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XARAÉS GRASS UNDER DIFFERENT IRRIGATION DEPTHS TO RECOVER AREAS CONTAMINATED WITH IRON MINING TAILINGS

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KEYWORDS

Degraded areas; bromatological components; pasture irrigation; tailing management; forage yield.

ABSTRACT

Iron mining tailings have limitations for plant growth and development due to low fertility, coupled with great restriction of physical characteristics such as low water retention, high density, and lack of structure. This study aimed to evaluate whether different irrigation depths applied to Xaraés grass grown in mining tailings influence its yield and bromatological aspects. The experiment was carried out in a completely randomized design with five irrigation depths (40, 60, 80, 100, and 120% of the crop evapotranspiration), two additional treatments consisting of grass grown in tailings with soil conditioner and in natural soil, and three repetitions. Forage dry mass, plant height, leaf: stem ratio, as well as neutral detergent fibre, acid detergent fibre, crude protein, and mineral matter content, were evaluated during four cutting cycles. Xaraés grass could establish and produce forage despite cultivation limitations in iron mining tailings, which are due to their properties. Irrigation depths showed positive and linear effects on Xaraés grass dry matter yield and heights of plants grown in iron mining tailings. The soil conditioner has potential for use in pasture cultivation in iron mining tailing.

INTRODUCTION

Brazil is the world's second-largest producer of iron ore. In 2018, production was estimated at 490 million tons, which corresponds to 19.6% of the world's production (USGS, 2019). Minas Gerais (MG) is the state that most contributes to ore exploration and, in 2017, accounted for 50.34% of the gross iron production in the country (ANM, 2019). The Quadrilátero Ferrífero region (Belo Horizonte, Itabira, and from Congonhas to Ouro Preto) is one of the largest mineral provinces in the world and one of the main areas for Fe mining in Brazil (Teixeira et al., 2021).

Mining activity has negative impacts due to the large amounts of tailings from beneficiation and their disposal at the end of processing into the building of dams (Andrade et al., 2016). These dams have to be constantly monitored to prevent sudden disruptions, as has already occurred in the history of mining in the country.

In November 2015, one of the largest environmental disasters occurred in Minas Gerais State, with the rupture of the Fundão dam, in the Bento Rodrigues district of Mariana. More than 50 million m³ of tailings were released into the environment. The tailings leaked into the Rio Doce River until its estuary in Espírito Santo (ES) State (Gomes et al., 2017).

Tailing mud displacement covered an area of 2,022 ha, which contained natural and cultivated pastures, natural and forestry vegetations, watercourses, buildings, the Santarém tailings dam, uncovered soils, and the Risoleta Neves Hydroelectric Plant (Carmo et al., 2017; Aires et al., 2018).

Several studies have addressed the impacts of that disaster under different approaches, namely: knowledge and monitoring of the affected area, changes in vegetation and land use, loss of vegetation, soil and tailings analysis, water quality and microbial activities, and socioeconomic impacts (Omachi et al., 2018; Gomes et al., 2017; Burritt & Christ, 2018; Queiroz et al., 2018; Cordeiro et al., 2019).

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Furthermore, among the concerns of agencies responsible for the recovery of the Rio Doce Basin is the management of tailings that invaded farming areas to reduce impacts and enable them to be exploited again.

However, iron mining tailings limit plant growth and development for promoting soil low fertility, coupled with great restrictions on its physical traits, e.g., low water retention, high density, and lack of structure (Barros et al., 2018).

Perennial grasses are often used to recover degraded areas, mainly due to their high-density root systems, including areas degraded by mining activity. Stumpf et al. (2017) demonstrated that the species *Urochloa brizantha* (Hochst. ex A. Rich.) R. Webster excelled to recover soil physical properties in degraded areas due to its root system characteristics. Moreover, the cultivars Marandu and Xaraés, of the species *U. brizantha*, are the most used and researched in Brazil (Duarte, 2017).

Allied to that, irrigation is a fundamental practice to increase crop yield when properly managed, at the right times and depths. Antoniel et al. (2016) evaluated forage production under different irrigation depths and found that forage yield increased when plants received amounts close to 100% of the crop reference evapotranspiration. These authors also reported that non-irrigated plants had their yield compromised.

Coarse texture and lack of structure of tailings affect their water storage capacity, which is important in the water management of crops. Nowadays, with the scarcity of water resources in several places, coupled with increases in electricity tariffs, efforts have been made to increase irrigation efficiency (Martínez-Romero et al., 2019).

In this context, this study aimed: (1) to evaluate whether the application of different irrigation depths into Xaraés grass cultivated in mining tailings can affect its development, yield, and bromatological aspects; (2) to compare its development, yield, and bromatological components when grown in tailings, natural soil, and tailings with soil conditioner.

MATERIAL AND METHODS

Experiment location and tailing collect

Iron mining tailings were collected at the Germano Dam in the city of Mariana - MG (20° 13' 01" S latitude, 43° 28' 10" W longitude, and 893 m altitude), with the help of Fundação Renova. Thirty tons of mining tailings were collected and transported to a lysimetric station (18 m length x 7 m width; 126 m² total area). This is located in the Experimental Irrigation Area of the Department of Agronomic Engineering (DAE), Federal University of Viçosa (FUV), in the city of Viçosa-MG, where the experiment was carried out (20º 46' 08" S latitude, 42º 52' 44" W longitude, and 675 m altitude).

Eighteen drainage lysimeters were filled with iron mining tailings. The lysimeters were 1.40 m long, 1.00 m wide, and 0.90 m deep, with edges close to the ground, with the lower part (0.15 m) being filled with gravel and sand. Each lysimeter received a layer of 0.65 m of iron mining tailings. Likewise, the other three drainage lysimeters were filled with gravel and sand in their lower part and completed with soil classified as Red Yellow Latosol (Oxisol). Each lysimeter had a bottom drain to collect surpluses and measure the volume of water drained. This technique is similar to those used by Oliveira et al. (2020) and Silva (2020).

