Original Research Article

Water Availabilities Associated with Natural Phosphate and Triple Superphosphate in Radish Cultivation

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ABSTRACT

Aims: The objective of this study was to evaluate the development of giant Crimson radish cultivated in a oxisol under phosphate fertilizer sources (natural phosphate, triple superphosphate, natural phosphate + triple superphosphate and control) associated with water availabilities (40, 80 and 120% of the field capacity).
Study design: The experimental design was completely randomized, in a 4x3 factorial scheme, with 4 replications (48 units).
Place and Duration of Study: The research was conducted in a greenhouse belonging to the Rondonópolis Campus of the Federal University of Mato Grosso, in the municipality of Rondonópolis (MT).
Methodology: The dystrophic Oxisol was used to fill the 1.5 dm^3 pots. The irrigation management was in accordance with the methodology of the maximum water retention capacity, by the gravimetric method. Phosphate fertilization was applied before sowing using 265 mg dm^{-3} phosphorus, varying the source used, triple superphosphate and Bayovar Natural phosphate. After the emergence of the plants, the other nutrients were applied to the soil. The variables related to vegetative development and after the harvest of radish were evaluated at 20 and 35 days after sowing.
Results: The variables fresh mass of the aerial part, dry mass of the tubercle, dry mass of the aerial part, fresh mass of tubercle and length of tubercle had the highest values with the use of triple superphosphate, and for the field capacities of 80 and 120%. The highest harvest index (1.51) was found for the use of Natural phosphate in the field capacity of 120%. The water consumption by the plants was higher with the use of triple superphosphate and field capacity of 120% (6,425.25 L). The efficiency of water use was better with the application of triple Superphosphate and 40% of the field capacity (0.0547 g mL^{-1}).
Conclusion: There was influence of both water availabilities and phosphate fertilization on the studied variables. Triple superphosphate associated with 80% of the field capacity allowed the best productivity averages for radish.

Keywords: horticulture, irrigation, Raphanus sativus L., phosphorus sources

1. INTRODUCTION

The oxisols located in Cerrado areas can commonly present low phosphorus levels due to their chemical and mineralogical nature, which is why phosphate fertilization becomes necessary to ensure crop yield [1].

The radish (*Raphanus sativus* L.), belonging to the Brassicaceae family, is characterized as a small plant. It needs large amounts of nutrients in a relatively short period. As a result, fertilizer application should be efficient using appropriately sources and doses.

The use of soluble phosphorus sources, such as superphosphates, causes an immediate availability of this nutrient in the soil, which causes its preference in the management of phosphate fertilization. However, these sources have a higher cost due to their industrialization process, and much of the phosphorus is subject to soil fixation, reducing their availability to plants [2].

The need to reduce costs with the application of chemical fertilizers leads to the need to research on the efficacy of natural phosphate fertilization as a means of increasing the economic viability of the crop.

Radish is characterized as a culture that is very sensitive to soil moisture variations [3]. The need to know the quantity and the correct time of water replacement for radish, as well as for other crops is fundamental and several factors are involved, such as the climatic conditions of the region, soil water balance and the physiological characteristics of the plant [4].

The authors [5] affirm that there are few researches addressing the issue of water management in the radish culture and that culture is extremely sensitive to variations in soil water content, presenting physiological disturbances in the deficit or excess of moisture. The water stress can impair its cultivation with undesirable effects on the commercial quality of the root.

The objective of this study was to evaluate the development of radish cultivated in a oxisol under sources of phosphate fertilizers associated with hydric availabilities.

2. MATERIAL AND METHODS

The experiment was conducted in a greenhouse, located at the Federal University of Mato Grosso, Rondonópolis Campus, geographic coordinates 16° 28' S, 50° 34' O, altitude 284 m. The climate of the region, in the Köppen classification, is of type Aw, that is, tropical with a dry season of winter. The average annual temperature is 24.6 °C, and the average annual rainfall is 1693 mm.

