Effect of water use efficiency on growth and yield of hot pepper under partial root-zone drip irrigation condition

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Abstract— Partial root-zone drip irrigation was tested to investigate effect of water use efficiency on growth and yield of hot pepper in a greenhouse condition. This study was conducted to compare effect of partial root-zone drip irrigation (PRDI) and examine how it affected soil water distribution, water use, growth, photosynthesis rate, stomatal conductance, transpiration rate and yield of hot pepper. The experiment was designed with three irrigation Schedule of 30%, 50% and 100% of ETo respectively, on four stages of plants growth; (i) Seedling and vegetative, (ii) flowering and fruit setting (iii) Vigorous fruit bearing (iv) Late fruit bearing. Irrigation water amount was calculated according to daily evaporation. There were nine treatments rows and irrigation was carried out three times per week.Results showed that, the average moisture content on both sides on each treatment was relatively constant or rose slightly as the highest was 25.20±0.23 and the lowest 21.05±069 for the right side while for the left side the highest was 24.66±0.68 and the lowest 21.59±0.22 as shown in table 3.2 and 3.3. High photosynthesis rate was recorded in treatment 1 with an initial irrigation schedule of 30% of ETo at seedling and vegetative growth, whereas, high stomatal conductance and transpiration rate were recorded in treatment 9 (control row) with 100% irrigation schedule of ETo throughout the four stages of plant growth. At 150 days after transplant hot pepper plants were harvested. The result further showed that moderate water at 50% of ETo during Vigorous fruit bearing can increase yield production and this was manifested in Treatment seven with irrigation schedule of 50% of ETo had the highest harvest yield of 3501g followed by treatment 9 (control) with 2982g and the lowest was recorded on treatment 6 with 1239g.The result also indicated that, treatments 1 and 8 also responded low to yield with 1489.86g and 1506.17g respectively, and also to dry biomass and water use efficiency, however, treatments 4, 2 and 3 recorded moderate yield. Fig 3.6 gives the full details of data analysis on yield, dry biomass and two water use efficiency.

Index Terms— partial root-zone drip irrigation; irrigation frequency; water use efficiency (WUE); hot pepper; growth stage; ETo Evapotranspiration

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1 INTRODUCTION

It would be much difficult to meet the food requirements in the future with the declining water resources and limited clean water reservoirs in the future, as 70% ~ 90% of the available water resources is used in food production. To cope with the water shortage problem, it is necessary to adopt effective water-saving agricultural countermeasures [19]. Efficient use of water by irrigation is becoming increasingly important. Agronomic measures such as varying tillage practices, mulching and anti-transpirants can reduce the demand for irrigation water and improve irrigation water use efficiency (IWUE). Development of novel water saving irrigation techniques represents another option for increase water use efficiency.

During the last two decades, water–saving irrigation techniques such as deficit irrigation (DI) and partial root zone drying (PRD) or alternative irrigation (AI) have been widely developed and tested for field crops and fruit trees. Most recently, these irrigation techniques are also being tested in vegetable crops such as tomatoes and hot pepper etc. [23]. In this paper, the principles of water-saving irrigation strategies such as the PRD mode and it's prospective for improving irrigation and crop water use efficiency in horticultural and agricultural production were discussed.

Particularly, the effective use of irrigation water has become a key component in the production of field crops and high-quality fruit crops in arid and semi-arid areas. Irrigation has been the major driving force for agricultural development in these areas for some time. Efficient water use has become an important issue in recent years under the critical situation of water resource shortage in some areas. Much effort has been paid to develop techniques such as RDI (regulated deficit irrigation), CAPRI [controlled alternate partial root-zone irrigation or partial root-zone drying (PRD in the literature)] to improve field and fruit crop water use efficiency [5], [6], [16], [17], [20], [9].

The natural soil has been constituted by physically and chemically weathered consequence of the rock, therefore it exists universally in nature. The Earth's surface layer with about 0.5-1.0m deep is constituted by soil and organic

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humus; it is often used for cultivation, and then called as the agricultural soil. Water takes up a higher percentage of the world and plays a key role in making earthly temperature equilibrium and concurrently being a main factor for changing the conformation of the earthly surface ceaselessly.

Nowadays, the tendency to develop irrigation in many countries is the sensible exploitation of existing hydraulics project systems and strengthening on the depth of irrigation techniques and methods to raise economic effect based on the utilizable effect of water resources. Selection and application of a sensible irrigation method is directly effective and of critical importance because irrigation techniques play a crucial role in water supply and distribution for crops directly and decide water losses in some extent at the field.

Besides, the current common irrigation techniques, such as flood and canal irrigation etc, still have a high degree of water losses.

Increasing water use efficiency (WUE) is one of the main strategic goals for worldwide researchers as well as decision makers due to water scarcity and continuing high demand of water for agricultural irrigation. With the low efficiency of irrigation water utilization, about another more 50% percent water is required; indeed which part could be met by increasing the effectiveness of irrigation. However, the agricultural irrigation uses over 70% of the world clean water and most of which is specially used in the protected environment [11]. Meantime, it is quite costly to use clean water and chemical solutions as fertilizers. In addition, the fast growing industrial sector competes with agriculture for water resources and the pollutants emitted became the source of most water pollution, which will push the agricultural activities to remote areas where there might be water scarcity and salinity as major problems.

The basic purpose of irrigation is supply of enough water into soil to ensure crops have the best development and growth. Traditional popular irrigation methods do not maintain suitable moisture for crop requirement in developing and growing, the extent of change in soil moisture is fairly significant (higher or lower than suitable moisture). Water saving irrigation technique is the best water supply technique and contributing to considerably higher productivity and quality of crops. Therefore, the development of water saving irrigation technology is urgent, and it will open up glorious prospects to plant industrial crops, fruit-trees, vegetables and other crops that have high economic values.