After filling the lysimeters, samples of mining tailings and soil were collected for physicochemical and hydric characterizations. Physical properties (Table 1) were analysed at the Soil Physics Laboratory, and chemical analysis (Table 2) was performed at the Soil, Plant Tissue, and Fertilizer Analysis Laboratory, both belonging to the Soil Department of the Federal University of Viçosa - UFV. The analyses were performed following the methods described by Teixeira et al. (2017). Soil-water retention curves were developed in the Soil Physics Laboratory of the Water Resources Reference Centre - DAE / UFV. In the analysis, mining tailings were measured for field capacity (FC) and permanent wilting point (PW), following the method described by Bastos et al. (2007).

TABLE 1. Physical-hydric characteristics of the mining tailings and soil used in the experiment.

Sample	Coarse sand	Fine sand	Silt	Clay	ME	FC	PW	D_p	D_b	Texture
	-----kg kg^{-1}-----							---g cm^{-3}---		
Tailing	0.109	0.593	0.225	0.074	0.06	0.134	0.016	2.92	1.53	Sandy loam
Soil	0.113	0.093	0.047	0.747	0.29	0.237	0.160	2.60	1.18	Clay

ME – Moisture equivalent; FC – Moisture at field capacity (the matric potential at which the field capacity was determined was 10 kpa); PW – Permanent wilting point; Dp – Particle density; Db – Bulk density

TABLE 2. Chemical composition of the mining tailings and natural soil used in the experiment.

Sample	pH	P	K	Na	Ca^{2+}	Mg^{2+}	Al^{3+}	H+Al	SB	ECEC	CEC	BS
	(H_2O)	-----mg dm^{-3}-----			-----cmol$_c$ dm^{-3}-----							%
Tailing	4.82	2.9	12	0.0	0.36	0.03	0.0	0.5	0.42	0.42	0.92	45.7
Soil	6.39	4.1	112	0.50	3.40	0.79	0.00	1.9	4.48	4.48	6.38	70.2

Sample	m	ESP	P-rem	Cu	Mn	Fe	Zn	Cr	Ni	Cd	Pb
	-------%-------		-----mg dm^{-3}-----								
Tailing	0.0	0.00	49.3	0.06	22.3	68.0	0.38	0.15	1.03	0.08	1.10
Soil	0.0	0.03	13.2	0.01	6.8	44.5	1.41	-	-	-	-

SB – Sum of bases; ECEC – effective cation exchange capacity; CEC – cation exchange capacity at pH 7.0; BS –Sum of bases saturation; m – Al saturation; ESP – Sodium saturation index; P-rem – Remaining phosphorus.

Pasture cultivation and irrigation management

The forage species used in this study was *U. brizantha* cv. Xaraés. It was selected due to its characteristics such as tolerance to poorly drained soils, high yield, rapid regrowth, and late flowering when compared to Marandu grass.

The experiment was conducted for six months, from grass sowing until its last cut for evaluation. Pasture establishment period comprised 60 days, which is when standardization cut was performed at 0.25 m from the ground. Thereafter, treatments began to be applied and evaluations were made during the pasture development. The cutting criterion was age, a 30-day cycle was then fixed, and pasture was cultivated for four cycles.

Before sowing, mining tailings were corrected for acidity, applying 1.21 tons limestone ha^{-1}. Implantation fertilization consisted of the application of 70 kg P_2O_5 ha^{-1}, whose source was single superphosphate, and 60 kg K_2O ha^{-1}, using potassium chloride. For the soil, there was no need for acidity correction, and fertilization was performed with 70 kg P_2O_5 ha^{-1}, using single superphosphate as a source.

Sowing was performed by applying 12 kg ha^{-1} of commercially coated Xaraés grass seeds harvested in the 2017/2018 crop season, with 85% germination, 60% purity, and 51% cultural value. The pasture was sown manually in rows spaced 0.28 m apart and at 0.02 m depth. Phosphate fertilizer was applied together with sowing, and potassium fertilizer was applied after seedling emergence to avoid problems of the fertilizer saline effect on seed vigour.

Maintenance fertilization was carried out between cutting and sprouting cycles, applying 150 kg ha^{-1} of N, 30 kg ha^{-1} of P_2O_5, and 200 kg ha^{-1} of K_2O, using urea, single superphosphate, and potassium chloride as sources, respectively. Topdressing was split into two for each cycle and spread on the soil surface, then irrigating the lysimeters thereafter.

In the additional treatment with soil conditioner, TerraCotten (selected fertilizers for balanced nutrition based on macro and micronutrients) was applied. The fertilizer consists of a mixture of water-absorbing polymers, fertilizers, and growth stimulators. A dose of 0.14 kg was applied per lysimeter, distributed between planting lines to avoid root system disturbance, as the grass was already implanted. The maximum immersion depth was 0.20 m.

At the beginning of the experiment, uniform irrigations were carried out in the area to ensure seed germination, uniformity, and pasture establishment. After the standardization cut, irrigation was managed daily through the drainage lysimeters. For that, three lysimeters were used, where an irrigation depth corresponding to 120% of the crop evapotranspiration (ETc) was applied.

Irrigation was managed in the morning by subtracting the volume drained from the volume irrigated the day before. This difference was applied to replace 100% of the crop evapotranspiration depth (Equation 1). From the reference depth (100% of the ETc), irrigations were performed in the other lysimeters according to the equivalent percentage of each treatment. Irrigation depths were converted into the volume by manually distributing water with a watering can over the area of the lysimeters.

$$ETc = I - D \tag{1}$$

wherein,

ETc: crop evapotranspiration (mm d^{-1});

I: irrigation depth corresponding to 120% of the ET_c (mm d^{-1}),

D: drained water depth (mm d^{-1}).

