ISSN 1808-8546 (ONLINE) 1808-3765 (CD-ROM)

CRESCIMENTO, PRODUÇÃO E QUALIDADE DE PLÁTANO SOB DIFERENTES DENSIDADES, ADUBAÇÃO E LÂMINAS DE ÁGUA

LENILSON WISNER FERREIRA LIMA[1]; EUGÊNIO FERREIRA COELHO[2]; ANA LUCIA BORGES[3]; BRUNO LAECIO DA SILVA PEREIRA[4]; DAMIANA LIMA BARROS[5] E JOSÉ CARLOS LOPES DE LIMA[6]

[1] Irrigação e Fertirrigação, Embrapa Mandioca e Fruticultura. Rua Embrapa S/N - Cx. Postal 007, Chapadinha, 44380-000, Cruz das Almas, BA, Brasil. E-mail: lenilsonlimaagro@gmail.com, Orcid: https://orcid.org/0000-0002-3073-0501;
[2] Irrigação e Fertirrigação, Embrapa Mandioca e Fruticultura. Rua Embrapa S/N - Cx. Postal 007, Chapadinha, 44380-000, Cruz das Almas, BA, Brasil. E-mail: eugenio.coelho@embrapa.br, Orcid: https://orcid.org/0000-0001-7079-6858;
[3] Solos e Nutrição de Plantas, Embrapa Mandioca e Fruticultura. Rua Embrapa S/N - Cx. Postal 007, Chapadinha, 44380-000, Cruz das Almas, BA, Brasil. E-mail: ana.borges@embrapa.br, Orcid: https://orcid.org/0000-0001-6993-7115;
[4] CCAAB, Universidade Federal do Recôncavo da Bahia, Rua Rui Barbosa, 710, Centro, 44380-000, Cruz das Almas, BA, Brasil. E-mail: brunolaecio_3@hotmail.com, Orcid: https://orcid.org/0000-0001-5784-5512;
[5] Irrigação e Fertirrigação, Embrapa Mandioca e Fruticultura. Rua Embrapa S/N - Cx. Postal 007, Chapadinha, 44380-000, Cruz das Almas, BA, Brasil. E-mail: damibarros@hotmail.com, Orcid: https://orcid.org/0000-0002-5134-567X;
[6] PPGEA, Universidade Federal do Recôncavo da Bahia, Rua Rui Barbosa, 710, Centro, 44380-000, Cruz das Almas, BA, Brasil. E-mail: josecarlosdude@hotmail.com, Orcid: https://orcid.org/0009-0000-0727-8353.

1 RESUMO

O cultivo de plátanos tem grande importância para a segurança alimentar mundial necessitando, assim, de informações sobre o uso de estratégias que permitam aumentar a sua produtividade. O objetivo deste trabalho foi avaliar o crescimento, produção, qualidade físico-química dos frutos e a produtividade da água do plátano, cv. D'Angola, cultivado em diferentes níveis de adubação, lâminas de água e densidade de plantas. Adotou-se o delineamento experimental em blocos casualizados, esquema de parcelas subsubdivididas, sendo três níveis de adubação (1,0; 1,25 e 1,5 da dose recomendada), duas lâminas de irrigação (60 e 100 % da evapotranspiração da cultura) e duas densidades de plantas (1.600 e 3.200 plantas ha^{-1}). A produtividade da água para a densidade de plantio de 3.200 plantas ha^{-1} superou em 69,87 % a PA para a densidade de 1.600 plantas ha^{-1}. Em termos de qualidade de fruto a menor densidade (1600 plantas ha^{-1}) apresentou-se com maiores valores das variáveis. O aumento na densidade de plantio de 1600 para 3200 plantas ha^{-1} promoveu acréscimo no ciclo produtivo, aumentando a produtividade de pencas na ordem de 69 %, o que é equivale a um incremento de 11 t ha^{-1}.

Palavras-chave: *Musa* spp., densidade de plantio, produtividade da água, produtividade.

LIMA, L. W. F.; COELHO, E. F.; BORGES, A. L.; PEREIRA, B. L. da S.; BARROS, D. L.; LIMA, J. C. L. de
GROWTH, PRODUCTION AND QUALITY OF PLANTAIN UNDER DIFFERENT DENSITIES, FERTILIZATION AND WATER LEVELS

Recebido em 20/04/2022 e aprovado para publicação em 09/10/2023
DOI: http://dx.doi.org/10.15809/irriga.2023v28n4p775-790

2 ABSTRACT

The cultivation of plantain is highly important for global food security; thus, information on the use of strategies to increase productivity is needed. The objective of this work was to evaluate the growth, production, physical-chemical quality of the fruits and water productivity of plantain, cv. D'Angola, cultivated with different fertilizer levels, water depths and plant densities. The experimental design was adopted in randomized blocks, with a subsubdivided plot scheme, with three levels of fertilizer (1.0, 1.25 and 1.5 of the recommended dose), two irrigation levels (60 and 100% of the crop evapotranspiration) and two plant densities (1,600 and 3,200 plants ha $^{-1}$). The water productivity at a planting density of 3,200 plants ha $^{-1}$ exceeded the PA at a density of 1,600 plants ha $^{-1}$ by 69.87%. In terms of fruit quality, the lowest density (1600 plants ha $^{-1}$) presented the highest values of the variables. The increase in planting density from 1600 to 3200 plants ha $^{-1}$ promoted an increase in the production cycle, increasing bunch productivity by approximately 69%, which is equivalent to an increase of 11 t ha $^{-1}$.

keyword: *Musa spp.*, planting density, water use efficiency, productivity.

3 INTRODUCTION

The African continent is the world's leading producer of plantains. Among the countries, Uganda stands out with a plantain production of 10,440,849.48 t, followed by the Democratic Republic of the Congo with 4,887,511.00 t and Ghana with 4,819,198.63 t (FAO, 2022). Brazil is the fifth largest banana-producing country in the world; however, this classification is generally used for all banana cultivars and varieties, including plantains (FAO, 2022).

Plantains (*Musa* spp., AAB) are herbaceous plants belonging to the Musaceae family that have large fruits with prominent corners and high starch contents (Soto, 2011). They are highly important for human food security. There is little information about plantain cultivation, especially in Brazil, and the use of technologies has been extrapolated from other varieties (Faria *et al*., 2010; Moura *et al*., 2002). This may be a limiting factor in obtaining better crop production rates and/or increasing the waste of inputs, especially water and fertilizers.

