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Irrigation depth and harvest date in sweet potato for conversion to biofuels

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This study aimed to evaluate the effect of different irrigation depths and harvest dates in sweet potato for conversion to biofuels. Irrigation treatments were 0.25, 0.50, 0.75, and 1.0 of crop evapotranspiration rates and a control treatment (without irrigation). Harvest dates were: 90, 120, 150, 180, and 210 days after planting (DAP). The sweet potato cultivar BRS Cuia (RNC-27.315) was utilized. The experimental design was a randomized block in factorial arrangement (irrigation depths combined with harvest dates) with four replications. Reference crop evaporation was calculated based on the method of FAO Penman-Monteith. Drip irrigation system was used and irrigation frequency was every seven days. The highest and lowest yield were at 90 and 210 DAP, respectively. The lowest yield variation was between 120 and 150 DAP. Control treatment had highest yield in all harvest dates. Efficient water use was greater with irrigation of 0.25 of ETc with 116.9 and 218.8 m^3 ha at 90 and 210 DAP, respectively. Starch content, crude protein, length and diameter of the root, and yield were influenced by different irrigation depths and harvest dates.

Key words: *Ipomoea batatas,* irrigation management, ethanol feedstock, drip irrigation, water deficit, efficient irrigation strategies.

INTRODUCTION

Sweet potato (*Ipomoea batatas*) had an average yield of 9.13 t ha^{-1} in a planted area of 500,350 ha, during 2013 in Brazil. The southern region is the main producer, accounting for 45% of production with 227,354 t. The state of Rio Grande do Sul produced 166,354 t, with an average productivity of 13.42 t ha^{-1}, which represents 73.9% of the southern region and 32.9% of the whole country production (IBGE, 2013). In 2009, world production was 102.7 million t cultivated in an area of 8.0 million ha, which provide an average yield of 12.8 t ha^{-1} (FAO, 2012). China is the largest producer, with a total production of 3.7 million t and an average yield of 23.1 t

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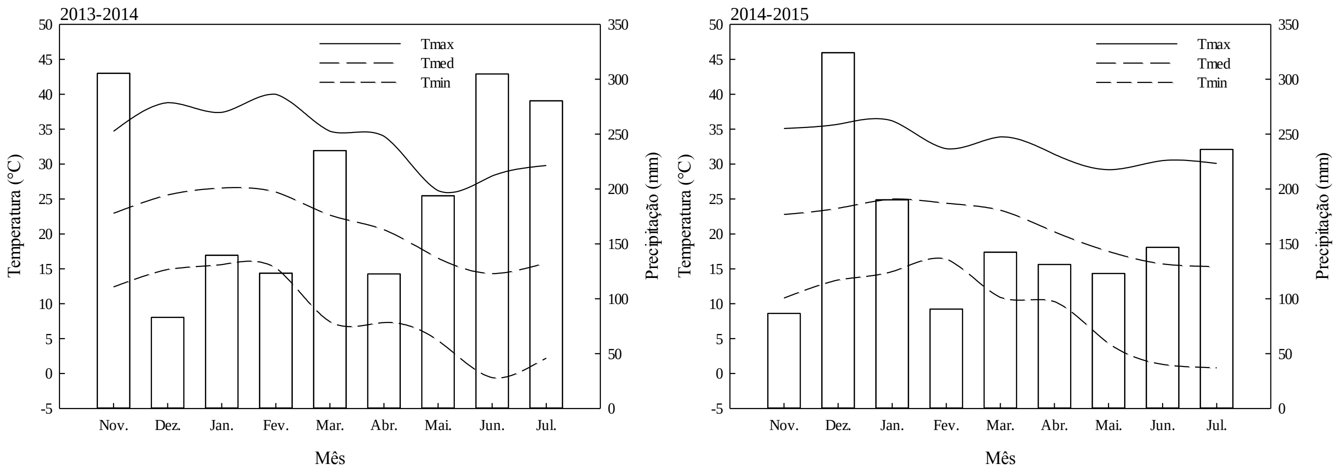

Figure 1. Climograph of experimental area during the 2013-2014 and 2014-2015 periods.

ha^{-1} (FAO, 2010).