The experimental design was completely randomized, in a 4x3 factorial scheme, with three phosphate fertilization sources (natural phosphate, triple superphosphate, natural phosphate + triple superphosphate and control) and three soil humidities (40, 80 and 120% of field capacity), with 4 repetitions, making 48 experimental units.

The dystrophic Oxisol [6] was used to fill the 1.5 dm^3 pots, collected in an area under Cerrado vegetation, in the depth of 0 to 0.20m and sifted for chemical and granulometric characterization according to [7] (table Table 1).

Table 1. Chemical and granulometric characteristics of the Oxisol that will be used.

pH	P	K	Ca	Mg	Al	H	BS	CEC	V	OM	Sand	Silt	Clay
$CaCl_2$	mg dm^{-3}		---------------cmol$_c$ dm^{-3}--------------						%	g dm^{-3}	-----------g kg^{-1}----------		
4.0	1.3	33	0.4	0.2	1.1	4.6	0.7	6.4	10.7	21.2	445	100	455

P = Phosphorus; K = Potassium; Ca = Calcium; Mg = Magnesium; Al = Aluminum; H = Hydrogen; BS = Bases sum; CEC = Cation Exchange Capacity; V = Basis Saturation; O.M. = Organic matter.

The soil base saturation increased 80%, and dolomitic limestone was applied according to the soil analysis results. After 30 days of soil limestone incubation, the giant Crimson radish was sown.

The fertilization with the treatments was applied before sowing using 265 mg dm^{-3} phosphorus (P_2O_5), varying the source used, triple superphosphate (45% P_2O_5) and Natural Bayovar phosphate (29% P_2O_5). After the emergence of the plants, the other nutrients were applied to the soil, 100 mg dm^{-3} of potassium (K_2O), using as source the potassium chloride, 50 mg dm^{-3} of sulfur (S), having as source the agricultural gypsum, and 100 mg dm^{-3} of nitrogen (N), using urea as source split in two times, being 50% after emergence and 50% seven days after the first installment [8].

The fertilization with micronutrients was performed seven days after the emergence of the plants, via aqueous solution, 4 mg dm^{-3} of copper (Cu) and 2 mg dm^{-3} of Boron (Bo) were applied, using as source the copper sulfate and boric acid, respectively.

The irrigation was performed from the determination of the maximum water retention capacity [9], by the gravimetric method, according to each treatment, 40, 80, and 120% of the field capacity.

The water replacement was performed manually with the aid of a scale until each experimental unit reached the weight corresponding to what was determined for each treatment. The irrigation management to maintain each treatment began to have variation 10 days after sowing, until then, all the experimental units were being maintained with 100% of the field capacity.

The variables related to the vegetative development of radish were evaluated at 20 and 35 days after sowing, which were plant height, number of leaves, and chlorophyll index SPAD. After harvesting, the following were evaluated: fresh and dry mass of leaves and tubercles, length and diameter of tubercles, harvest Index, water use efficiency and water consumption.

Plant height was determined with the aid of a graduated ruler; the number of sheets was counted manually. The chlorophyll index was estimated with the Minolta® 502 portable meter.

The fresh mass of the aerial part and roots, after the separation of the aerial part and roots, was measured with the aid of a semi-analytical balance. The dry mass of the aerial part and roots was obtained after the samples were dried in a forced ventilation stove at 65 ºC, until it reached a non-variable value with the weighing on a semi-analytical balance.

The efficiency of water use comprised the ratio between the amount of dry mass of roots produced in relation to water consumption added in each treatment during the crop cycle. The harvest index refers to the relationship between the dry biomass of the commercial part and the total dry biomass of the plant.

The data were subjected to analysis of variance by the F test ($P > 0.05$). When significant difference was observed, the Tukey test ($P > 0.05$) was performed with the use of the statistical software SISVAR [10].

