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Emergence and Initial Development of Amaranth (*Amaranthus cruentus* L.) BRS Alegria at Different Depths of Seeding and Water Availability

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Authors' contributions

This work was carried out in collaboration with all the authors. Author ALS performed the experiment and wrote the first draft of the manuscript. Author AB managed the statistical analysis of the study. All the authors discussed the results, read and approved the final manuscript.

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ABSTRACT

The depth of seeding and the availability of water influence the seed germination process. Amaranth has small seeds from 1.0 to 1.5 mm and limited nutrient reserves and, after emergence, slow growth. Thus, the objective of this work was to evaluate the emergence and formation of amaranth seedlings. The experiment was carried out in a vegetation house at the Federal University of Mato Grosso - Brazil, between October and November 2018. The factor "A" refers to two seeding depths (10 and 20 mm) and the factor "B" to four of water availability (100%, 80%, 60% and 40% of retention capacity). The emergency, first count and emergency speed index were evaluated. Height, diameter, root length, number of leaves, mass of fresh and dry matter were also

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evaluated. The emergence of the seedlings, independently of the seeding depth, was greater in water availability of 100 and 80%. There was interaction of factors for the first count and emergency velocity index. The first emergency count was higher in water availability of 100%. At a seeding depth of 10 mm, the first count of emerging seedlings was similar in water availability of 100, 80 and 40%. While, at a depth of 20 mm, the first count was higher at water availability of 60%. The emergency speed index was higher for 100% water availability at 10 mm seeding depth, while at 20 mm depth the water availability had no effect on the emergency speed index. The water availability of 60 and 40% of the retention capacity reduces the height of the plant, the diameter of the stem, the length of the root, the number of leaves, the mass of fresh and dry matter. Increased seeding depth reduces height, number of leaves and production of fresh and dry amaranth matter.

Keywords: Amaranthus cruentus L.; emergence; seedling establishment; water deficit; seed deposition.

1. INTRODUCTION

Amaranth (*Amaranthus cruentus* L.) is a pseudo-cereal that, when compared to most cereals, stands out for presenting higher amounts of proteins, fibers, vitamins C and A and minerals, and that can be consumed as vegetables and grains [1]. The BRS Alegria cultivar originated from the lineage of *Amaranthus cruentus* AM 5189, from the United States, in which selection was performed mainly in the rapid establishment, tolerance to water deficit, biomass production, nutrient cycling and use as human and animal food [2].

The *A. cruentus* has seeds without dormancy, cylindrical shape, slightly flattened, and small thickness, with a diameter of 1.0 to 1.5 mm and thickness of 0.5 mm and have limited reserves of nutrients for the emergence that restrict the depth of sowing [3]. In view of this, it is important to determine the best seeding depth in order to minimize the vulnerability of the seeds to bad weather, as well as not to accentuate their depth, because thus there is an increase in the physical barrier that must be overcome by the seedling [4].

The emergence of seedlings is a process that involves many factors, including genetic and environmental nature. Among the environmental factors are temperature, humidity, oxygen availability, soil structure and sowing depth [5]. The depth of seeding is extremely important because the greater the depth of seeding, especially in small seed species, there is an impediment to the emergence of the seedling due to the lack of sufficient energy for the rupture of the soil layer, in addition to damage caused by low temperatures and low oxygen level. In smaller depths, the greater the susceptibility of the seeds to water stress [4]. The depth of soil in which the seed is capable of germinating and producing are variable among species and different types of soil management, presenting ecological and agronomic importance [6].

In the germination process, water is another factor that has a strong influence on the germination mechanism. At the beginning of the germination process the seed absorbs water and expands. At this stage, the growth of the embryo must be sufficient to reach the surface of the soil, where it will find light for its development [4]. According to [7] the speed of water absorption by the seed depends on the species and the availability of soil water. The greater the amount of water available for the seeds, the faster the absorption will be.

According to [8] the emergence process and the seedling stage represent a particularly sensitive period. During this phase, the seedling requires a full water supply sufficient to maintain turgescence during extension growth and differentiation of the cell wall.

The germination phase is one of the most important processes for the development of agricultural crops and intervenes in time for the beginning of other phases. Soil type, seeding depth, soil moisture regime and lighting should be taken into account when planning the seeding of amaranth, as it interferes with the emergence and weight of seedlings of different species [3]. In this context, this study aimed to evaluate the emergence and initial development of amaranth cv. BRS Alegria in different water availability and seeding depths.

