water restriction
 101 (Figure 2), which shows that 60 days of soil moisture are sufficient for the plant to accumulate
 102 enough dry matter to reach the maturity of the grains. However, for the treatments with
 103 suppression of irrigation at 45 days, it suffered a significant reduction in accumulated dry matter,
 104 with averages of 3,940 kg ha⁻¹. The value of biomass produced, of 6,120 kg ha⁻¹, can be,
 105 according Erasmo et al. [2], used in no-tillage system, in the region of Brazilian savannah, as dry
 106 season cropping, due to stability of grains and biomass production.

107 The *A. caudatus*, due to its smaller size, reached lower dry mass values than the other species
 108 studied, but the behavior was similar, with production of biomass about 2,284.51 kg ha⁻¹ and
 109 2,350.35 kg ha⁻¹ for 60 and 90 days of water supply, which differentiated from the 1,947.15 kg ha⁻¹
 110 of dry matter produced with only 45 days of irrigation. It was noticed for this species (*A.*
 111 *caudatus*), after the fruiting, a tendency of the plants to drop, by senescence, the lower leaves
 112 when submitted to the water stress. This may also explain the fact that treatment with suppression
 113 of irrigation at 45 days showed a reduction in accumulated mass at 63 days, a fact that did not
 114 occur when irrigation was maintained beyond this date.



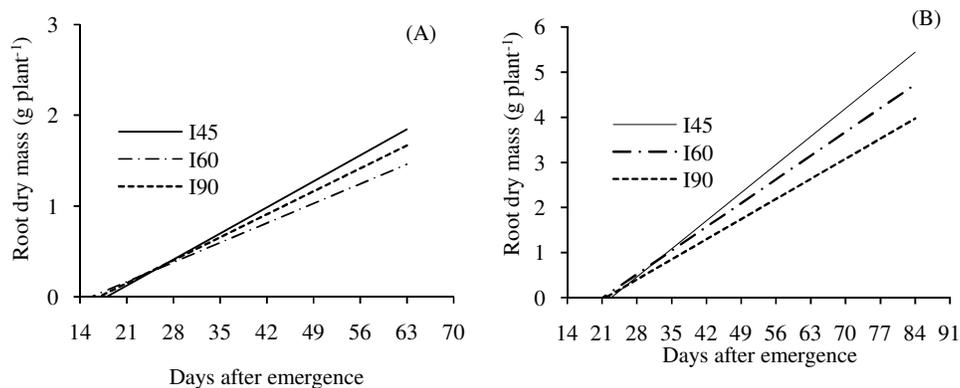
I45= 0,659**x ² - 14,531**x + 126,99	R ² = 0,95	I45= 0,759**x ² - 16,927**x + 100,94	R ² = 0,99
I60=1,250**x ² - 42,561*x + 338,17	R ² = 0,98	I60=1,247**x ² - 43,414*x + 391,57	R ² = 0,97
I90=1,174**x ² - 36,456x + 311,31	R ² = 0,81	I90=1,011**x ² - 20,099**x + 68,357	R ² = 0,98

** Significant at 1% probability, according to the analysis of variance and regression.

Figure 2. Shoot dry matter mass of the *Amaranthus caudatus* (A) e *Amaranthus cruentus* (B) plants subjected to irrigation up to 45 days (I45), up to 60 days (I60) and during the whole cycle (I90).

115 Root growth with water restriction was altered for both *A. caudatus* and *A. cruentus* (Figure 3).
 116 Under these circumstances, the tendency of the plant roots were grow to lower, more moist soil
 117 layers until the water supply is exhausted in the environment [18]. If water has been available, as
 118 in the treatment with full irrigation, the plants would concentrate their roots in the superficial
 119 layers, where the growth is easier, with the expenditure of less energy.

120 Increasing the amount of root during drought helps the plant to obtain water at deeper levels in
 121 the soil profile, as well as helping to avoid water deficits in the more superficial layers of the soil
 122 [20]. When in an adverse situation of water deficiency, the plants prioritize greater allocation of
 123 photoassimilates to the roots, favoring the search for moisture and less water loss due to
 124 transpiration, if it were invested in the increase of aerial part.



