Int.J.Curr.Microbiol.App.Sci (2018) *7*(2): 1073-1080

International Journal of Current Microbiology and Applied Sciences
ISSN: 2319-7706 **Volume 7 Number 02 (2018)**
Journal homepage: http://www.ijcmas.com

Original Research Article https://doi.org/10.20546/ijcmas.2018.702.133

Comparative Effects of Deficit Irrigation and Partial Root Zone Drying (PRD) on Growth, Yield and Water use Efficiency of *Rabi* Maize

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Keywords

Partial Root Zone Drying (PRD), Growth, Yield, *Rabi* maize

Article Info

Accepted:
10 January 2018
Available Online:
10 February 2018

A B S T R A C T

This study evaluates the effect of partial root zone drying (PRD) and deficit irrigation (DI) strategies on crop yield and water use efficiency of the furrow irrigated *rabi* maize under the North Bihar Condition. The experiment was conducted at DRPCAU, experimental farm. The treatments were (1) control (CI) in which irrigation water was applied to both sides of root system; (2) Deficit irrigation (DI50, DI75) in which 50% and 75% irrigation water of CI supplied to both sides of the root system; (3) partial rootzone drying (1PRD, 2PRD), 1PRD with half of the root system exposed to soil drying and other half kept well-watered with 50% irrigation water of CI, and 2PRD with 50% irrigation water of CI supplied, half to fixed side of the root system and (4) Rainfed (No irrigation). Irrigation significantly ($P \leq 0.05$) influenced the yield status of maize. Maize yield increases with the increase in level of irrigation. DI50 (T_3), 1 PRD (T_4) and 2 PRD (T_5) significantly reduced yield, compared to CI treatments (T_1). The reduction of yield in treatment T_4 compared to control was 9.50 %. But the other side of the analysis suggests that in terms of yield treatment 1 PRD (T_4) outperformed the treatments T_3 (DI - 50) and T_5 (2 PRD). The highest irrigation water use efficiency (WUE) was found in treatment T_4 (1 PRD) with a value of 269.38 kg/ha-cm, and the lowest one was found in treatment T_1 (FI) as 148.8 kg/ha-cm. The statistical analysis of the data revealed that water use efficiency is significantly superior in treatment T_4 compared to rest of the treatments. Water use efficiency of maize decreased with increase in irrigation levels for all the treatments of furrow irrigation system.

Introduction

Maize (*Zea mays* L.) is an important cereal crop in world after wheat and rice. The importance of maize lies in its wide industrial applications besides serving as human food and animal feed. It is the most versatile crop with wider adaptability in varied agro-ecologies and has highest genetic yield potential among the food grain crops. Maize is called 'queen of cereal' as it is grown throughout the year due to its photo-thermoinsensitive character and highest genetic yield potential among the cereals. In India, maize is cultivated throughout the year in most of states of the country for various purposes including grain, feed, fodder, green cobs, sweet corn, baby corn, pop corn and industrial products. There are three distinct seasons for the cultivation of maize in India:

Kharif, Rabi in Peninsular India and Bihar, and *Spring* in northern India. Maize is predominately a *Kharif* season crop but in past few years *Rabi* maize has gained a significant place in total maize production in India. *Rabi* maize is grown on an area of 1.2 million ha with the grain production of 5.08million tonnes, with an average productivity of 4.00tha^{-}1. The predominant Rabi maize growing states are Andhra Pradesh (45.5%), Bihar (20.1%), Tamil Nadu (9.3%), Karnataka (8.5%), Maharastra (7.7%), West Bengal (5.3%). The *Rabi* maize in Bihar state is occupying 0.412 million hectare area out of a total area of 0.645 million hectare during 2010-11. This indicates the acceptance of *Rab*i maize technology by farmers of this state by clear cut comparative advantage over *Kharif* maize due to low incidence of diseases and insects-pests as well as slow growth of weeds. These factors singly and in combination favoured the adoption of *Rabi* maize cultivation in Bihar. The rainfall during *Rabi* is rather inadequate for successful cultivation of high-yielding maize hybrids. In fact, timely availability of assured irrigation is one of the major factors determining the success of crop. Where soils are generally light, it is desirable to schedule the irrigation 70% soil moisture availability throughout the period of crop growth and development.