Evaluation work on bananas is rare, mainly due to the scarcity of varieties that allow for more than one potentially productive cycle. In other words, in the case of other banana trees, the evaluation of varieties is carried out for at least two cycles. In the case of bananas, the evaluation can be carried out in a single cycle since many genotypes are currently cultivated as annual crops (Arantes; Donato; Silva, 2010). Thus, the generation of knowledge that has local validity and verification, aimed at obtaining technological improvements for each cultivation situation, becomes essential (Costa *et al*., 2012).

Phytosanitary strategies such as increasing the density of fruit tree planting have become a global trend since this practice promotes better use of soil, labor and inputs, in addition to increasing productivity. However, appropriate use of technologies, such as fertigation, phytosanitary management and crop management, is necessary (Biswas; Kumar, 2010). However, plant responses to increased plant density are site-specific and related to interactions among the soil, water, genotype and environment.

Studies on the combination of technologies with high plant population densities are necessary for cultivated bananas (Santos *et al*., 2019). This is because increasing the planting density reduces excess solar radiation; reduces the emergence of weeds, which reduces the use of herbicides; helps cool plants; reduces water evaporation from the soil; and improves the growth, development and productivity of banana plants (Donato *et al*., 2013). This strategy of increasing plant density in the case of plantain crops seeks to overcome the problems associated with the high incidence of borers, which limits these plantations to a single cycle of potential productivity. In other words, increasing the number of plants per clump can be equivalent, in terms of production potential, to more than one cycle in the same year.

However, high plant densities can increase the time elapsed for flowering and harvesting (Magalhães *et al*., 2020; Santos *et al*., 2019). Athani, Revanappa and Dharmatti (2009) concluded that increasing the number of plants per unit area affects the production per plant and the percentage of plants harvested, which influences growth factors and total productivity. Therefore, the best planting density should be adjusted considering the characteristics of the cultivar, the type of soil, the climatological factors of the region, crop management, and the associations between technologies that increase productivity and water use efficiency.

Water use efficiency can be defined as the ratio between commercial yield and the water effectively used by the crop as evapotranspiration (Jensen, 2007) and is essential for crops in regions with scarce water resources. Simsek *et al*. (2005) and Zhang *et al*. (2004) calculated water use efficiency by the ratio between commercial yield and crop evapotranspiration, whereas Aujla, Thind and Butar (2005) used a ratio between yield and the total amount of water received by the plants (irrigation + precipitation).

Water use efficiency can be increased by reducing irrigation depth, which can save water and increase profits without decreasing yield (Melo *et al*., 2010; Oliveira; Coelho Filho; Coelho, 2013; Teixeira; Quaggio; Mellis, 2011). The effects of planting density and irrigation depth were evaluated in the first and second production cycles of 'Prata Anã' banana and in the first production cycle of 'BRS Platina' banana by Magalhães *et al*. (2020) and Santos *et al*. (2019), respectively. These factors are usually analyzed in the first two cycles of banana cultivation, since as a plant increases in size, positive responses are not expected with increasing planting density in successive cycles. Water use efficiency increases with decreasing gross irrigation depth to be applied or with increasing crop productivity (Coelho *et al*., 2013a), which can be achieved by increasing plant density.

In this sense, this work aimed to evaluate the growth, production, physical-chemical quality of fruits and water productivity of banana cv. D'Angola subjected to different plant densities, fertilization rates and water depths.

4 MATERIALS AND METHODS

The study was conducted from June 2013 to November 2014 in the experimental area of Embrapa Cassava and Fruits, located in the municipality of Cruz das Almas, Bahia, Brazil, at an altitude of 220 m, with geographic coordinates of 12°40'19” south latitude and 39°06'22” west longitude of Greenwich. The climate of the region is classified as humid to subhumid, with an average annual rainfall of 1200 mm, an average monthly temperature of 24°C and an average annual relative humidity of 80% (Souza; Souza, 2001). Soil samples were collected at depths of 0 to 0.20 m, 0.20 to 0.40 m and 0.40 to 0.60 m and sent to the Soil Physics Laboratory and the Soil and Plant Nutrition Laboratory, both at Embrapa Cassava and Fruit Growing, Cruz das Almas, Bahia, for chemical and physical–hydric analyses of the soil, the results of which are shown in Tables 1, 2 and 3.

Table 1. Physical attributes of the soil in the experimental area.

Layer	d_s	Texture			Porosity		Textural class
		Sand	Silt	Clay	Macro	Micro	
m	g cm $^{-3}$	—— g kg $^{-1}$ ——			—— % ——		
0 - 0.20	1.43	766.0	61.0	173.0	15.53	15.09	Sandy Loam
0.20 - 0.40	1.53	699.0	47.0	254.0	10.95	17.79	Sandy Clay Loam
0.40 - 0.60	1.34	547.0	81.0	372.0	13.45	19.79	Sandy Clay

d_s - soil density. Source: Author (2024).

Table 2. Volumetric moisture in equilibrium with the soil matric potential of the experimental area.

Depth (m)	Voltage (kPa)					Water available (m^3 m-3)
	-10	-33	-100	-300	-1500	
0 - 0.20	0.1406	0.1167	0.1083	0.1032	0.0930	0.0478
0.20 - 0.40	0.1801	0.1571	0.1473	0.1365	0.1328	0.0472
0.40 - 0.60	0.1947	0.1691	0.1595	0.1491	0.1478	0.0469

Font and Author (2024).

Table 3. Chemical attributes of the soil before implementation of the experiment.

	pH in water	P [/2]	K [/2]	Ca [/3]	Mg [/3]	Al [/3]	In [/2]	V	MO [/4]
Prof. (m)	-	mg dm $^{-3}$	.................cmol $_c$ dm $^{-3}$				....	%	g kg $^{-1}$
0 - 0.20	8.1	53	0.37	2.4	1.6	0	0.26	100	11.75
0.20 - 0.40	7.3	41	0.45	1.7	1,2	0	0.14	100	7.96

[2] Mehlich-1 extractor; [3] KCl/1 M extractor; [4] Modified Walkley & Black.
Font and Author (2024).

The irrigation water came from a reservoir located near the experimental area, whose physical–chemical analysis revealed the following results: electrical conductivity (EC) = 650 dS m $^{-1}$; hydrogen potential (pH) = 7.6; sodium adsorption ratio (SAR) = 3.6; and irrigation water classification (USSL) = C2S1.