I45= 0,041**x - 0,7411	R ² = 0,63	I45= 0,089**x - 2,031	R ² = 0,72
I60= 0,031**x - 0,485	R ² = 0,78	I60= 0,0751**x - 1,588	R ² = 0,87
I90= 0,036**x - 0,609	R ² = 0,69	I90= 0,064**x - 1,384	R ² = 0,83

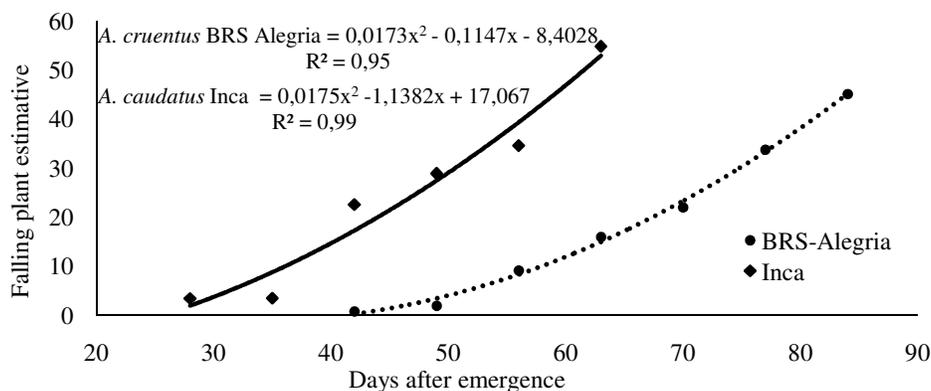
** Significant at 1% probability, according to the analysis of variance and regression.

Figure 3. Root dry mass per plant of the *Amaranthus caudatus* (A) e *Amaranthus cruentus* (B) subjected to irrigation up to 45 days (I45), up to 60 days (I60) and during the whole cycle (I90).

125 The possibility of tipping the amaranth increased with the development of the plant because the
 126 mass of its panicle grew at the same time as the plant continued to grow, as shown in Figures 4.
 127 The *A. caudatus* and *A. cruentus*, respectively, got emergence of panicles at 28 and 42 DAE,
 128 reaching 44.18% and 36.95% of the shoot matter mass of the plant at the time of harvest. In this
 129 sense, because the panicle is in the apex of the plant, the higher the plant and the heavier the
 130 panicle were, the greater was the falling plant estimation.

131 The Falling plant estimation (FPE), proposed in this work, seemed to be sensitive to the variables
 132 used, due to its increasing and quadratic behavior (Figure 4), consistent with what was observed
 133 during the development of the studied plants. In the presence of winds, a bending moment
 134 appears that is a direct function of the plant height and the panicle mass. The plant height had
 135 quadratic response, as a function of time, and the panicle mass had linear response, thus, the
 136 bending moment had quadratic behavior as well.

137 It is observed that in this work that the FPE for *A. caudatus* was larger than *A. cruentus* and
 138 perceptible values appeared earlier, because it had an earlier develop cycle, developed
 139 proportionally larger panicles, and reached maturation earlier. However, the FPE depends on
 140 other factors than the species and water availability, such as fertilization, density and time of
 141 sowing, as well as occurrence of winds.



142 **Figure 4. Falling plant estimation (dimensionless) of the *Amaranthus caudatus* Inca and**
 143 ***Amaranthus cruentus* BRS Alegria, regardless of the water availability time.**
 144

145 The thousand-grain weight was not affected by the water stress, but there was a significant
 146 difference between the studied species (Tukey test ($p < 0.05$)). The *A. caudatus* seeds had a mean
 147 of 863 mg, higher than that found for *A. cruentus*, which presented a mean of 780 mg. These data
 148 lead us to infer that the species *A. caudatus* has grains of greater diameter and thickness when
 149 compared to *A. cruentus*.

