Water use efficiency and productivity of habanero pepper (Capsicum chinense Jacq.) based on two transplanting dates

Rutilo López-López, Marco Antonio Inzunza-Ibarra, Ignacio Sánchez-Cohen, Andrés Fierro-Álvarez and Ernesto Sifuentes-Ibarra

ABSTRACT

Habanero pepper production was assessed with drip irrigation and plastic mulch, based on two transplanting dates. The objectives of the study were: (i) to evaluate the effect of two transplanting dates and the use of plastic mulch on water productivity and habanero pepper fruit yield under drip irrigation conditions; and (ii) to determine the profitability and economic viability of the product in the regional market. The work was conducted in the municipality of Huimanguillo, state of Tabasco, Mexico, in loam soils classified as Eutric Fluvisol. The Jaguar variety of habanero pepper, developed by INIFAP and possessing better genetic and productive characteristics, was used. Two transplanting dates were studied, (i) 30 January 2013 and (ii) 15 February 2013, with and without plastic mulch. The conclusions were: (i) application of irrigation depths based on crop evapotranspiration (ETc) and plastic mulch transplanted on 30 January increased the fruit yield of the crop and improved the benefit–cost ratio of the production system; and (ii) water use efficiency based on the 30 January transplanting date was 8.68 kg m⁻³ of water applied with plastic mulch, 6.51 kg m⁻³ without plastic mulch, and 3.65 kg m⁻³ for the 15 February transplanting date with plastic mulch.

Key words | crop productivity, drip irrigation, plastic mulch, profitability, water use efficiency

INTRODUCTION

The habanero pepper is a traditional crop in southeastern Mexico. In 2012, 955.6 ha were planted with habanero pepper, resulting in production of 5,183.2 t. The state of Yucatan is the leading producer of habanero pepper with a planted area of 708.4 ha and a production volume of 3,295.2 t, followed by the states of Tabasco, Campeche, and Quintana Roo with 143, 51.2, and 36.5 ha, respectively (SIAP 2012).

The potential habanero pepper yield for the state of Tabasco in the spring–summer (S–S) cycle is 29.5 t ha⁻¹, and for the autumn–winter (A–W) cycle it is 31.2 t ha⁻¹. These yields are higher than the national average of 7.8 t ha⁻¹. At an experimental level, López & Mirafuentes (2004) reported yields of 27.5 t ha⁻¹, in the A–W cycle, which were obtained with a planting density of 22,300 plants per hectare using plastic mulch and fertigation.

Drip irrigation has played a major role in reducing the water applied to agricultural crops. Nevertheless, this method of irrigation has highlighted the need for improved irrigation methods, scheduling and control. For instance, Sezen et al. (2006) studied the effect of irrigation methods, irrigation frequency, and different pan coefficients on bell pepper yields under Ankara, Turkey conditions, obtaining a crop yield of 2.78 t ha⁻¹ with trickle irrigation using a 6-day irrigation interval and a pan coefficient of 0.5. Drip irrigation resulted in a similar crop yield compared to surface irrigation but 2.4 t ha⁻¹ higher than furrow irrigation, reducing the applied water volume.
The importance of irrigation water use efficiency (WUE) has increased in recent years and the surface drip irrigation method is an alternative that contributes in a sustainable way to rational water use by improving irrigation efficiencies for agriculture. Drip irrigation improves WUE, mainly through the efficient implementation of water volume (Stanghellini et al. 2003; Jones 2004; Kirnak & Demirtas 2006). With drip irrigation systems, water and nutrients can be applied directly to a crop’s root zone, having a positive impact on yield, saving water and increasing irrigation efficiencies (Phene & Howell 1984).

The bell pepper (Capsicum annuum L.) crop is classified as a plant sensitive to water stress (Doorenbos & Kassam 1986). It is usually grown during the A-W period in plantations of 1–2 ha and irrigated with water from shallow wells. This condition has been documented by several authors (Smitte et al. 1994; Delfine et al. 2001; Antony & Singandhupe 2004; Sezen et al. 2006) who studied yield reductions due to the effect of water stress.