3. RESULTS AND DISCUSSION

The plant height and the number of leaves, at 20 and 35 days after sowing, were influenced by phosphate sources and water availabilities in isolation. At 20 and 35 days after sowing, the lowest plant height was found for the field capacity of 40%. Thus, it can be attributed the smallest results at the height of radish plants, to the water deficit caused by the lower water supply when compared to the other treatments (Table 2; Figure 1).

The highest plant heights in relation to the fertilizer source were observed with triple superphosphate and Natural phosphate + triple superphosphate, with no statistical difference between them at 20 and 35 days after sowing. The lowest height was found where there was no application of phosphorus (Table 2; Figure 1). The difference in the plant's height of radish observed as a function of the phosphate sources may be related to the solubility characteristics and the dynamics of phosphorus release presented by the phosphate fertilizers used in the research.

The authors [11] analyzed the growth of radish under different irrigation depths and observed that the blade of 100% of the reference evapotranspiration allowed the higher growth of plants in height. It can be emphasized that vegetables ~~in general~~, in general, deserve attention as to the water availability~~,~~ because they are extremely sensitive plants to water, and their lack may compromise the growth of the plant and its excess impair the respiration of the roots and the appearance of diseases [12]. The authors [13] evaluated phosphorus doses in the beet crop, observed that the plants with the omission of phosphorus presented reduced aerial part and that there was no development of the tubercle.

Table 2. Vegetative development of radish as a function of water availabilities and phosphate fertilization at 20 to 35 days after sowing

Field capacity	Plant height		Number of Leaves	
	20 days	35 days	20 days	35 days
40%	13.26B	19.95B	5.44B	6.18B
80%	16.03A	24.23A	5.81AB	7.00A
120%	17.45A	23.46A	6.06A	6.00B
Phosphate fertilization	20 days	35 days	20 days	35 days
Control	8.60C	10.75C	3.83C	4.75B
NF	16.32B	24.22B	6.00B	6.58A
TS	18.62A	28.18A	7.00A	7.25A
NF + TS	18.78A	27.04A	6.25B	7.00A

Means followed by different letters in the column indicate the difference by the Tukey test (P > 0.05). Natural phosphate (NF), triple Superphosphate (TS) and natural phosphate + triple superphosphate (NF + TS)

In field field capacity of 80%, the highest number of leaves was observed in both developmental stages, however, at 20 days after sowing~~,~~; it did not differ statistically from the field capacity of 120%. The authors [14] studying the morphological characteristics and productivity of the radish subjected to different irrigation levels in the production phase of the crop did not observe a statistical difference between the treatments, however, the authors [11] working with the radish culture subjected to different irrigation levels found that 125% of the field capacity favored the increase in the number of leaves (Table 2).

In the two assessments performed, triple superphosphate treatment was responsible for the highest number of leaves, not differentiating statistically from the treatments Natural phosphate and Natural phosphate + triple superphosphate at 35 days after sowing. According to [15] the natural phosphate appears as an alternative for its lower cost and with the benefit of being made available gradually throughout the whole cycle of the plant, which may explain the significant difference existing in the first evaluation, because the fertilization with the triple superphosphate makes the match readily available to the plant.

For [16], phosphorus deficiency interferes in the leaf area, because there is a limitation in the number of leaves, also affected by water availability for the crop. According to [17], the importance of phosphorus as a nutrient for the development of the crop explains the difference found in the control in relation to the treatments with different sources of phosphorus.

Figure 1. Whole radish plants due to water availability and phosphate fertilization.

For the SPAD reading performed at 20 and 35 days after sowing, the highest chlorophyll index was obtained by the control with the field capacities of 40% and 120%. It was observed that the phosphate source fertilization did not statistically alter the chlorophyll index for the field capacity of 80%. Water availability did not influence the results in the use of triple superphosphate (Table 3).