2. MATERIALS AND METHODS

This work was carried out between October and November 2018, in the vegetation house of the

Faculdade de Agronomia e Zootecnia (FAAZ), of the Universidade Federal de Mato Grosso - Cuiabá (15º37'0.9'' S, 56º3'58'' W, 174 m). The climate of the region according to the koppen classification is the humid dry tropical climate (Aw), with a maximum annual average temperature of 33°c and an average minimum of 22°c on average over the last ten years [9]. The air temperature and relative humidity data recorded during the experiment are shown in Fig. 1.

The soil used in this experiment is classified as Cambisolo Háplico [10] and was collected at a depth of 0 to 200 mm. It presents a particle size composition of 133 g kg^{-1} of clay, 30 g kg^{-1} of silt and 837 g kg^{-1} of total sand, 0.32 dm^3 dm^{-3} of macroporosity and 0.22 dm^3 dm^{-3} of microporosity, whose chemical analysis revealed: Organic matter = 9 g/dm^3, cation exchange capacity = 50.1, percentage of saturation by bases = 66%, pH = 5.4, P = 25 mg dm^3, K, Ca, Mg and AL+H = 4.1, 21, 8 and 17 mmolc dm^3, respectively.

The soil was distorted, homogenized, sieved with a 2.0 mm mesh and placed to dry outdoors (AFT) for 10 days. To calculate the water retention capacity of the soil, about 130 g of AFT was placed in each tube of 55000 mm^3, and then water was added to raise them to saturation condition. To avoid water loss by evaporation, the tubes were covered with plastic film and aluminum foil and placed for free drainage until they reached constant mass. Humidity was determined by the gravimetric method. Based on the difference in mass between the tubes with soil at maximum retention capacity (15%), the blades were calculated for the available water conditions pre-determined according to [11].

Sowing was carried out on October 16, 2018, using amaranth seeds cultivar BRS Alegria, and seven seeds were deposited per tubete. The control of the seeding depth was performed by means of a millimeter stake. Thinning was done on the third day after the emergency and only one plant remained in each tube.

To evaluate the emergence and development of amaranth seedlings, two seeding depths, 10 and 20 mm, and four hydraulic availabilities, 100%, 80%, 60% and 40% of maximum retention capacity were studied. Daily samples of each treatment were weighed twice a day (morning and afternoon) in order to replace the evapotranspired water.

The standard emergency test was performed daily, and the seeds that originated seedlings with the aerial part totally immersed, well formed and free of infection were considered emergent, according to the Rule for Seed Analysis described in [12]. Seven days after sowing, the emergency velocity index (EVI) of amaranth seedlings was obtained, as proposed by [13].

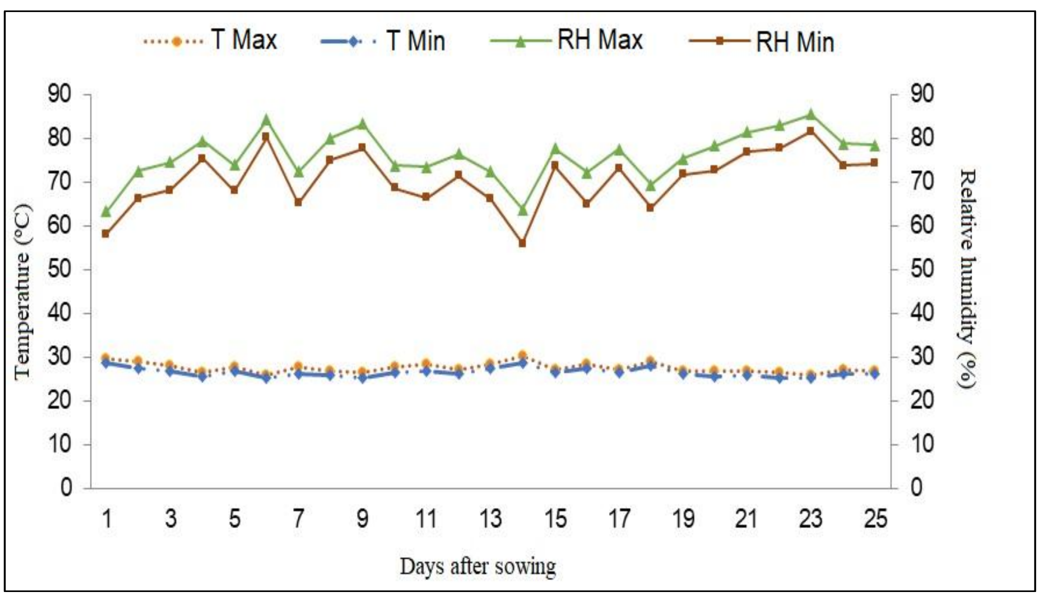

Fig. 1. Average values of maximum temperature (T Max) and minimum (T Min) and maximum humidity (RH Max) and minimum (RH Min) relative air recorded during the experiment

