academicJournals

Vol. 11(42), pp. 4181-4188, 20 October, 2016
DOI: 10.5897/AJAR2016.11650
Article Number: 0FCA96D61248
ISSN 1991-637X

http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

Full Length Research Paper

Irrigation productivity and water-use efficiency in papaya crop under semi-arid conditions

Erialdo de Oliveira Feitosa*, Antonio Flávio Batista Araújo, Calorine Maria Bayma Oliveira, Fernando Bezerra Lopes and Eunice Maia de Andradre

Department Agricultural Engineering, Federal University of Ceará, , Campus of Pici, 60455760 - Fortaleza, Ceará, Brazil.

Received 1 September, 2016; Accepted 14 October, 2016

Papaya (*Carica papaya* L.) has a great economic importance in tropical and subtropical countries, Brazil being one of the largest producers of papaya in the world. This crop requires a considerable amount of water during its cycle, making proper irrigation management essential for optimal water use. Improving water-use efficiency can increase levels of agricultural production as well as the efficient use of water resources in semi-arid regions.The aim of this work was to evaluate productivity and water-use efficiency of irrigation inpapaya. The research was carried out in the Curupatiirrigation Perimeter, located in the semi-arid region of Brazil. The volume of water applied to the crop was quantified by calculating the number of operating hours of the pump unit supplying the irrigated lot, determining the flow rate of the emitters used in the irrigation system, and evaluating the soil moisture profile.The total volume of water applied was 2,663,296.20 m^3, for a yield that ranged from 80 to 106 t ha^{-1}. For water-use efficiency, it was found that for each kilogram of papaya produced, 1,042 m^3 of water were consumed, giving a productivity of 0.95 kg m^3. The water-use efficiency was affected by the different types of soil in the irrigation perimeter.

Key words: Water-use efficiency, irrigation management, irrigated agriculture, production, *Carica papaya L*.

INTRODUCTION

Brazil is the world's third largest producer of fruit, ranking second in the production of papaya (*Carica papaya* L.) with around 12.5% of world production (FAO, 2015).

Irrigated agriculture is a substantial activity today, a result of the continuous increase in the demand for food due to the growth in population. The activity emerged in the Northeast of Brazil following a significant growth in the market, and has resulted in greater production and higher incomes for the sector, especially fruit farming, which has assumed a prominent place in this scenario (Lopes et al., 2011).

In this context, the fruit farming is of great importance for the semi-arid region of northeastern Brazil, since the adoption of irrigation technology in the cultivation of papaya has resulted in increased production. However, the water use efficiency (WUE) is related to irrigation management. In this sense, in the region under study, the producers establish arbitrary periods of irrigation, generally over-irrigating, for fear that the crop may suffer from water stress and affect production. Thus,

*Corresponding author. E-mail: erialdofeitosa5@gmail.com.br. Tel: +55 85 3366 9757. Fax: +55 85 3366 9215.