150 These values were near to the obtained for other researchers for *A. cruentus* BRS Alegria.
 151 Spehar et al. [12] found, under Brazilian savannah conditions of cultivation, a mass of 680 mg. In
 152 Croatia, Pospisil et al. [21] obtained, in three consecutive years, mean values varying from 702 to
 153 757 mg. In another field study, by Gimplinger et al. [3], in the extreme west of Austria, a mass of
 154 670 mg was obtained. These data show little variation in the thousand-grain weight for this
 155 species and allow to infer that this characteristic for this species should be close to 700 mg. No
 156 data was found for *A. caudatus* Inca.

157 Productivity presented at least one cause of significant variation and the unfolding of the
 158 interaction between water regime and species for productivity is shown in Table 1. Comparing the
 159 species within the water regime, it was observed that in the suspension of irrigation at 45 days, *A.*
 160 *caudatus* was superior to *A. cruentus*, with higher productivity. The productivity of the two
 161 amaranth species did not differ when water was available up to 60 DAE. However, water supply
 162 up to 90 days favored *A. cruentus* in yield, which was 25% higher than that of *A. caudatus*.

163 *A. caudatus* was able to express its productive potential with only 45 days of water supply,
 164 showing that this species is tolerant to end-of-cycle water stress because it did not suffer a

165 significant drop in grain production, in relation to other water regimes, even though it presented
166 lower total mass accumulation than the other stress regimes (Figure 2).

167 Another important factor is that the plant can save water for use in later periods, for example to
168 achieve seed production [22]. Thus, the effects on grain production were attenuated, and there
169 was no significant difference between treatments of water stress in *A. caudatus*. Another
170 important factor is the stage of development that the water stress occurred, at 45 DAE, and *A.*
171 *caudatus* was already in full anthesis, which prevented the productivity decrease [23].
172 Considering these results, it may be recommended to use *A. caudatus* for late cultures during the
173 dry season cropping.

174 When the water was supplied for 60 and 90 DAE there was no difference in the yield of this
175 species, in relation to the water supply only in the first 45 DAE. In this case it is necessary to
176 consider that the plants reached the harvest point with 63 DAE and all the water applied after this
177 time was unnecessary.

178 **Table 1. Yield (kg ha^{-1}), water-productivity ($\text{kg ha}^{-1} \text{mm}$) and harvest index (%), to unfold**
179 **the interaction in *Amaranthus caudatus* Inca and *Amaranthus cruentus* BRS Alegria in**
180 **different water regimes.**

Water regimes (Irrigation)	Yield (kg ha^{-1})		Water-productivity ($\text{kg ha}^{-1} \text{mm}$)		Harvest index (%)	
	<i>A. caudatus</i>	<i>A. cruentus</i>	<i>A. caudatus</i>	<i>A. cruentus</i>	<i>A. caudatus</i>	<i>A. cruentus</i>
Up 45 days	1,285.7 Aa	702.1 Cb	5.80 Aa	3.18 Bb	0.60 Aa	0.21 Bb
Up 60 days	1,591.0 Aa	1,544.9 Ba	6.34 Aa	6.20 Aa	0.27 Bb	0.53 Aa
Up 90 days	1,510.5 Ab	2,008.6 Aa	4.15 Bb	6.40 Aa	0.49 Aa	0.32 Bb
CV (%)	12.22		14.13		8.13	

181 Means followed by the same letter, uppercase in the columns and lowercase in the lines, for the same
182 variable, do not differ among themselves by the Tukey test at 5% probability. CV: Coefficient of variation.

183 The yield of *A. cruentus* was affected by the available water and the highest yields were obtained
184 when the water was available for longer crop period. This species has been shown to be more
185 productive than *A. caudatus*, but is dependent on water available to achieve high yields.

186 Water stress had a significant effect on grain yield for this species, so severe water restriction
187 (I45) reduced grain yield by 65%. The productivity found in the treatments I45 and I60 compared
188 to the treatment I90, are related to the fact that in the first two treatments the water deficit
189 occurred in the critical period, that is, from the preflowering to the beginning of the grain filling,
190 so the recovery of the productive capacity of the culture did not occur satisfactorily, since
191 reproductive events are faster than those observed during vegetative growth stage [24].