Rainfall events were disregarded from the water balance since lysimeters were covered by a structure made of MDF board (1.60 x 1.20 m) and transparent plastic, placed at 0.60 m from the soil surface. Thus, rainfall did not interfere with the water balance of the plots. The structures were only placed on the lysimeters during the occurrence of rains, being removed immediately afterwards to prevent plastic from interfering with the development of the plants.

During the four cultivation cycles, data on daily average temperature, relative humidity, solar radiation, and rainfall were obtained from the digital database of the National Institute of Meteorology (INMET), whose automatic weather station was at 750 and 24 m horizontal and vertical distance, respectively, from the experiment site.

Evaluation of yield and bromatological components

Plants in each lysimeter were measured for height at the cutting time using a graduated ruler. The height measures were based on the visual horizon of leaves, measuring four samples per lysimeter. After measuring, the forage was cut. Two forage samples were collected from each experimental unit for dry mass yield and leaf: stem ratio determinations. To do so, a square frame (0.50 x 0.50 m) was placed onto each lysimeter to delimit the sampling area. Then, forage material was cut with scissors at 0.25 m above the soil level and placed into plastic bags for fresh weight determination. Other forage samples were placed into paper bags for dry weight determination. Another portion of the sample was manually separated into leaves and stems for leaf: stem ratio determination.

The samples were pre-dried at 55 ºC in a forced circulation oven, according to the method of INCT-CA G-001/1 by Detmann et al. (2012). According to these authors, high drying temperatures may cause loss of volatile compounds or complex carbohydrates with protein, directly interfering with bromatological composition analyses. Leaf: stem ratio was calculated by dividing leaf lamina dry mass by stem dry mass. The results of forage dry mass yield were expressed as tons ha^{-1}.

Bromatological analyses were performed at the Laboratory of Forage and Silage Microbiology of the Department of Animal Science (Federal University of Viçosa – UFV), using previously dried samples and then ground in a 1-mm sieve knife-mill. Bromatological components were determined following the methods of the Association of Official Analytical Chemists. Barros et al. (2019) also used the same analysis methods with Xaraés grass.

For dry matter contents (method 934.01), samples were placed in porcelain crucibles with previously known weights and oven-dried at 105 °C for 16 hours, and then weighed in an analytical balance. After dry matter determination, samples were incinerated in a muffle furnace at 600 °C for four hours for total burning of organic matter, then quantifying mineral matter contents (method 942.05) in each sample.

Neutral detergent fibre (NDF) is the fibrous fraction of a forage that is insoluble in a neutral environment and composed of hemicellulose, cellulose, and lignin. In turn, acid detergent fibre (ADF) is the non-digestible part of a forage that is composed of cellulose and lignin.

Samples to determine NDF (method 978.10) were packed in TNT (non-woven) bags. These bags were placed individually in universal collectors and added with a solution of neutral detergent and thermostable α-amylase without sodium sulphite. The collectors were then autoclaved at 105°C for one hour; then, the samples were washed, dried, and weighed. In sequence, ADF content was evaluated (method 973.18). To do so, autoclaving, washing, drying, and weighing were repeated using the acid detergent solution but no thermostable α-amylase enzyme addition.

For crude protein (method 984.13), total nitrogen contents were determined using 0.2 g of sample in a test tube, following digestion, distillation, and titration steps. Finally, using a correction factor, crude protein content in the sample was estimated.

Experimental design and data analysis

The experiment was carried out under a completely randomized design with seven treatments and three replications. Five treatments consisted of five irrigation depths (D40, D60, D80, D100, and D120), which corresponded to 40, 60, 80, 100, and 120% of the crop evapotranspiration (ETc). Two additional treatments were conducted consisting of grass grown in mining tailings with soil-conditioner (CD40) and another under natural soil (NS) conditions, applying water depths corresponding to 40 and 100% of the ETc, respectively.

Data were subjected to analysis of variance and regression. Means of the seven treatments were compared by Tukey's test at a 5% probability level. The effects of the five irrigation depths were compared by regression analysis. The models were chosen based on the significance of regression coefficients, using a "t" test at a 5% probability level. The determination coefficient (R^2 = Sum sq regression/Sum sq treatment) and the behaviour of the phenomena under study were assessed. All statistical procedures were performed in R software (R Core Team, 2021).

RESULTS AND DISCUSSION

Weather data

Figure 1 shows the daily data on rainfall, relative humidity, average temperature, and solar radiation in the four cycles evaluated.