Traditional irrigation principles and methods have been challenged and modified [14]. Ideally WUE should be improved by reducing leaf transpiration. Stomata control plant gas exchange and transpiration/water loss and investigation has shown that stomata may reduce their opening according to the available amount of water in the soil [3], [22]. The advantage of such a regulation is that the plant may delay the onset of an injurious leaf water deficit and so enhance their chance of survival with unpredictable rainfall, the so-called optimization of water use for CO2 uptake and survival [12], [2]. Recent evidence has shown that such a feed-forward stomatal regulation works through a chemical signal, the increased concentration of abscisic acid (ABA) in the xylem flow from roots to shoots. Part of the root system in drying soil can produce a large amount of ABA while the rest of the root system in wet soil can function normally to keep the plant hydrated [23]. The result of such a response is that, plant can have a reduced stomatal opening in the absence of a visible leaf water deficit.

In this study, in order to determine the effect of partial root-zone drip irrigation on hot pepper plants growth in a green house, an efficient partial root-zone irrigation field work was designed and carried out at a greenhouse of Key Laboratory of Agricultural Engineering Water saving-park at Jiangning campus of Hohai University, Jiangsu Province, Nanjing, China. In this experiment, quantitative monitoring of indoor positioning systems and practical validation approach and mechanism combined with production practice were applied.

As in the term “partial root-zone drip irrigation”, “partial” means that at least some part of the soil water content was controlled above a certain percentage of their field capacity and the root system was divided into two parts, North and South and water was applied to the parts.

Nine rows were established with 22 plants per row, comparisons were made in terms of plant growth, shoot physiology and water use efficiency (WUE) using irrigation frequencies; 30%, 50% and 100% respectively at various growth stages.

2. MATERIALS AND METHODS

2.1 Description of features of the experimental site and experimental design

Experiments were conducted under greenhouse condition on hot pepper at the water-saving park of Hohai University campus of Jiangning located on latitude 310 57’N, longitude 1180 50’E, Nanjing, P.R. China in summer (May to September) , 2010.

In the greenhouse, there are systems of water supply, radiator and ventilator, shield from the sun and thermometer, hygrometer and a rubber bowl as evaporation pan were also provided to serve for experimenting. The weather features in the green house were different from outside with regard to temperature and air; however the outside weather influenced the inside directly. Relative weather features during the 19th May to the 29th September 2010 are given in Table 2.1.

Table 2.1: weather features in the greenhouse

Weather	9:00		13:00	
	Temperature	Humidity	Temperature	Humidity
Max	42	80	38	74
Min	20	30	21	30
Average	31	55	29.5	52

2.2 Soil Properties

Soil is the medium of plants growth and development. The soil in the experimental site in the greenhouse had heavy and strong texture with rather yellow or light color. When it is dry, there appeared a lot of rifts (cracks) on the surface. Table 2.2 displays the soil properties at the experiments site.

Table2.2: Soil properties of the 0-0.3m layer at the experimental plot

Soil type	Bulk density (g/cm^3)	Field capacity (%)	pH	Layer depth
Clayloam	1.35	25.8	6.4	0-0.3m

2.3 Design of the experiment

Based on weather features, soil, crop type, equipments and irrigation method, the experiment was designed with three irrigation schedule, i.e. 30%, 50% and 100% of ETo, for four stages of plants growth: (A) Seedling and vegetative stage (B) Flowering and fruit setting stage (C) Vigorous fruit bearing stage (D) Late fruit bearing stage. Irrigation water amount was calculated according to daily observed pan-evaporation.

There were eight treatment rows and one control row. During seedling and vegetative stage, treatment 1 and 5 had 30% and 50% irrigation schedule of ETo, respectively, while the rest had 100% of ETo. At flowering and fruit setting stage treatments 2 and 6 had irrigation schedule of 30% and 50% of ETo accordingly. Treatments 3 and 7 had 30% and 50% of ETo at vigorous fruit bearing stage, while treatments 4 and 8 had 30% and 50% of ETo irrigation schedule in the late fruit bearing stage. In treatment, the control, the amount of irrigation water was constant throughout the experiment (100%) of ETo. The above was in accordance to water deficit from the evaporation pan. Hot pepper irrigation was regularly carried out three times per week on Mondays, Wednesdays and Fridays.

Tables 2.3, shows irrigation schedule in (%) of Eto at various stages of plants growth and development.

Table 2.3 Irrigation frequencies in (%) at various stages of plant growth

Treatments	Seedling & Vegetative stage	Flowering & Fruit Setting Stage	Vigorous Fruit Bearing Stage	Late Fruit Bearing Stage
1	30	100	100	100
2	100	30	100	100
3	100	100	30	100
4	100	100	100	30
5	50	100	100	100
6	100	50	100	100
7	100	100	50	100
8	100	100	100	50
9 (ck)	100	100	100	100

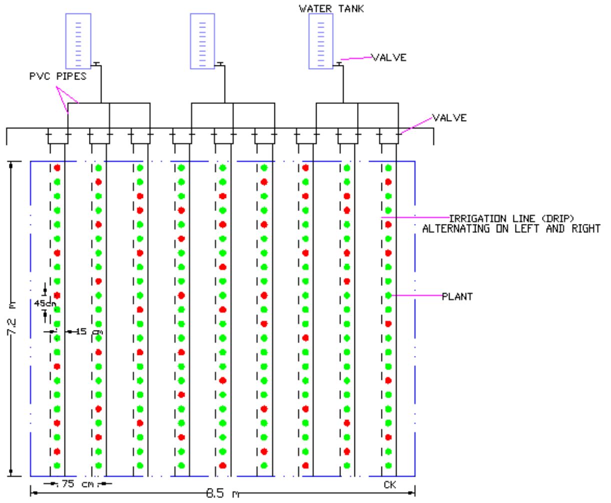

Fig. 2.1 Sketch showing drip line network and plant locations

The experimental plot was 8.5m × 7.2m. There were nine (9) treatments, with each treatment growing 22 plants of pepper. The interval of rows and plants were 75cm and 45cm, respectively. Each plant represents one emitter on the irrigation line at a distance of 15cm between the plant and the emitter. In every treatment, six pepper plants were randomly selected as shown in Figure 1 for data collection, recording and analyzing.