Searching for new raw materials produced from biomass for production of clean and renewable fuels has received great attention. The ethanol production has become an international priority, which will redefine a new geopolitical position due to the entry of countries in the biofuel production route (Silveira et al., 2008; Santana et al., 2013). According to Souza (2005), the ethanol production from starch has been studied in countries holding high technology, such as Germany, Belgium, Denmark, United States, Canada, and China. Among other reasons, sweet potato has great biomass yield to obtain ethanol, associated with planting hardiness and two annual harvests. The ethanol derived from sweet potato is very competitive in terms of yields in comparison with sugarcane, with a production of 170 L t^{-1}, compared with only 80 L t^{-1} from the sugarcane ethanol (Silveira, 2008). The crop can be an alternative to the ethanol plants and farmers during the growing season after the sugarcane planting (Pavlak et al., 2011).

The water resources for agriculture are declining and the population continues to grow. Proper management and irrigation water quality have fundamental importance for achieving high yield, quality, cost reduction, and rational water use (Padrón et al., 2015a).

Regarding the need of raw materials diversification for the production of biofuels, sweet potato appears as an alternative for having a high starch production potential. Moreover, this crop can be used in the sugarcane off-season and also in regions where the weather conditions are not adequate for sugarcane planting. In this context, this study aimed to evaluate the effect of different irrigation depths and harvest dates in sweet potato for conversion to biofuels in Santa Maria-RS, Brazil.

MATERIALS AND METHODS

The experiment was carried out in a field at the experimental area of the Polytechnic School of the Federal University of Santa Maria, Rio Grande do Sul (RS), Brazil, located at 29°41'25"S, 53º48'42"W, and altitude of 110 m, during the periods of 2013-2014 and 2014-2015. The predominant soil in the region is Paleudalf and shows a frank texture, according to Soil Taxonomy (USDA, 1999). According to the Köppen-Geiger climate classification, the climate of the region is humid subtropical (Cfa). Rainfall, minimum, average, and maximum temperature are shown in Figure 1. Among 2013-2014 and 2014-2015 periods, the minimum, average, and maximum temperature ranged from 13.8, 16.2, 12.3 and 7.0; 15.6 and 9.6°C, respectively, showing greater variation in the first period. The maximum rainfall obtained in the 2013-2014 period was in June and during 2014-2015 period in January, and the minimum rainfall was in December in both periods.

The experimental design was a randomized block in a factorial design with four replications, where the factors were the irrigation depths and harvest dates. The treatments consisted of applying supplementary irrigation depths: 0.25, 0.50, 0.75, and 1.0 of reference evapotranspiration and a control treatment (without irrigation). The harvest dates were: 90, 120, 150, 180, and 210 Days after Planting (DAP). The experimental unit consisted of 20 m^2 (4x5 m), and 400 m^2 of total experimental area, without plants on the border. The sweet potato cultivar used was BRS Cuia variety (RNC-27,315), which is commonly utilized in the region and launched by EMBRAPA in 2011 as a variety developed for the State of Rio Grande do Sul (Castro et al., 2011). Planting was carried out in December 2013 and November 2014, with spacing of 1 m between rows and 0.4 m between plants, totaling 1,000 plants and plant density of 2.5 m^{-2}.

Localized drip irrigation was used with spacing of 0.20 m between drippers and flow of 0.8 L h^{-1}. One spherical gate to regulate the irrigation times and one pressure control valve to obtain regular pressure were installed in each experimental unit. The irrigation strategy consisted of keeping soil moisture at field capacity from planting to 20 DAP, ensuring the establishment of seedlings. Irrigation treatments were applied after the initial phenological stage (20 DAP) with irrigation frequency of every seven days and irrigation continued until 90 DAP.

The reference evapotranspiration (ETo) was calculated based on the methodology of Penman-Monteith/FAO (Equation 1), and the crop evapotranspiration (ETc) at a standard condition was based on Equation 2 (Allen et al., 2006). Climate data were obtained from the weather station of the Federal University of Santa Maria, linked to the National Institute of Meteorology, localized approximately 2000 m from the experimental area. Rainfall (mm), maximum and

Table 1. Soil attributes of the experimental area.

Soil layers (m)	pH water	Ca	Mg	Al	(H+Al)	CEC efet.	Saturation (%) Al	Saturation (%) Base	Index SMP	OM (%)	S	P-Mehlich
		$cmol_c\ dm^{-3}$									$mg\ dm^{-3}$	
0-0.2	5.8	9.7	3.5	0.2	3.9	13.8	1.6	76.1	6.2	3.3	11.0	14.2
0.2-0.3	5.2	8.5	2.4	0.8	6.6	12.0	7.9	63.4	5.8	2.5	7.1	11.5

	Bulk density (g cm^{-3})	Field capacity ($m^3\ m^{-3}$)	Infiltration (mm h^{-1})	Texture
0-0.2	1.42	0.31	15.0	Loam
0.2-0.3	1.38	0.34		Clay-loam

Table 2. Evapotranspiration, irrigation depth, and number of irrigations in the experimental periods.