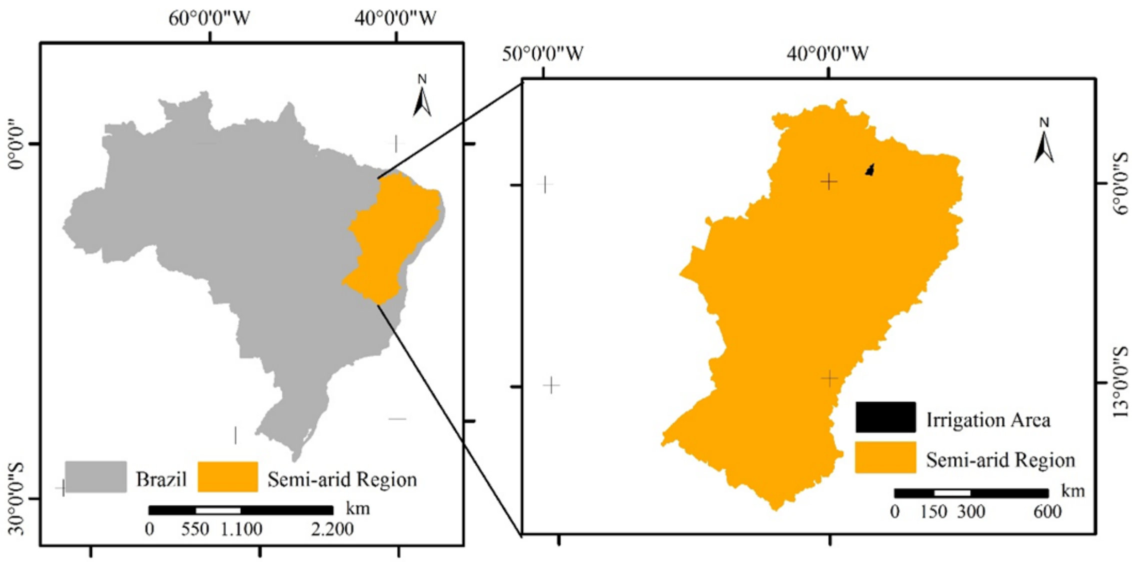

Figure 1. Location of the semi-arid region of Brazil and the Curupatiirrigation Perimeter.

occasioning a decrease in the WUE, which brings as consequence, application of excess water, soil nutrient profile washing and increase in energy consumption.

Water use efficiency (WUE) is one of the parameters used to calculate the relationship between the productivity obtained with a crop for a specific volume of applied water (Loomis, 1983). According to Melo et al. (2010), WUE increases when there is a reduction in the depth of water applied, with no reduction in production, essential in arid and semi-arid regions, due to problems of water shortage. Lima et al. (2010), point out that with an increase of only 1% in WUE in the semi-arid region of the Northeast of Brazil, it is estimated that there would be a saving of 165,000 L of water per irrigated hectare per year.

Second Guoju et al. (2016), improving water-use efficiency was a key factor in the continual increase in crop productivity in arid and semi-arid regions of northwestern China. For Gomes and Testezlaf (2007) the WUE reduces water loss and supplies the water required by plants for their development; also, irrigation management is important in obtaining high yields, in addition to the preservation of the environment.

Several researchers have sought to identify the interference that occurs and that impairs the efficient application of water, in order to maximise water-use efficiency (Souza et al., 2005; Medeiros, 2003; Peixoto et al., 2005; Carvalho et al., 2006). Such interference stems from the level of education of the producers and the quality of the irrigation water, to management techniques in the field.

It is worth pointing out that, although there are studies into sustainable water management, such reports are scarce, especially under arid and semi-arid conditions, requiring further investigation in order to ensure the best economic, social and environmental use of the resource. With this is mind, the aim of this work was to evaluate productivity and water-use efficiency in irrigated papaya in the semi-arid region of Brazil.

MATERIALS AND METHODS

Location of the study area

The trial was carried out in an irrigated area located in the semi-arid region of Brazil (Figure 1). Under study was the CurupatiIrrigation Perimeter, located in the town of Jaguaribara, in the State of Ceará, Brazil.

Edaphoclimatic characterisation

The climate according to the Köppen classification is type BSw'h', hot semi-arid with average monthly temperatures greater than 18°C. The average annual rainfall in the region is 810 mm, with 80% of the total rainfall occurring from January to April.

The predominant soils are Neosols, Luvisols and Argisols, with the predominant native vegetation in the region being deciduous thorn forest, dense shrub-like caatinga, open shrub-like caatinga, and mixed dicot-palm forest (IPECE- 2007). Other climatic characteristics of the region under study can be found in Table 1, including average values for the 2000 to 2015 historical series.

Description of the Curupatiirrigation Perimeter

The irrigation district comprises an area of 189 ha, divided into lots of 1.5 ha, benefitting 144 producers. Of these, 63 produce irrigated papaya through a system of drip irrigation, making up an area of 94.5 ha. The remaining 94.5 ha is cultivated with guava irrigated by a micro-sprinkler system, of benefit to 81 producers.

The water in the perimeter comes from the Castanhão reservoir, pumped by a 500 hp floating motor pump set with a flow rate of 0.33 m^3s^{-1}. This was used to supply the distribution channel. The

Table 1. Climatic characteristics.

Parameter	Value	Unit
Average annual insolation	3,096	h $year^{-1}$
Average annual potential evaporation	1,830	Mm $year^{-1}$
Maximum average annual temperature	32.00	ºC
Average annual temperature	27.50	ºC
Minimum average annual temperature	26.00	ºC
Average annual relative humidity	67.95	%
Average annual wind speed	3.80	m s^{-1}

Source: INMET (2016).

water was pumped from the channel to the irrigated lots by a further set of four 75 hp motor pumps.