In heavy soils, a moisture level of 30% during the vegetative stage and 70% during the reproductive and grain –filling period is desirable for obtaining optimum yield. Four to six irrigations are needed during the *Rabi* crop season. The rainfall during *Rabi* is rather inadequate for successful cultivation of high-yielding maize hybrids. In fact, timely availability of assured irrigation is one of the major factors determining the success of crop. Where soils are generally light, it is desirable to schedule the irrigation 70% soil moisture availability throughout the period of crop growth and development.

Drought is one of the most common environmental stresses that may limit agricultural production worldwide. Many crops, including maize, have high water requirements and in most countries supplemental irrigation is necessary for successful crop production. However, in many countries as a consequence of global climate changes and environmental pollution, water use for agriculture is reduced. Therefore, great emphasis is placed in the area of irrigation engineering, crop physiology and crop management for dry conditions with the aim to make plants more efficient in water use. Recent results demonstrated that regulated deficit irrigation (RDI) and partial root drying (PRD) are the irrigation methods that tend to decrease agricultural use of water. Partial root drying (PRD) is an irrigation technique where half of the root zone is irrigated while the other half is allowed to dry out. The treatment is then reversed, allowing the previously well-watered side of the root system to dry down while fully irrigating the previously dry side. Compared to RDI, implementing the PRD technique is simpler, requiring only the adaptation of irrigation systems to allow alternate wetting and drying of part of the rootzone. Partial root-zone irrigation (PRI) under furrow irrigation is a deficit irrigation strategy in which only part of the root system is exposed to watering, while the rest part is left in drying soil. PRI has been found as a potential water saving technique over full root-zone irrigation, without affecting the yield and yield attributes of various crops in water scarce environments (Prabhakar and Srinivas, 1995; Ramlan and Nwokeocha, 2000; Singh and Murthy, 2001; Kang *et al.,* 2000; Kirda *et al.,* 2004; Liu *et al.,* 2006; Patanèa *et al.,* 2011) Keeping above in view an attempt was made to study the response of different level of irrigation and partial root drying regimes on crop growth, crop yield and water use efficiency of Rabi maize under North Bihar Condition.

Materials and Methods

The present study was undertaken with a view to determine the effect of different level of irrigation and partial root drying regimes on biometric parameters of crop growth, yield and water use efficiency of Rabi Maize.

Study area

The experiments were conducted in the experimental fields of Dr. Rajendra Prasad Central Agricultural University, Pusa. The study area is situated in Samastipur district of Bihar on the western and Southern bank of river Burhi Gandak at an altitude of 52.00 m above mean sea level and lies at $25^0$46' N latitude and 86^0 10' E longitude. The climate is sub-tropical characterized mainly by hot-dry summer and cool winter. The average annual rainfall is 1260 mm out of which approximately 90 per cent is received from middle of June to middle of October. The period from last week of November to February receives occasional showers. May-June is the hottest months of the year. January is the coldest month with average maximum temperature ranging from 21.4 to 23.7^0C and minimum from 5.7 to 8.8^0C. Rise in temperature takes places at slow pace from February and picks-up from March and reaches the climax somewhere during May-June. The maximum relative humidity falls range of 85-95% during rainy months of July-September and the minimum in the range of 40-60% during summer month of March-April. The highest record of solar radiation is 650 ly/day in the month of May and lowest 380 ly/day in the month of December.

Experimental plan

The experiments were conducted in the experimental fields of Dr. Rajendra Prasad Central Agricultural University, Pusa. The experiment was laid out in randomized block design having Six treatments replicated four times with a plot size of 6 m x 5.0 m. One meter gap was provided between each plot to avoid the effect of irrigation treatments. The crop selected for the study was Rabi Maize. The variety of the rabi Maize was hybrid DKC 9120.The seeds were sown at a row spacing of 0.50 m, and plant spacing of 0.20 m in each plot. The crop was sown in 3^{rd} week of November 2015. The treatment details of the experiment are presented in Table 1.

The irrigation scheduling was based on soil moisture determination using gravimetric sampling. All plants were fully watered (field capacity) in the evening before starting the experiment. The following irrigation treatments were applied with the help of furrow irrigation system (Four replicates per treatment): (1) control (CI) in which irrigation water was applied to both sides of root system when soil water content was 60% of field capacity; (2) Deficit irrigation (DI50, DI75) in which 50% and 75% irrigation water of CI supplied to both sides of the root system; (3) partial rootzone drying (1PRD, 2PRD), 1PRD with half of the root system exposed to soil drying and other half kept well-watered with 50% irrigation water of CI, and 2PRD with 50% irrigation water of CI supplied, half to fixed side of the root system.