2.4 Pepper water requirement and irrigation water amount

2.4.1 Pepper water requirement

Calculating water requirement of pepper would establish one more coefficient called Tg, Tg depended on every growing stage and physical morphology of pepper for water supply adjustment to ensure pepper develop well and get high yield.

Field evaporation in the experimental model is calculated as follows:

$$ET = ET_{pan} * K_{pan} \qquad (2.1)$$

Daily evapotranspiration is calculated at climax period of pepper as follows:

$$ET_0 = (0.1 + \frac{S}{100}) * ET \qquad (2.2)$$

Calculated water requirement for pepper by drip irrigation technique is shown below:

$$D_{irr} = T_g * ET_0 \qquad (2.3)$$

Where:

D_{irr}: Calculated water requirement for pepper by drip irrigation technique according to growing stages (mm);

S(%): The vertical pepper leaf canopy percentage on the ground at 13:00;

ET_{pan}: Evaporation of Pan was measured three times per week on Monday, Wednesday and Friday (mm);

K_{pan}: Coefficient of Pan in the Greenhouse, Select Kpan = 0.8;

T_g : Water requirement coefficient by growing stage;

2.4.2 Irrigation water amount

The irrigation water amount is given as below:

$$W_t - W_o = \left(P + G + R_{in} + F_s\right) - \left(CR + D + R_f + F'_s\right) \qquad (2.4)$$

Where:

W_t , W_o: Water storage in soil before and after irrigating period (mm);

P: Useful precipitation (mm);

G: Water from water table (mm);

R_{in}: Surface water flows in (mm);

F_s : Soil water flows in (mm);

CR: Crop water requirement (mm);

D: Deep percolation (mm);

R_f: Surface water runoff (mm);

F'_s: Soil water runoff (mm);

W_t –W_o is irrigation water requirement (IR) to increase present soil moisture to the rank of optimal moisture limit.

The experimental model was carried out in the Greenhouse and the experimental plot was filled highly, so parameters such as useful precipitation (P), surface water flows in (R_{in}), soil water flows in (Fs), surface water runoff (R_f) and soil water runoff (F'_s) were equally considered as zero.

With partial root-zone drip irrigation technique, water was saved maximum so deep percolation (D) was equaled zero.

Water from water table (G) was also considered zero. During the experimental period, the variation of soil moisture content was determined and recorded; it would be analyzed in the next section for detailed explanation.

Therefore, the equation (2.4) is shown as follows:

$$W_t - W_0 = -CR \qquad (2.5)$$

Or

$$IR = -CR \qquad (2.6)$$

The equation (2.5) and (2.6) mean that enough water was supplied for compensation of daily evapotranspiration of hot pepper.

From equations (2.3) and (2.6), the irrigation requirement equation is shown as:

$$IR = D_{irr} = T_g * ETo \qquad (2.7)$$

Water amount of each block for controlling irrigation was calculated as:

$$W(i) = m(i) * D_{irr} \qquad (2.8)$$

Alternatively, water volume of each block for controlling irrigation was calculated as:

$$V(i) = W(i) * A * 10^{-3} \qquad (2.9)$$

Where:

W(i) : Water amount of each row for controlling irrigation (mm);

V(i) : Irrigation water volume of each row (m3);

m(i) : The level establishment coefficient of irrigation;

m_1=100%/1.0 (high level);

m_2=50%/0.5 (medium level);

m_3=30%/0.3 (low level);

A: Area of one experimental plot m2, A= 8.5m * 7.2m= 61.2 m^2;

2.5 Measurements of soil moisture content, hot pepper growth, yield and production analysis

Soil moisture content was measured at layer of 0-40cm deep by methods of Time Domain Reflectometry (TDR) machine and soil samples taken after irrigation time. During the period of experiment, soil moisture was measured on alternate side (left and right) three times a day, at 9:00 am, 12:00 noon and 3:00 pm daily. Data will be discussed in preceding section.

Leaf area index (LAI) was measured at every stage with LAI 2000. Plant height was determined by measuring the tallest portion of the haulm on each treatment during the four growth stages of hot pepper. In addition, plant development characteristics were determined including branches, leaf number. At the 150th day after transplanting, the plants were harvested. Shoots were removed and shoot dry weight was determined by drying the material at 80 0C for at least 48 hours. The roots were washed carefully for each treatment and dried and weighed as described above. During the course of experiment, photosynthesis and stomatal conductance were measured with LI 6400 on two occasions from the newly expanded leaf to the 5th older leaf. Measurements were taken between 10:00 and 12:00. Irrigation water use efficiency which was used to evaluate comparative benefits of the irrigation treatments was calculated.

Two kinds of Water use efficiency were calculated for each treatment as the harvest yield and the total dried biomass (shoot+roots) and each was divided by the total amount of water actually irrigated.

Wuey = yield/gross irrigation

Wuez = dry biomass/gross irrigation

2.6 Statistical analysis

The research experiments were designed as randomized complete treatments, with each replicate representing a separate treatment. Treatment effects in the experiment were analyzed using analysis of variance (ANOVA) procedure of SPSS software Version 14.0. Treatment means were separated by least significant difference (LSD) test at $p \leq 0.05$ unless otherwise specified. Also, Microsoft XL was used in data analysis.

RESULT AND DISCUSSION

Results

3.1 Volume of irrigation water

Total volume of irrigation water was calculated during the four stages of plant growth using the formula V=πr2h for the cylindrical water tank in the green house during the research, where π=constant=22/7, r=radius of the tank=0.15m and h=height of irrigation water level in accordance to evaporation pan reading.

Table 3.1 and figure 3.1 show the total volume of irrigation water for hot pepper grown under partial root-zone drip irrigation in a greenhouse. Results showed that treatment 9 (control) with a constant irrigation schedule of 100% ETo throughout the experimentation period, had the highest volume of irrigation water with a total of 0.0116325m3 and the lowest was recorded in treatment 3 with irrigation schedule of 30% ETo at Vigorous fruit bearing stage with a total volume of 0.00779978m3. Treatments 1 and 2 almost had equal volume of irrigation water of 0.0109395m3 and 0.0108405m3 respectively while Treatments 5 and 6 almost had equal volume of irrigation water of 0.0111375m3 and 0.01106679m3 respectively, with little variation.

