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EFFECTS OF IRRIGATION METHODS ON THE GROWTH, YIELD AND WATER USE EFFICIENCY OF TOMATOES IN RED RIVER DELTA ALLUVIAL SOIL

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ABSTRACT

This experiment was conducted during the winter of 2014 on the alluvial soils of the Red River delta to evaluate the effect of irrigation method on the growth, yield and water use efficiency of tomato. Soils used for experiments are alluvial, neutral, less acidic, not silted annually. Experimental results have shown that drip irrigation positively affected growing period, plant height, fruiting rate, yield and water use efficiency. Drip irrigation prolonged tomato growing period from 6 - 11 days compared to furrow irrigation; plant height in the treatments with drip irrigation was also higher compared with furrow irrigation. The fruiting rate in the treatments with drip irrigation was higher than in furrow irrigation, the highest fruiting rate was obtained in drip treatment T4 with (70 - 100)% βdr (βdr is field capacity) of 71.3%. Drip irrigation has increased individual yield of tomato plants from 8.9 - 36.3%, while reduced the amount of irrigation water from 22 - 39.1% and water use efficiency increased from 30 - 57% compared to furrow irrigation. The drip irrigation treatment with (70 - 100)% βdr (T4) achieved highest individual yield and water use efficiency (2788.2 gplant^{-1}; 16 kgm^{-3}).

Keywords: Drip irrigation, Red river delta, tomato, water use efficiency.

Ảnh hưởng của phương pháp tưới đến sinh trưởng, năng suất và hiệu quả sử dụng nước của cà chua trên đất phù sa sông hồng

TÓM TẮT

Thí nghiệm được tiến hành trong vụ đông năm 2014 trên đất phù sa sông Hồng nhằm đánh giá ảnh hưởng của phương pháp tưới đến sinh trưởng, năng suất và hiệu quả sử dụng nước của cây cà chua. Đặc tính đất thí nghiệm là đất phù sa trung tính ít chua không được bồi hàng năm. Kết quả thí nghiệm cho thấy, tưới nhỏ giọt ảnh hưởng tích cực đến thời gian sinh trưởng, chiều cao cây, tỷ lệ đậu quả, năng suất và hiệu quả sử dụng nước. Tưới nhỏ giọt kéo dài thời gian sinh trưởng của cây cà chua từ 6 - 11 ngày so với tưới rãnh và chiều cao cây ở các công thức tưới nhỏ giọt cũng cao hơn so với tưới rãnh ở giai đoạn 10 tuần sau trồng.Tỷ lệ đậu quả của cây cà chua ở các công thức tưới nhỏ giọt cao hơn so với tưới rãnh, cao nhất là công thức tưới nhỏ giọt (70-100)% $\beta_{đr}$ (CT4) 71,3%. Tưới nhỏ giọt làm tăng năng suất cá thể của cây cà chua từ 8,9 - 36,3%, đồng thời tiết kiệm được lượng nước tưới từ 22 - 39,1% và tăng hiệu quả sử dụng nước từ 30 - 57% so với tưới rãnh. Trong đó công thức tưới nhỏ giọt (70 - 100)% $\beta_{đr}$ (CT4) đạt năng suất cá thể và hiệu quả sử dụng nước cao nhất (2788,2 g/cây; 16 kg/m^3).

Từ khóa: Cà chua, đất phù sa sông Hồng, hiệu quả sử dụng nước, tưới nhỏ giọt.

1. INTRODUCTION

In agricultural production, water has a very important role. According to FAO, watering is the leading determinant, is an indispensable demand, serves to regulate nutrients, aeration, microorganisms in the soil, and directly impacts productivity. The yield of irrigated crops has been showen to increase over rain fed crops: the yield of irrigated potato increased from 65 - 74%

compared to non-irrigated one (Nguyen Thi Hang Nga and Le Thi Nguyen, 2004); irrigated beet yield increased 69.8% compared to non-irrigated one; soybean yield increased from 2.9 tons ha^{-1} (non-irrigated) to 4.9 tonnes ha^{-1} (irrigated) (Babovic *et al.*, 2006); irrigated spring groundnut yield in the Northern hills may be increased by 43% compared to non-irrigated (Tran Hung *et al.*, 2011); and irrigated tomato yield increased 51.7% compared to non-irrigated (Helyes *et al.*, 2012). According to Subba Reddy *et al.* (2015), tomato yield increased by 15.5% (by furrow irrigation) and 76.1% (by drip irrigation) compared with non-irrigated. However, in the current context of increasing water demand of economic sectors, water resources are facing depletion (Schaible and Aillery, 2012), the objective of irrigation is not only to achieve high output per unit area, but also to save irrigation water.