There is a significant reduction in fruit yield when there are limitations on the amount of water applied during periods of vegetative growth, flowering, and fruiting (Doorenbos & Kassam 1986). Della Costa & Gianquinto (2002) state that continuous deficit irrigation (DI) significantly reduced the total fresh weight of fruit. The highest marketable yield was found at irrigation of 120% crop evapotranspiration (ETc); no significant differences in marketable production were found with 40, 60, 80, and 100% ETc. Antony & Singandhupe (2004) reported that total bell pepper production was lower at the lowest irrigation levels (40% ET). Dorji et al. (2005) compared traditional irrigation against the drip system with DI for growing pepper and found that the water saving by DI was approximately 50% compared to traditional irrigation.

The habanero pepper has been subject to comprehensive studies, especially under protected cultivation, on the effect of irrigation frequency and regimes on growth, yield, and WUE. However, in comparison with other vegetable crops grown under open-field conditions, there is little information on the influence of regulated DI on yield, growth, fruit quality, and WUE responses.

Transplanting time, for the vast majority of horticultural crops, is a factor of the utmost importance, because it has an effect on product marketing in regional and national markets, and consequently on crop productivity and irrigation WUE. The transplanting date should be the date when weather conditions and pests, mainly silver leaf whitefly (Bemisia tabaci), do not limit crop productivity and also when product prices on the market allow for an attractive return.

The objectives of the study were to: (i) determine the effects of two transplanting dates and use of plastic mulch on both the fruit yield and the WUE of the habanero pepper crop under drip irrigation conditions; and (ii) determine the profitability and economic viability of the product in regional and national markets.

MATERIALS AND METHODS

Experimental site

The study was conducted in a 2,600 m² area at the Huimanguillo Experimental Field, during the period from January to June 2013, in the municipality of Huimanguillo, Tabasco, Mexico, geographically located at 17°46’N and 91°28’W, at an altitude of 35 m. The climate is warm and humid, mean annual rainfall is 2,000 mm. Water was drawn from a deep well, which, according to the total salt and sodium content (E.C. = 0.5–0.7 dS m⁻¹), was classified as C₁S₁.

Physical and chemical soil properties

The soil used is classified as Eutric Fluvisol. The texture is clay loam, with a slightly acidic pH, and low organic matter content. Based on soil texture, at a depth of 0–20 cm, the bulk density, field capacity, and permanent wilting point are 1.35 g cm⁻³, 36%, and 18%, respectively.

Experimental design and treatments

The applied treatments were two transplanting dates, namely 30 January and 15 February 2013, with and without plastic mulch. The treatments were distributed in a completely randomized design with four replications. The experimental unit consisted of three, five-meter-long rows (15 m²), where the variable green fruit yield per cut and total yield was recorded.

Seedling production in trays and planting density

Habanero pepper seeds were sown on 18 December 2012 in 200-cavity trays. The Jaguar variety was used. The substrate was peat moss plus vermiculite (1:1). The seedlings were irrigated with Steiner nutrient solution (50% diluted). Seventy trays were sown, based on spacing of 1.5 m between rows.
and 0.4 m between plants, for a planting density of 16,500 plants per hectare.

**Land preparation, adaptation, and plastic mulch installation**

Land preparation consisted of making three passes at a depth of 35 cm with heavy harrows and creating planting beds with a two-disc harrow. Once the planting bed was built and the irrigation tubing placed, silver and black plastic mulch was installed manually. The mulch was 1.2 m wide, for a 0.6-m bed, and 2.28 mm thick (gauge). Partial perforations of 6 cm in diameter and 40 cm apart were made.

**Transplanting**

Transplanting was performed at 35 days after emergence in the trays; seedling characteristics at the time of transplanting were 10 cm in height, 2 mm in diameter, and six to eight fully expanded true leaves.

**Irrigation**

To estimate crop water needs, the class-A pan evaporation method was used for calculating reference evapotranspiration (ET₀) from Equation (1).

\[
ET₀ = EvK_t
\]  

where \( Ev \) is the daily evaporation obtained in a weather station pan located in the Huimanguillo Experimental Field, \( K_t \) is the pan coefficient assumed equal to 0.8 (Door-enbos & Pruitt 1977; Allen et al. 2006). The values of the crop coefficient \( K_c \) were obtained from Allen et al. (2006) for green peppers without plastic mulch and were: 0.6, 1.05, and 0.9 in the initial (vegetative), middle (flowering), and final (maturation) crop development stages, respectively. The adapted \( K_c \) for habanero pepper with plastic mulch were 0.4, 0.8, and 0.7 in the vegetative, flowering, and maturation stages, respectively. With the \( K_c \), ETc was estimated using Equation (2).

\[
ET_c = ET₀K_c
\]  

The drip irrigation method was used. Nominal characteristics were 16 mm internal diameter, 6 mil (0.15 mm) gauge, 1.02 L h⁻¹ flow, spacing between emitters of 0.2 m, and 55.2 kPa (8 psi) pressure. Soil moisture was monitored using tensiometers and watermark sensors at 15 and 30 cm deep.