Table 3.1 Total volume of irrigation water at growth stages

Treatment	Seedling and vegetative stage	Flowering and fruit setting stage	Vigorous fruit bearing stage	Late fruit bearing stage	Total irrigation water, 4 stages of growth (m)	Total volume of irrigatior water (m3)
	Total irrigation water (m)	Total irrigation water (m)	Total irrigation water (m)	Total irrigation water (m)		
1	0.0042	0.016	0.0775	0.057	0.1547	0.0109395
2	0.014	0.0048	0.0775	0.057	0.1533	0.0108405
3	0.014	0.016	0.0233	0.057	0.1103	0.00779978
4	0.014	0.016	0.0775	0.0171	0.1246	0.008811
5	0.007	0.016	0.0775	0.057	0.1575	0.0111375
6	0.014	0.008	0.0775	0.057	0.1565	0.01106679
7	0.014	0.016	0.0388	0.057	0.1258	0.00889586
8	0.014	0.016	0.0775	0.0285	0.136	0.00961714
9 (ck)	0.014	0.016	0.0775	0.057	0.1645	0.0116325
Total	0.1092	0.1248	0.6046	0.4446	1.2832	0.09074057

The volume of water in cubic centimetre is given by πr2h for the cylindrical tank in the green house where r= radius of the tank and = 0.15m, π= constant= 22/7 and h=height= height of irrigation water in the tank.

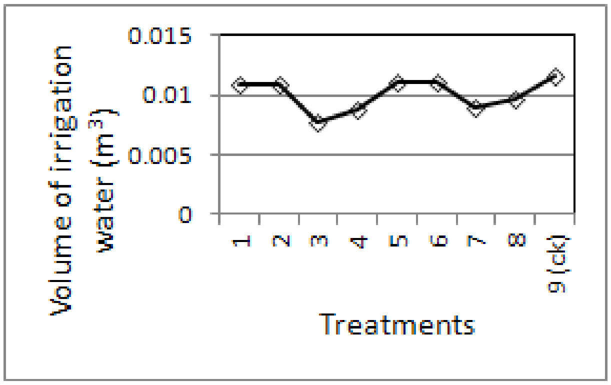

Fig 3.1 total volume of irrigation water (m^3)

3.2 Soil moisture variation, at given time intervals, 9:00, 12:00 and 15:00

3.2.1 Soil moisture variation, right side

Soil moisture readings were taken with the use of TDR at 9:00, 12:00 and 15:00 of 3 hours intervals. In treatment 1, soil moisture reading was high at 9:00, less at 12:00 and latter increased at 15:00. Treatments 3 and 8 had a decline in soil moisture from 9:00 to 15:00 while treatments 2, 4, 5 and 6, had a decline at 12:00 and an increase at 15:00. Treatment 9 (control) had an increase at 12:00 and a decrease at 15:00. These variations are attributed to the alternate wetting and drying on both sides of the rooting zone. Soil moisture recordings were taken along the drip lines at a distance of 15cm from the plants. Six plants were selected randomly from each treatment for data collection and analysis. Irrigation was carried out at 8:30am throughout the experimentation period.

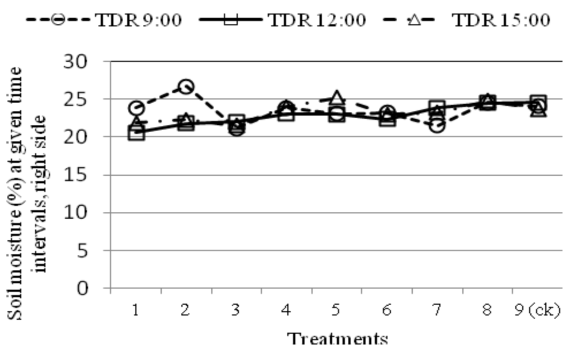

Fig 3.2 Soil moisture at giving time intervals right side (%)

3.2.2 Soil moisture variation, left side

Soil moisture recording for the nine experimental treatments were taken at 3 hours intervals, at 9:00, 12:00 and 15:00 respectively. As a result of the alternate drying and wetting of the rotting zone on both sides (left and Right) there were alternate increase or decrease in magnitude of soil moisture during the time of experimentation for the nine treatments after irrigation water application.

The result in fig 3.3 shows that treatment 1 had a high moisture recording of 22.2% at 9:00 followed by 21.1% at 15:00 and was low at 12:00. Treatments 2, 3 and 8 had a decrease in magnitude of moisture with 27.1%, 22.8%, 22% and 21.8%, 21.4%, 20.1% and 25.6%, 25.2%, 25% respectively. On the other hand, Treatments 4, 5 and 6 recorded high moisture reading at 15:00. However treatments 7 and 9(control) recorded high moisture reading at 12:00 after the first three hours of irrigating. These variations may be attributed to the alternate drying and wetting of the root-zone and the movement of water within the soil pore space and the roots. Absorption of water by soil particles in the dry zone from the wetted zone might have caused the increase in soil moisture at 15:00 for some rows as shown in figure 3.3.

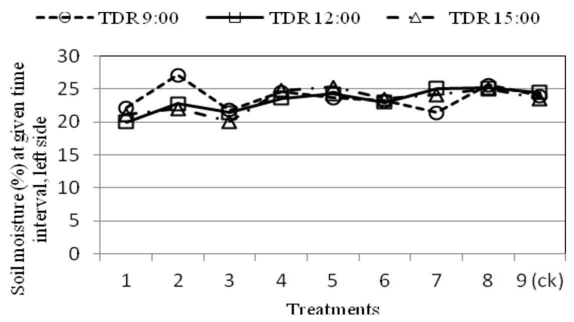

Fig 3.3 Soil moisture at giving time intervals left side (%)

3.3 Soil water content variation

Average soil moisture contents in different parts of the nine treatments established on partial root-zone drip irrigation, are shown in tables 3.2 and 3.3 respectively. Observed data were collected on both sides of each treatment (left and right). It is clear that the soil water contents in the two parts of each treatment were not the same for all the nine treatments, for they alternately increase or decrease. Moreover, it was found that soil moisture content was relatively constant or rose slightly in the non-irrigated part for a short while after the other part was irrigated. This may be caused by the redistribution of water through the root systems. We are investigating this by sap flow measurement technology for the main roots in the two parts.