Treatment	ETc (mm) 90 DAP	ETc (mm) 120 DAP	ETc (mm) 150 DAP	ETc (mm) 180 DAP	ETc (mm) 210 DAP	Irrigation depth (mm)	Number of irrigations (days)
Period 2013-2014							
$T_{0.25}$	107.1	129.4	140.6	147.4	154.4	83.9	14
$T_{0.50}$	214.3	258.9	281.2	294.8	308.9	167.9	
$T_{0.75}$	321.4	388.3	421.8	442.2	463.3	251.8	
$T_{1.0}$	428.5	517.7	562.4	589.6	617.8	335.7	
Period 2014-2015							
$T_{0.25}$	99.0	127.8	144.9	156.8	164.5	68.3	16
$T_{0.50}$	198.0	255.5	289.8	313.6	328.9	136.6	
$T_{0.75}$	297.0	383.3	434.6	470.4	493.4	204.8	
$T_{1.0}$	396.0	511.0	579.5	627.2	657.9	273.1	

minimum temperature (ºC), maximum and minimum relative air humidity (%), insolation (hours), and wind speed (m s^{-1}) were collected daily.

$$\mathrm{ETo} = \frac{0.408\,\Delta\,(Rn - G) + \gamma\,\frac{900}{T + 273}\,U_2.(e_s - e_a)}{\Delta + \gamma\,(1 + 0.34\,U_2)} \quad (1)$$

$$\mathrm{ETc} = \mathrm{kc} \times \mathrm{ETo} \quad (2)$$

Where ETo is the reference evapotranspiration (mm day^{-1}), Rn is net radiation value at crop surface (MJ m^{-2} day^{-1}), G is soil heat flux density (MJ m^{-2} day^{-1}), and T is daily mean air temperature at 2 m height (°C). Also, U_2 , es, ea, Δ, and γ represent wind speed at two meters height (m s^{-1}), saturation vapor pressure (kPa), actual vapor pressure (kPa), slope of the saturation vapor pressure curve (kPa $°C^{-1}$), and psychrometric constant (kPa $°C^{-1}$), respectively. Conversion factor for the term (Rn-G) of (MJ m^{-2} dia^{-1}) to (mm dia^{-1}) was 0.408. Moreover, ETc stands for crop evapotranspiration (mm) and kc is the single crop coefficient. The chemical analysis of soil was determined in soil laboratory of Rural Science Center (UFSM). Bulk density, field capacity and infiltration test were performed in field as reported in (Padrón et al., 2015b) (Table 1).

Root mass yield was evaluated in ten plants per plot in each harvest. Also, the length and diameter of the root were evaluated in each harvest, using digital caliper. For root development comparison in each crop, the roots were ranked in commercial production (200 g to 500 g) and industrial production (less than 200 g and greater than 500 g). The chemical analysis of the root: starch and protein, content were evaluated in three plants in each harvest, obtaining a composed sample. The samples were evaluated in the Pisciculture Laboratory of UFSM, using the method of AOAC 996.11 adapted by (Walter et al., 2005). Furthermore, the Water productivity (WP), with total yield (kg ha^{-1}) divided by evapotranspiration (mm) (Equation 3) and irrigation water productivity (IWP), with the fresh total yield (kg ha-1) divided by total irrigation water applied (Equation 4) (Padrón et al., 2015c).

$$\mathrm{WP} = \frac{\text{Total yield (kg ha}^{-1}\text{)}}{\text{Evapotranspiration (mm)}} \quad (3)$$

IWP = Total yield (kg ha-1) / Irrigation water applied (mm) (4)

The main tasks of agronomic management were: applied 3.5 t ha^{-1} of dolomitic lime to correct pH, distributed to haul and embedded with grid, fertilization (47.5 kg ha^{-1} of urea, 225 kg ha^{-1} of triple superphosphate 42% P, and 262.5 kg ha^{-1} of potassium chloride), these applications were in accordance with the chemical analysis of soil. Also was performed, weed control, and spraying of insecticide and fungicide. Statistical analysis was performed using SPSS® software, version 20. Comparison of means was performed by Tukey test at 5% probability. Data were clustered if not presented interactions among the years.