Fixing the levels of water availability to interpret the phosphate sources fertilization was observed that in the field capacity of 40% the fertilization performed with triple superphosphate and the control obtained lower results to the other sources of fertilization, in the other field capacities the results were statistically equal. Interpreting the variation of irrigation levels in each fertilizer source, the lowest chlorophyll index were observed in the sources Triple superphosphate + Natural phosphate and Natural phosphate in the field capacity of 120%, with no significant difference in the other fertilization sources (Table 3).

As there is no difference in the fertilization source, the results corroborate with the work of the authors [18] that evaluated the effect of N, P and K doses on the indirect measurement of chlorophyll in the rootstock of lemon lime and verified that the SPAD index is influenced by the nitrogen content that is altered by fertilization, there is no significant effect for phosphorus, and the reading decreases with phosphorus doses higher than 25 mg dm^{-1}, explaining the highest indexes in the control in the SPAD reading performed 20 days after cycle.

Table 3. Chlorophyll index Index (SPAD) of radish as a function of water availabilities and phosphate fertilization at 20 to 35 days after sowing (DAS)

Field capacity	Phosphate fertilization			
	Control	NF	TS	TS+NF
	SPAD at 20 DAS-CV 6.88%			
40%	39.00aA	38.72aA	32.65aB	36.62aAB
80%	34.57bA	35.05abA	32.50aA	32.45bA
120%	39.25aA	31.70bB	30.57aB	33.05abB
Field capacity	Control	NF	TS	TS+NF
	SPAD at 35 DAS - CV 10.94%			
40%	37.17aAB	43.42aA	32.27aB	41.90aA
80%	33.85aA	38.52abA	36.57aA	36.02abA
120%	34.77aA	32.05bA	33.97aA	31.60bA

Means followed by different lowercase letters in the columns and uppercase in the lines indicate difference by the Tukey test ($P > 0.05$). Natural phosphate (NF), Triple superphosphate (TS) and Natural phosphate + Triple superphosphate (NF + TS)

For the fresh mass of the aerial part, there was an interaction between treatments. The highest mean was for treatment with triple superphosphate with the field capacity of 80%, not statistically differentiating from the triple superphosphate treatment with 40% of field capacity and triple Superphosphate + Natural phosphate treatment with 80% of field capacity (Table 4).

According to the authors [19], the vegetables have their development influenced by the soil moisture conditions, with water deficiency being one of the most limiting factors for obtaining good productivity and quality in the production of vegetables, but excess water can also be harmful. The authors [20] analyzing the behavior of the radish culture submitted at different water replacement rates, found an increase in the aerial mass in a quadratic way to increase the level water applied.

According to the authors [8], the increase in phosphorus levels provides an increase in leaf area. The results show how the absence of phosphate fertilization influenced the development of the radish culture, providing the smallest averages of the fresh mass of the aerial part, cording with that found by the authors [19] where the deficiency and excess water promoted a reduction in the productivity of vegetables.

Table 4. Fresh mass of the aerial part and dry mass of the radish tubercles as a function of water availabilities and phosphate fertilization

Field capacity	Phosphorus sources			
	Control	NF	TS	TS+NF
	Fresh mass of aerial part-CV 18.12%			
40%	1.51aD	11.99bC	24.00aA	18.00bB
80%	3.43aC	21.01aB	26.80aA	25.25aAB
120%	2.53aB	16.01bA	18.77bA	19.56bA
Field capacity	Control	NF	TS	TS+NF
	Dry The dry mass of tubercles-CV 40.5%			
40%	0.05aB	0.37bAB	1.45bA	1.07bAB
80%	0.13aB	1.69aA	2.37abA	1.98abA
120%	0.1aB	2.62aA	3.12aA	2.57aA

Means followed by different lowercase letters in the columns and uppercase in the lines indicate difference by the Tukey test ($P > 0.05$). Natural phosphate (NF), Triple superphosphate (TS) and Natural phosphate + Triple superphosphate (NF + TS)