**Fertigation**

Base fertilization consisted of applying 100 kg of diammonium phosphate, equivalent to 18 kg of nitrogen and 46 kg of phosphorus, at the time of building the beds and placing the plastic mulch. The fertilization formula applied in the fertigation was 200-150-80, distributed according to the phenological stage of the crop (initial, middle, and final). The sources of soluble fertilizers were Fertigro liquid by Cosmocel S.A. (8-24-00; Monterrey, México), ammonium sulfate (21-00-00), monoammonium phosphate (12-60-00), potassium nitrate (13-00-46), and 20% phosphoric acid. Fertigation application frequency was twice a week. Fertilizers were injected using a venturi injector (Mazzei Injector Company, LLC, Bakersfield, CA, USA).

**Pest and disease control**

This was done using trap crops of corn (Zea mays L.) planted along the edges of the terrain and applications of insecticides such as cypermethrin, endosulfan, and methamidophos at doses of 0.5, 1, and 1 L ha⁻¹, respectively. The broad mite (Polyphagotarsonemus latus) was controlled with spirodiclofen (envidor) and abamectin (biomec, hortimec, and agrimec) at doses of 240 g ha⁻¹ of active ingredient and 0.5 L ha⁻¹, respectively. The silverleaf whitefly (B. tabaci) appeared in April and was combated using insecticides based on imidacloprid, deltamethrin, and ethyl chlorpyrifos plus permethrin. Disease prevention was performed with mixtures of carbendazim at a ratio of 1 plus 2 cc. of propamocarb hydrochloride per liter of water. For the prevention of fungal and bacterial diseases, copper oxychloride plus terramycines (oxytetracyclines) were used, respectively.

**Harvest**

The harvest began when a high percentage of fruits showed the characteristic crop harvest indices: deep green color and hard texture. There were a total of eight cuts over 2.5 months (April, May, and June).

**Measurement variables**

ETc were calculated from reference evapotranspiration and the adapted crop coefficients. Green fruit yield was obtained.
from eight cuts made during the harvest period; direct and investment costs and net income based on an average product price of US$1.13 per kilogram were obtained.

WUE was obtained by dividing the total green fruit yield in kg ha⁻¹ by the total water supply in m³ ha⁻¹ (Ismail 2010).

**Statistical and economic analysis**

Analysis of variance and Student’s t-tests were performed for the two populations (Equation (3)) for the variable fruit yield and irrigation WUE.

\[
t_0 = \frac{(X_A - X_B)}{S_p \sqrt{\frac{1}{n_A} + \frac{1}{n_B}}}
\]

where \(X_A\) and \(X_B\) were the population mean \(A\) and \(B\), respectively; \(S_p\) was the weighted standard deviation and \(n_A\) and \(n_B\) were the number of samplings of the population \(A\) and \(B\), respectively. The null hypothesis was \(H_0: X_A = X_B\) vs. \(H_1: X_A \neq X_B\). \(H_0\) was turned down if \(t_0 > t_{\alpha/2}(n_A + n_B - 2)\).

The treatments were compared using Tukey’s test (\(\alpha = 0.05\)). The economic analysis was performed using the income analysis method for annual crops projected for the next 10 years (Gittinger 1985).

**RESULTS AND DISCUSSION**

**Irrigation water use efficiency**

The rainfall amount during the experimental cycle of the crop for the 30 January transplanting date to 31 May was 262.5 mm, and the irrigation depth applied was 363.5 mm with plastic mulch and 415 mm without it. For the 15 February transplanting date to 15 June (crop cycle), the rainfall amount was 439.5 mm, and the irrigation depth applied was 315 mm. Under rain-fed agriculture, rainfall depth has an effect on the soil matric potential; nevertheless, in this case, the water, when in contact with the plastic mulch, ran off to the walkways and percolated, or it was directed to the drains to prevent possible diseases.