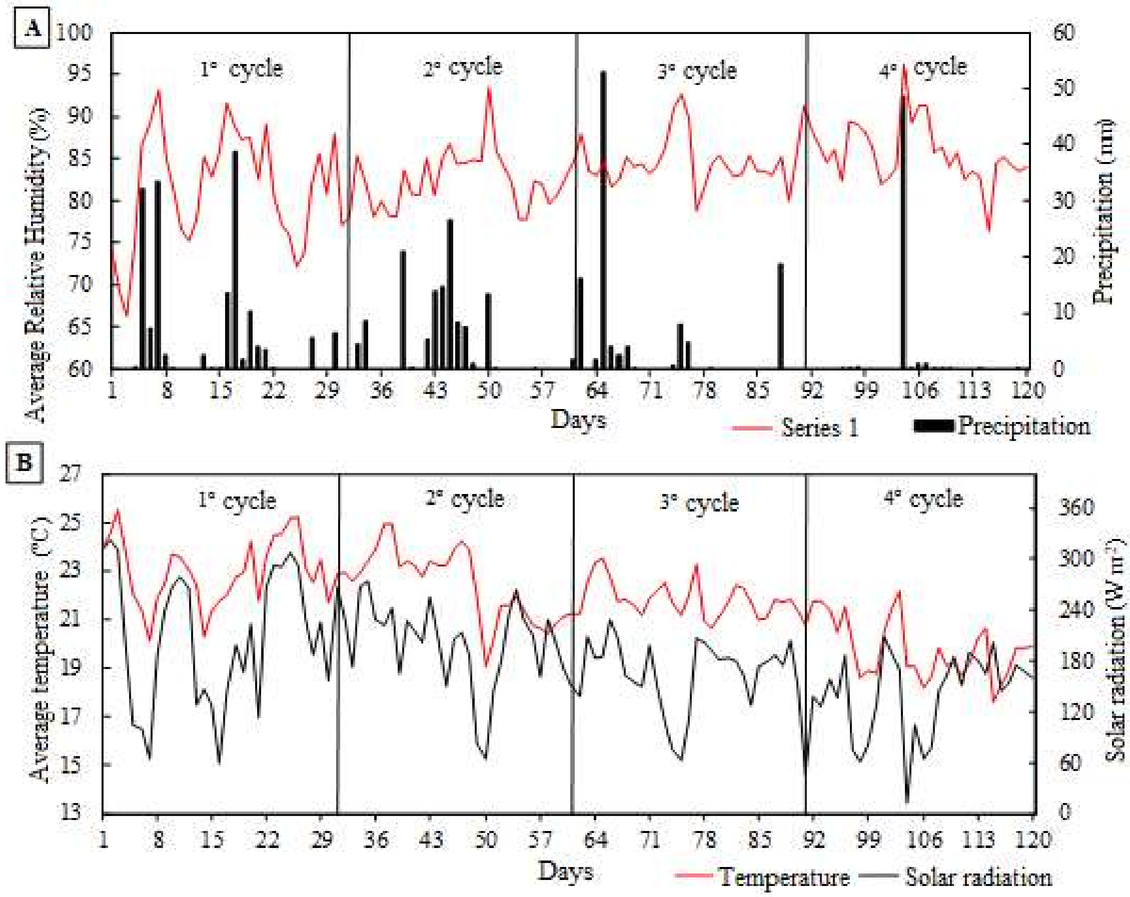

FIGURE 1. Average relative humidity (%) and daily rainfall (mm) (A), variation of average air temperature (°C), and daily solar radiation (W m^{-2}) (B) variation during the experimental period.

The largest rainfall event (52.8 mm) occurred on day 65 during the third cutting cycle. Accumulated rainfall for the four cutting cycles was 162, 124, 115, and 53 mm, in that order. Average relative humidity varied between 66 and 96% and occurred on the second and fourteenth days, respectively. The highest daily average temperature (25.5 °C) occurred on the third day during the first cutting cycle. The day before occurred the highest solar radiation incidence (322.40 W m^{-2}), while the lowest (12.15 W m^{-2}) coincided with the day when the highest relative humidity was recorded, as it rained most of the day. Notably, the lowest average daily temperature (17 °C) occurred on the one hundred fifteenth day of evaluation.

Table 3 shows the results of all variables analysed by Tukey's test, comparing all treatments during the four cutting cycles.

TABLE 3. Forage dry mass (t ha^{-1}), plant height (m), leaf: stem ratio, NDF (%), ADF (%), crude protein (%), and mineral matter (%) of Xaraés grass in four crop cycles grown in mining tailings subjected to different irrigation depths and tailings with soil conditioner, and grown in natural soil.

Treatment	FDM (t ha^{-1})	PH (m)	LSR	NDF (%)	ADF (%)	CP (%)	MM (%)
				Cycle 1			
D40	2.41 b	0.75 b	1.66 a	66.88 a	33.86 a	7.38 a	6.49 b
D60	2.93 b	0.80 ab	1.57 a	67.51 a	34.22 a	7.07 a	7.07 b
D80	3.54 ab	0.81 ab	1.55 a	65.84 a	33.30 a	8.27 a	7.69 ab
D100	3.62 ab	0.82 ab	1.52 a	66.28 a	32.89 a	7.93 a	7.53 ab
D120	4.53 a	0.89 a	1.60 a	64.63 a	33.84 a	7.23 a	8.68 a
CD40	3.22 b	0.83 ab	1.62 a	67.25 a	33.41 a	7.95 a	6.94 b
NS	3.61 ab	0.88a	1.65 a	65.41 a	31.89 a	8.03 a	7.75 ab
CV (%)	13.19	4.83	6.29	1.66	1.32	13.31	6.96
				Cycle 2			
D40	1.44 b	0.43 b	4.57 a	58.25 a	29.39 a	15.08 a	8.94 a
D60	1.57 b	0.42 b	4.61 a	56.24 a	27.83 a	14.79 a	8.76 a
D80	1.85 b	0.42 b	4.76 a	56.57 a	28.33 a	15.16 a	8.71 a
D100	2.18 ab	0.48 b	5.19 a	55.65 a	27.64 a	15.32 a	8.54 a
D120	2.72 a	0.58 a	4.47 a	56.74 a	28.31 a	14.25 a	9.34 a
CD40	1.81 b	0.44 b	4.38 a	55.38 a	27.17 a	15.35 a	9.85 a
NS	3.00 a	0.57 a	4.93 a	58.34 a	28.93 a	13.50 a	7.76 a
CV (%)	14.96	5.74	36.24	3.14	4.70	8.08	8.70
				Cycle 3			
D40	1.81 c	0.72 a	3.87 b	59.38 a	30.62 a	12.24 a	8.20 a
D60	2.43 bc	0.75 a	4.34 ab	58.62 a	29.15 a	10.95 a	8.11 a
D80	3.15 ab	0.79 a	4.68 ab	60.49 a	30.67 a	9.83 a	7.74 a
D100	4.23 a	0.80 a	5.81 ab	61.09 a	31.34 a	9.88 a	8.01 a
D120	4.30 a	0.80 a	6.34 a	63.57 a	32.40 a	8.08 a	8.01 a
CD40	3.45 ab	0.78 a	4.54 ab	57.84 a	28.98 a	11.50 a	8.69 a
NS	4.08 a	0.79 a	5.96 ab	59.59 a	29.66 a	10.03 a	7.16 a
CV (%)	14.25	4.84	16.35	3.25	5.26	15.13	8.88
				Cycle 4			
D40	1.28 b	0.45 c	3.30 a	55.46 a	27.96 a	14.16 a	8.89 a
D60	1.65 ab	0.47 bc	3.55 a	55.89 a	28.09 a	12.91 a	8.26 ab
D80	1.66 ab	0.52 abc	3.57 a	56.72 a	28.79 a	12.86 a	8.86 a
D100	2.34 a	0.53 ab	3.95 a	55.98 a	27.75 a	13.39 a	8.72 a
D120	2.61 a	0.58 a	3.02 a	58.50 a	30.30 a	13.79 a	8.93 a
CD40	2.27 ab	0.48 bc	3.32 a	58.69 a	30.10 a	13.98 a	8.98 a
NS	2.10 ab	0.59 a	3.95 a	58.15 a	30.16 a	12.70 a	7.36 b
CV (%)	18.26	5.69	22.62	3.55	4.17	7.23	5.63