Tomato (*Lycopersicon esculentum* Miller) belongs to the Solanaceae family and is a valuable nutrious fruit vegetable, with high economic value and nutrient value, is a favorite food, and is a priority vegetable having strong development trends for both quality and quantity. Tomato is grown in many different eco-regions in Vietnam.

The Red River delta is the region with suitable climatic and soil conditions for tomato plants' development. The main tomato season is in winter, and growing in the driest months of winter, water crisis occurs in the period from flowering to ripening, which lasts approximately 2 months. Soil has insufficient levels of moisture at this stage which may lead to anincrease in the rate of flowers falling, small fruits, andstalled growth (Ta Thu Cuc, 2004). Providing enough water and keeping the soil moist during this period is very important.

Currently, the supply of water for crops in Vietnam is still mainly by traditional irrigation methods such as furrow irrigation or strip irrigation. However, these irrigation methods have the disadvantage of being difficult to control the amount of water, moisture distribution is uneven, and theyusea lotof water. In conditions ofmore scarce water resources day by day, the application of modern water-saving irrigation methods is necessary. The drip irrigation method is a high-tech irrigation method and overcomes the disadvantages of the traditional irrigation methods (Pham Ngoc Hai *et al.*, 2007). In the drip irrigation method, water is delivered to the root horizon with an exact amount and thereby saves water, growth and yieldare increased,and it leads to high water use efficiency (Raina *et al.*, 1999; Imtiyaz *et al.*, 2000; Rajbir singh *et al.*, 2009; Subba Reddy *et al.*, 2015).

In recent years in Vietnam, the situation of research and application of drip irrigation focuses primarily on key industrial plants such as coffee and tea, fruit crops of high economic value such as grape, orange, and grapefruit, and medicinal plants (Nguyen Quang Trung, 2006; Ha Van Thai, 2007; Tran Chi Trung, 2010; Tran Hung and Duong Thi Bich Van, 2012). Other vegetables such as tomato, cabbage, potato, etc. have not been focused on, especially in mass production conditions. Hence the widespread adoption of drip irrigation technology for vegetable crops in general and for tomato production in particular is very limited.

The purpose of this study was to evaluate the effect of irrigation methods on the growth, yield and water use efficiency of winter tomato on Red River alluvial soils, thereby providing recommendations for appropriate water saving irrigation methods, which provide the highest yield and contribute to rationale completion for drip irrigation in tomato farming.

2. MATERIALS AND METHODS

2.1. Materials, location, time

Tomato variety: Savior F1 hybrid variety has a semi-finite growth.

Irrigation method: furrow irrigation and drip irrigation methods.

Location: experiment field, Faculty of Land management, Vietnam National University of Agriculture.

Soil type: Eutric Fluvisols

Study time: from Oct. 2014 to Mar. 2015

Meteorological conditions during the study are shown in Table 1.

The study period was winter – spring, therefore the precipitation was very small, the total rainfall was 323.2 mm in whole cropping season, mainly in Oct. 2014. Rainfall in the remaining months was negligible. The highest average temperature was 26.4°C and the lowest was 17.1°C.

2.2. Methods

* Soil characteristics

Texture: Robinson (pipette)

Bulk density: cylinder method

Moisture: cylinder method, calculate by % of dry soil weight

pH(KCl): pH meter

OC%: Walkley&Black

P_2O_5avai.: Oniani

K_2Oavai.: Matslova, measure by flame photometer

Hydrolysis N: Tiurin and Kononova.