192 The amaranth cycle can vary between 100 and 170 days, depending on the region, being smaller
193 in hot climate regions [25]. *A. cruentus* BRS Alegria reached the harvest point at 86 DAE, being
194 earlier than the crop done in Austria, where they obtained harvest at 119 days [3]. In the case of
195 *A. caudatus*, the productive cycle obtained in this work was only 63 DAE and no reference was
196 found about the productive cycle for the Inca variety. Considering that the average crop cycles of
197 cultivated grains, such as soybean, maize and sorghum are over 90 days [26], it can be considered
198 that the Inca variety has a very short crop cycle similar to that of beans [27].

199 The amaranth is a promising plant for the Brazilian savannah and researchers can raise the yield
200 of *A. cruentus* beyond the values obtained here, as reported by other authors, in different
201 environments. The yield obtained in studies conducted for two consecutive years in southern
202 Germany reached 3,495 kg ha^{-1} for additions of 100 kg ha^{-1} of nitrogen, with harvest index of
203 0.32 [28]. In experiments in the extreme west of Austria, in Chernozem soil, obtained grain yields
204 of up to 2,950 kg ha^{-1} for *A. hypochondriacus* and 3,000 kg ha^{-1} for *A. cruentus*.

205 Table 1 also shows the water-productivity in the species and the interaction with the water
206 regimes. For *A. caudatus*, water regime of treatment I90 obtained the lowest value, being
207 statistically different from treatment I45 and I60. In *A. cruentus*, treatment I45 obtained the
208 lowest water-productivity, that is, increase in water availability promoted an increase in yield in
209 this species. The highest values of water productivity were in the treatment I60 for *A. caudatus*

210 and in the treatment I90 for *A. cruentus*, of 6,34 and 6,40 kg ha⁻¹ mm respectively. Values
 211 between 5.7 kg ha⁻¹ mm [27] and 7.3 kg ha⁻¹ mm [29] were obtained when studying the efficiency
 212 use of water-productivity in bean, being similar to the amaranth study.

213 It was possible to verify the effect of the water deficit and the interaction between water regimes
 214 and species on the harvest index. It was observed that the most efficient species in the conversion
 215 of dry matter mass to grains, in treatment I45, was *A. caudatus* (Table 1). Thus, the greater
 216 capacity of dry matter conversion in economic product (grain yield), at a time when the
 217 environmental conditions no longer favor the crop, becomes a good indicator of resistance to
 218 drought. The harvest index is an efficiency measure to evaluate this conversion, which is used in
 219 many studies [30].

220 The highest harvest index found in *A. caudatus* is due to the fact that it has a relatively large
 221 panicle and a small plant size, thus the proportion of grains in relation to the total dry matter of
 222 the plant is higher, increasing the harvest index. In this sense, experimental results have shown
 223 that smaller plants, adapted for stress conditions, result in higher harvest index in relation to
 224 larger plants [30].

225 4. CONCLUSION

- 226 I. The *Amaranthus caudatus* Inca expressed its grain yield with only 45 days of water
 227 supply, being indicated for crops in the Brazilian savannah, at the end of the rainy
 228 season, when the cultivation period is smaller (dry season), approximately 45 days;
- 229 II. The *Amaranthus cruentus* BRS Alegria can be cultivated at the end of the rainy
 230 season, when the water availability is at least 60 days, because this species showed
 231 sensitivity to water stress, with decreases in yield and lower harvest index;
- 232 III. The water stress caused in the amaranth plants an increase in the roots dry matter
 233 mass and a reduction in the shoots dry matter mass and these variables are indicated
 234 for the study of water stress in amaranth;
- 235 IV. The formula developed "Falling Plant Estimation" presented satisfactory data, being
 236 feasible to be used to evaluate the possibility of losses in the harvesting of amaranth
 237 by falling plants, when subject to the water stress.