Micropropagated seedlings of the D'Angola plane tree, genomic group AAB, and Terra subgroup (*Musa Acuminata* x *Musa balbisiana*) were used. The spacing used was 2.5 m between plants and 2.5 m between rows of plants. During planting, holes 0.40 m long × 0.40 m wide × 0.40 m deep were dug. The foundation fertilization consisted of 100 g of the micronutrient mixture in the form of oxysilicates (FTE BR 12) and 12 L of cured cattle manure per clump. Before the flowering of the plants, a new application of 12 L of cured cattle manure was made. Phosphorus (P_2O_5) was applied to the hole before transplanting, in the form of simple superphosphate, at a dose of 165 g per clump.

Topdressing fertilization was performed weekly via fertigation with the aid of an injection pump, with urea used as the nitrogen source and potassium chloride used as the potassium source. The amounts of nitrogen (N) and potassium applied to the banana cv. D'Angola were 1.0, 1.25 and 1.5 of the recommended dose; for nitrogen, 200, 250 and 300 kg ha $^{-1}$ year $^{-1}$ and potassium

300, 375 and 450 kg ha $^{-1}$ year $^{-1}$, respectively; therefore, the fertilization level was 1 - 200 kg ha $^{-1}$ year $^{-1}$ of N and 300 kg ha $^{-1}$ year $^{-1}$ of K_2O; the fertilization level was 2 - 250 kg ha $^{-1}$ year $^{-1}$ of N and 375 kg ha $^{-1}$ year $^{-1}$ of K_2O; and the fertilization level was 3 – 300 kg ha $^{-1}$ year $^{-1}$ of N and 450 kg ha $^{-1}$ year $^{-1}$ of K_2O.

A localized drip irrigation system with one lateral line per row of plants was used, with three self-compensating emitters of 4 L h $^{-1}$ per plant, with one emitter next to the plant and two others spaced 0.5 m from the first emitter. The experimental design included randomized blocks with four replications in a split-subplot scheme. The plots comprised fertilization levels 1, 2 and 3; the subplots comprised the irrigation depths: 60% of ETc and 100% of ETc (Table 4); and the subplots comprised the plant densities: 1,600 plants ha $^{-1}$ (one plant per clump) and 3,200 plants ha $^{-1}$ (two plants per clump).

Irrigation management was carried out by associating the ETo data collected at the station with the soil moisture data. Moisture was monitored three times a week, with readings taken early in the morning, before irrigation, via a TDR100 (time domain reflectometry) sensor. The sensors were installed at depths of 0.20 m and 0.40 m 0.25 m from the plant in the direction of the dripper plant. Using the retention curve and considering the moment of irrigation due to critical moisture, which corresponds to a 25% reduction in available water, the water depth corresponds to the ETc since the last irrigation was applied.

The biometric growth variables studied during floral emission were plant height, pseudostem diameter, number of functional leaves and leaf area. This last variable was estimated by the length and maximum width of the third leaf of the plant, based on equation (1) proposed by Alves, Silva Júnior and Coelho (2001).

$$AF = 0{,}901 * (C * L)^{1{,}2135} \qquad (1)$$

where:
AF - Total leaf area (cm²);
C - Length of the third sheet (cm);
L - Width of the third sheet (cm).

To describe the cycle phases, the total number of days from planting to flowering (DPF), the number of days from flowering to harvest (DFC) and the number of days from planting to harvest (DPC) were evaluated. During the harvest period, the following parameters were evaluated: number of leaves, weight of bunches per bunch, weight of stalks per bunch, bunch mass (weight of bunches + weight of stalks), number of bunches per bunch, number of fruits per bunch, length and average diameter of the fruit (central finger of the second and penultimate bunches), in addition to the productivity of bunches and bunches.

Water productivity (WP) was obtained from the relationship between productivity and the calculated gross irrigation depth, expressed in kg mm $^{-1}$, according to Loomis (1983) (eq. 2).

$$PA = \frac{PROD}{LBA} \qquad (2)$$

where:
P A = Water productivity (kg mm $^{-1}$);
PROD = Productivity of bunches of each treatment (kg ha $^{-1}$);
LBA = Gross applied depth corresponding to crop evapotranspiration in each treatment on irrigation days (mm).

To determine the postharvest attributes of the fruits of the banana cultivar D'Angola, the second bunch of each bunch of useful plants from the treatments was removed. The following evaluations were performed: bunch weight; fruit weight; number of fruits per bunch; fruit length determined by measuring the external curvature of each fruit from the shoulder to the end of the fruit; and fruit diameter from the middle region of the fruit. The percentages of fruit pulp and fruit moisture or loss by desiccation were also evaluated via a semianalytical balance (IAL, 2005).

Soluble solids (SS) were obtained via a portable refractometer, and the results were expressed as sugar percentages and °Brix values (LFA, 1973). The total titratable acidity (AT) of the fruit pulp and the percentage of malic acid (g 100 g $^{-1}$ of fresh tissue) were determined according to the AOAC (1975). The fruit ripeness index (SS/AT), i.e., the proportion of sugar per acid, was obtained from the ratio between soluble solids (SS) and total titratable acidity (AT) (Sinclair, 1961). The pH was determined via the potentiometric method with a benchtop pH meter (IAL, 2005).