* Experiment arrangement

Soil moisture, to ensure normal tomato growth and development, was from 70 - 75% of field capacity (Ta Thu Cuc, 2004; standard 10 TCN 219: 2006). Therefore, experimental irrigation treatments were built on the basis of moisture at 60 - 80% of field capacity. With the drip irrigation method, irrigation treatments were divided into 3 irrigation limits (60 - 70%; 70 - 100%; 80 - 100% of field capacity (β_{dr})).

The experiment consisted of 5 treatments, distributed in randomized complete blocks with 3 replicates and 15 treatment plots in total. The area of each plot was 6m^2 (6 m x 1 m), treatment plots were raised into beds 20cm high and between plots was a 30 cm wide furrow.

Treatment 1 (T1): no irrigation

Treatment 2 (T2): Furrow irrigation

Treatment 3 (T3): Drip irrigation to (60 - 100)% field capacity (β_{dr})

Treatment 4 (T4): Drip irrigation to (70 - 100)% field capacity (β_{dr})

Treatment 5 (T5): Drip irrigation to (80 - 100)% field capacity (β_{dr})

* The technical procedures that apply standard 10 TCN 219: 2006

* Density, space of plants: 32000 plants ha^{-1}, 60 cm x40 cm

* Fertilizer: Treatments were applied the same fertilizer base, fertilizer method and dose was following the technical procedure for 1 ha: 02 tons of Song Gianh microbiological fertilizer + 100kg N + 80kg P_2O_5 + 120 kg K_2O

Application method: base fertilizer: 100% of microbiological fertilizer + 100% P_2O_5 + 1/3 N + 1/3 K_2O. The left N and K_2O were divided into 3 doses for top dressing in 3 stages: flowering, first harvest and main harvest.

Irrigation: Irrigation was according to the soil moisture.

- For furrow irrigation (T2): the amount of water was calculated with the irrigation limit (70-100)% β_{dr}. Water was brought into the furrow with 5 cm diameter hoses and flow of 0.5 L sec^{-1}.

Table 1. Meteorological data during the study (Oct. 2014 - Mar. 2015)

Year	2014			2015		
Month	10	11	12	1	2	3
Rainfall (mm)	146.7	35.1	18.6	29.7	20.4	72.7
Ave. temperature (^{0}C)	26.4	22.7	17.1	17.7	19.1	21.6
Air humidity (%)	78	82	71	81	85	90
Daily evaporation (mm)	3	2.3	2.8	2.1	1.6	1.3

Source: Meteorological data from HaDong station, Hanoi 2014, 2015.

- For drip irrigation (T3, T4, and T5): the amount of water was calculated with the respective irrigation limit.

PE irrigation pipe was used. The main pipe's diameter was 25 mm, the branch pipe's diameter was 06 mm and drippers were placed close to the plant roots so every plant had 1dripper with a flow of 0.43 L hr^{-1}.

* The observed indicators

Soil moisture:

Soil moisture was measured at the depths of active tomato roots, the soil was divided into layers of 0 - 5 cm, 5 - 10 cm, 10 - 15 cm, 15 - 20 cm, 20 - 25 cm, and 25 - 30 cm.

Soil samples were taken at each depth with 3 replicates by hand auger. Soil moisture was calculated as percentage by dry soil weight.

Observations of the growth and yield:

+ Growth targets: growing time, plant height

+ The yield component factors: number of flowers/plant, number of fruits/plant, fruiting rate, average fruit weight, individual productivity, theoretical productivity, actual productivity.

2.3. Data analysis

The data were processed by the analyzed using the Statistical Tool for Agricultural Research (STAR).

3. RESULTS AND DISCUSSION

3.1. Some soil characteristics

- pH_{KCl} 7; OC 1.92%;
- P_2O_5avai.: 332 mg kg^{-1} soil;
- K_2Oavai.: 55.3 mg kg^{-1} soil;
- N: 80.5 mg kg^{-1} soil
- Texture: clay 5.7%, limon (silt) 40.3%, sand 54%
- Bulk densityd = 1.3gcm^{-3}
- Field capacity β_{dr} = 32.24% (of dry soil weight)
- Permanent wilting point β_h = 12.16% (of dry soil weight)

The soil is alluvial soil, silt texture, neutral acidity, quite high in organic matter, and rich in available nitrogen and phosphorous. The soil bears the typical basic characteristics of Red River alluvial soil (Siderius, 1992; Tran Van Chinh *et al.,* 2006).