At 20 days after emergence, the following characteristics were analyzed:

Height of the plants, measured with a measuring tape from the base to the apex of the plant (mm);

Diameter of the stem, measured close to the ground with a digital caliper (mm);

Root length, measured with a measuring tape (mm);

Number of leaves, by counting the total number of completely expanded leaves in each plant;

Mass of fresh and dry matter of the aerial part + root (g), obtained, respectively, by weighing the fresh plant and after drying in an oven at 65 ± 3°C until reaching constant weight.

The design was entirely randomized in a 2x4 factorial scheme, the first factor being two seeding depths and the other factor, four water availability, with 15 random repetitions of each treatment. The results obtained were submitted to analysis of variance by Test F. The mean of the emergency variables and the emergency velocity index were compared using the Tukey test at 5% probability, and the seedling growth variables were compared using the Scott Knott test at 5% probability.

3. RESULTS AND DISCUSSION

The emergency began on the second day after sowing and lasted four days. There was no interaction between water availability and seeding depth for the emergence of amaranth seedlings. In the water availability of 100 and 80% of the maximum retention capacity, the seedlings presented better emergence. For the seeding depth there was no difference between the treatments Table 1.

Averages followed by the same letter do not differ statistically from each other by the Tukey Test at the 5% probability level.

The water availability and seeding depths studied did not affect the percentage of amaranth emergence. However, it was found that in lower water availability and greater seeding depth, there is a delay in the emergence, as shown in Fig. 2.

To obtain a good emergence of amaranth seeds it is necessary to maintain adequate soil moisture, although, once established, the seedlings can grow correctly even with water limitations [14]. In addition to appropriate moisture, another determining factor in amaranth germination is the depth of seeding. As [4] the emergence of amaranth seedlings gradually decreases with increasing seeding depth. According to the authors, the adequate seeding depth increases the emergence speed of the seedlings, reducing the risks of soil pest attack and favoring the rapid establishment of the crops.

Table 1. Average seedling emergence values, in%, of *A. cruentus* cv. BRS Alegria in water availability of 100, 80, 60 and 40% of the retention and seeding capacity of 10 and 20 mm depth (Five days)

	Sowing depth		
Water availability	**10 mm**	**20 mm**	**Mean**
100 %	75.00	61.66	68.33 a
80 %	67.50	54.16	60.83 ab
60 %	46.66	52.50	49.58 bc
40 %	45.83	45.83	45.83 c
Mean	58.75	53.54	

The ability of the seed to germinate under wide environmental conditions, where it was sown, determines its vigour and consequently its competitive capacity. The first emergency count as well as the emergency speed index are indicative of the vigour and sensitivity of the seedlings to the environment. Table 2 shows the interaction between water availability and seeding depth for the first emergency count. For both 10 and 20 mm seeding depths, the first emergency count was higher for 100% water availability. In the seeding depth of 10 mm a higher value was obtained in the first count for the water availability of 100, 80 and 40%. At a depth of 20 mm, the highest value obtained in the first count was for the water availability of 60% of the retention capacity.

Averages followed by the same letter, upper case in the column and lower case in the row, do not differ statistically from each other by the Tukey Test at the 5% probability level.

For the emergency speed index, interaction between the factors was verified. At the seeding depth of 10 mm, 100% water availability provided a higher emergency speed index. For the depth of 20 mm, water availability did not cause any difference in the emergency speed index. The water availability of 40, 60 and 80% at the seeding depths did not cause effects on the emergency speed index, however, in the water availability of 100% the highest emergency speed index was observed at a depth of 10 mm Table 3.

Reducing the percentage and emergence rate of seedlings is one of the consequences of the interaction of the physiological potential of seeds with environmental conditions. During the germination process, the presence of an adequate level of hydration that allows the reactivation of metabolism is of paramount importance, culminating in the growth of the embryonic axis of the seed [15].