The dry mass of the tubercless showed interactions between the phosphorus sources and the water availability. For the field capacity of 80% and 120%, the three phosphate sources did not differ statistically in relation to the treatment with water deficit, which had the lower weight of dry mass and no difference between the phosphorus sources (Table 4). The treatment with water availability of 120% of the field capacity was higher in all phosphorus sources in relation to the others, where triple superphosphate promoted the greater accumulation of dry matter of the tubercles. The authors [21] when studying the production of the radish crop cultivated in pots with different irrigation levels, based on evaporation fractions of the class A tank in 80%; 100%; 120 and 0% (water stress), showed that there were no differences between the 3 irrigation levels applied to the dry mass of the tubercles and a reduction of 64% of the matter for the plants subjected to water stress when compared to the control treatment (100%).

The increase in water availability was not detrimental to the development of the crop. The authors [22] report that the increase in irrigation levels (50%, 75%, 100% and 125% ETc) causes linear progression in the mass of radish tubercles cultivated both in dry and rainy seasons.

The authors [8] in their study with radish submitted to phosphate fertilization, found that there was an influence on the dry mass of the root as a function of the phosphorus doses. The soluble phosphates source (triple superphosphate) accumulates more phosphorus in the vegetative parts of the plants, mainly part area and second in the root [23]. A nutrient source that manages to make available to the plant regulated doses of non-loss phosphorus throughout its cycle, contributes to the increase of energy and development, so the triple superphosphate with higher water availability stood out.

In the dry mass of the aerial part, it was verified that there was a significant difference in relation to the applied irrigation level and the phosphate source fertilization, with no interaction between treatments. In relation to water availability with 80% of the field capacity, the highest dry mass value of the aerial part was obtained, not differentiating statistically from the lamina of 120% of the field capacity, and the lowest dry mass was obtained with the treatments subjected to water deficit (Figure 2).

The authors [22] have obtained Results that relate the decrease in the dry mass of the aerial part of the radish in a situation of deficit and excess of water availability, ; a tendency followed in the study performed.

In relation to the phosphate source fertilization the dry mass of the aerial part followed the same tendency of other variables analyzed, where the absence of phosphate fertilization resulted in lower yield. The treatment that obtained the highest dry mass of the aerial part was with the incorporation of triple superphosphate, not differentiating statistically from the treatment Triple superphosphate + Natural phosphate (Figure 2).

The authors [8] evaluated the growth of radish plants subjected to phosphorus doses and verified the influence of phosphate fertilization on the radish culture, where they obtained a quadratic regression adjustment for the effect of the increase of the P_2O_5 doses. The authors [24] found similar results for the lettuce crop as a function of different phosphate sources fertilization, presenting higher results for the mineral fertilization in relation to the fertilization performed with the natural phosphorous.