Table 3.2 soil ***moisture content on right side***

Treatments	Soil moisture
1	21.05±0.692c
2	23.96±1.57a
3	21.34±0.27bc
4	24.36±0.37a
5	24.74±0.60a
6	23.27±0.15ab
7	23.53±1.10a
8	25.20±0.23a
9 (CK)	24.01±0.46a

Table 3.3 soil moisture content on left side

Treatments	Soil moisture
1	22.13±0.95bc
2	23.81±1.72abc
3	21.59±0.22c
4	23.47±0.48abc
5	23.79±0.72abc
6	22.86±0.25abc
7	22.87±0.72abc
8	24.66±0.68a
9 (CK)	24.14±0.24ab

The values in tables 3.2 and 3.3 represent mean ± standard error (S.E), (n=3). For a given variable, mean values not sharing common letters are significantly different ($p \leq 0.05$)

3.4 Root Growth, Root/Shoot Ratio and Leaf Water Content

3.4.1 Root growth

Table 3.3 and figure 3.4 shows root establishment in the soil with respect to available water as a function of root growth for the different nine rows under partial root-zone drip irrigation with varying irrigation schedules. Soil drying inhibited root growth, as indicated by treatment 1 with an initial irrigation schedule of 30% of ETo at seedling and vegetative growth stage, the result was not similar to that in maize [16]. Root growth was recorded high in treatment 4 with an irrigation schedule of 30% ETo and lowest in treatment 8 with an irrigation schedule of 50% ETo at late fruit bearing stage respectively, as shown in table 2.3. Moderate plant growth were recorded on treatments 2 and 6 with an average of 20.76cm and 20.98cm respectively for the six hot pepper plants selected randomly on each treatment for data collecting, recording and analyzing. The above analysis can be attributed to the effect of water as an important component on plant growth and development and also as a result of the uneven growth among plant. As a result of water stress, plant roots can grow deeper because of hydrotropism (movement of plant root in search of water for the manufacture of its own food through photosynthesis). Therefore plant growth was recorded high on row 4 which had an irrigation schedule of 30% ETo at later fruit bearing stage which was a very crucial stage since water was highly needed for the formation of fruit which has high water content than dry mass.

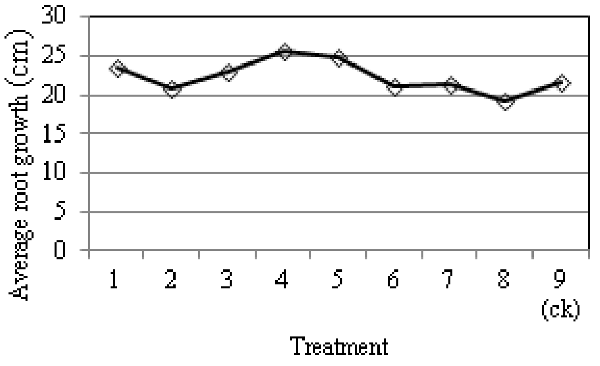

Fig 3.4 Root growth (cm)

3.4.2 Root/shoot ratio

In the research experiments the root/shoot ratio was increased in treatments 1 and 4 with the highest been recorded on treatment 4, suggesting that shoot growth is more sensitively inhibited than roots when irrigation frequency is low. It is interesting that Partial root-zone drip irrigation and rewetting at 30% of ETo irrigation level during seedling growth for treatment 1 and 30% of ETo rewetting for treatment 4 at late fruit bearing stage significantly increased the root/shoot ratio compared to all other treatments, and was decreased in treatment 2 during flowering and fruit setting stage, with 30% of ETo irrigation schedule. Also Treatment 9 with irrigation schedule of 100% ETo throughout the four stages of plant growth, treatment 8 with an irrigation schedule of 50% ETo at late fruit bearing stage and treatment 7 with irrigation schedule of 50% ETo at vigorous fruit bearing stage, had low root/stem ratio of 0.206, 0.207 and 0.203 respectively while the remaining treatments showed moderate root/stem ratio. The figure below gives the analysis of root/stem ratio for the nine experimental treatments.

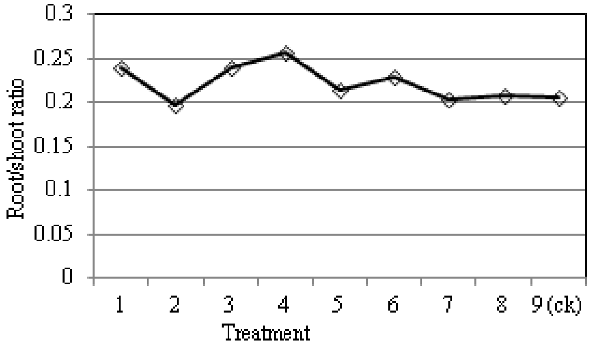

Fig 3.5 Root/Stem ratio

3.4.3 Leaf water content

Figure 3.5 and table 3.3 show leaf water content of hot pepper grown under green house condition. Available water content on leaves was high for treatment 8 which had an irrigation schedule of 100% ETo at the initial 3 stages of plant growth and 50% at late fruit bearing stage. The least average water content on leaf was recorded on treatment 5, thus signifying that root growth and available water content in plants depend on the available amount of irrigation water. Six healthy plants were selected on each treatment on the start of experimentation for data collection and analysis and averages taken for the 9 treatments. It will be noted that, root development was severely inhibited in treatment 1 with an initial 30% irrigation schedule of ETo at seedling and vegetative stage, suggesting a too aggressive water deficit thus signifying lowest leaf water potential. It will be agreed that water resources is a key component for agricultural production and development as plants totally depend on it for their growth and development. Therefore any scarcity of water to plants can hinder production and photosynthesis. Leaves of plants are responsible for the manufacture of plant food through dissolved mineral salt, water and sun light, thus any stress of water can result into poor performance of the plants. Leaf water potential is the available water in the leaves that accelerate photosynthesis thus the less the water potential in leaves, the more significant production become affected as less food is being manufactured by the plant. Thus the difference between the wet and dry weights of the leaf to the ratio of the wet weight as a percentage is what is termed the leaf water potential given by; (wet weight-dry weight/wet×100%=leaf water potential)