238 COMPETING INTERESTS

239 We declare that no competing interests exist.
 240
 241

242 REFERENCES

- 243
- 244 1. Bianchini MGA, Beleia ADP, Bianchini A. Changes in chemical composition of whole flours
 245 from grains amaranth after different thermal treatments. Rural Science, [online], 2014; 44
 246 (1): 167-173.
 - 247 2. Erasmo EAL, Domingos VD, Spehar CR, Didonet J, Sarmento RA, Cunha AM. Avaliação de
 248 variedades de amaranto (*Amaranthus* spp.) em sistema plantio direto no sul de Tocantins.
 249 Bioscience Journal, 2004;20: 171-176. Portuguese.
 - 250 3. Gimlinger DM, Dobos G, Schonlechner R, Kaul HP. Yield and quality of grain amaranth
 251 (*Amaranthus* sp.) in Eastern Austria. Plant Soil and Environment, 2007; 53(3):105–112.
 - 252 4. Ballabio C, Uberti F, Di Lorenzo C, Brandolini A, Penas E, Restani P. Biochemical and
 253 Immunochemical Characterization of Different Varieties of Amaranth (*Amaranthus* L. ssp.)
 254 as a Safe Ingredient for Gluten-free Products. Journal Agricultural, Food Chemistry. 2011;59
 255 (24):12969-12974.
 - 256 5. Teixeira DL. Crescimento, reprodução e efeito da perda de área foliar em amaranto cv BRS
 257 Alegria. 2011. 86 p. Dissertação (Agronomia) - Faculdade de Agronomia e Medicina
 258 Veterinária, Universidade de Brasília, Brasília, 2011. Portuguese.

- 259 6. Spehar CR, Trecenti R. Agronomic performance of traditional and innovative species for
260 double and dry season cropping in the Brazilian savannah high lands. *Bioscience Journal*.
261 2011;27(1): 102-111.
- 262 7. Achigan-Dako EG, Sogbohossou OED, Maundu P. Current knowledge on *Amaranthus* spp.:
263 research avenues for improved nutritional value and yield in leafy amaranths in sub-Saharan
264 Africa [on line]. *Euphytica*, Dordrecht. 2014.
- 265 8. Parra-Cota FI, Peña-Cabriales JJ, Santos-Villalobos S, Martínez-Gallardo NA, Délano-Frier
266 JP. *Burkholderia ambifaria* and *B. caribensis* promote growth and increase yield in grain
267 amaranth (*Amaranthus cruentus* and *A. hypochondriacus*) by improving plant nitrogen
268 uptake. *Plos One*, 9(2): 2014.
- 269 9. Shukla DK, Prasad B, Pratap T. Weed management strategies for better yield and economics
270 of grain amaranth (*Amaranthus hypochondriacus*) in mountain agriculture. *Journal of Hill
271 Agriculture*, Tehri Garhwal. 2014;5(2): 194-197.
- 272 10. Teixeira DL, Spehar CR, Souza LAC. Agronomic characterization of amaranth for
273 cultivation in the Brazilian Savannah. *Pesquisa Agropecuária Brasileira*, 2003;38(1): 45-51.
- 274 11. Pittelkow FK. Avaliação agrônômica do amaranto em Lucas do Rio Verde, MT. 2014. 91p.
275 Tese (Doutorado em Agricultura Tropical) - Universidade Federal de Mato Grosso, Cuiabá,
276 2014. Portuguese.
- 277 12. Spehar CR, Teixeira DL, Lara Cabezas WAR, Erasmo EAL. Amaranth BRS Alegria:
278 alternative for diversification of cropping systems. *Pesquisa Agropecuária Brasileira*,
279 2003;38: 659-663.
- 280 13. Köppen W. Grundriss der Klimakunde: Outline of climate science. Berlin: Walter de
281 Gruyter, 1931. 388p.
- 282 14. BRASIL. Ministério da Agricultura, Pecuária e Abastecimento. Regras para Análise de
283 Sementes. Secretaria de Defesa Agropecuária. Mapa/ACS, 2009. 395p. Portuguese.
- 284 15. Christiansen EJ. Irrigation by sprinkling. Berkeley: University of California, 142p
285 (Bulletin,670). 1942.
- 286 16. Duarte EAA, Melo Filho PA, Santos RC. Agronomic characteristics and harvest index of
287 different peanut genotypes submitted to water stress. *Revista Brasileira de Engenharia
288 Agrícola e Ambiental*, 2013;17(8): 843-847.
- 289 17. Santos MER, Fonseca DM, Euclides VPB, Nascimento Júnior D, Queiroz AC, Ribeiro Júnior
290 JI. Structural characteristics and falling index of *Brachiaria decumbens* cv. Basilisk on
291 deferred pastures. *Revista Brasileira de Zootecnia*. 2009;38(4):626-634.
- 292 18. Souza NKR, Amorim SMC. Growth and development of *Physalis angulata* Lineu under
293 water deficit. *Ciências Agrárias Ambientais*, 2009;7(1): 65-72.
- 294 19. Silva EC, Nogueira RJMC. Growth evaluation of four wood species cultivated under water
295 stress under greenhouse conditions. *Revista Ceres*, 2003;50(288): 203-217.
- 296 20. Ludlow MM, Muchow RC. A critical evaluation of traits for improving crop yields in water-
297 limited environments. *Advances in Agronomy*, 1990;34: 107-153.
- 298 21. Pospisil A, Pospisil M, Varga B, Svecnjak Z. Grain yield and protein concentration of two
299 amaranth species. (*Amaranthus* spp.) as influenced by the nitrogen fertilization. *European
300 Journal Agronomy*. 2006;25: 250-253.
- 301 22. Saha S, Strazisar TM, Menges ES, Ellsworth P, Sternberg L. Linking the patterns in soil
302 moisture to leaf water potential, stomatal conductance, growth, and mortality of dominant
303 shrubs in the Florida scrub ecosystem. *Plant Soil*, 2008;313: 113-127.
- 304 23. Kelling CRS. Efeito da disponibilidade de água no solo sobre os componentes do balanço
305 hídrico e o rendimento do feijoeiro. 1995. 91p. Dissertação (Mestrado em Agronomia).
306 Universidade Federal de Santa Maria, Santa Maria, 1995. Portuguese.
- 307 24. Morizet J, Togola D. Effect et arrière-effect de la sécheresse sur la croissance de plusieurs
308 génotypes de maïs. In: Conférence Internationale Des Irrigations Et Du Drainage, 1984,
309 Versailles. Les besoins en eau des cultures. 1984: 351-360. French.
- 310 25. Mujica-Sánchez A, Berti-Díaz M, Izquierdo J. El cultivo del Amaranto (*Amaranthus* spp.),
311 producción, mejoramiento genético y utilización. FAO - Oficina Regional de la FAO para
312 América Latina y el Caribe. 1997. Spanish.