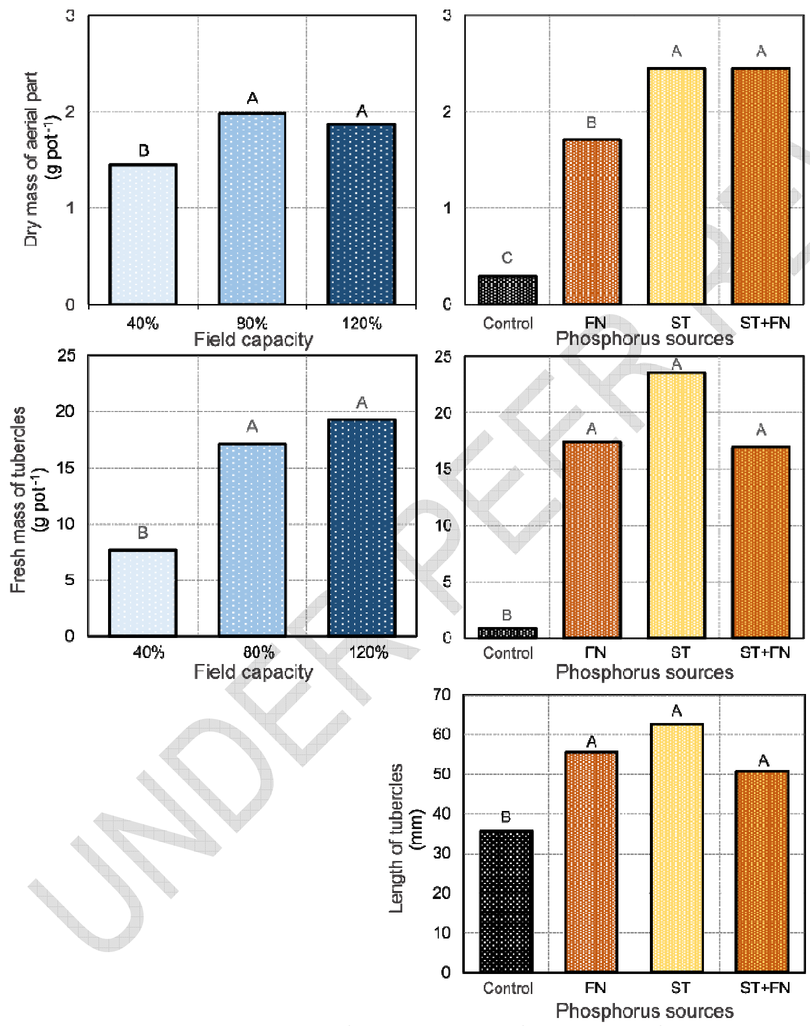

Figure 2. Dry The dry mass of aerial part, the fresh mass of tubercles, and length of tubercles in the function of water availabilities and phosphate fertilization. Means followed by different lowercase letters in the columns and uppercase in the lines indicate difference by the Tukey test ($P > 0.05$). Natural phosphate (NF), Triple superphosphate (TS) and Natural phosphate + Triple superphosphate (NF + TS)

The fresh mass of the tubercles showed a significant difference isolated for phosphate fertilization and water availability. The treatments with water availability of 80% and 120% of the field capacity presented higher mean weight, not differing statistically. Under water deficit (40% of the field capacity), the fresh mass of the tubercles had a yield 55.34% lower than the treatment with the volume indicated for the crop (80% of the field capacity), and the treatment with excess (120% of the field capacity) with 12% gain in fresh weight in relation to this (Figure 2).

The authors [14] in their work with different levels irrigation applied to the radish culture, verified an increase in the diameter of the bulb and the fresh mass of the root with the increase of the slides applied. The result shown in this study, in addition to stating that the water deficit hinders the development of the radish tubercles, pointed out that the excess of water did not impair the accumulation of fresh mass, presenting means similar to the treatment with optimum water availability, as recommended for this vegetable.

The authors [12] worked with different water availability levels and observed that the highest fresh matter production of the root was found when it used up to 80% of the available water in the soil and that the gain in the matter was 129.70% higher treatment in relation to the treatment of 20%. In the same study, they also found better average dry mass for treatment with 80%, which was 166.6% higher than the 20% treatment.

The phosphate sources did not differentiate between them for the fresh mass of the tubercle, but were superior to the absolute control, reinforcing the importance of the phosphorus for the development of the crop (Figure 2). The Triple superphosphate had higher yield between the averages for the fresh mass. The authors [23] also observed higher dry matter production of sorghum roots for treatment with Triple superphosphate without significant difference for Arad Natural phosphate.

For the fresh mass of the tubercles, it is possible to demonstrate based on the experimental results that the natural phosphates have intermediate performance between the control without phosphorus and the soluble phosphates.

The diameter of the tubercles showed no significant difference for phosphate fertilizers and water availabilities. For the length of the tubercles, a significant difference was obtained in isolation only as a function of phosphate fertilizers (Figure 2). The treatment that provided the highest mean length of the tubercles was triple superphosphate (6.26 cm), not differing statistically, by Tukey's test, Natural phosphate, and Triple superphosphate + Natural phosphate.