RESULTS AND DISCUSSION

The evapotranspiration, number of irrigations, and applied irrigation for the periods of the experiment are presented in Table 2. Comparing the periods of trials, the

Table 3. Accumulated rainfall (mm) in the experimental period.

Period	Days after planting				
	90	120	150	180	210
2013-2014	302.8	582.2	696.6	866.2	1,234.0
2014-2015	565.8	681.0	862.6	930.4	1,057.8

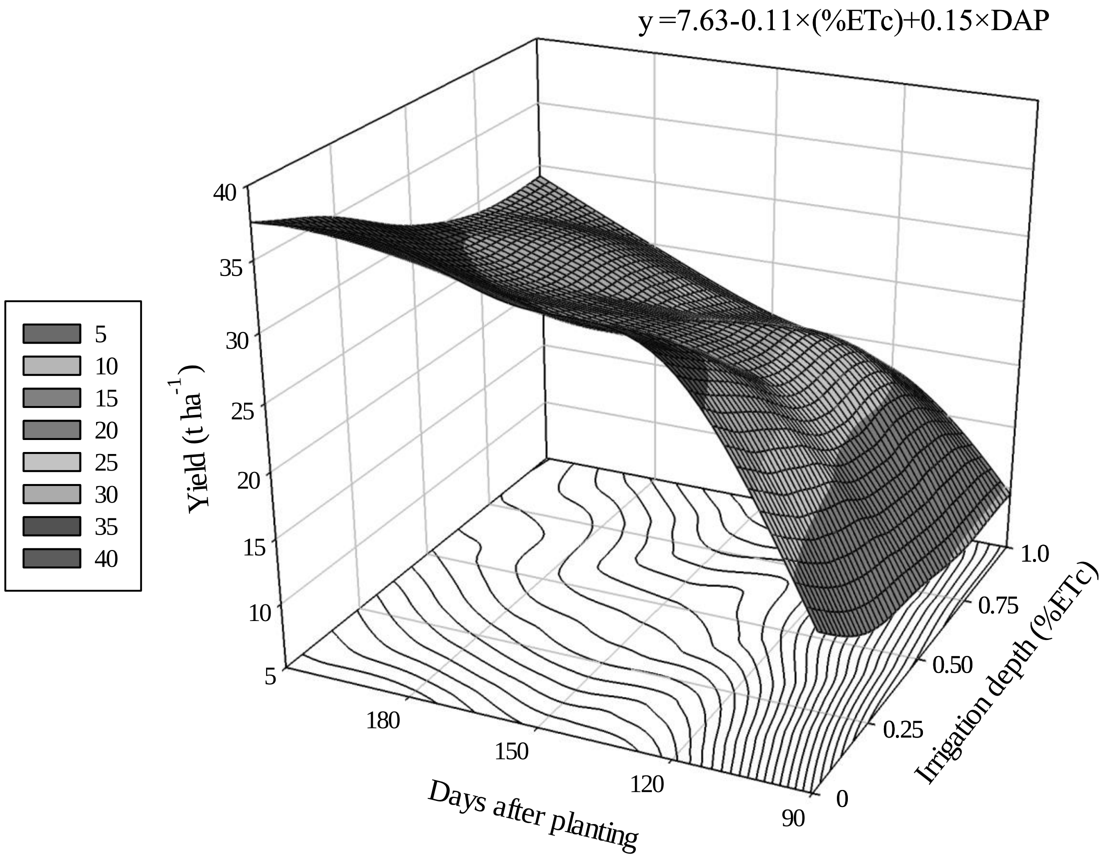

Figure 2. Yield response surface of sweet potato according to the harvest dates and irrigation depths.

difference of irrigation depth of 100% ETc was 62.6 mm and 2 days in the number of irrigations. The period of 2013-2014 showed a lower number of irrigation days but greater irrigation depth applied compared to the 2014-2015 period. It can be inferred that this difference occurred due to weather conditions, temperature, and rainfall. The maximum cumulative evapotranspiration was higher in the 2014-2015 period, showing a difference of 40.1 mm, being different in the first two harvests at 90 and 120 days after planting (DAP). Nogueira et al. (2015) determined the evapotranspiration and irrigation depth for sweet potato with 125 DAP in locality of Santa Maria-RS during a period of 20 years, obtaining an average of 562.2 mm and 266.6 mm, respectively.

The accumulated rainfall at each harvest date are shown in Table 3. The greater cumulative rainfall was in the 2013-2014 period. The greater variation was from 180 to 210 DAP, with 367.8 mm and between 90 and 120 DAP, with 279.4 mm. The 2014-2015 period the greater variation was of 127.4 mm from 180 to 210 DAP and between 90 and 120 DAP, with 115.2 mm.