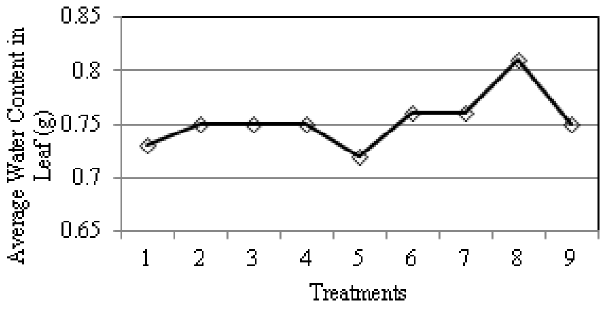

Fig 3.6 Leaf Water Content

Table 3.4 Root growth, root/stem ratio and leaf water Content

Treatment	Average root growth (cm)	Average number of leaves	Average dry root weight (g)	Average dry stem weight (g)	Root/stem ratio	Average 3 leaf wet weight (g)	Average 3 leaf dry weight (g)	Average water in leaf
Row 1	23.38	155	0.92	2.92	0.24	0.99	0.26	0.73
Row 2	20.76	169	0.98	3.98	0.198	1.14	0.28	0.75
Row 3	23	133	1.11	3.54	0.239	1.16	0.28	0.75
Row 4	25.6	158	0.96	3.36	0.257	1.09	0.27	0.75
Row 5	24.84	261	2.21	8.05	0.215	1.23	0.35	0.72
Row 6	20.98	119	0.99	3.35	0.228	1	0.24	0.76
Row 7	21.28	191	1.05	4.11	0.203	1.02	0.24	0.76
Row 8	19.22	146	1.04	3.99	0.207	1.14	0.22	0.81
Row 9 (ck)	21.62	178	1.32	5.09	0.206	1.15	0.29	0.75

3.5 Leaf photosynthesis, stomatal conductance and transpiration rate

When compared to the other seven treatments, treatments 1 and 9 under partial root-zone drip irrigation for hot pepper at the four stages of plant growth had high records of photosynthesis rate; stomatal conductance and transpiration rate were recorded high in treatment 9, the control row which had irrigation schedule of 100% ETo throughout the four stages of plant growth. Treatment 3, 4, 6, 7 and 8 had moderate while treatment 2 and 5 exhibited the lowest photosynthesis rate, stomatal conductance and transpiration rate. However, treatment 1 exhibited photosynthesis rate as compared to stomatal conductance and transpiration rate. Data was collected in June and August during flowering and late fruit bearing stages and during this period, treatments 3 and 7 had irrigation schedule of 30% and 50% of ETo respectively, while the remaining treatments had 100% irrigation schedule of ETo at flowering stage. On the other hand treatments 4 and 8 had 30% and 50% of ETo irrigation schedule respectively, while the others had 100%. The average readings were taken as shown in Table 2.3.

Table 3.5 Photosynthesis rate, Stomatal conductance and transpiration rate of hot pepper plants subjected to partial root-zone drip irrigation

Row	Observations/ Indicators		
	Photo.(μmol·$m^{-2}s^{-1}$)	Cond. (mol·. $m^{-2}s^{-1}$)	Trmol. (mol·S^{-1})
1	14.91±0.24a	0.367±0.020a	5.19±0.47a
2	12.27±1.35a	0.270±0.030a	3.84±0.65a
3	13.17±0.13a	0.303±0.026a	4.64±0.59a
4	13.43±0.48a	0.330±0.021a	4.92±0.47a
5	12.88±2.53a	0.290±0.095a	4.33±1.22a
6	13.20±1.31a	0.300±0.055a	4.35±0.69a
7	13.90±0.52a	0.340±0.040a	4.78±0.47a
8	13.30±1.23a	0.313±0.038a	4.60±0.34a
9 (ck)	14.24±1.16a	0.373±0.050a	5.24±0.30a

The values of table represent means ± standard error (S.E), (n=3). For a given va
values sharing common letters are not significantly different (p=0.05)

The figures in the table 3.5, shows how water stress can affect photosynthesis rate, stomatal conductance and transpiration rate in crops when there is water deficit within the plant rooting zone.

3.6 Irrigation water Volume, biomass, yield and water use efficiency

3.6.1 Irrigation water volume

Table 3.6 and fig 3.7 summarises the total irrigation water use for the nine experimental treatments in cubic meters (m3). Treatment 9(control) with 100% irrigation schedule of ETo had the highest irrigation water volume followed by treatments 5 and 6. Moderate irrigation water volumes were recorded in treatment 1 and 2 while the lowest was recorded on treatment 3. The causes for such variations is as a result of irrigation schedule of 30%, 50% and 100% of ETo used on the 9 treatments within a specific growing period of hot pepper (seedling and vegetative growth, flowering and fruit setting stage, vigorous fruit bearing stage and late fruit bearing stage). Further analysis would be made on the important of irrigation water on Biomass production, yield and two kinds of water use efficiency. It will be noted that, water is a useful commodity for agricultural production and development especially when crops depend on it for growth and development.