For all of the lots of papaya producers utilized the irrigation drip system located, in which The water was carried to the lots by 75 and 50 mm diameter PVC tubing. The papaya crop was planted in rows spaced 4 m apart with 1.8 m between plants, being that the drip emitters were spaced 0.4 m apart, with an equivalent flow rate of 2.0 L h^{-1}.

For better efficiency in applying the water to the soil, hourly irrigation pulses were adopted, giving a total of four pulses for each 0.75 ha sector day^{-1}. The rainfall volume during the crop cycle was also calculated, as the motor pump sets were turned off during the rainy season.

First, questionnaires were carried out to the papaya producers in the irrigated perimeter to obtain information on the irrigation system, the agricultural practices being used, the power installed and the general characteristics of the adopted production system, and to monitor the technical team in the irrigation perimeter.

For the sample calculation, we used a probabilistic technique, in which all elements of the population have equal probability, different from zero, being selected for the sample. estimated the sample size by applying the method proposed by Fonseca and Martins (1996):

$$n = \frac{Z^2 * p * q * N}{d^2 * (N-1) + Z^2 * p * q} \quad (1)$$

Where, N: the total population of 63 families; d: the sampling error definite at 10%; Z: standard deviation of 1.96 which corresponds to a confidence level of 90%; p and q: are the percentage of positive sample elements and unfavorable (50%) to the searched attribute.

Soil analysis

To characterise the textural and chemical class of the soil in the irrigated area, samples were collected from the 0-30, 30-60, 60-90 and 90-120 cm layers. The samples were analysed at the Soil and Water Laboratory of EmbrapaAgroindústria Tropical, in Fortaleza, Ceará.

To determine the moisture content of the soil profile in the irrigated area, further samples were taken from the 0-30, 30-60, 60-90 and 90-120 cm layers, and then analysed by the Laboratory of Hydrology of the Department of Agricultural Engineering at the Federal University of Ceará, Pici Campus. Samples were collected only a soil sample for each lot, corresponding to 18 samples, according to determination of the number of lots of papaya producers to be interviewed.

Productivity of the papaya

Analysis of average crop yield was based on the ratio of papaya produced to the area under cultivation, as per Equation 2.

$$Pav = \frac{p}{x} \quad (2)$$

Where, Pav is average productivity, in kg ha^{-1}; p is papaya produced in kg; x is area under cultivation, in ha.

Water-use efficiency

The water-use efficiency (WUE) was obtained from the ratio between crop production and the volume of water applied, as per Loomis (1983).

$$WUE = \frac{p}{v} \quad (3)$$

Where, WUE is water-use efficiency in kg m^{-3}; p is crop production, in kg; v is volume of water applied in m^3.

Statistical analysis

Descriptive statistics were used to analyse the following parameters: Mean value, standard deviation and coefficient of variation. The data were analysed using the SPSS v 16 software. The Excel software was used for graphing and regression analysis of the correlations between the different parameters being evaluated.

RESULTS AND DISCUSSION

Producer profile

Interviews were conducted randomly in the Curupatiirrigation Perimeter, where 18 producers were interviewed, of which 67% reported that they had had no previous experience with irrigated agriculture. Due to the lack of knowledge of this technique of irrigation management, water-use efficiency was low.

According to Lopes et al. (2011), when conducting interviews with lot owners in the Lower AcaraúIrrigation Perimeter, they found that 77.78% of the producers had had no experience with irrigated agriculture before arriving in the area. They concluded that existing irrigation management in the perimeter was inadequate, and that producers could not determine when or how