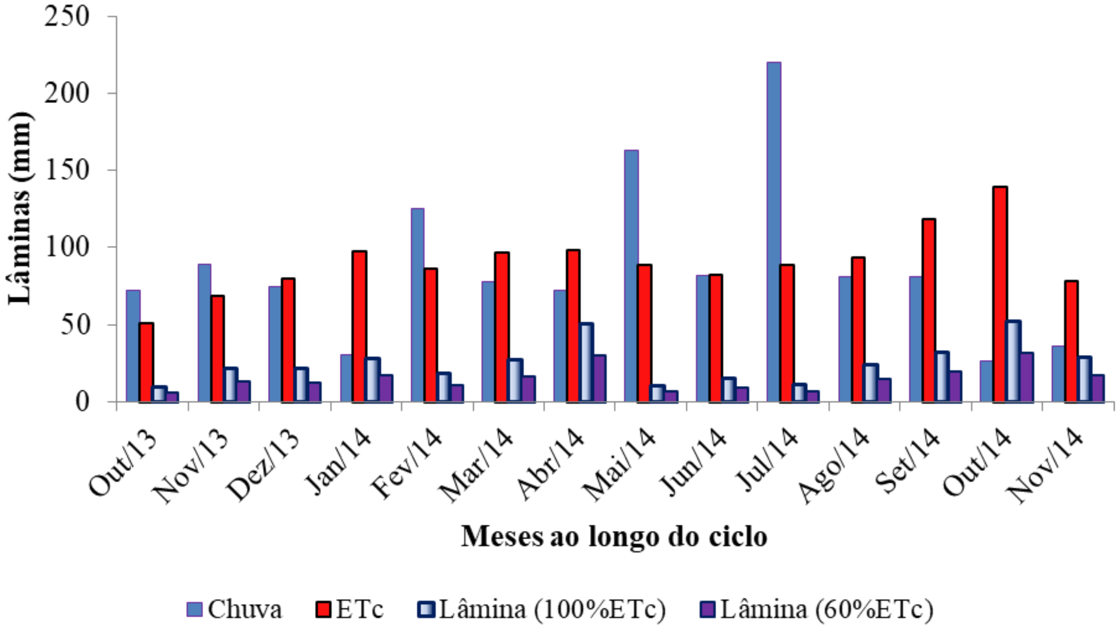
For nutritional evaluation, samples were collected from the third leaf from the apex, with the inflorescence at the stage of all female clusters uncovered (Borges, 2004). These samples were sent to the irrigation and fertigation laboratory, taken to greenhouses, where they were kept for one week at 65°C, crushed and then sent for chemical analysis.

The data were statistically evaluated via the normality test once the homoscedasticity of the data was confirmed. The data were analyzed in the statistical program R (TEAMS R, 2023) via the Tukey mean test 1 and 5% significance and the normality test of the residues via the Shapiro–Wilk test and homogeneity of variances (Kolmogorov–Smirnov). The dependent variables were then observed regarding the effects of fertilization, water depth, and plant density and the unfolding of their interactions. The means of the dependent variables influenced by the fertilization levels and the unfolding of their interactions were then compared via the Tukey test. The means of the dependent variables that were influenced by depth and planting density were subjected to the F test.

5 RESULTS AND DISCUSSION

The total precipitation throughout the cycle was 1230.8 mm, with an average of 87.9 mm month $^{-1}$. Irrigation during the crop cycle was supplementary, with precipitation occurring throughout the crop cycle (Figure 1). The greatest irrigation depth applied was in the treatment with 100% ETc or 354.0 mm. The periods of greatest irrigation need were from December 2013 to April 2014 and from August to November 2014. In the first period mentioned above, depths of 146 and 87 mm were applied via irrigation for the treatments with 100 and 60% ETc, respectively, corresponding to a total of 41% of the water depth applied throughout the cycle. In the second period mentioned above, the amount of water applied via irrigation was 138 and 83 mm for the treatments with 100 and 60% ETc, respectively, corresponding to 39% of the total share of the irrigation depths applied. From April 2014 onward, the share of irrigation effectively decreased; this phase included the reproductive period of the crop, due to the excess water in the soil (Figure 1). This phase has the highest water demand of the crop and is theoretically the most sensitive to the effects of the irrigation depth treatments.

Figure 1. Crop evapotranspiration (ETc), precipitation (rainfall) and irrigation levels applied during the cycle of the 'D'Angola' plane tree.



Font and Author (2024).

In this treatment, 141.6 mm more water was applied than in the treatment with 60% ETc or 212.4 mm (Table 4). According to Coelho, Oliveira and Pamponet (2013b), the most suitable water depth for D'Angola plantations in coastal plateau conditions is 940 mm. However, in this study, the smallest water depth applied plus the precipitation added up to a total of 1443 mm, a value higher than the value described above.

Table 4. Total water depth applied throughout the experimental period.

Applied blade – mm			
Etc		**ETc + Precipitation**	
100%	**60%**	**100%**	**60%**
353.98	212.39	1584.78	1443.19

Font and Author (2024).

The growth variables (number of total live leaves, height, diameter, total leaf area), as well as the variables of the cultivation phases (days from planting to flowering, period of fruit filling and days from planting to harvest), were not influenced ($p>0.05$) by the fertilization levels studied. Among the growth variables, only the number of days from planting to flowering was influenced by the irrigation depth and by the fertilization × depth interaction. Plant density did not influence the period of fruit filling; however, this same variable was influenced by the fertilization × density interaction.

Table 5 presents the mean values for the growth variables of the crop phases according to the planting densities. The means of all growth variables for the 3200 plants ha $^{-1}$ planting density were greater, except for the stem diameter, where the lowest plant density (1600 plants ha $^{-1}$) provided a pseudostem diameter with a relatively high value; similarly, Athani, Revanappa and Dharmatti (2009) and Coelho, Oliveira and Pamponet (2013b), evaluating different crop spacings in banana, reported the maximum pseudostem diameter for the lowest plant density. However, Coelho, Oliveira and Pamponet (2013b) reported values, on average, of 12.09 leaves, which was greater than those of the treatments with only one plant (Table 5).

Table 5. Growth variables and periods for flowering and harvesting of the banana cv. 'D'Angola'.

Density	NFT	ALT	DPS	AFT	DPF	DPC
plants ha $^{-1}$	**-**	**—— m ——**		**m ^{2}**	**——— days ——**	
1600	14.23 b	3.05 b	0.22 to	10.68 b	315.15 b	421.40b
3200	26.32 a	3.28 a	0.20 b	21.29 a	346.82 a	458.31a

Averages followed by distinct letters in the column, within each attribute, differ statistically by the F test (p<0.05); NFT - total number of leaves; ALT - pseudostem height; DPS - pseudostem diameter; AFT - total leaf area; DPF - number of days from planting to flowering; DPC - number of days from planting to harvest (total period of the cycle).
Source: Author (2024).

Faria *et al.* (2010) evaluated Terra-type plane trees with 1666 plants ha $^{-1}$ and reported that cv. D'Angola stood out, with an average of 14.2 leaves per plant at the time of flowering. The average value of the total leaf area, similar to the total number of leaves, for density (3200 plants ha $^{-1}$) was 10.61 m² greater than that for density (1600 plants ha $^{-1}$), providing an increase of 8% in the number of leaves, which also presented higher values for the variable plant height (Table 5). Belalcázar (2002), working with the planting density of the Dominico–Hartón plane tree (Musa AAB Simmonds) at a spacing of 3.0 × 2.0 m, with one, two and three plants per clump, obtained heights of 3.5 m, 4.2 m and 4.3 m, respectively, indicating that population density influences plant height.