According to the results of the statistical analysis, it was noted that the phosphorus availability for the plants was not distinguished among the phosphate fertilizers, noting, however, that the mean length of the tubercles submitted to fertilization with triple superphosphate presented an increment of 11.4% in relation to the average of the tubercles that received fertilization with the Natural phosphate, which may indicate that there was release of the nutrient in a faster way.

For the variable related to the Harvest Index (Table 5), there was a significant interaction at 1% of probability between the phosphate fertilization and water availabilities. The highest index (1.51) was obtained with the Natural phosphate associated with 120% of the field capacity, not differing statistically from the rate of 1.3 of the treatment with Triple superphosphate to 120% of the field capacity.

Table 5. Harvest Index, water consumption and efficiency of radish water use as a function of Natural phosphate (NF), Triple superphosphate (TS), Natural phosphate + Triple superphosphate (NF + TS) and control associated with water availabilities.

Field capacity	Phosphorus sources			
	Control	NF	TS	TS+NF
	Harvest Index-CV 40.12%			
40 %	0.33Aa	0.25cA	0.57bA	0.62aA
80 %	0.35aA	0.85bA	0.87baA	0.73aA
120 %	0.29aC	1.51aA	1.3aAB	0.94aB
Field capacity	Control	NF	TS	TS+NF
	Water consumption by plants-CV 5.13%			
40%	377.75cB	365.75cB	762.25cA	558.5cAB
80%	669.5bA	987.25bB	1369bC	1053.75bB
120%	5243.5aC	4875aD	6425.25aA	5695.5aB
Field capacity	Control	NF	TS	TS+NF
	Water use efficiency-CV 28.86%			
40	0.0046aB	0.0429aA	0.0547aA	0.0048aA
80	0.0070aB	0.0408aA	0.0400bA	0.0431aA
120	0.0006aA	0.0093bA	0.0068cA	0.0072bA

Lowercase letters equal to the columns and uppercase in the lines, showed no significant difference by the Tukey test at 5% significance.

The fraction of the culture that is economically valuable is denominated the harvest index, which identifies the ability of a hybrid to combine high total production capacity and to allocate the accumulated dry matter to the commercial part of the plant [25] functioning as a measurement of the transport efficiency of photoassimilates to the tubercle [26].

Higher values observed in a cultivar show higher conversion efficiency of products synthesized in material of economic importance [27]. In the present study, the treatment with use of Natural phosphate as fertilization was highlighted when the field capacity was 120%.

Water consumption (Table 5) showed significant interaction between phosphate fertilization and water availability at 1% significance by the Tukey test. The treatment that presented the highest water consumption (5695.5 L) was the Triple superphosphate associated with 120% of the field capacity, differing from all other treatments due to water availability and phosphate fertilization.

There was a significant interaction between phosphate fertilizers and hydric availabilities for water use efficiency, according to the analysis of variance at 1% significance (Table 5). The treatment that presented a more efficient use of water by plants was Triple superphosphate associated with field capacity of 40%, differing from other water availabilities, 80 and 120% of field capacity, and not differing from other treatments related to phosphorus, including the witness. The efficiency values ranged from 0.0006 to 0.0547 g mL^{-1}, indicating that the fertilization with Triple superphosphate and Natural phosphate did not differ when subjected to the same water availability.

The authors [11] work with the cultivation of radish under different levels irrigation, found higher values on the efficiency of water use, ranging from 1.59 to 7.56 kg m^{-3}, thus needing 132 to 229 liters of water to produce 1 kg of radish.

4. CONCLUSION

There was influence of both water availabilities and phosphate fertilization on the studied variables.

Water deficit (40% of field capacity) had a negative influence on plants development.

In relation to phosphate sources, the use of triple superphosphate was highlighted.

Triple superphosphate associated with 80% of the field capacity allowed the best productivity averages for radish.

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