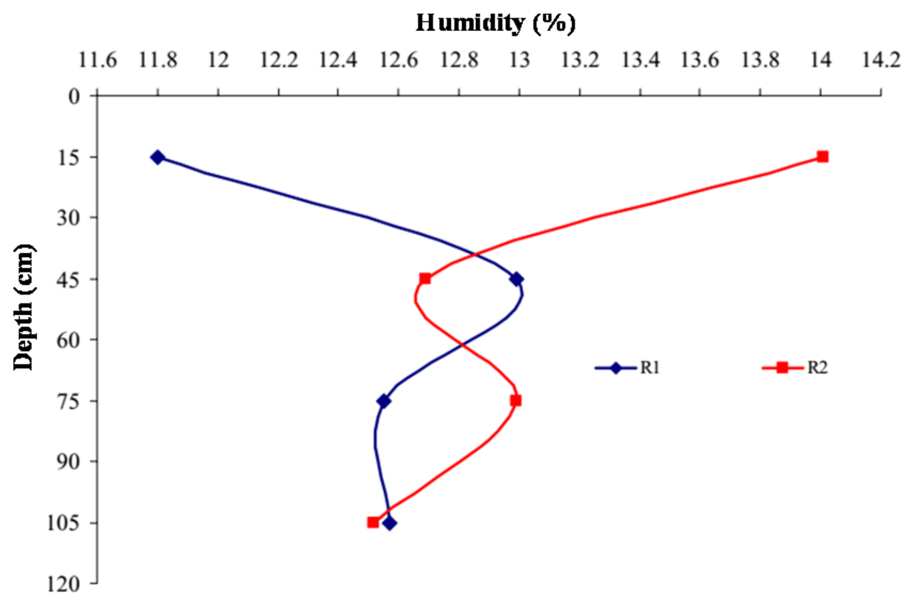

Figure 2. Soil moisture profile in the Curupatiirrigation Perimeter.

much to irrigate.

Thus a lack of knowledge or experience with the techniques of irrigation increases the likelihood of producer failure since, as per Branco (2003), Vanzela et al. (2003) and Andrade et al. (2009), the success of irrigated agriculture bears a close relation to the level of education and knowledge of the technique being practiced.

For Lacerda and Oliveira (2007) the low level of education explains the poor effectiveness of public policies which aim to promote development, since the low level of schooling acts to limit access to information, communications, human and social capital, and especially the adoption of technology.

Technical assistance in the CurupatiIrrigation Perimeter was provided by the Secretary for Agriculture of the State of Ceará, currently known as the Secretary for Agrarian Development (SDA), and by the Company for Technical Assistance and Rural Extension for the State of Ceará (EMATERCE), both with offices in the City of Jaguaribara. The permanent presence of two agricultural technicians in the area offered the same technical guidance to all the producers,who therefore received the same orientation and adopted the same irrigation management.

Irrigation management

As producers in the perimeter had no experiments with irrigation technique, was determined the soil moisture content to a depth of 120 cm, and thus identified the existence of water losses by deep percolation, in which were carried out two samples in two periods identified with R1 and R2 in four depths.

Figure 2 shows that in the beginning of the period of irrigation (R1) and in the period of greatest demand for water by the crop (R2) content of the soil showed differences in the first layer (0-30 cm), due the biggest difference of soil matric potential of in this layer, because the soil is dry at the start of irrigation, being that with the exception of the first layer (0-30 cm), the values for soil moisture were similar.

A water loss through deep percolation was observed too; thereby decreasing water-use efficiency, as calculation of the irrigation depth had been carried out to a depth of 80 cm. Coelho et al. (2005), studying the root systems of papaya crops under different irrigation systems in the Northeast of the country, concluded that 80% of the root system of papaya irrigated by surface drip occurred at a depth of 45 cm, with at least 60% of the roots being concentrated at 25 cm, reaching a maximum depth of 75 cm.

In was thus found that the soil moisture content from 90 to 120 cm is compatible with the other profiles studied, characterising the excessive use of water and fertiliser in a root zone not available to the root system of the papaya.

Lopes et al. (2009), when estimating the water requirement of the coconut (*Cocos nucifera*) in the Lower AcaraúIrrigation Perimeter, found that due to not employing any method of determining soil moisture, the producer usually over-irrigated, for fear that the crop might suffer from water stress and affect production.

The excessive application of water to a layer of soil not exploited by the roots, results in an increase in the volume of water used and power consumed. In addition, the soil profile is washed of nutrients in the root zone of the crop, thus affecting development and productivity, as

Table 2. Management adopted and productivity of the papaya in the Curupatiirrigation Perimeter.

Producer	Crop	Area (ha)	Irrigation System	Productivity (t ha^{-1})
01	Papaya	1.5	Drip	93
02	Papaya	1.5	Drip	106
03	Papaya	1.5	Drip	93
04	Papaya	1.5	Drip	93
05	Papaya	1.5	Drip	86
06	Papaya	1.5	Drip	93
07	Papaya	1.5	Drip	93
08	Papaya	1.5	Drip	80
09	Papaya	1.5	Drip	93
10	Papaya	1.5	Drip	93
11	Papaya	1.5	Drip	83
12	Papaya	1.5	Drip	100
13	Papaya	1.5	Drip	100
14	Papaya	1.5	Drip	100
15	Papaya	1.5	Drip	100
16	Papaya	1.5	Drip	100
17	Papaya	1.5	Drip	93
18	Papaya	1.5	Drip	93

well as decreasing water-use efficiency.