Results and Discussion

The effect of different levels of irrigation and partial root drying on biometric parameters such as plant height, stem diameter, Crop yield and water use efficiency were analysed statistically and compared with control.

Plant height

The plant height of tagged plants was measured at 120 days after sowing. The average plant height after 120 days of sowing was, 237, 226, 207, 221, 192 and 132 cm for treatments T_1, T_2, T_3, T_4, T_5 and T_6 respectively (Table 2). The results showed that the effect of PRD on the growth of the whole plant was significant and the decline in plant height at the end of the experiment was 6.8 % compared to well-watered plants (Table 2). The analysis revealed that the plant height is significantly superior in treatment-1 (control (CI) in which irrigation water will be applied to both sides of root system) compared to the rest of the treatments at 120 DAS. But when the comparison was made between treatment, T_4 (1PRD with half of the root system exposed to soil drying and the other half kept well watered with 50 % irrigation water) and other remaining treatments it was found that plant height of maize in treatment, T_4 is significantly superior than treatment, T_5 (2PRD with 50 % irrigation water of CI supplied, half to fixed side of the system) and treatment, T_3 (deficit irrigation (DI-50) in which 50 % of irrigation water of CI supplied to both side of the system) and it is significantly lower compared to treatment, T_2 (Deficit irrigation (DI- 75) in which 75 % of irrigation water of CI supplied to both side of the system). There was a significant effect of partial root drying technique with half of the root system exposed to soil drying and the other half kept well watered with 50 % irrigation water over the other two treatments T_3 and T_5 where the same amount of water was applied. The height of plant under treatment T_4 is higher by 11.3 and 19.1 percent compared to treatment T_3 and T_5.

Stem diameter

The average stem diameter after 120 days after transplanting was 8.78, 8.54, 7.76, 8.09 and 7.44 mm for treatments T_1, T_2, T_3, T_4 T_5 and T_6 respectively (Table 3). The highest stem diameter was recorded for treatment T_1 (control) with a value of 8.8 cm, followed by treatment T_2 with a value of 8.5cm and then treatment T_4 with a value of 8.1cm. The analysis revealed that stem diameter was statistically at par for treatments $T_{1,}$ and T_2. The stem diameter was significantly superior in Treatment T_1 and T_2 compared to other treatments. Stem diameter under treatment T_4 was significantly superior to treatment T_5 and at par with treatment T_3.The decline in stem diameter in treatment T_4 compared to control was only 7.2%.

Crop yield

Irrigation significantly ($P \leq 0.05$) influenced the yield status of maize. Maize yield increases with the increase in level of irrigation. DI50 (T_3), 1 PRD (T_4) and 2 PRD (T_5) significantly reduced yield, compared to CI treatments (T_1). The analysis of the data revealed that the yield of maize was found highest for treatment T_1 with a value of 10.54 t/ha, followed by treatment T_2 with a value of 10.10 t/ha and then treatment T_4 with a value of 9.54t/ha.

The reduction of yield in treatment T_4 compared to control was 9.50 %. But the other side of the analysis suggests that in terms of yield treatment 1 PRD (T_4) outperformed the treatments T_3 and T_5. The crop yield is higher by 13.6 % and 13.7 % in treatment T_4 compared to treatment T_3 and T_5 which uses the same amount of water. The similar results have been reported by other researchers for different crops affected by Partial Root Zone Drying Method of Irrigation (Guang-Chen *et al.*, 2008, Yazar *et al.*, 2009, Panigrahi and Sahu, 2013, Yactayo *et al.*, 2013).

This higher fruit yield in control could be ascribed to different factors. Firstly, it might be due to the higher vegetative growth and LAI that is essential for intercepting the radiation, which means more photosynthate are produced and allocated to the fruits. The second factor could be optimum soil water condition during the crop growth period.