The period in days from planting to flowering (DPF) and days from planting to harvest (DPC) for the treatment with 3200 plants ha $^{-1}$ was longer than that with 1600 plants ha $^{-1}$, increasing by 31.67 days at flowering and 36.91 days at harvest (Table 5). These results are in agreement with those of Belalcázar (2002); however, the increase in days in the vegetative phase can be compensated for by the increase in production, indicating the use of up to three tillers per clump for cv. Dominico-Hartón, where the author reported 15.5, 18.0 and 20.0 months of vegetative cycles for one, two and three plants per clump, respectively. A significant effect of the blade × fertilization interaction was observed on the average number of days from planting to flowering. Compared with plants subjected to 100% ETc, those subjected to 60% ETc were subjected to fertilization 18 days earlier 3. The treatment with F1 subjected to 100% ETc resulted in an earlier cycle, which did not differ from that of the treatment with F2, regardless of the irrigation depth applied (Table 6). Moura *et al*. (2002), working with the 'Comprida Verdadeira' plane tree in Amaraji-PE, found an average of 322 days from planting to flowering for a 2.0 × 2.5 m spacing, a value similar to those described in this experiment.

The density × fertilization interaction had a significant effect (p<0.05) on the number of days of fruit filling (DEC). The density of 1600 plants ha $^{-1}$ presented earlier fruit development than did the density of 3200 plants ha $^{-1}$. The DEC was influenced by fertilization, with a density of 3200 plants ha $^{-1}$, where the plants subjected to fertilization 1 presented later fruit filling than the other plants did, mainly compared with those in the treatment with fertilization 2 (Table 6).

Table 6. Days elapsed between planting and flowering (DPF) for the interaction between fertilizer dose and irrigation depth and days elapsed between planting and filling (DEC) for the interaction between fertilizer dose and planting density.

Fertilizing	**Etc**		**Density (plants ha $^{-1}$)**	
NK $_2$ O (kg ha $^{-1}$ year $^{-1}$)	**60%**	**100%**	**1,600**	**3,200**
	DPF		DPC	
1 - 200-300	322.51 aA	319.03 aA	102.23 aA	120.67 bB
2 - 250-375	324.54 aA	336.04 aB	105.58 aA	105.91 aA
3 - 300-450	332.76 aA	351.03 BC	110.92 aA	107.90 aAB

Means followed by the same lowercase letter in a row do not differ from each other according to the F test ($p<0.05$). Means followed by the same uppercase letter in the same column do not differ from each other according to the Tukey test ($p<0.05$).
Source: Author (2024).

The mean values of the production variables, including the number of total live leaves, number of fingers per bunch, number of bunches per bunch, bunch mass per bunch, bunch productivity, bunch and water productivity, were not influenced ($p>0.05$) by the fertilization level studied. The source of variation in irrigation depth influenced ($p<0.05$) only the water productivity variable. The planting density influenced ($p<0.05$) all the production variables. The interactions of fertilization × depth, fertilization × density and depth × density did not significantly affect any production variable.

The average number of live leaves at harvest decreased by 5.9 and 13.2 for densities of 1600 plants ha $^{-1}$ and 3200 plants ha $^{-1,}$ respectively, in relation to the average value of this variable during floral emission (Tables 6 and 8), which can be explained according to Silva *et al*. (2006) reported that the translocation of photoassimilates for fruit formation becomes the preferential drain of the plant.

The number of fruits per bunch (NFR) was greater for the treatments with a density of 3200 plants ha $^{-1}$, presenting a percentage variation in relation to the density of 1600 plants ha $^{-1}$ of 81.27%. Coelho, Oliveira and Pamponet (2013b), working with a planting density of 2000 plants ha $^{-1}$, reported an average of 34.47 fruits per bunch, values slightly higher than those verified in this study at a density of 1600 plants ha $^{-1}$ or 29.47 fingers (Table 7). These results do not match the results of Scarpare Filho and Kluge (2001), who tested different spacings of the banana tree 'Nanicã' and reported that the number of fruits per bunch tended to be greater at lower densities.

The number of bunches per bunch of the two productive plants per clump (Table 7) at a density of 3200 plants ha $^{-1}$ increased in relation to the density (1600 plants ha $^{-1}$) of 92.92%. Cavalcante *et al*. (2014), when studying banana cv. D'Angola at different planting densities (1111, 1333, 1666, 2000, and 2500 plants ha $^{-1}$) aimed at controlling black sigatoka, an increase in the number of bunches with increasing density from 1666 to 2500 plants ha $^{-1}$ on the order of 87% was reported. Coelho, Oliveira and Pamponet (2013b), working with cv. D'Angola at a density of 2000 plants ha $^{-1}$ under the same soil and climate conditions as those used in the present study, reported an average number of bunches of 6.36, which was close to the value found at a density of 1600 plants ha $^{-1}$.

Table 7. Variables evaluated in the harvest of the banana cv. 'D'Angola'.

Density	NFT	NFR	NPE	MPE	MCA	PPE	PCA	SHOVEL
plants ha $^{-1}$	-----------------------------			(kg)	(kg)	(t ha $^{-1}$)	(t ha $^{-1}$)	(kg mm $^{-1}$)
1600	8.33b	29.47b	6.78b	10.18b	10.91b	16.28b	17.46b	25.89b
3200	13.16a	53.42a	13.08a	17.25th	18.51a	27.60a	29.61a	43.98a

Means followed by the same lowercase letter in the columns do not differ from each other according to the F test ($p<0.05$). NFT - number of total live leaves; NFR - number of fruits per bunch, NPE - number of bunches per bunch, MPE - bunch mass per bunch, MCA - bunch mass, PPE - bunch productivity, PCA - bunch productivity and PA - water productivity.
Source: Author (2024).

The mass of bunches (MPE) and bunches (MCA) at a density of 3200 plants ha $^{-1}$ resulted, on average, in increases of 69.45% and 69.66%, respectively, in relation to the density of 1600 plants ha $^{-1}$ (Table 7). The yields of the bunches (PPE) and PCA in the treatments with two plants/clump (3200 plants ha $^{-1}$) exceeded those of the other treatments by 69.53 and 69.61%, respectively, for the same density of 1600 plants ha $^{-1}$ (one plant clump $^{-1}$). The increase from one to two productive plants per clump resulted in increases in productivity per hectare of 11.32 and 12.15 t ha $^{-1}$ for PPE and PCA, respectively (Table 7). The average productivity considering the density of 1600 plants ha $^{-1}$ was higher than that obtained by Cavalcante *et al*. (2014), who obtained 17.73 t ha $^{-1}$ with a density of 1666 plants ha $^{-1}$ under the conditions of Acre.