Another major problem is the risk of salinisation at deeper layers due to leaching. According to Chaves et al. (2006) and (2009) studying the risks of soil degradation and the dynamics of soil salinity in the Araras Norte Irrigation Perimeter in Ceará, they found increases in soil salinity at the deeper layers, expressing the occurrence of the leaching process as a result of excessive irrigation depths.

Productivity of the papaya

Based on the matrix formed from the questionnaires given to the 18 producers in the Irrigation Perimeter, a profile of the producers was prepared in relation to the irrigation management adopted, and a survey of the productivity in each of the lots (Table 2). Where in the management adopted in relation the time of irrigation, fertilization, phytosanitary treatment were the same for all lots.

It can be seen from Table 2 that the productivity varied from 80 to 106 t ha^{-1}, with an average yield of 96.78 t ha^{-1} and a standard deviation of 6.40 t ha^{-1}. It was found that productivity for 77.78% (14 producers) was around the average (96.78±6.40), 5.56% (1 producer) had significantly higher productivity than the average, and 16.68% (3 producers) had a productivity lower than or equal to 90 t ha^{-1}, less than the average. The mean values found in the 18 lots of the Irrigation Perimeter exceeded the national average productivity of 60 t ha^{-1} for the variety of the Formosa group grown in the area.

According to Tolk et al. (2016), differences in the productivity ranking of the soils of one region compared with those from other regions emphasize the effects of interaction between the environment and the soil on crop production, as does the structural class of the soil in which the crops are grown.

The significant increase in papaya production in the Curupati Irrigation Perimeter, compared to the national average, can be attributed to irrigation technology, as well as the climatic conditions of the region, which favour cultivation of the fruit. According to Lima et al. (2015), proper irrigation is essential to maintain or increase production in cultivated areas, where there is greater competition for water resources requiring an increase in water-use efficiency and a reduction in environmental impact.

For Santos et al. (2008), studying the effect of different irrigation depths on a papaya crop, there was a linear increase in crop productivity for the increasing volume of water applied. However, it should be investigated whether this increase in productivity justifies the large amount of water used, that is, water-use efficiency, and the relationship between production and the volume of water used, should be considered.

Water-use efficiency

To determine water-use efficiency as well as the volume of water used in the production of one kilogram of papaya, both the water applied by the irrigation system and rainwater throughout the crop cycle were considered,

Table 3. Volume of water applied in the Curupatiirrigation Perimeter.

Year	Volume of rain water (m^3)	Volume of irrigation water (m^3)	Total (m^3)
2006	-	165,628.80	165,628.80
2007	152,793.00	1,058,184.00	1,210,977.00
2008	260,712.00	1,025,978.40	1,286,690.40
	Total volume uppled		2,663,296.20

Table 4. Water-use efficiency for each lot in the Curupatiirrigation Perimeter.

Producer	Production (kg)	Volume of water applied (m^3)	WUE (m^3 kg^{-1})
01	139,500	147,960.9	1.06
02	159,000	147,960.9	0.93
03	139,500	147,960.9	1.06
04	139,500	147,960.9	1.06
05	129,000	147,960.9	1.15
06	139,500	147,960.9	1.06
07	139,500	147,960.9	1.06
08	120,000	147,960.9	1.23
09	139,500	147,960.9	1.06
10	139,500	147,960.9	1.06
11	124,500	147,960.9	1.19
12	150,000	147,960.9	0.99
13	150,000	147,960.9	0.99
14	150,000	147,960.9	0.99
15	150,000	147,960.9	0.99
16	150,000	147,960.9	0.99
17	139,500	147,960.9	1.06
18	139,500	147,960.9	1.06

as shown in Table 3.

Based on the total volume of water applied, it was possible to calculate the water requirement for each kg of papaya produced, as shown in Table 4, in which total volume of water applied in each lot was the same for all, once the irrigation management adopted was the same, namely irrigation time was the same in all lots.

The average value for WUE in the CurupatiIrrigation Perimeter was 1.05 m^3 kg^{-1}, that is, for each 1.05 m^3 of water applied, 1 kg of papaya was produced. The standard deviation was 0.08 m^3 kg^{-1}, the coefficient of variation was 7.17%, and the minimum and maximum values for WUE were 0.93 and 1.23 m^3 kg^{-1}, respectively.