Yield in terms of harvest dates and irrigation depths are shown in Figure 2. Statistical analysis showed interaction among irrigation depths and harvest dates. The lowest yield was at 90 DAP and showed a statistically significant difference at the level of 5% probability between treatments. The yield increased during the period of 90 to 210 DAP in 21, 23, 20, 20, and 20 t ha^{-1}; from 120 to 210 DAP in 5, 7, 8, 6, and 11 t ha^{-1}; from 150 to 210 DAP in 3, 5, 4, 5, and 8 t ha^{-1} at T_0, $T_{0.25}$, $T_{0.50}$, $T_{0.75}$, and $T_{1.0}$, respectively, with the greater variation during the periods described in $T_{0.25}$, $T_{1.0}$ e $T_{1.0}$, respectively. The 210 DAP

Table 4. Water productivity and irrigation water productivity of sweet potato as a function of the harvest dates and irrigation depths.

Treatment	Water productivity(*) and irrigation water productivity (kg m^{-3})				
	Days after planting				
	90	120	150	180	210
T_0(*)	40.6	63.0	61.0	61.8	58.9
$T_{0.25}$	116.9	218.7	210.0	209.3	218.8
$T_{0.50}$	52.5	92.0	95.4	93.3	97.9
$T_{0.75}$	30.9	59.7	55.9	60.8	61.0
$T_{1.0}$	22.9	35.2	36.5	40.7	45.7

period showed greater yield, even when the period of 120 to 150 DAP was the period which demonstrated the lowest variation in reference to 210 DAP. It can be inferred that for this variety and these study conditions, the optimal harvest date was between 120 and 150 DAP, agreeing with Castro et al. (2011), which commented that the harvest period for variety BRS Cuia is between 120 and 140 DAP, with planting from August for this region.

In all harvests, the highest yield was at T_0 and the smallest in $T_{1.0}$. With this climatic conditions and soil characteristics (moisture retention and texture), irrigation influenced the crop yield during the study period. However, irrigation is necessary in prolonged periods of dry weather. Also, greater vegetative development was observed in treatments under irrigation in comparison to T_0. In the study area, Erpen et al. (2013) used the sweet potato variety Princess and recommended supplementary irrigation only after long periods without rainfall of 10 to 15 days. Mantovani et al. (2013) studied different water depths (50, 75, 100, and 125% of ETc) in two fresh potato cultivars (Amanda and Duda) and they concluded that increasing water depth resulted in increased yield of tuberous roots of both cultivars. However, this increase was not linear, reaching a maximum yield of 49.8 t ha^{-1} with application of 325.5 mm for Amanda cultivar and 67.1 t ha^{-1} with the application of 347.0 mm for Duda. Moreover, the maximum efficiency in the water use for sweet potato cultivars was reported as 237 and 146 m^3 ha^{-1}, for Amanda and Duda, respectively. Also, Júnior et al. (2009) studied the same sweet potato cultivars (Amanda and Duda) in rainfed condition and they found productivities ranging from 22.0 to 45.4 t ha^{-1}. Cardoso et al. (2005) evaluated traits of tuberous roots of 16 sweet potato clones and they observed maximum yield of 28.5 t ha^{-1}, fresh matter of 14.1 t ha^{-1}, and commercial root yield of 21.3 t ha^{-1}. Queiroga et al. (2007) assessed the physiology and production of sweet potato cultivars in function of harvest date and they obtained the highest total yield values (20.7 t ha^{-1}) and commercial roots (17.7 t ha^{-1}) at 155 DAP. Miranda (2006) evaluated sweet potato clones and obtained root yield of 25 t ha^{-1} with the Brazlândia Roxa cultivar and 33 t ha^{-1} with the Brazlândia Rosada cultivar at 150 DAP. In Porteirinha-MG, Resende (1999) assessed eight sweet potato cultivars and recorded average commercial roots yield of 17.5 and 10.8 t ha^{-1} in conditions of supplementary irrigation and rainfed, respectively. Also, in the northern region of Minas Gerais, Resende (1999) studied sweet potato cultivars under irrigated conditions and rainfed. The Brazlândia Branca cultivar stood out for its commercial yield (22.3 t ha^{-1}), followed by the cultivars Paulistinha (21.3 t ha^{-1}) and Princesa (19.0 t ha^{-1}), which showed no significant differences among themselves. Moreover, the lowest yield was obtained by the cultivar Brazlândia Roxa (13.5 t ha^{-1}), which showed no significant differences with the cultivars Coquinho, Rama Roxa, Arroba, and Brazlândia Rosada. Probably, the low yield occurred in the period of 150 DAP because it is considered insufficient for its full vegetative growth, resulting in greater-yielding of scrap roots (7.2 t ha^{-1}), and roots with weight below 80 g. Peixoto et al. (1989) found that the Brazlândia Roxa was the later cultivar and it showed the highest yield of scrap when harvested at 152 days. Regarding to rainfed experiment, there was a commercial yield ranging from 8.2 to 17.6 t ha^{-1}. Moreover, Thompson, Smittle and Hall (1992) comment that marketable yields increased with applied irrigation amounts until a total water application of 76% of pan evaporation was reached and then decreased rapidly with applied irrigation amounts. Weight loss and decay of roots during storage showed quadratic responses to irrigation amounts and were minimal at the irrigation level of maximum yields.