The better the availability of water for the seeds, the faster the absorption will be, consequently, greater emergence, quality and vigour of the seedlings [7]. However, according to [16] each species presents different strategies of adaptation and tolerance to the lack of water in the substrate and for each species there is a critical water potential value, below which germination does not occur.

Averages followed by the same letter, upper case in the column and lower case in the row, do not differ statistically from each other by the Tukey Test at the 5% probability level.

Regarding the establishment of the plants, the analysis of variance indicated that there was an effect of the isolated factors. There was an effect of water availability for all the variables studied. For the seeding depth there was an effect on the height of plants, number of leaves per plant and on the mass of fresh matter. For the variable dry matter mass there was an effect of the interaction of factors.

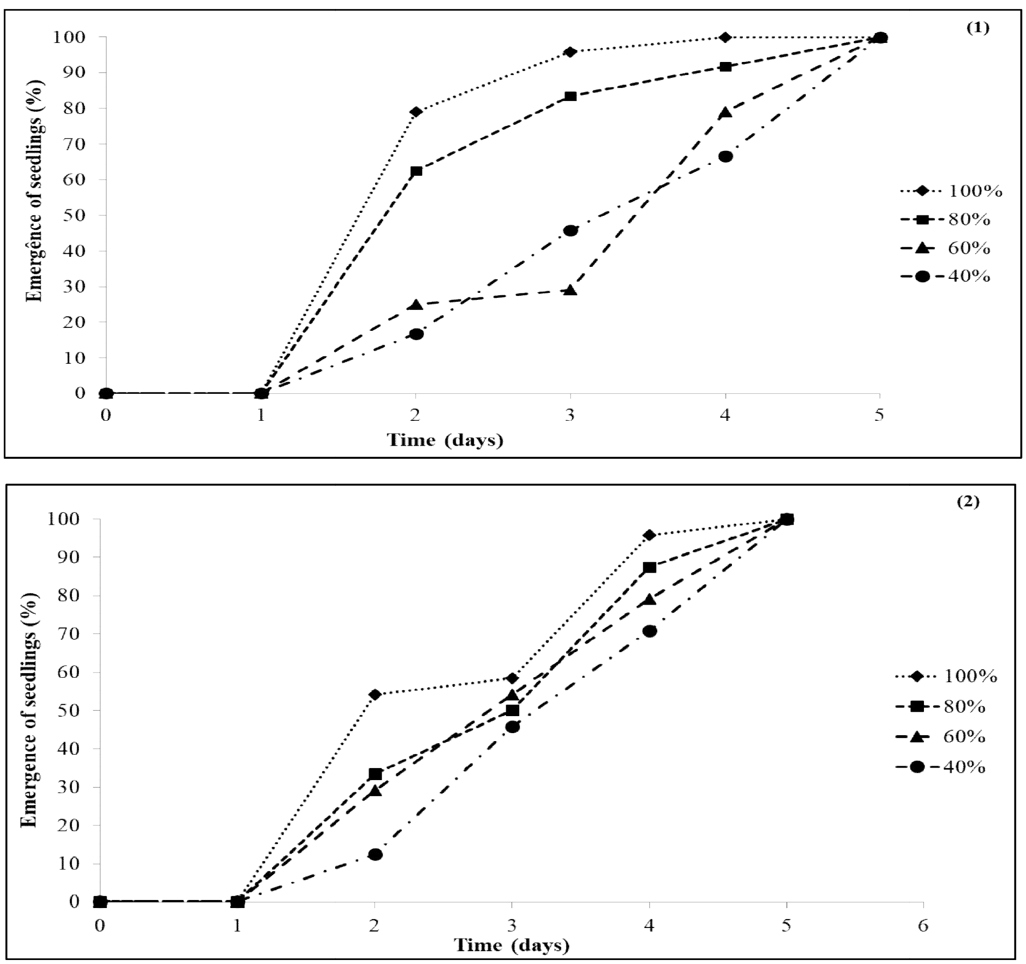

Fig. 2. Emergency curves of seedlings of *A. cruentus* cv. BRS Alegria at water availability 100, 80, 60 and 40% of the water retention capacity at sowing depth of 10 mm (1) and 20 mm (2)

Table 2. First emergency count (two days), in%, of *A. cruentus* cv. BRS Alegria seedlings in water availability of 100, 80, 60 and 40% of the retention and seeding capacity of 10 and 20 mm depth