The greatest production was shown in lot 02, with a consequent greater efficiency in the use of water, 0.93 m^3 kg^{-1}, due to the irrigation management being suitable for the type of soil in the lot; unlike lot 08, which had the lowest production and consequently low water-use efficiency, 1.23 m^3 kg^{-1}.

This variation in water use efficiency is attributed to the types of soil in the Irrigation Perimeter. In lot 02 the soil is a Luvisol; these are soils of high natural fertility, endowed with clays with a high capacity for holding water and nutrients, and are commonly found in the Northeast of Brazil, where they are distributed mainly in the semi-arid region. However, in lot 08 the soil type is a Neosol; these are little-evolved soils, of sandy sediments with low water retention capacity, contributing significantly to the reduction in productivity, and consequently to the low water-use efficiency.

According to Gomes et al. (2008), the ratio of macro- to micro-pores in Neosols is large, given the high degree of rounding of the quartz grains that make up these soils and that favours significant vertical percolation of the water, reflected in high hydraulic conductivity. This, coupled with the low clay and low organic matter content, contributes to poor particle cohesion, almost total lack of aggregation, and an intense leaching process. As a result, the soils are also ecologically fragile, due to their low capacity for water and nutrient retention for plants (Zuo et al., 2008).

In relation to Luvisols, Maia Filho et al. (2013), in their study on the effect of manure on water consumption and sunflower production in two types of soil, found that plants grown in Luvisols showed better growth characteristics, with the soil type significantly affecting both the water consumption and water-use efficiency of the sunflower crop.

In this regard, it is worth noting that the soil type has a significant influence on water-use efficiency. Furthermore, irrigation management cannot be the same for all lots in the area, due to the variability of the soil. According to Tenhunen et al. (2002), soil moisture conditions significantly influence water-use efficiency in arid and semi-arid regions.

Therefore, even with the application of an excessive irrigation depth in relation to the projected irrigation depth, which will be different for each type of soil, the volume of water per kilogram of papaya produced was lower than values found by Souza et al. (2006), when studying irrigation efficiency for different types of soil texture in Irrigation Perimeters of Ceará.Those authors obtained results that displayed a range of values from 0.18 to 0.5 kg m^{-3}, showing that for a sandy-loam texture, only 0.18 kg of unhusked rice were produced for each 1.0 m^3 of water applied. Whereas, for a silty-clay texture, 0.5 kg of unhusked rice were produced for each 1.0 m^3 of water applied.

The values found for WUE can therefore be considered satisfactory, since irrigated agriculture in dry regions requires large quantities of water, whereas to produce one kilogram of grain in humid regions, less than 0.5 m^3 of water is needed; in arid regions this volume varies from 1.5 to 2.5 m^3 (Andrade and D'Almeida, 2006).

As per Tari (2016), who found values for water-use efficiency from 1.02 to 1.30 kg m^{-3}, in a study of the effects of different irrigation strategies on productivity, quality and water-use efficiency in a wheat crop under semi-arid conditions.

For Guoju et al. (2016), improving water-use efficiency is a key factor for the continual increase in crop productivity in arid and semi-arid regions. However, it is also important to point out the possible decrease in production due to increases in the WUE, since the improvement in yield under conditions of limited water with greater water-use efficiency is substantial, a reduction in water consumption would increase the WUE, but possibly reduce production (Blum, 2005, 2009).

In this context, the WUE is an important parameter in identifying constraints on improving the efficient use of water, as well as being a tool for increasing crop production and economising water, in addition to preserving the environment. It should be considered an important attribute in helping farmers increase their income through productivity and water savings, especially in areas deprived of water (Liu et al., 2013).

Conclusions

The low level of education associated with lack of knowledge of irrigation technique favors the decrease of WUE. In particular, the WUE was of 1.05 m^3 to produce 1 kg of papaya, expressing a productivity of 0.95 kg m^{-3}. The management of irrigation similar, adopted for the different types soils of Irrigated area affect significantly the water-use efficiency, as per observed in the variation of values of WUE from 0.93 to 1.23 m^3 kg^{-1}. Therefore, emphasize the level of instruction as irrigation strategy to improve WUE and productivity, in view of aspects observed regarding the level of knowledge of farmers with the technique of irrigation, notedly it becomes necessary to an instruction process of farmers with the purpose of capacitate them to the domain of technological degree that irrigation requires.

Conflict of interests

The authors have not declared any conflict of interests.