Water productivity (WP) and irrigation water productivity (IWP) depending on the harvest dates and irrigation depths is shown in Table 4. The WP decreased as water depth increased from $T_{0.25}$ to $T_{1.0}$. The WP was higher in $T_{0.25}$ due to the yield increase and it showed the highest values between 120 and 150 DAP, agreeing with the optimal harvest period. The difference in WP of 150-210 DAP, ranged from 4.3 to 20%, in $T_{0.25}$ and T_{100}, respectively. WP at T_0 was similar to $T_{0.75}$ due to the increase in yield in T_0 and the decrease in $T_{0.75}$. Mantovani et al. (2013) studied different irrigation depths and efficient water use in two sweet potato cultivars and they claimed that the increase in the applied water depth resulted in increased water use efficiency up to a maximum of 16.1 kg m^{-3}, with the application of 301.8 mm for the Amanda cultivar and 20.0 kg m^{-3}, with the application of 332.4 mm for Duda cultivar. Therefore, these values represent the depth of maximum water use by the studied sweet potato cultivars.

The root diameter and length of sweet potato as a function of the harvest dates and irrigation depths are shown in Figure 3. The largest diameters were found at 90, 120, and 210 DAP in T_0 and the lowest diameter was found at 90 DAP in $T_{0.5}$. The largest length was at 210 DAP in $T_{0.5}$. Regarding the values, the lower length values were observed in the roots with greater diameter values. Moreira et al. (2011) studied morphophysiological and productive traits of eight sweet potato cultivars. They

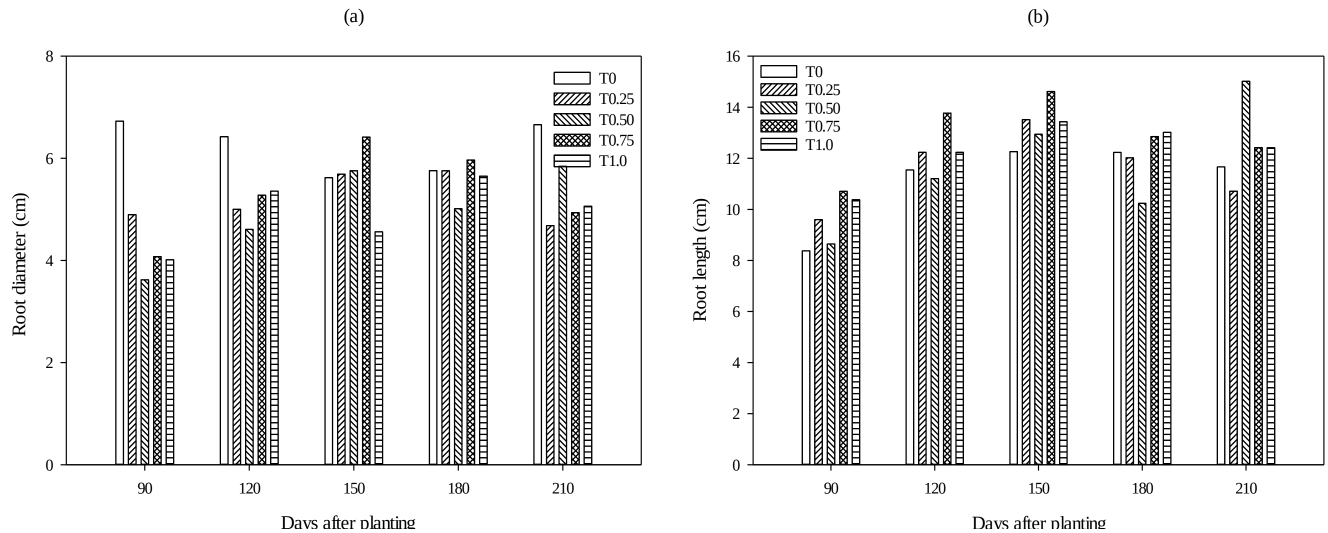

Figure 3. (a) The diameter and (b) length of sweet potato root according to harvest dates and irrigation depths.