	Sowing depth		
Water availability	**10 mm**	**20 mm**	**Mean**
100 %	79.17 Aa	54.17 Ab	66.67
80 %	62.50 Ba	33.33 Bb	47.91
60 %	25.00 Cb	29.17 Ca	27.08
40 %	16.67 Da	12.50 Db	14.58
Mean	45.82	32.29	

Table 3. Average values of the emergency velocity index of *A. cruentus* cv. BRS Alegria seedlings in water availability of 100, 80, 60 and 40% of the retention and seeding capacity of 10 and 20 mm depth

	Sowing depth		
Water availability	**10 mm**	**20 mm**	**Mean**
100 %	8.49 Aa	3.67 Ab	6.08
80 %	3.94 Ba	3.15 Aa	3.55
60 %	2.73 Ba	3.00 Aa	2.86
40 %	2.55 Ba	2.72 Aa	2.64
Mean	4.43	3.13	

The average height of the seedlings can be seen in Fig. 3 (1). The average plant height was higher at 100% water availability. It was observed that the water availability of 60% and 40% of the maximum retention capacity restricted the average height of plants in 23.45 and 24.39%, respectively, when compared with the water availability of 100%. For the seeding depth there was a higher average height of amaranth plants at a depth of 10 mm. The increase in height reduced by 7.57%.

For the diameter of the stem it was observed a higher average value in the water availability of 100% of the maximum retention capacity, while in the water availability of 60% and 40% of the maximum retention capacity there was a reduction of 17.24 and 20.68%, at the same time, in the average diameter of the amaranth stem, as shown in Fig. 3 (2). The average stem diameter for the depths was 2.31 mm.

In Fig. 3 (3) it can be seen that the average length of the root in amaranth plants was greater in the water availability of 80% of the maximum retention capacity. In the availabilities of 100 and 60% of the maximum retention capacity the average root length was similar. The shortest average length of the root was observed in the water availability of 40%, where a reduction of 14.13% in the length of the root was observed. The mean value of the root length for the depths was 8.62 mm.

A higher number of leaves were observed in the plants under water availability of 100% of the maximum retention capacity. There was a reduction of 15.28% in the number of leaves per plant in water availability of 40%. At a seeding depth of 20 mm, the plants had fewer leaves. The increase in depth reduced the number of amaranth leaves by 7.08%, as shown in Fig. 3 (4).

As for the mass of fresh matter, a higher weight of amaranth plants is observed under water availability of 100%. For the availability of 80 and 60% of the retention capacity, a reduction of 35.76 and 42.38%, respectively, was observed in the mass of fresh matter. The mass of fresh matter was lower in the seeding depth of 20 mm Fig. 3 (5).

For the dry matter mass there was significant interaction between water availability and seeding depth as seen in Fig. 3 (6). At a depth of 10 mm, the dry matter mass was lower at 60% and 40% of the maximum retention capacity. In the seeding depth of 20 mm, a lower average weight of dry matter mass is observed in the water availability of 40% of the maximum retention capacity. For seeding depth, it can be seen that in the water availability of 100%, 60% and 40% of the maximum retention capacity there was no difference between the seeding depths. In the water availability of 80% of the maximum retention capacity, the highest average weight of dry matter mass was in the depth of 10 mm of seeding.

During the early stages of plant growth, the water in the soil plays an important role in the vegetative development of the crop, which will later influence the crop yields. According to [17] the emergence of seeds and the establishment of plants is a process that depends on water availability, since plants are generally more sensitive to water deficit in the early stages of development. The decrease in water availability in this phase reduces the development of plants, characterized by a reduction in the length of plants and less accumulation of dry mass [18].

In the cultivation of millet [19] they found greater height in plants in the water availability of 60%. [20] in a study comparing three conditions of water stress (30 and 60% of field capacity and flooding) observed that the number of leaves was higher in the availability of 30 and 60%.

According to [21], insufficient soil moisture contributes to some negative effects on amaranth, such as growth, altered biomass allocation and decrease in the yield of dry matter mass production due to inadequate leaf area growth. Although the response of this crop to severe stress conditions is not fully known, amaranth responds to moderate stress conditions with an increase in root development that allows water extraction at greater depths [22].

With regard to the establishment of the plant according to the depth of seeding, it is observed that amaranth responds negatively to the increase in seeding depth. The authors report a decline in the dry matter mass of amaranth seedlings with an increase in seeding depth. In results found by [3], the most adequate seeding depth for amaranth was 15 mm, which provided more vigor to the plants.