- 313 26. EMBRAPA. Empresa Brasileira de Pesquisa Agropecuária. Centro de Pesquisa de Milho e
314 Sorgo. Sete Lagoas, MG, 2015. <http://www.cnpms.embrapa.br/irriga/ajudairriga.html>. Access
315 in July 25, 2015. Portuguese.
- 316 27. Brito JED, Almeida ACS, Lyra GB, Ferreira Junior RA, Teodoro I, Souza JL. Yield and
317 water use efficiency in bean crops (*Phaseolus vulgaris* L.) under different soil covers
318 submitted to water restriction. *Revista Brasileira de Agricultura Irrigada*. 2016;10(2):565-
319 575.
- 320 28. Erley GS, Kaul HP, Kruse M, Aufhammer W. Yield and nitrogen utilization efficiency of the
321 pseudocereals amaranth, quinoa, and buckwheat under differing nitrogen fertilization.
322 *European Journal Agronomy*. 2005;22: 95–100.
- 323 29. Stone LF, Moreira JA. Effects of soil tillage systems on the water use and on common bean
324 yield. *Pesquisa Agropecuária Brasileira*. 2000;35(4): 835-841.
- 325 30. Durães FOM, Magalhães PC, Oliveira AC, Fancelli AL, Costa JD. Partição de fitomassa e
326 limitações do rendimento de milho (*Zea mays* L.) relacionadas com a fonte dreno. *Revista*
327 *Brasileira de Fisiologia Vegetal*, São Carlos, 1993;5(1):1-120. Portuguese.

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