3.2. Effects of irrigation methods on tomato growth

Results in Table 2 showed that irrigation did not affect the plant growth period from planting to flowering, but delayed fruit formation by 5 to 9 days and extended plant growth from 3 to 14 days compared to the control treatment (T1).

Irrigation treatments made tomatoes ripen later and extended the growing period, however drip irrigation treatment of 70-100% β_{dr} (T4) made tomatoes ripen later and they had 14 days longer growing period compared to the control treatment. While other drip irrigation treatments (T3, T5) extended the growing period by 9 days, the shortest growth period was for the furrow irrigation treatment (T2), which was extended by 3 days compared with no irrigation. This can be explained in that drip irrigation, water and nutrients are absorbed slowly into the soil around the base of the plant, so the time providing nutrients and water is longer and soil moisture is distributed more evenly (Pham Ngoc Hai *et al.*, 2007).

Table 2. Effects of irrigation methods on tomato growth

Treatment	Duration from plant date to … (days)			
	Flowering	Fruit formation	First harvest	Last harvest
T1	35	44	95	153
T2	34	45	101	156
T3	34	45	101	162
T4	35	46	104	167
T5	33	44	100	162

3.3. Effects of irrigation methods on the plant height

Experimental results showed that irrigation significantly affected plant height through several stages compared to the not irrigated control. Tomato height in the irrigation treatments increased rapidly from 4 weeks after planting at a rate of 10.5 to 12.6 cm $week^{-1}$, while the non-irrigation treatment had a weekly growth rate of only 8.6 cm $week^{-1}$. Plant height increased the most in weeks 6 and 7 after planting. In the period of 10 weeks after planting, plant height in the irrigated treatments was from 6.4 to 22.2 cm higher than in the non-irrigated one. These results were similar to the studies of Imtiyaz *et al.* (2000) and Rajbir Singh *et al.* (2009).

Different irrigation methods had different effects on plant height in the observed stages, and this difference was evident in the period of 10 weeks after planting. The drip irrigation methods (T3, T4, T5) all increased plant height compared with the furrow irrigation treatment (T2). The height difference between the treatments of the drip irrigation and the furrow irrigation were from 4.2 to 15.8 cm. These results are similar with the results of the study by Subba Reddy *et al.* (2015).

However, among the drip irrigation methods, different drip irrigation treatments affected plant height differently. The drip irrigation treatment of 70 - 100% β_{dr} (T4) increased the plant height the highest by 111.4 cm, greater than the plant height in the T3 and T5 treatments in this observing period (99.8 and 101.3 cm).

3.4. Effect of irrigation methods on fruiting rate

The results in table 4 show that irrigation and the irrigation methods did not have much affected on the number of racemes, but significantly affected the number of flowers and the number of fruits on the plant so the fruiting rate increased in comparison with the control treatment. The fruiting rate increased from 3.6% - 14.4% compared with no irrigation.

The drip irrigation methods had a positive effect in that they increased the tomato fruiting rate higher than furrow irrigation from 0.9 to 10.8%, but the results were uneven. The drip irrigation treatment with a moisture limit of 70 - 100% β_{dr} increased the fruiting rate the most by 71.3%, followed by the two drip irrigation treatments with moisture limits of 80 - 100% β_{dr} (T5) and 60 - 100% β_{dr} (T3) with lower fruiting rates (64.6% and 61.4%, respectively), and these two treatments were significantly different from one another. These results are consistent with research by Liu *et al.* (2009). According to the authors, different soil moisture limiting drip irrigation methods affected tomato fruiting rate differently.