The irrigation depths correspond to the crop evapotranspiration previously estimated based on pan evaporation and crop coefficients adapted for the different phenological stages of the habanero pepper. Based on green fruit yields obtained in the three treatments and the irrigation depth applied, WUE was 8.68 and 6.51 kg m⁻³ for the 30 January date, with and without plastic mulch, respectively (Table 1). The lowest WUE value, 3.65 kg m⁻³, was obtained for the 15 February transplanting date. Nagaz et al. (2012) found lower WUE values in bell pepper (Capsicum annum L.), between 2.31 and 5.49 kg m⁻³, which varied depending on irrigation depths applied with different DI equivalents (394–750 mm).

Irrigation WUE when plastic mulch was used was greater than when it was not used on the 30 January transplanting date, and it was also significantly different with respect to the 15 February date. Clearly, the plastic mulch significantly increased WUE under the experimental conditions; however, the vast majority of researchers report water productivity based on applied depth and not crop evapotranspiration.

In the first soil layer (15 cm), moisture tension was 0 to −18 kPa throughout the crop cycle, while in the 30-cm soil layer, moisture tension ranged from −8 to −25 kPa. The soil moisture tension values indicated that the irrigation depths applied to the crop were sufficient to meet crop water requirements, i.e., the effort that the plant makes to absorb water through its roots did not reach critical moisture tension levels, or less than field capacity (< −33 kPa). Applied irrigation depths ranged from 2.5 to 7 mm per day, based on the estimation of crop evapotranspiration. The use of adapted crop coefficients, taking into account the plastic mulch, allows increasing WUE, and as a result, there were water savings of approximately 18.5% compared with the crop coefficients proposed by Allen et al. (2006), for growing green pepper (0.6, 1.05, and 0.9).

**Table 1** | Effect of plastic mulch and transplanting date on fruit yield and water use efficiency of habanero pepper

<table>
<thead>
<tr>
<th>Source</th>
<th>Yield (t ha⁻¹)</th>
<th>Stan. dev. (t ha⁻¹)</th>
<th>WUE (kg m⁻³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cover</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>With plastic</td>
<td>27.44 a</td>
<td>2.61</td>
<td>8.68 a</td>
</tr>
<tr>
<td>Without plastic</td>
<td>20.52 a</td>
<td>5.10</td>
<td>6.51 b</td>
</tr>
<tr>
<td>Mean</td>
<td>23.98</td>
<td>4.05*</td>
<td>7.60</td>
</tr>
<tr>
<td>HSD</td>
<td>7.01</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transplanting date</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>13 January 2013</td>
<td>27.40 a</td>
<td>2.61</td>
<td>8.60 a</td>
</tr>
<tr>
<td>15 February 2013</td>
<td>11.47 b</td>
<td>3.26</td>
<td>3.65 b</td>
</tr>
<tr>
<td>Mean</td>
<td>19.45</td>
<td>2.94*</td>
<td>6.12</td>
</tr>
<tr>
<td>HSD</td>
<td>5.11</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Values are accumulated averages of eight cuts at Huimanguillo Experimental Field. Values with the same letter within a column are equal according to Tukey’s test with \(P < 0.05\); HSD: honestly significant difference. *Weighted standard deviation.
Effect of plastic mulch on fruit yield

Analysis of variance in fruit yield showed significant differences among treatments \( (P = 0.052) \). Tukey’s test \( (\alpha = 0.05) \) indicated that the effect of plastic mulch on fruit yield with the 30 January transplanting date was statistically the same as the effect without the mulch (Table 1).

An average fruit yield of 27.44 t ha\(^{-1}\) was obtained with the plastic mulch, compared to 20.52 t ha\(^{-1}\) without it, representing a 25.2% increase in fruit yield. This value exceeds the average experimental yield obtained by López & Mirafuentes (2004), which was 22 t ha\(^{-1}\), and was similar to the productive potential of improved varieties, which is 30 t ha\(^{-1}\) for spring–summer and A–W cycles.

Figure 1 shows the fruit yield of habanero pepper per cut, revealing that in cut number 2, the maximum values of 9.5 t ha\(^{-1}\) with plastic mulch and 4.7 t ha\(^{-1}\) without it were reached.