ACKNOWLEDGEMENTS

The authors wish to thank the Fundação Cearense de Apoio ao Desenvolvimento Científico e Tecnológico - FUNCAP, and the Secretária do Desenvolvimento Agrário do Estado do Ceará –DAS. Thanks also go to the Associação de Produtores do Perimetro Irrigado Curupati

REFERENCES

Andrade EM, Carneiro Neto JA, Rosa MF, Palácio HAQ, Rodrigues JO (2009). Classificação da sustentabilidade das unidades de produção agrícola no perímetro irrigado Araras Norte, Ceará. Sci. Agrária, Curitiba 10(2):157-164.

Andrade EM, D'Almeida DMBA (2006). A irrigação e os riscos de degradação dos recursos naturais. In: Rosa MF, Gondim RS, Figueirêdo MCB. (Editores Técnicos) Gestão Sustentável no Baixo Jaguaribe, Ceará. Fortaleza: Embrapa Agroind. Trop. pp. 221-244.

Blum A (2005). Drought resistance, water-use efficiency, and yield potential are they compatible,dissonant, or mutually exclusive. Aust. J. Agric. Res. 56:1159-1218.

Blum A (2009). Effective use of water (EUW) and not water-use efficiency (WUE) is the target of crop yield improvement under drought stress. Field Crops Res. 112:119-123.

Carvalho CM, Eloi WM, Lima SCRV, Pereira JMG (2006). Desempenho de um sistema de irrigação por gotejamento na cultura da goiaba. Irrigation 11(1):36-46.

Chaves LCG, Andrade EM, Crisostomo LA, Ness RLL, Lopes JFB (2006). Risco de degradação em solo irrigado do Distrito de Irrigação do Perímetro Araras Norte, Ceará, Rev. Ciênc. Agron. 37(3):292-298.

Chaves LCG, Santos JCN, Meireles ACM, Andrade EM, Araújo Neto JR (2009). Dinâmica da salinidade do solo em áreas do Distrito de Irrigação Araras Norte, Ceará. Rev. Ciênc. Agron., 40(4):522-532.

Coelho EF, Santos MR, Filho MAC (2005). Distribuição de Raízes de Mamoeiro SobDiferentes Sistemas de Irrigação Localizada em Latossolo de Tabuleiros Costeiros, Rev. Bras. Frutic. Jaboticabal 27(1):175-178.

FAO (Food and Agriculture Organization of the United Organizations) (2015). Productio Crops Primary. Disponível em:<http://faostat.fao.org/>. Acesso em: 10 de mai. de 2016.

Fonseca JS, Martins GA (1996). Curso de estatística. 6 ed. São Paulo: Atlas 320p.

Gomes EP, Testezlaf R (2007). Manejo de irrigação na tomaticultura de mesa. P 39.

Gomes MAF, Pereira AS, Queiroz SCN, Ferracini VL, Jardim ICSF, Diogo A (2008). Movimento do herbicida imazetapir em um NeossoloQuartzarênico típico e em um Latossolo de textura média das nascentes do rio Araguaia, município de Mineiros (GO). Pesticidas: Rev. Ecotoxicol. Meio Amb. Curitiba 18:115-122.

Guoju X, Fengju Z, Juying H, Chengke L, Jing W, Fei M, Yubi Y, Runyuan W, Zhengji Q (2016). Response of bean cultures' water use efficiency against climate warming in semiarid regions of China. Agric. Water Manage. 173:84-90.

INMET (Instituto Nacional de Meteorologia) (2016). Climatologia: mapas. Disponível em: <http://www.inmet.gov.br>. Acesso em:14 de abr. de 2016.

IPECE (Instituto de Pesquisas e Estratégia Econômica do Ceará) (2007). Disponível em: <www.ipece.ce.gov.br>. Acesso em: 03 de jun. de 2016.

Lacerda NB, Oliveira TS (2007). Agricultura irrigada e a qualidade de vida dos agricultores em perímetros do Estado do Ceará, Brasil. Rev. Ciênc. Agron. 38(2):216-223.

Lima JEFW, Ferreira RSA, Christofidis D (2010). O uso da irrigação noBrasil. Disponível em: <www.cf.org.br/cf2004/ irrigacao.doc>. Acessoem: 12 de maio de 2016.