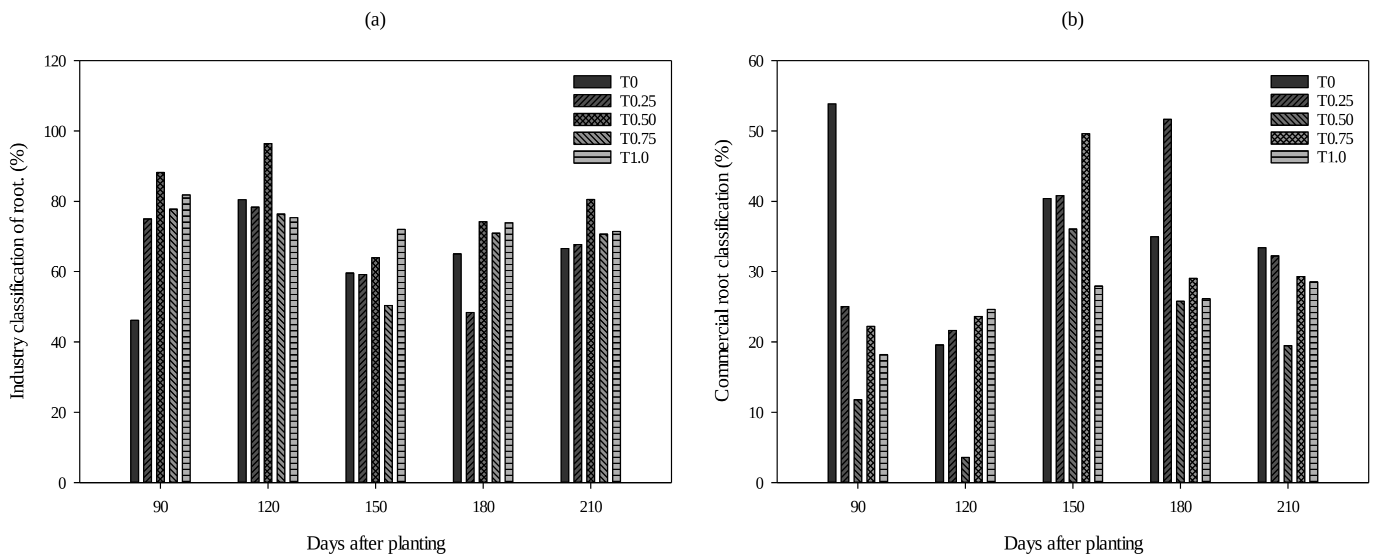

Figure 4. Classification of (a) industrial and (b) commercial roots of sweet potato according to harvest dates and irrigation depths.

observed that Paraná and Coquinho cultivars obtained the lowest length values, with 8.5 and 8.3 cm, respectively, and with the largest diameter values (5.7 cm in both cultivars). Meantime, the roots of ESAM 2 cultivar, which is included in the group of the longest roots (12.3 to 12.1 cm), were thinner (4.4 cm). Cardoso et al. (2005) evaluated 16 sweet potato clones and also evidenced this behavior and this clones had a mean length value of the roots of 13.9 cm.

The sweet potato root classification according to harvest dates and irrigation depths is shown in Figure 4. In this research, only two classifications (Industrial and Commercial) were done because the ethanol industry processes any type of classification. At all harvest dates and irrigation depths, industrial production exceeded the commercial one. Resende (2000) reported the harvest date influence on sweet potato cultivars under rainfed conditions performing harvests at 150 and 200 DAP. The authors assessed the following traits: commercial yield (roots weighing 100 to 800 g), scrap (roots below 100 g, cracked, deformed, greenish, brocade, and with veins), medium weight of commercial root, and commercial roots classification in percentage (Type 1- roots weighing 100 to 400 g and Type 2- roots weighing 400 to 800 g). Silva and Lopes (1995) verified that the harvest date did not change the commercial roots weight. However, they

Table 5. Total starch and crude protein (CP) in dry matter of sweet potato according to harvest dates and irrigation depths.