The water productivity (WP) at a planting density of 3200 plants ha $^{-1}$ exceeded the WP at a density of 1600 plants ha $^{-1}$ by 69.87%, which means that in the treatment with a density of 3200 plants ha $^{-1}$, there was an increase in the WP of 18.1 kg of banana per 10 m3 of water per hectare due to the increase in productivity of 11.32 t ha $^{-1}$ (Table 7). This increase in efficiency is expected because of the greater increase in productivity for the same applied depth. Pamponet (2013) evaluated two planting densities from the second cycle (2000 and 4000 plants ha $^{-1}$) with cv. Prata-Anã irrigated by a microsprinkler and reported an increase in BP for a density of 4000 plants ha $^{-1}$ in relation to 2000 plants ha $^{-1}$ as a result of an increase in bunch productivity of 80--85% in relation to a density of 2000 plants ha $^{-1}$.

The 60% ETc depth was more efficient than the 100% ETc depth, with an increase in PA of 8.87 kg of banana per millimeter of water or per 10 m3 of water per hectare (Table 8). This difference represented an increase of 29.1% in the PUA, with savings of 141.6 mm of water from the highest to the lowest irrigation depth. Under the experimental conditions, there was no effect of depth on productivity. The PAs were close to or greater than the maximum water use efficiency, corresponding to the 922 mm depth (29.6 kg mm $^{-1}$) considered the most suitable for this cultivar obtained by Coelho, Oliveira and Pamponet (2013b) under the same soil and climate conditions.

Table 8. Average water productivity (WP) of banana cv. 'D'Angola'.

Blade	SHOVEL (kg mm $^{-1}$)
60% of ETc	39.37 a
100% of ETc	30.50 b

Means followed by the same letter in the same column do not differ from each other according to the F test ($p<0.05$).
Font and Author (2024).

The analysis of variance revealed that the physical quality variables of the fruits of the banana cv. D'Angola (average mass of the 2nd bunch, number of fingers of the 2nd bunch, average finger mass, fruit length, fruit diameter, pulp mass, pulp diameter, peel thickness, and pulp yield) and the chemical variables (hydrogen potential, total soluble solids, total titratable acidity, SS/AT ripening index and fruit moisture percentage) of the fruits of the 2nd bunch of the banana cv. D'Angola were not influenced by the fertilization level studied ($p>0.05$). The irrigation depth had an effect only on the number of fruits in the 2nd bunch and on the fruit moisture percentage ($p<0.05$). The planting density influenced ($p<0.05$) the following variables: bunch weight, number of fruits, fruit length, pulp weight, titratable acidity and maturation index (SST/ATT). The interactions of fertilization × blade, fertilization × density and blade × density had no effect ($p>0.05$) on any of these variables.

The average values of the physical quality variables of the fruits of the banana cultivar D'Angola in the treatments with one productive plant per clump were greater than those of the plants in the treatment with two productive plants per clump. These results are in agreement with those of Scarpare Filho and Kluge (2001), who reported that the adoption of low densities (1666 and 1333 plants ha $^{-1}$) results in the production of larger fruits, although with lower production than high densities do.

The pulp mass and fruit length variables in this study were greater for the treatments with one productive plant per clump than for the treatments with two productive plants per clump. Faria *et al.* (2010), under the conditions of Guanambi, BA, which works with phytotechnical evaluations of Terra-type bananas, reported an average fruit length of cv. D'Angola of 26.1 cm, which is lower than the average value obtained in this experiment for the two densities.

Table 9. Variables evaluated in fruits of banana cv. 'D'Angola'.

Density	MPE	NDE	MMD	CFR	DFR	MPO	ECS	DPO	PUT
plants ha $^{-1}$	(g)	-	(g)	(cm)	(mm)	(g)	(mm)	(mm)	(%)
1600	2095.4a	6.69a	319.22	29.88a	44.63	208.28a	4.47	36,38	65.4
3200	1827.1b	5.92b	294.91	27.98b	43.5	191.04b	4.42	35.38	64.86

*Meanings without letters in the columns do not differ from each other according to the F test ($p<0.05$). MMP - average mass of the 2nd hand of the bunch, NDE - number of fingers of the 2nd hand of the bunch, MMD - average finger mass, CFR - fruit length, DFR - fruit diameter, MPO - pulp mass, DPO - pulp diameter, ECS - peel thickness, RPO - pulp yield.
Source: Author (2024).

The titratable acidity was also greater in the treatments with one productive plant per clump. However, the average maturation index was greater for treatments with two plants per clump, which can be explained by the fact that this index is inversely proportional to titratable acidity, a value that was greater for density with one plant per clump (Table 10).

Table 10. Variables evaluated in the pulp of the fruits of the banana cv. 'D'Angola'.

Density	**pH**	**SST**	**ATT**	**SST/ATT**	**UMI**
plants ha $^{-1}$	**-**	**(°Brix)**	**(%)**	**-**	**(%)**
1600	4.47	10.91	0.54 to	20.55 b	41.86
3200	4.42	11.23	0.49 b	22.83 a	39.29

*Means without letters in the columns do not differ from each other according to the F test (p<0.05). pH - hydrogen potential, TSS - total soluble solids, ATT - total titratable acidity, SS/AT - ripening index (Ratio No.) and UMI - fruit moisture percentage (UMI). **Source**: Author (2024).

The number of fingers and the percentage of fruit moisture for the treatments under the 100% ETc were greater than those for the plants subjected to 60% ETc (Table 11). The values of fruit moisture percentage described in this experiment were lower than those described by Silva (2013) in cv. D'Angola under the conditions of Cruz das Almas-BA, where values ranging from 47 to 62% were reported in a study with different doses of nitrogen and irrigation levels.

Table 11. Averages of the number of fingers of the 2nd hand of the bunch (NDE) and percentage of fruit moisture (UMI) of the fruits of the banana cv. D´Angola.

Blades	**NDED**	**Humid**
	-	**(%)**
60% ETc	5.98 b	39.02 b
100% ETc	6.63 a	42.13 a

Means without letters in the columns do not differ from each other according to the F test (p<0.05).
Source: Author (2024).