Lima RSN, Figueiredo FAMMA, Martins AO, Silva de Deus BC, Ferraz TM, Gomes MMA, Sousa EF, Glenn DM, Campostrini E (2015). Partial rootzone drying (PRD) and regulated deficit irrigation (RDI) effects on stomatal conductance, growth, photosynthetic capacity, and water-use efficiency of papaya. Sci. Hortic. 183:13-22.

Liu X, Shao L, Sun H, Chen S, Zhang X (2013). Responses of yield and water use efficiency to irrigation amount decided by pan evaporation for winter wheat. Agric. Water Manage. 129:173-180.

Loomis RS (1983).Crop manipulations for efficient use of water: An overview. In:Taylor HM, Jordan WR, Sinclair TR. Limitations to efficient water use in crop production. (ed). Am. Soc. Agron., Crop Soc. Am. Soil Sci. Soc. Am., Madison WI. pp. 345-374.

Lopes FB, Andrade EM, Aquino DN, Lopes JFB (2009). Proposta de um índice de sustentabilidade do Perímetro Irrigado Baixo Acaraú, Ceará, usando análise multivariada.Rev. Ciênc. Agron. 40(2):185-193.

Lopes FB, Souza F, Andrade EM, Meireles ACM, Caitano RF (2011). Determinação do padrão do manejo da irrigação praticada no Perímetro Irrigado Baixo a Acaraú, Ceará, via análise multivariada. Irrig. Botucatu. 16(3):301-316.

Maia Filho FCF, Mesquita EF, Guerra HOC, Moura MF, Chaves LHG (2013). Effect of cattle manure on sunflower production and water use in two types of soil. Rev. Ceres Viçosa 60(3):397-405.

Medeiros SS, Soares AA, Ramos MM, Mantovani EC, Souza JAA (2003). Avaliação do manejo de irrigação no perímetro irrigado de Pirapora, MG. Rev. Bras. Engenharia Agríc. Ambiental. Campina Grande 7(1):80-84.

Melo AS, Suassuna JF, Fernandes PD, Brito MEB, Suassuna AF, Aguiar Neto AO (2010). Crescimento vegetativo, resistência estomática, eficiência fotossintética e rendimento do fruto da melancieira em diferentes níveis de água. Acta Sci. Agron. Maringá 32(1):73-79.

Peixoto JFS, Chaves LHG, Guerra HOC (2005). Uniformidade de distribuição da fertirrigação no distrito de irrigação Platô de Neopolis. Rev. Biol. Ciênc. Terra. 5(2).

Santos FSS, Viana TVA, Azevedo BM, Oliveira CW, Sousa AEC (2008). Efeito de diferentes lâminas de irrigação na cultura do mamão. Eng. Agríc. Jaboticabal 28(4):673-680.

Souza F, Barbosa FC, Teixeira AS, Costa RN (2006). Eficiência de Irrigação em Perímetros Irrigados do Estado do Ceará – Brasil. In: Red de Riegos CYTED, 2006, Texcoco. Red de Riegos CYTED. Madri, Programa Iberoamericano de Ciencia y Tecnología para El Desarrollo (CYTED), 2006. pp. 1-15.

Souza IH, Andrade EM, Silva EL (2005). Avaliação hidráulica de um sistema de irrigação localizada de baixa pressão, projetado pelo software "bubbler". Engenharia Agríc. Jaboticabal 25(1):264-271.

Tari AF (2016). The effects of different deficit irrigation strategies on yield, quality, and water-use efficiencies of wheat under semi-arid conditions. Agric. Water Manage. 167:1-10.

Tenhunen J, Roupsard O, Rambal S (2002). Severe drought effects on ecosystem CO_2 and H_2O fluxes at three Mediterranean evergreen sites: revision of current hypotheses? Glob. Change Biol. 8:999-1017.

Tolk JA, Evett SR, Xu W, Schwartz RC (2016). Constraints on water use efficiency of drought tolerant maize grown in a semi-arid environment. Field Crops Res. 186:66-77.

Vanzela LS, Hernandez FBT, Dourado LAC, Mauro F (2003). Tendência de adoção de tecnologias por parte dos irrigantes do cinturão verde em Ilha Solteira SP. In: Congresso Brasileiro de Engenharia Agríc., Goiânia. Anais... 1 CD ROM. v. 22.

Zuo X, Zhao H, Zhao X, Zhang T, GuoY, Wang S, Drake S (2008). Spatial pattern and heterogeneity of soil properties in sand dunes under grazing and restoration in Horqin Sandy Land, Northern China. Soil Till. Res. 99(2):202-212.