Means followed by the same letter in the column do not differ by Tukey's test at a 5% significance level. D40, D60, D80, D100 and D120 – irrigation depths corresponding to 40%, 60%, 80%, 100%, and 120% of the crop evapotranspiration; CD40 – iron mining tailing with soil conditioner; NS – natural soil; CV – coefficient of variation; FDM – forage dry mass; PH – plant height; LSR – leaf: stem ratio; NDF – neutral detergent fibre content; ADF – acid detergent fibre content; CP – crude protein content; MM – mineral matter content.

Forage dry mass yield

Forage dry mass (FDM) was influenced by irrigation depths in all cycles evaluated (p <0.01). FDM yield had a positive linear response with increasing irrigation depths from 40 to 120% of ETc (FIGURE 2).

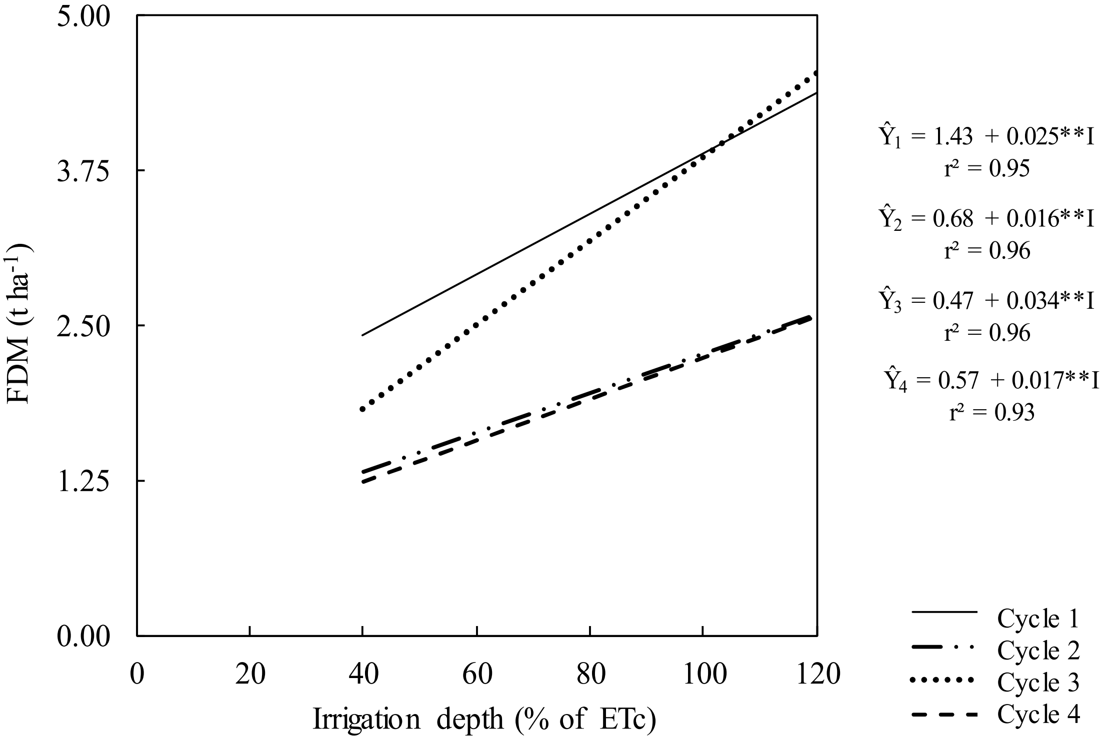

FIGURE 2. Forage dry mass (FDM) (t ha^{-1}) of Xaraés grass irrigated with different irrigation depths grown in mining tailings.
** Significant at the 1% probability level by the t-test.

In all cycles evaluated, the lowest FDM averages were observed for D40, while the highest for D120. Therefore, increasing irrigation depths proved to be efficient in increasing FDM. Another important fact to note is that the productive potential of irrigated mining tailings at D100 was the same as that of natural soil at D120. This finding is important because it shows that one of the objectives of this study was achieved, that is, tailings have considerable productive potential.

Barros et al. (2019) observed that soils with high water contents decrease plant dry matter yield as it increases water contents in cells and therefore decreases dry matter contents. We, however, observed the opposite since irrigation increases reflected significant increases in FDM. Corroborating these results, Antoniel et al. (2016) studied the FDM yield of *U. brizantha* cv. Piatã and found maximum values in treatments with irrigation at 83, 131, 119, and 96% of the reference evapotranspiration (ET_0), respectively.