Analysis of variance revealed that the fertilization level and irrigation depth had no effect (p>0.05) on any of the foliar macro- or micronutrients analyzed. However, density had an effect only on phosphorus and sulfur (p<0.05). The interactions had no effect on the foliar macro- or micronutrients analyzed (p>0.05) (Table 12). The macro- and micronutrient contents in the present study (Table 12) were within the recommended ranges for nitrogen (2.65--3.12 dag kg $^{-1}$), phosphorus (0.13--0.17 dag kg $^{-1}$), potassium (2.2--2.53 dag kg $^{-1}$), boron (14--30 mg kg $^{-1}$) and zinc (14--16 mg kg $^{-1}$) according to Borges and Silva Júnior (2001).

Table 12. Results of macro- and micronutrient contents in the third leaf of the banana cultivar 'D'Angola'.

Density	N[1]	P[2]	K[2]	S[2]	Ca[2]	Mg[2]	B[3]	Cu[2]	Fe[2]	Mn[2]	Zn[2]	Na[2]
plants ha $^{-1}$	....................dag kg $^{-1}$						------------------mg kg $^{-1}$ ------------------					
1600	2.98	0.18b	3.22	0.19b	0.84	0.34	15.73	3.97	82.2	29.23	14.73	45.26
3200	3.05	0.19a	3.3	0.22a	0.84	0.34	17.57	3.78	89.37	30.21	16.04	47.22

*Soil Laboratory of the EPAMIG North of Minas Regional Unit; 1 - Sulfuric digestion - Kjeldahl method; 2 - Nitric-perchloric digestion; 3- Dry digestion dag/kg = (%); mg/kg = (ppm). Means without letters in the columns do not differ from each other according to the F test ($p<0.05$).
Source: Author (2024).

6 CONCLUSIONS

The increase in planting density from 1,600 for 3,200 plants ha $^{-1}$ promoted a longer production cycle, both from planting to flowering and from planting to harvest, in banana cv. 'D'Angola' (*Musa* spp., AAB).

Two plants per clump increased the productivity of bunches and clusters by 69.53 and 69.61%, equivalent to increases of 11.32 and 12.15 t ha $^{-1}$, respectively.

The water productivity at a planting density of 3,200 plants ha $^{-1}$ was 69.87% greater than that at a density of 1,600 plants ha $^{-1}$.

The 60% ETc blade was more efficient in terms of water use than the 100% ETc blade was, with an increase in water productivity of 8.87 kg of bananas per millimeter of water.

The increase in planting density reduced the length and diameter of the fruit; however, it did not reduce the commercial quality of the fruit or increase the ripening index.

7 REFERENCES

ALVES, AAC; SILVA JUNIOR, JFS; COELHO, EF Estimation of banana leaf area by simple and nondestructive methods. *In* : BRAZILIAN CONGRESS OF PLANT PHYSIOLOGY, 8, 2001, Ilhéus. **Proceedings** [...] . Ilhéus: Brazilian Society of Plant Physiology, 2001. v. 1, p. 1-3.

ARANTES, AM; DONATO, SLR; SILVA, SO Relationship between morphological characteristics and production components in plantains. **Brazilian Agricultural Research** , Rio de Janeiro, v. 45, n. 2, p. 224 - 227, 2010.

AOAC. **Official methods of analysis** . 12 ed. Washington, DC: Association of Analytical Chemistry, 1975.

ATHANI, S.; REVANAPPA, I.; DHARMATTI, PR Effect of plant density on growth and yield in banana. **Journal Agricola Scientific** , Karnataka, v. 22, no. 1, p. 143-146, 2009.

AUJLA, MS ; THIND, HS; BUTAR, GS Cotton yield and water use efficiency at various levels of water and N through drip irrigation under two methods of planting. **Agricultural Water Management** , Amsterdam, v. 71, no. 1, p. 167-179, 2005.

BELALCÁZAR, CS High densities of wood in sycamore, a profitable and sustainable production alternative. **Acorbat** . Memories XV meeting. Held in Cartagena de Indias, Colombia. Medellin (COL). Asociación de Bananeros de Colombia AUGURA. 2002.

BISWAS, BC; KUMAR, FND High Density Planting: Success Stories of Banana Farmers. **Fertilizer Marketing**

News , New Delhi, v. 41, n. 6, p. 3-10, 2010. Available at: https://faidelhi.org/Article%20-Dr%20Biswas/Dr%20B%20C%20Biswas%20-%20June%20issue%20of%20Mktg%20news.pdf. Accessed on: April 10, 2015.

BORGES, AL Liming and fertilization. *In* : BORGES, AL; SOUZA, LS **Banana cultivation** . Cruz das Almas: Embrapa Cassava and Fruit Growing, 2004. p. 32-44.

BORGES, AL; SILVA JUNIOR, JF Liming and fertilization. *In* : ALVES, EJ **The cultivation of the banana tree** . Cruz das Almas: Embrapa Cassava and Tropical Fruit Growing, 2001. p. 35-40.

CAVALCANTE, MJB; ANDRADE NETO, RC; LEDO, AS; GONDIM, TMS; CORDEIRO, ZJM Phytotechnical management of banana, cultivar D'angola (AAB), aiming at the control of black sigatoka. **Caatinga Magazine** , Mossoró, v. 27, n. 2, p. 201-208, 2014.

COELHO, EF ; COELHO FILHO, M. A .; COTRIM, CE; SILVA, AJP Mechanisms for optimizing water use efficiency in tropical fruit trees. ITEM. **Irrigation and Modern Technology** , Brasília, DF, v. 99, p. 48-53, 2013a.

COELHO, EF; OLIVEIRA, RC; PAMPONET, AJM Water requirements of Terra type banana trees in coastal tableland conditions. **Brazilian Agricultural Research** , Rio de Janeiro , v. 48, no. 9, p. 1260-1268, 2013b.

COSTA, FS; SUASSUNA, JF; MELO, AS; BRITO, MEB; MESQUITA, EF Growth, productivity and water use efficiency in irrigated banana plantations in the semiarid region of Paraíba. **Caatinga Magazine** , Mossoró, v. 25, n. 4, p. 26-33, 2012.