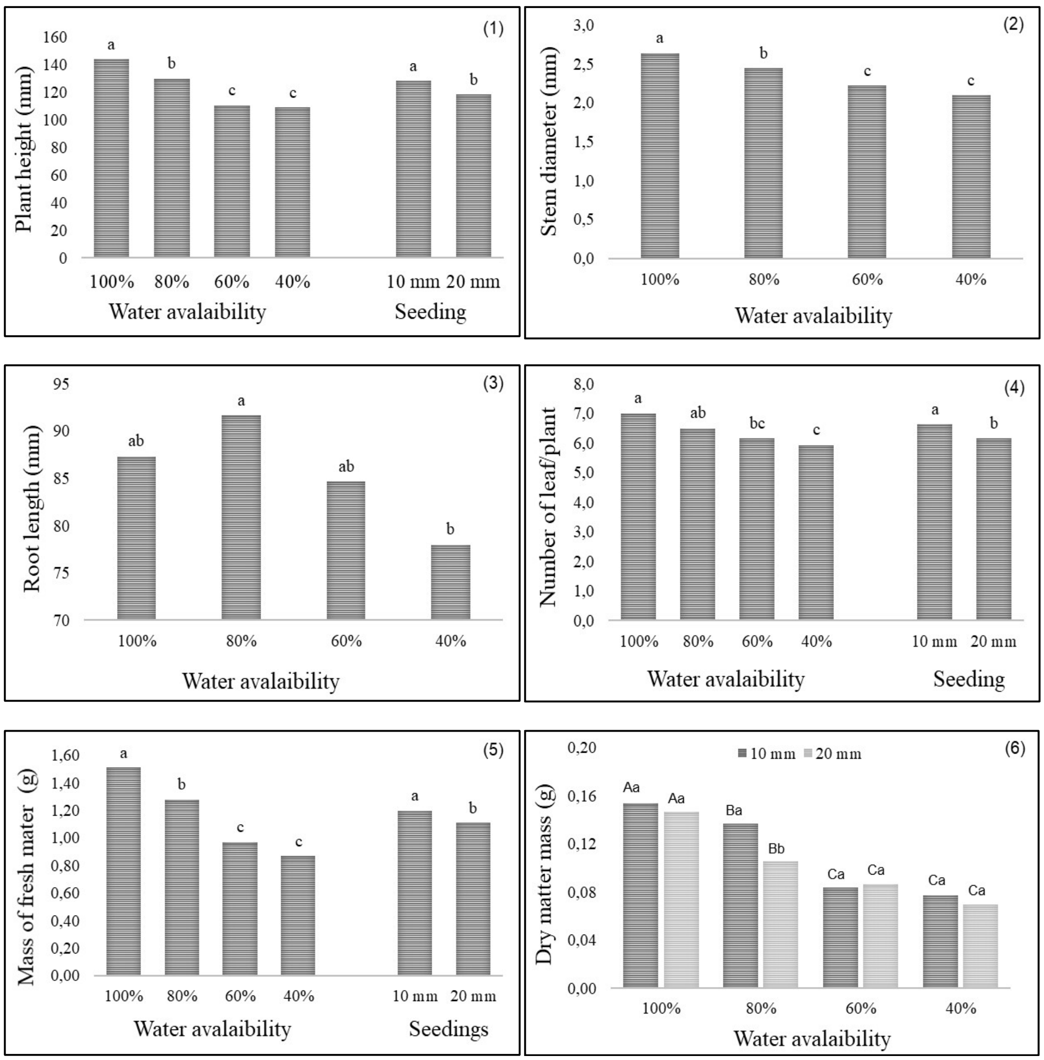

Fig. 3. Average values for height (1), stem diameter (2), root length (3), number of leaves (4), fresh (5) and dry (6) material mass of *A. cruentus* cv. BRS Alegria in water availability of 100, 80, 60 and 40% of retention and seeding capacity of 10 and 20 mm depth. Averages followed by the same letter, capital or lowercase, do not differ statistically from each other by the Scott Knott Test at the 5% probability level

4. CONCLUSION

The emergence and emergency speed of amaranth seedlings is higher at 100% water availability. Water availability of 60-40% of maximum retention capacity reduces plant height, stem diameter, root length, number of leaves, fresh and dry matter mass of amaranth. The height of plants, the number of leaves per plant and the production of fresh and dry matter from amaranth decreases with increased seeding depth.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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