The treatment with soil conditioner and irrigation of 40% of the ETc (CD40) produced more than the D40 treatment in all cycles although they were statistically the same in the first two cycles. CD40 treatment produced 25, 21, 48, and 44% more FDM than did D40 in the four cycles, respectively. Therefore, soil conditioner use has the potential to increase the production of forage grown on mining tailings in the long term. This compost can thus aid the recovery of areas impacted by mining activity.

Plant height and leaf: stem ratio

Irrigation depths positively affected plant height in all cutting cycles (p <0.01). Therefore, plant height increased as water replacement increased between 40 and 120% of the ETc (FIGURE 3). In the third cutting cycle, irrigation depths did not affect plant height, with its sample at $\hat{Y}$=0.77 on average. Moreover, leaf: stem ratio (LSR) was positively influenced by irrigation depths from 40 to 120% of the ETc, but only in the third cycle (p <0.01). In the first, second, and fourth cycles, the leaf: stem ratio was not influenced by increasing irrigation depths, and their samples were $\hat{Y}_1$= 1.58, $\hat{Y}_2$= 4.72, and $\hat{Y}_4$= 3.47, respectively (FIGURE 3).

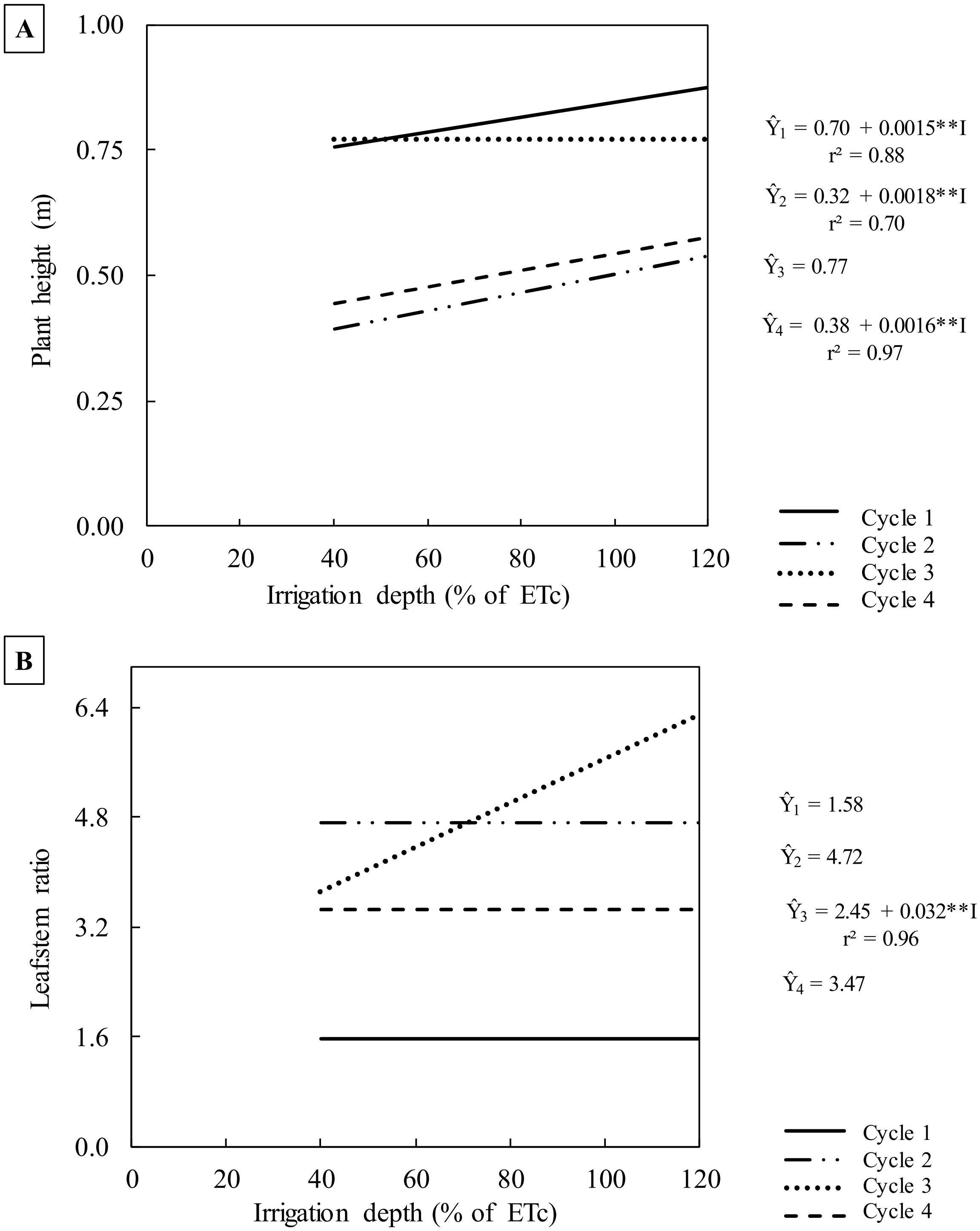

FIGURE 3. Plant height (A) and leaf: stem ratio (B) of Xaraés under different irrigation depths grown in mining tailings.
** Significant at the 1% probability level by the t-test.

Analysing the LSR of all treatments by Tukey's test, differences were found only in the third cycle (p <0.05) (Table 3). In the first, second, and fourth cycles, no statistical difference was observed among treatments. It might have occurred due to the pre-established cutting height of 0.25 m for all cycles. In the third cycle, LSR in D40 was 3.87, which differed only from D120, whose LSR was 6.34.

Corroborating our results in the third cycle, Beloni et al (2018) studied two cultivars of *U. brizantha* (Marandu and Paiaguás), *Urochloa decumbens* cv. Brasilisk, and *Dactylis glomerata* cv. Medly and observed that plants receiving total irrigation grew more than plants subjected to water stress; thus, irrigation is an important practice to improve forage growth and quality.