Treatment	Days after planting									
	90		120		150		180		210	
	Starch	CP	Starch	PB	Starch	PB	Starch	PB	Starch	PB
T_0	65.8	2.9	67.1	3.3	71.7	3.6	52.3	3.1	54.6	3.5
$T_{0.25}$	68.1	3.7	69.2	3.8	73.8	3.7	58.6	3.8	66.5	4.4
$T_{0.50}$	66.4	3.4	67.9	3.5	72.1	3.4	64.0	3.5	60.1	3.5
$T_{0.75}$	62.6	4.8	63.6	4.9	67.4	5.5	67.9	4.3	59.8	3.9
$T_{1.0}$	69.9	3.7	70.5	3.9	74.9	4.7	63.4	3.1	60.1	4.2

observed significant effect among cultivars, wherein the ESAM 3 had 257.0 g per commercial root, higher than the roots weight of the other cultivars and it was classified as Extra A, having possibly better commercial acceptance. Silva et al. (2015) studied the sweet potato cultivars performance for traits related to the root yield. In 2012, the authors observed that Beauregard cultivar stood out for the number and weight of roots. However, this cultivar did not show the greater values for average commercial roots weight that year, averaging 390 g. Good performance for these traits was repeated in 2013, along with the BRS Rubissol cultivar. The average commercial roots weight, the average value presented by the cultivars was 470 g in 2012, and 440 g in 2013. Those values were slightly above the ideal commercial size, which is 200 to 400 g (Miranda, 1989). Thus, the harvest date can be advanced for these cultivars, although the optimal size may vary depending on market requirements (Queiroga et al., 2007).

The total starch and crude protein in dry matter in function of harvest dates and irrigation depths are shown in Table 5. Starch content and crude protein were influenced by harvest dates and irrigation depths. In all treatments, starch content and crude protein were increased up to 150 DAP, showing the highest concentration at this date. Thereafter, they began to decline, where the starch content obtained lower values at 90 DAP. The irrigation depth influenced the starch content and crude protein, with the highest and lowest values of starch content in $T_{1.0}$ (150 DAP) and T_0 (210 DAP) and crude protein in $T_{0.75}$ (150 DAP) and T_0 (90 DAP), respectively. Tubers presented starch granules and variable amounts of sugar, depending on environmental conditions, harvest dates, and variety.

As stated in Braun et al. (2010), starch corresponds from 60 to 80% of dry matter and sugars: glucose, fructose, and sucrose are the major carbohydrates present in the tubers. As reported by Silveira (2008), the conversion into ethanol takes around 160 L t^{-1} for sweet potato clone samples with an average yield of 65.5 t ha^{-1} and average starch concentration of 24.4% in natural weight (NW). Starch content in plant roots may fluctuate depending on the fertilization. Therefore, the study and knowledge of the influence of this factor in the accumulation of starch content in plant roots will provide quality and yield improvements (Malavolta, 2006). Júnior et al. (2012) in the study of productive and qualitative characteristics of vines and roots of sweet potato, the crude protein contents in the roots of the evaluated genotypes were similar among themselves and ranged from 3.9 to 4.6% and they were also similar to the results found by Leonel et al. (1998), which reported crude protein content of 4.6% and higher than those found by Batistuti et al. (1992), of 1.1 to 1.7%, analyzing eight sweet potato cultivars. Lázari (2011) evaluated agronomic and physicochemical traits of 100 industrial sweet potato accesses of the breeding program in laboratory. They used fermenting measurer and obtained average ethanol yields of 151.67 and 234.33 L t^{-1} of root. Moreover, Thompson et al. (1992) comment that the glucose content was maximum at a total water amount of 94% of pan evaporation and fructose content decreased with increased amounts of irrigation.

Conclusions

Sweet potato was influenced by different applied irrigation depths and harvest dates, with an increase in starch content and a decrease in yield. The best harvest date was among 120 to 150 days after planting, where the variety demonstrated the highest yield potential in all evaluated variables. The most efficient water productivity was in the treatment 0.25 of evapotranspiration. In the studied conditions, sweet potato did not require irrigation with the established strategy, but more research is necessary on other frequencies and irrigation strategies. Due to the hardiness of the crop, low cost management, short cycle, and good starch production, sweet potato demonstrates feasibility for conversion to biofuels, being an alternative to the diversification of energy sources.

Conflict of Interests

The authors have not declared any conflict of interests.

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