Table 3. Effect of irrigation methods on the plant height

Treatment	Plant height (cm)							
	3TST	4TST	5TST	6TST	7TST	8TST	9TST	10TST
T1	20.4	29.0	36.9	55.2	70.0	78.5	84.8	89.2
T2	21.0	33.6	42.2	61.8	79.4	85.5	92.2	95.6
T3	21.5	32.0	42.8	62.3	81.0	86.2	93.2	99.8
T4	23.9	35.0	46.8	66.4	85.1	94.4	102.1	111.4
T5	22.3	33.5	43.2	63.9	81.5	88.9	95.1	101.3
$LSD_{0.05}$	*2.26*	*3.77*	*5.78*	*6.96*	*9.37*	*9.59*	*10.26*	*13.16*
CV (%)	*5.49*	*6.13*	*7.24*	*5.97*	*6.27*	*5.88*	*5.83*	*7.03*

Note: TST: weeks after planting

Table 4. Effect of irrigation methods on the fruiting rate of Saviortomato variety

Treatment	Number of racemes/plant	Number of flowers/plant	Number of fruits/plant	Fruiting rate (%)
T1	7.9	40.6	23.1	56.9
T2	8.8	45.2	27.3	60.5
T3	9.7	47.4	29.1	61.4
T4	11.7	52.3	37.3	71.3
T5	10.6	47.9	30.7	64.6
$LSD_{0.05}$	*1.57*	*7.05*	*5.41*	*8.86*
CV (%)	*8.55*	*8.02*	*9.76*	*7.48*

Table 5. Effect of irrigation methods on tomato yield

Treatment	Number of fruits/plant	Ave. fruit weight (gfruit^{-1})	Individual yield (g plant^{-1})	Theoretical yield (tons.ha^{-1})	Actual yield (tons.ha^{-1})
T1	23.1	59.4	1377.9^{c}	44.1	36.1^{c}
T2	27.3	65.7	1775.7^{b}	56.8	49.8^{b}
T3	29.1	66.9	1949.0^{b}	62.4	51.6^{ab}
T4	37.3	75.1	2788.2^{a}	89.2	60.3^{a}
T5	30.7	67.3	2066.1^{b}	66.1	53.0^{ab}
$LSD_{0.05}$	*5.41*	*9.11*	*433.08*	*13.86*	*9.92*
CV (%)	*9.76*	*7.24*	*11.55*	*11.55*	*10.50*

Note: - The same letter in the same column displays a insignificant difference, different letters in the same column displays a significant difference.

3.5. Effect of irrigation methods on tomato yield

Irrigation had a positive impact on the average fruit weight. The results in table 5 showed that the average fruit weight in the non-irrigated control treatment was quite lower than those of the irrigated treatments, from 6.3 to 15.7 g fruit^{-1}. However, the average fruit weight of the different irrigation methods was unevenly different. The average fruit weight was highest in the drip irrigation treatment with70-100% β_{dr} and was 75.1 g fruit^{-1}, while the remaining irrigation treatments (T2, T3, T5) had approximately the same average fruit weight.

Table 5 also shows that the tomato yield in the drip irrigation treatment was higher than in the furrow irrigation treatment and the non-irrigated control treatment. The difference in yield between treatments with irrigation and without irrigation was significant at the 95% confidence level.

In the drip irrigation methods, individual yield was highest in the drip irrigation treatment with 70 - 100% β_{dr}, 2788.2 g plant^{-1}, followed by the treatment with 80 - 100% β_{dr} (T5) with a yield of 2066.1 g plant^{-1} and the drip irrigation treatment with 60-100% β_{dr} (T3) with a yield of 1949.0 g plant^{-1}. This can be explained that with drip irrigation methods, if soil moisture was kept at more than 80% or less than 65% at the stage of developing fruit, tomato yield would be reduced. Yield would be higher if soil moisture was maintained from 70-75% of field capacity in the periods of flowering and fruiting (Liu *et al.*, 2009).

The furrow irrigation treatment got the lowest individual yield among the irrigation treatments (1775.7 g plant^{-1}), from 8.9 - 36.3% lower than the drip irrigation treatments. Several previous research studies also presented similar results, in that tomato yield in furrow irrigation was from 40% (Bafna *et al.*, 1993; Raina *et al.*, 1999) to 52% (Subba Reddy *et al.*, 2015) lower than in drip irrigation.