Bromatological components

In none of the evaluated cycles, irrigation depths had no influence on neutral detergent fibre (NDF) content (p > 0.05), presenting averages of $\hat{Y}_1$= 66.23%, $\hat{Y}_2$= 56.69%, $\hat{Y}_3$= 60.63%, and $\hat{Y}_4$= 56.50% for the first, second, third, and fourth cycles, respectively (FIGURE 4). Likewise, after application of the Tukey's test, neither quantitative nor additional treatments showed differences in NDF content in any of the cycles (p > 0.05) (Table 3). Moreover, applied irrigation depths promoted no significant differences in ADF content from 40 to 120% of the ETc ($p > 0.05$) in any of the cutting cycles, with averages of $\hat{Y}_1$=33.62, $\hat{Y}_2$= 28.30, $\hat{Y}_3$= 30.83, and $\hat{Y}_4$=28.57, respectively (FIGURE 4). Again, comparing all treatments by the Tukey's test, ADF contents in grasses grown on iron mining tailings, with or without conditioner, did not differ from that in natural soil ($p > 0.05$) (Table 3).

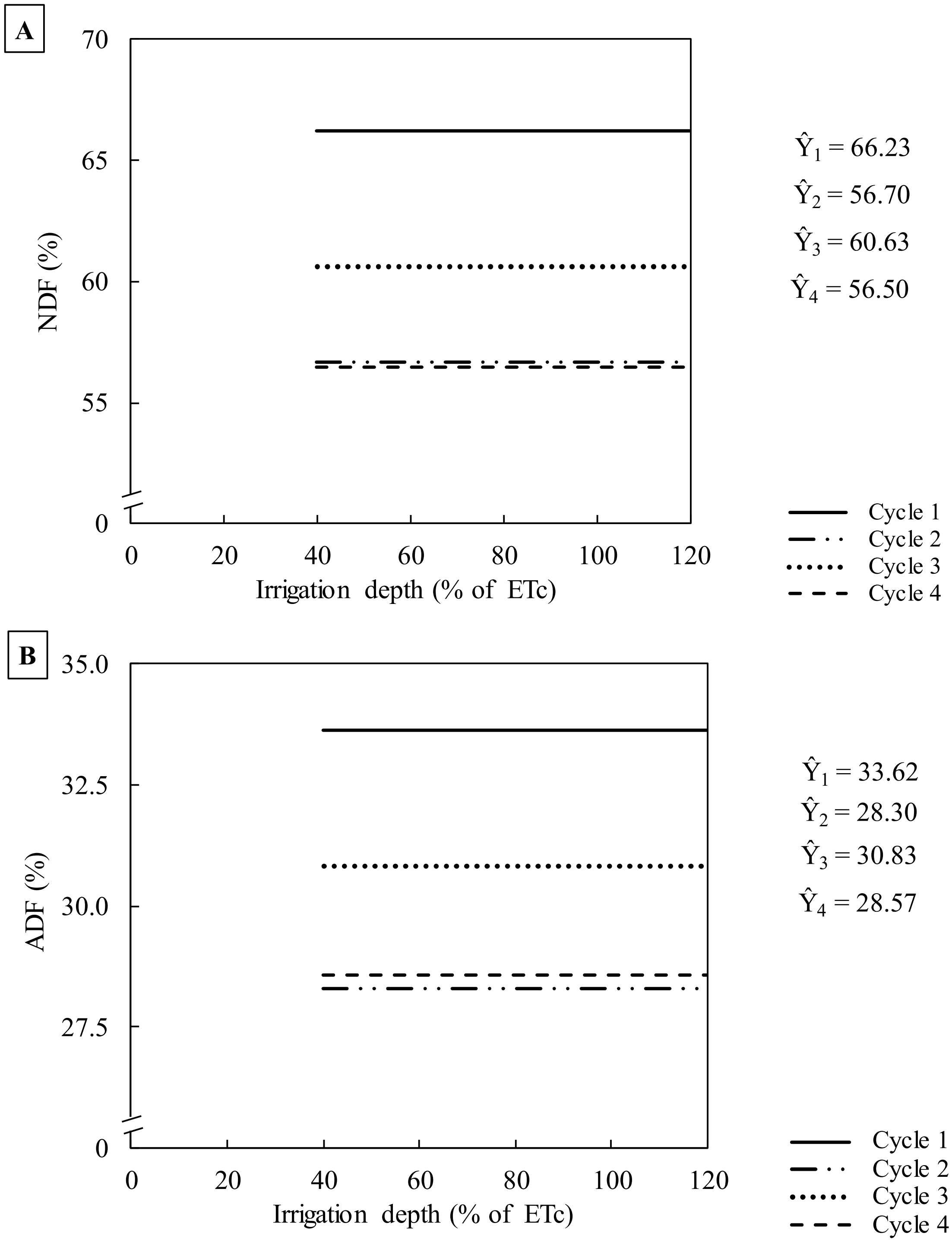

FIGURE 4. Neutral detergent fibre - NDF (A) and acid detergent fibre - ADF (B) in Xaraés grasses under different irrigation depths and grown on mining tailings.

** Significant at the 1% probability level by the t-test.

The lower ADF contents in the second and fourth cycles can be explained by the conditions forage plants were growing, with lower growth of plants and leaves in formation and expansion. According to Magalhães et al. (2015), ADF is indicative of forage energy value and, the lower its contents, the higher the forage nutritive value.

The content of crude protein (CP) in Xaraés grass was not influenced by irrigation depths between 40 and 120% of the ETc in the first, second, and fourth cutting cycles ($p > 0.05$), with averages of $\hat{Y}_1$= 7.58, $\hat{Y}_2$= 14.92, and $\hat{Y}_4$= 13.42, respectively. In the third cycle, irrigation depths had a negative influence on CP contents, which decreased as water content applied increased ($p < 0.01$) (FIGURE 5).