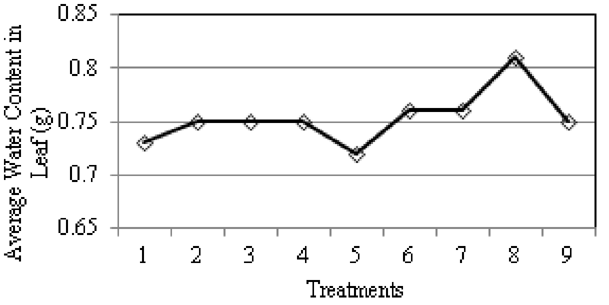

Fig 3.7 Total Volume of irrigation water in (m^3)

3.6.2 Biomass

Biomass production is affected by the amount of available water to crop either through precipitation or irrigation. As water deficit affect photosynthesis rate so is the biomass affected. As the photosynthesis data suggest above, moderate soil drying (the 50% irrigation schedule of ETo) on treatment 5 at seeding and vegetative growth and all other growth stages having 100% irrigation schedule of ETo produced a greater biomass of 10.26g as compared to treatment 9(the control) with 6.41g, which had 100% irrigation schedule of ETo throughout the four stages of plant growth at the same soil drying level, however biomass was markedly reduced in treatment 1 with 3.84g which had an initial irrigation schedule of 30% ETo at seedling and vegetative growth with severe soil drying. These phenomena may be attributed to the lack of enough irrigation water supplied at the seedling and vegetative growth which is the most critical stage in plant establishment and growth.

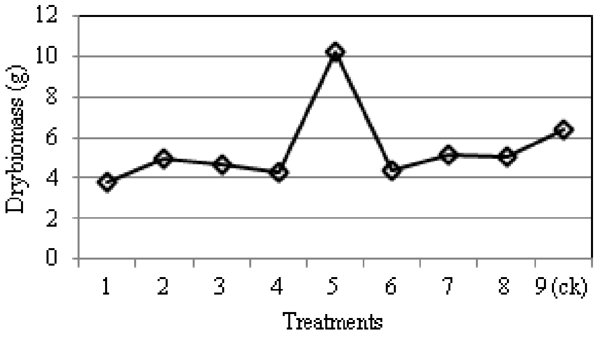

Fig 3.8 Dry Biomass

3.6.3 Yield

Yield was measured in gram for the nine rows after harvest. The results showed that treatment 6 with irrigation schedule of 50% of ETo at flowering stage and a total irrigation water volume of 0.0116679m3 had the lowest yields of 1239.06g followed by treatment 1, 8, 3 and 2 with yields of 1489.86g, 1506.17g, 1925.12g and 1936.28g respectively. Treatment 7 with an irrigation schedule of 50% of ETo at vigorous fruit bearing stage and 100% for the other stages recorded high yield of 3501g with a total irrigation water of 0.00889586m3. Treatment nine (the control) with a uniform irrigation schedule 100% of ETo had the highest total irrigation water volume but had a yield of 2982.70g after treatment 7. Moderate yields were recorded in treatment 4 and 5 with a yield of 2131.17g and 2677.90g accordingly.

The above analysis show that, water is an essential component in fruit formation in plants thus timing of irrigation water schedule for crops and scarcity of water supply to plant, can affect crop yield as manifested with hot pepper grown under greenhouse condition with varying irrigation water schedule of 30%, 50% and 100% of ETo respectively during the four growth stages.

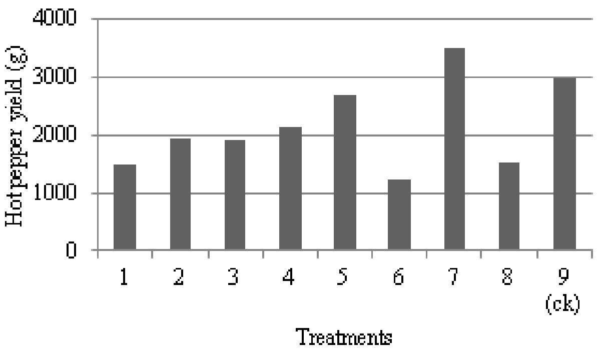

Fig 3.9 Hot pepper yield (g)

3.6.4 Water use efficiency

Two kinds of water use efficiency were determined and calculated for each treatment row as harvest yield WUEy (yield/gross irrigation and total dried biomass (stem+root) divided by the total amount of water actually irrigated; WUEz (dry biomass/gross irrigation). Results showed that, water use efficiency on yield was recorded high on treatment 7 with a total of 393578.59g/m3 followed by treatment 9 (the control) with a yield of 256410.92g/m. The result for this may be attributed to the moderate irrigation schedule of 50% of ETo at vigorous fruit bearing which might have reduced due to fruit rot if irrigation water should have been applied at 100% of ETo. The lowest was recorded on treatment 6 with a total yield of 111962.01g/m3 followed by treatment 1, 8 and 2 with yields of 136190.87g/m3, 156613.09g/m3 and 178615.38g/m3 respectively. Moderate water use efficiency on yield was recorded on treatments 3, 4 and 5 with 246817.85g/m3, 241876.06g/m3 and 240439.96g/m3 respectively.

On the other hand, water use efficiency on dry biomass was recorded high on row 5 with 921.21g/m3 and low on row one with 351.02g/m3. However, row 9 (control row) with irrigation frequency of 100% ETC throughout the four stages of plant growth and development was fourth in terms of dry biomass water use efficiency with a value of 551.04g/m3. It will be noted that, the ratio of irrigation water to yield and to dry biomass affected water use efficiency in both, thus signifying that water is an important resource for growth and yield of crops, therefore any scarcity in its supply will affect such growth and yield, thereby reflecting on water use efficiency. Figure 3.21, 3.22 and table 3.4 summarizes the two kinds of water use efficiency as analysed above.