DONATO, SLR; SANTOS, MR; COELHO, EF; OLIVEIRA, PM Water use efficiency in banana plants . *In* : INTERNATIONAL MEETING OF THE ASSOCIATION FOR COOPERATION IN RESEARCH AND INTEGRAL DEVELOPMENT OF MUSACEAE (BANANAS AND PLANTAINS), 20., 2013, Fortaleza. **Proceedings** [...]. Fortaleza: Instituto Frutal: Acorbat Internacional, 2013. Available at: http://www.alice.cnptia.embrapa.br/alice/handle/doc/967128. Accessed on: April 1, 2016.

FAO. **The State of Food Security and Nutrition in the World 2021** . Rome: FAO, 2022 . Available at: https://www.fao.org/faostat/en/#rankings/countries_by_commodity. Accessed: March 15, 2023.

FARIA, HC; DONATO, SLR; PEREIRA, MCT; SILVA, SO Phytotechnical evaluation of ground-type banana plants under irrigation in semiarid conditions. **Agrotechnology Science** , Lavras, v. 34, n. 4, p. 830-836, 2010.

IAL. **Physicochemical methods for food analysis** . 4th ed. Brasília, DF: Ministry of Health, 2005.

JENSEN, ME Sustainable and productive irrigated agriculture. *In* : HOFFMAN, GJ; EVANS, RG; JENSEN, ME; MARTIN, DL; ELLIOTT, RL **Design and operation of farm irrigation systems** 2. ed. Saint Joseph: ASABE, 2007. p. 33-56.

LFA. **Laboratory in Food Analysis** . London: Butterworths, 1973, p.58-60.

LOOMIS, RS Crop manipulations for efficient use of water: An overview. *In* : TAYLOR, HM; JORDAN, W.R.; SINCLAIR, TR **Limitations to efficient water use in crop production.** (ed).

Madison: American Society of Agronomy, Crop Society of America, and Soil Science Society of America, 1983. p. 345-374.

MAGALHÃES, DB; DONATO, SLR; SANTOS, MR; BRITO, CFB; FONSECA, VA; SOUZA, BS Yield of 'Prata-Anã' banana plants under water deficit and high plant density. **Brazilian Journal of Fruit Growing** , Jaboticabal, v. 42, n. 5, p. e-046, 2020. DOI: https://doi.org/10.1590/0100-29452020046 . Available at: https://www.scielo.br/j/rbf/a/6jtsyHnQVXLRt64TnVtK8Bx/?lang=en. Accessed on: February 13, 2024.

MELO, ASD; SUASSUNA, JF; FERNANDES, PD; BRITO, MEB; SUASSUNA, AF; AGUIAR NETTO, ADO Vegetative growth, stomatal resistance, photosynthetic efficiency and fruit yield of watermelon at different water levels. **Acta Scientiarum. Agronomy** , Maringá, v. 32, n. 1, p. 73-79, 2010.

MOURA, RJM; SILVA JUNIOR, JF; SANTOS, VF; GOUVEIA, J. Spacing for the cultivation of 'true long' banana (*Musa* AAB) in the Mata Sul region of Pernambuco (1st cycle). **Brazilian Journal of Fruit Growing** , Jaboticabal, v. 24, n. 3, p. 697-699, 2002.

OLIVEIRA, JM; COELHO FILHO, MA; COELHO, EF Growth of Grande Naine banana tree subjected to different irrigation depths in coastal tableland. **Brazilian Journal of Agricultural and Environmental Engineering** , Campina Grande, v. 17, n. 10, p. 1038-1046, 2013.

PAMPONET, AJM **Evaluation of irrigation depths for banana cv. Prata Anã on two plant densities** . 2013. Dissertation (Master in Agricultural Sciences) – Center for Agricultural, Environmental and Biological Sciences, Federal University of Recôncavo da Bahia, Cruz das Almas, Bahia, 2013.

TEAMS R. **The R Project for Statistical Computing** . Version R-4.3.2. Vienna: Cran R, 2023. Available at: https://www.r-project.org/. Accessed: February 13, 2023.

SANTOS, MR; DONATO, SLR; MAGALHÃES, DB; COTRIM, MP Precocity, yield and water-use efficiency of banana plants under planting densities and irrigation depths, in semiarid region. **Tropical Agricultural Research** , Goiânia, v. 49, n. e53036, p. 01-10, 2019.

SCARPARE FILHO, JA; KLUGE, RA Production of 'Nanicã' banana in different plant densities and spacing systems. **Brazilian Agricultural Research** , Brasília, DF, v. 36, n. 1, p. 105-113, 2001.

SILVA, ACP **Nitrogen and irrigation levels in the production and accumulation of nutrients in banana cultivar D'Angola** . 2013. Dissertation (Master in Agricultural Sciences) - Center of Agricultural, Environmental and Biological Sciences, Federal University of Recôncavo da Bahia, Cruz das Almas, 2013.

SILVA, SO; PIRES, ET; PESTANA, RKN; ALVES, JS; SILVEIRA, DC Evaluation of Cavendish banana clones. **Agrotechnology Science** , Lavras, v. 30, n. 5, p. 832-837, 2006.

SIMSEK, M.; TONKAZ, T.; KAÇIRA, M.; ÇÖMLEKÇIOĞLU, N.; DOĞAN, Z. The effects of different irrigation regimes on cucumber (*Cucumbis sativa* L.) yield and yield characteristics under open field conditions. **Agricultural Water Management** , Amsterdam, v. 73, no. 3, p. 173-191, 2005.

SINCLAIR, WB **Division of agricultural sciences** . Kazan: Oranpa University. 1961.

SOTO, M. Situation and technological advances in global banana production. **Revista Brasileira de Fruticultura** , Jaboticabal, v. 33, p. 13-28, 2011.

SOUZA, L.D .; SOUZA, L.S. **Physical-hydric characterization of soils in the area of the National Center for Cassava and Fruit Research** . Cruz das Almas: Embrapa Cassava and Fruit, 2001. (Research Bulletin, n. 20).

TEIXEIRA, LAJ; QUAGGIO, JA; MELLIS, EV Fertilizer efficiency gains in banana under irrigation and fertigation. **Brazilian Journal of Fruit Growing** , Jaboticabal, v. 33, p. 272-278, 2011.

ZHANG, Y.; KENDY, E.; QIANG, Y.; CHANGMING, L.; YANJUN, S.; HONGYONG, S. Effect of soil water deficit on evapotranspiration, crop yield and water use efficiency in the north China plain. **Agricultural Water Management** , Amsterdam, v. 64, no. 1, p. 107-122, 2004.