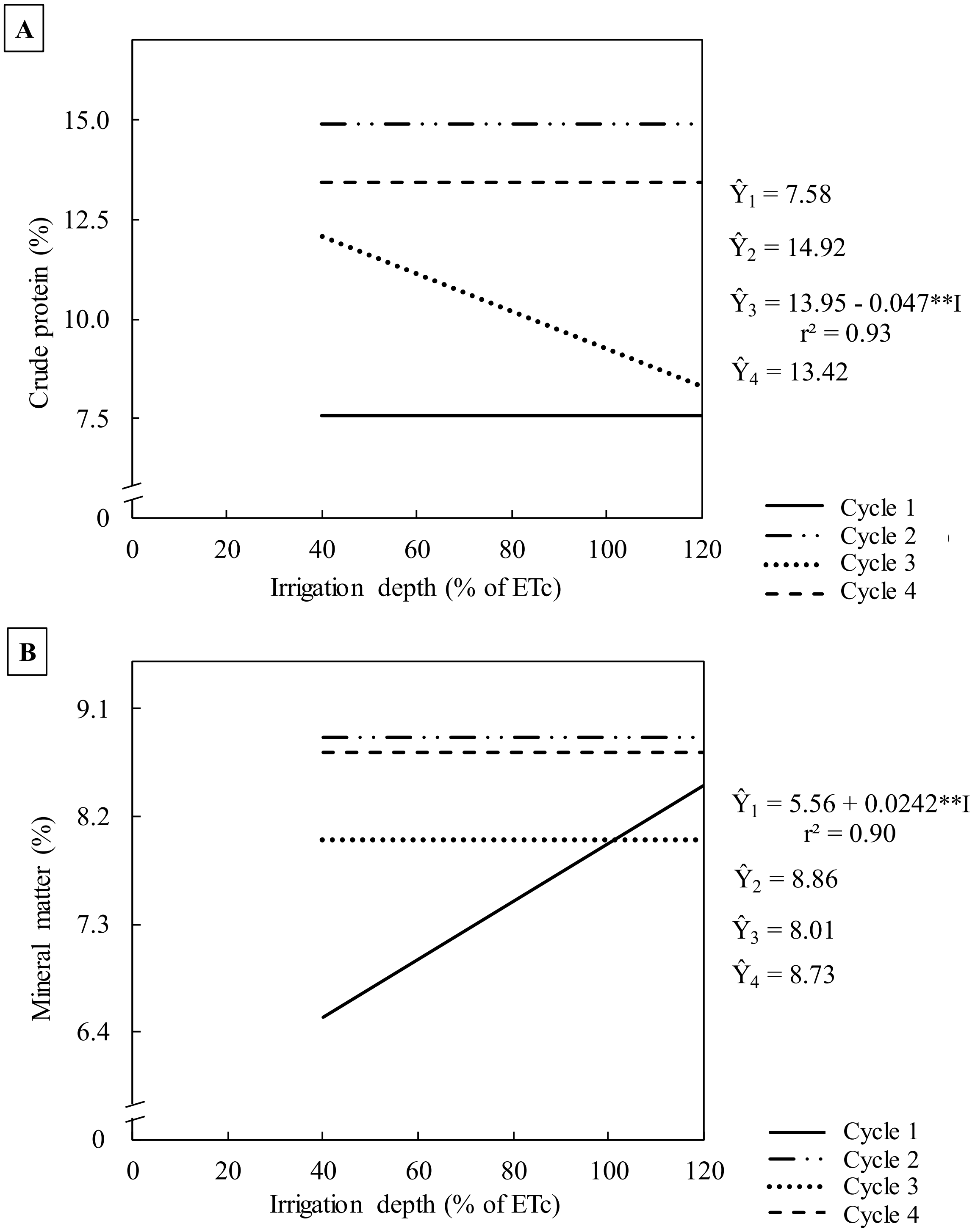

FIGURE 5. Crude protein - % (A) and mineral matter - % (B) in Xaraés grasses under different irrigation depths grown on mining tailings.

** Significant at the 1% probability level by the t-test.

As irrigation depths increased from 40 to 120% of the ETc, mineral matter (MM) contents in Xaraés grass increased in the first cutting cycle (p <0.01). However, in the other cycles, irrigation depths did not affect MM contents (p > 0.05), whose averages were $\hat{Y}_2$= 8.86, $\hat{Y}_3$= 8.01, and $\hat{Y}_4$= 8.73 in the second, third, and fourth cycles, respectively (FIGURE 5).

Using the comparison test, crude protein contents were influenced by all treatments in none of the cycles (p > 0.05). For mineral matter contents, treatment D120 had a significant difference from treatments D40, D60, and CD40 in the first cycle (p <0.05). In the second and third cycles, no significant differences were found among treatments (p > 0.05). In the fourth cycle, grass cultivation in natural soil showed lower MM contents when compared to those cultivated on iron mining tailings (Table 3).

Accumulation of minerals in the soil is important for absorption by forage plants, as mineral replacement is crucial in grazing systems to meet the nutritional demands of forage plants and maintain their yield and soil fertility (Ribeiro & Pereira, 2011). In the fourth cycle, MM content in NS treatment can be explained because plants needed to change their structure due to their low heights and high dry matter yield compared to other treatments.

CONCLUSIONS

Limitations imposed by the properties of iron mining tailings do not affect Xaraés grass establishment and forage production.

Irrigation depths positively and linearly affect dry mass yield and plant height of Xaraés grass grown on iron mining tailings, with the largest increments at an irrigation depth of 120% of the crop evapotranspiration.

Treatments D100, D120, and natural soil (NS) are very similar and do not differ statistically for the attributes studied in the cutting cycles of Xaraés grass. Moreover, soil conditioner (CD) has no significant results.

Neutral detergent fibre, acid detergent fibre, and crude protein contents are not affected when Xaraés grass is grown on iron mining tailings, regardless of the irrigation depth, tailing cultivation with a soil conditioner or natural soil.

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