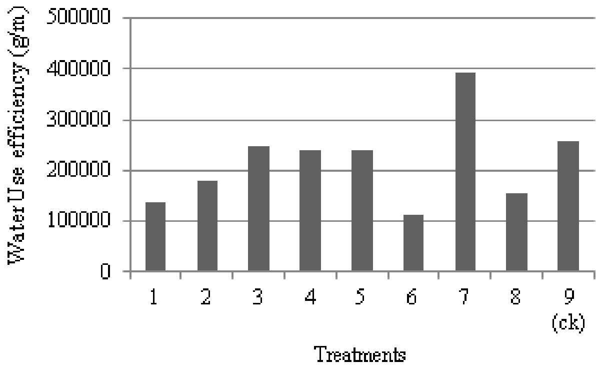

Fig. 3.10 Yield water use efficiency (g/m3)

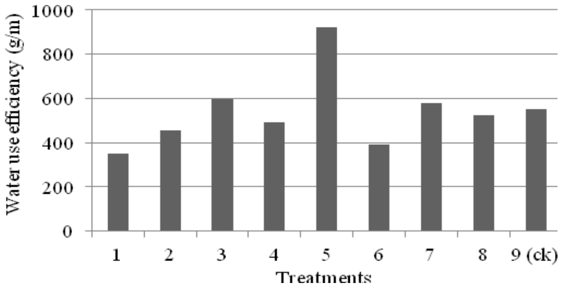

Fig 3.11 Dry Biomass Water use efficiency (g/m3)

Table 3.6 Total irrigation water volume, biomass, yield and WUE of hot pepper plants subjected to partial root-zone drip irrigation

Irrigation Treatment	Irrigation water use (m^3)	Dry Biomass (g)	yield (g)	WUE_y (g/m^3)	WUE_z (g/m^3)
Row 1	0.0109395	3.84	1489.86	136190.87	351.02
Row 2	0.0108405	4.96	1936.28	178615.38	457.54
Row 3	0.00779976	4.65	1925.12	246817.85	596.17
Row 4	0.008811	4.32	2131.17	241876.06	490.30
Row 5	0.0111375	10.26	2677.90	240439.96	921.21
Row 6	0.01106679	4.34	1239.06	111962.01	392.16
Row 7	0.00889586	5.16	3501.22	393578.59	580.05
Row 8	0.00961714	5.03	1506.17	156613.09	523.02
Row 9 (ck)	0.0116325	6.41	2982.70	256410.92	551.04

Discussion and conclusions

The results of this study showed that partial root-zone drip irrigation (PRDI) could save 40% of water without a reduction in yield. This irrigation treatment probably saved water without a trade-off of dried biomass production for the same water consumption because stomatal opening was continuously regulated by a root drying signal [3], [10], [4]. As the early split-root experiment devised by

[1] would have suggested, drying part of the root system can indeed inhibit stomatal opening to some degree but keep the shoot turgid at the same time. When roots are in the drying soil, even in a situation where only part of the root system is dried, substantial abscisic acid (ABA) can be produced in the roots and transported through xylem to the shoots where stomatal opening can be regulated [3]. Partial root-zone drip irrigation (PRDI) takes advantage of such a physiological response and exposes part of the root system alternately to the drying soil. As described in earlier paper [16], such a method of watering can restrict water loss and yet, and at the same time, the rate of photosynthesis of the treated plants can be comparable to that of the plants in the control row treatment.

How could the rate of photosynthesis be maintained while the transpiration rate is inhibited at the same time, i.e. when stomatal conductance for gas diffusion is decreased? This is probably explained by the fact that the relationship between photosynthesis and stomatal opening is a saturation relationship, especially in C4 plants such as maize where CO2 supply rarely limits its assimilation, while the relationship between transpiration and Stomatal opening is a linear one. The initial reduction of Stomatal opening from its maximum may reduce conductance more than photosynthesis [13]. This leaves a window in which any reduction in Stomatal opening from their "luxury" state may save plants water with only a small effect on photosynthesis. Such regulation can occur in the absence of a visible leaf water deficit and may be regarded as a "feed-forward" mechanism with which plants may maximise their survival according to the availability of water in the soil. Obviously, reducing water loss, by narrowing their Stomatal opening before any catastrophic leaf wilting occurs, can potentially save water and therefore enhance the chance of a plant's survival [12], [2].

Biomass production might have been more affected than photosynthesis for different soil drying patterns (Table 3 and Table 4) because the measurements of leaf photosynthesis were made between 9:30–10:300h, for the 9 rows and the difference for different soil drying patterns was not maximal in this period. If the measurements had been made between 11:00 and 15:00 h, the daily average differences of photosynthesis for different treatments would probably have been greater than in Table 4.

It is still unclear why the alternate and not the fixed part of the root system respond to drying soil in this way. It might be that prolonged exposure of roots to dried soil caused anatomical changes in the roots [19], e.g. suberization of the epidermis, collapse of the cortex and loss of succulent secondary roots. These changes are such that the roots in the dried soil may become like "pipes" and do not respond to the dried soil anymore. Alternate drip may improve this situation through a continuous stimulation of new secondary roots on these "pipes". It has been shown that rewetting can greatly enhance the initiation and growth of lateral roots [18] and the newly formed roots may recover the sensitivity of the roots to the drying soil.

In conclusion, the results have shown that the partial root zone drip irrigation (PRDI) to part of the root system is more efficient and is useful for agricultural production especially in water resource management as compared to other irrigation systems. Treatment 7 with moderate irrigation schedule of 50% of ETo at vigorous fruit bearing recorded high yield of 3501.22g as compared to treatment 9 (control) with 100% irrigation schedule of ETo throughout the four stages of plant growth with a yield of 2982.7g. This signifies that moderate watering at vigorous fruit bearing can enhance high yield production.

The partial root-zone drip irrigation (PRDI) method can save a substantial amount of water and maintain yield in hot pepper production with little or no difference in areas where irrigation is essential. This irrigation method is being tested in the field, and preliminary data suggest that a substantial amount of water can be saved without loss of yield (Kang and Pan, unpublished data). Even if the cost of establishing partial root-zone drip irrigation system is greater, this result should be of significant value to arid and semiarid areas because many such areas face a shrinking availability of water resource. A sustainable use of water resources is becoming an increasingly urgent world-wide topic as water demand is increasing due to world population expansion followed by the high rate of global warming.

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