Table 6. Total irrigation water amount and water use efficiency of tomato

Treatment	Actual yield (tonsha^{-1})	Total irrigation water (m^{3}ha^{-1})	Water use efficiency (kgm^{-3})
T1	36.1	-	-
T2	49.8	4900	10.2
T3	51.6	3521	14.7
T4	60.3	3770	16.0
T5	53.0	4016	13.2

3.6. Effects of irrigation methods on water use efficiency of tomato

Different irrigation treatment had different total irrigation water amounts. The furrow irrigation treatment (T2) had from 22 to 39.1% greater irrigation water usage than that of drip irrigation, and the drip irrigation treatment with 60 - 100% β_{dr} (T3) had the lowest total irrigation water amount.

Water use efficiency is defined as the ratio between actual yield to the total irrigation water amount used for crops (Semiz and Yurtseven, 2010; Tya and Othman, 2014). Results in table 6 are the total irrigation water amounts for tomatoes grown under different irrigation treatments and water use efficiencies.

The above results showed that the water use efficiency in drip irrigation treatments was higher than in the furrow irrigation treatment, this was one of the advantages of the drip irrigation methods. This result was similar to the results of Semiz and Yurtseven (2010) and Reddy *et al.*, (2015). Of the drip irrigation treatments, T4 70 - 100% β_{dr} had the highest water use efficiency with a medium amount of water, and treatment T5 80 - 100% β_{dr} demanded the largest amount of water, but water use efficiency was the lowest. Comparing the furrow irrigation treatment (T2) with drip irrigation treatment with 70 - 100% β_{dr} (T4), although they maintained the same soil moisture of 70% β_{dr} during growth, the T4 treatment demanded 1130 m^3 ha^{-1} (approximately 30%) less water than that of T2 and the water use efficiency was 5.8 kg m^{-3} higher than that of T2.

4. CONCLUSIONS

On Red River alluvial soils, drip irrigation had a positive impact on the growth, yield and water use efficiency of winter tomatoes.

Drip irrigation prolongs the tomato growing period from 6 - 11 days compared with furrow irrigation and from 9 - 14 days compared to the non-irrigated control treatment. Plant height in the drip irrigation treatments was higher than in the furrow irrigation method and it was evident at 10 weeks after planting. The drip irrigation treatment with 70 - 100% β_{dr} (T4) had the longest growing period (167 days) and the greatest plant height (100.7 cm).

Drip irrigation increased the tomato fruiting rate in comparison with furrow irrigation but unevenly. The drip irrigation treatment with 70 - 100% β_{dr} (T4) had the highest fruiting rate of 71.3%, 7.3% higher than furrow irrigation, and the fruiting rate of the drip irrigation treatment of 60 - 100% β_{dr} (T3) was also higher than that of furrow irrigation treatment, but the difference between these two treatments was not significant.

Drip irrigation increased individual the yield of the tomato plants from 17.3 to 1012.5 g plant^{-1} (8.9-36.3%) when compared with furrow irrigation. In the drip irrigation treatments, the highest yield was from drip irrigation treatment with 70 - 100% β_{dr} (T4), followed by the drip irrigation treatment with 80 - 100% β_{dr} (T5), and the lowest yield was from drip irrigation treatment with 60 - 100% β_{dr} (T3).

Drip irrigation saved irrigation water from 22 to 39.1% and increased water use efficiency from 3.0 - 5.8 kg m^{-3} compared with furrow irrigation. Of which, the drip irrigation treatment with 70 - 100% β_{dr} (T4) gained the highest individual yield and water use efficiency (2788.2 g $plant^{-1}$; 16kg m^{-3}).

In this study, drip irrigation maintained soil moisture of 70% β_{dr} during growth, and brought the highest yield and water use efficiency for winter tomatoes on alluvial soils of the Red River Delta.

5. RECOMMENDATIONS

The above research results only come from one year of experimentation, so to be able to make assessments and recommendations more accurate, the experiment should be repeated in more winter seasons.

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