These differences in fruit yield, although not as notable as in other crops, were due to the plastic mulch increasing crop yield (biomass) and harvest precocity. There was a temperature rise and a general increase in crop transpiration due to the transfer of sensitive and reflexive heat from the surface of the plastic mulch to the adjacent vegetation. Allen et al. (2006) stated that the transpiration rate of crops in the plastic mulch increases by an average of 10–30% during the crop cycle; by contrast, without plastic mulch, \( K_c \) decreases by an average of 10–30% due to the reduced evaporation in the soil, estimated at 50–80%.

It is worth mentioning that the agronomic practices, such as pesticide use, were those of common use in that part of the country (southeast). These practices have proven to diminish the damage caused by insects.

Effect of transplanting date on fruit yield

The analysis of variance presented in Table 1 shows the difference in fruit yield between the two transplanting dates evaluated \( (P < 0.001) \). With the 15 February transplanting date, the lowest fruit yield values \( (11 \text{ t ha}^{-1}) \) were obtained due to the high temperatures, above 40 °C (Figure 2), which occurred during the final growing period, and the resulting high incidence of silverleaf white fly \( (B. \text{ tabaci}) \). Figure 3 shows the effect of the transplanting dates on the different pepper cuts. Differences can be observed in fruit yield, showing higher values for January. The 30 January transplanting date significantly increased \( (P \leq 0.01) \) fruit yield by 58% compared to that of 15 February, because the crop transplanted on the latter date was affected by silverleaf whitefly \( (B. \text{ tabaci}) \) as a result of increasing temperatures in the months of April and May.

Economic analysis

The profitability analysis of the habanero pepper production system with drip irrigation and plastic mulch is presented in Table 2. The benefit–cost ratio (BCR) was 3.32, based on an average selling price of US$1.3 per kg. Direct crop costs

![Figure 1](https://iwaponline.com/wst/article-pdf/71/6/885/468862/wst071060885.pdf)  
**Figure 1** | Yield of habanero pepper with drip irrigation, with and without plastic mulch.
were US$22,843 per hectare, plus investment costs of US$2,592.6 for the irrigation system. Direct crop costs correspond to practices carried out including land preparation, seedling production in trays, fertigation, pest and disease control, and final harvesting. Investment costs were for the construction of a deep well (10.2 cm in diameter and 18 m in depth), plus the acquisition of the drip irrigation system. Economic analysis indicates that the crop has a return from the first year, based on an average yield of 22 t ha\textsuperscript{-1} and an average price of US$1.13 per kg. Cash flow is positive from the first year (US$15,929) and the most attractive financial efficiency indicators, such as net present value (NPV), internal rate of return (IRR), and BCR, were obtained. For the 15 February transplanting date, lower financial indicators were obtained: a benefit–cost ratio of 1.66, with an IRR of 48.21% and cash flow from the first year of US$3,707.4, based on a yield of 11 t ha\textsuperscript{-1}. The results obtained in real terms are presented in Table 2. The profitability of growing

Figure 2 | Variation of maximum and minimum temperatures, precipitation, and irrigation depths during habanero pepper crop cycle.

Figure 3 | Effect of two planting dates on fruit yield in kg ha\textsuperscript{-1} per cut in the growing of habanero pepper with drip irrigation.
habanero pepper is greater if plastic mulch is used and transplanting is done in January, since it reaches average product prices in the range of US$1.6 per kg of green fruit.

**CONCLUSIONS**

The combination of plastic mulch and drip irrigation has proven its efficacy in terms of both WUE and economic productivity. The application of irrigation depths, based on crop evapotranspiration, and the application of plastic mulch along with the 30 January transplanting date increased fruit yield by 25.2% and water productivity by 29.7% compared to treatment without plastic mulch and by 57.5% compared with the 15 February transplanting date.

**REFERENCES**


López, L. R., Mirafuentes, H. F. 2004 Sistema de fertirrigación y acolchado plástico en la producción de chile habanero (*Capsicum chinense* Jacq) (Fertigation system and plastic mulch for the production of habanero pepper (*Capsicum chinense* Jacq). In: *Primera Convención Mundial del Chile* (Consejo nacional de productores de chile, ed). (First World Chile Convention (National Chile producers Council.)) 27–29 junio, León, Gto, México, pp. 223–229.