Table.1 Experimental details of furrow irrigation and PRD regimes on *Rabi* maize crop

Irrigation Treatments	Details of irrigation treatments
T_1 (CI)	Control in which irrigation water will be applied to both sides of root system when soil water content was 60% of field capacity.
T_2 (DI-75)	Deficit irrigation (DI- 75) in which 75 % of irrigation water of CI supplied to both side of the system
T_3 (DI- 50)	Deficit irrigation (DI-50) in which 50 % of irrigation water of CI supplied to both side of the system
T_4 (1 PRD)	Partial rootzone drying, 1PRD with half of the root system exposed to soil drying and the other half kept well watered with 50 % irrigation water of CI.
T_5 (2 PRD)	PRD with 50 % irrigation water of CI supplied half to fixed side of the root system.
T_6 (Rainfed)	No Irrigation

Table.2 Effect of irrigation treatments on crop height of *Rabi* maize after 120 DAS

Treatment	Crop Height (cm)
T_1	**236.75_a**
T_2	**226.25_{ab}**
T_3	**207.25_c**
T_4	**221.00_b**
T_5	**191.75_d**
T_6	**131.50_e**
CD(P<0.5)	**12.67**
SEM	4.20
CV	4.15

Values are mean of four replicates. For a given variable, mean value not sharing common letters are significantly different ($P < 0.05$)

Table.3 Effect of irrigation treatments on stem diameter of *Rabi* maize after 120 DAS

Treatment	Stem Diameter (cm)
T_1	**8.78_a**
T_2	**8.54_a**
T_3	**7.76_{bc}**
T_4	**8.09_b**
T_5	**7.44_c**
T_6	**6.38_d**
CD(P<0.5)	**0.41**
SEM	0.14
CV	3.48

Values are mean of four replicates. For a given variable, mean value not sharing common letters are significantly different ($P < 0.05$)

Table.4 Effect of various irrigation treatments and PRD on crop yield (t/ha)

Treatment	Crop Yield (t/ha)
T_1	**10.54**$_a$
T_2	**10.10**$_a$
T_3	**8.40**$_b$
T_4	**9.54**$_c$
T_5	**8.39**$_b$
T_6	**1.75**$_d$
CD(P<0.5)	**0.52**
SEM	0.17
CV	4.24

Values are mean of four replicates. For a given variable, mean value not sharing common letters are significantly different (P < 0.05)

Table.5 Effect of various irrigation treatments on water use efficiency of *Rabi* Maize

Treatment	Water Use Efficiency (Kg/ha-cm)	Water Productivity (Kg/m^3)
T_1	**148.80**$_d$	1.48
T_2	**190.15**$_c$	**1.90**
T_3	**237.13**$_b$	**2.37**
T_4	**269.38**$_a$	**2.69**
T_5	**237.02**$_b$	**2.37**
T_6	-	-
CD(P<0.5)	14.56	
SEM	4.83	
CV	5.35	

Values are mean of four replicates. For a given variable, mean value not sharing common letters are significantly different (P < 0.05)

The other important outcome is the performance of crop under 1 PRD treatment (T_2) which undergoes alternate wetting and drying. Exposing a portion of the rootzone to drying has been reported to initiate rapid root growth on rewetting (Gersani and Sachs, 1992) with enhanced hydraulic conductivity. Increase in the rate of water uptake by two fold when roots in the dry soil were rewetted and sometimes this bring even higher then well irrigated controls was reported in pear (Kang *et al.*, 2002). This assists the plant to meet the requirement when only half of the root zone is supplied with water (Tan *et al.*, 1981).

Water use efficiency/water productivity

The highest irrigation water use efficiency (WUE) was found in treatment T_4 269.38 kg/ha-cm, and the lowest one was found in treatment T_1 (FI) as 148.8 kg/ha-cm. The statistical analysis of the data revealed that water use efficiency is significantly superior in treatment T_4 compared to rest of the treatments. The highest water use was observed in treatment FI as 708mm, the lowest was found in PRD-50 as 354 mm. Water use efficiency of maize decreased with increase in irrigation levels for all the treatments of furrow irrigation (Table 5).

The maintenance of yield in the PRD resulted in highly significant increases in water use efficiency (Table 4). The data reveals that the yield loss in PRD treatment was only 9.5 % compared to control whereas amount of water applied was 50 % less than the control irrigation. Although the treatment T_4 (1 PRD) received approximately 50 % water supplied to control, the drought level may not be severe enough to decrease plant growth to the same degree. Partial stomatal closure may have reduced water use at the same time maintained crop net photosynthesis, as stomatal resistance together with boundary layer resistance are the major controlling resistances for transpiration, while for CO_2 uptake mesophyll resistance is often the greater controlling resistance (Jones 1992). The PRD treatment may cause a better utilization of soil water reverses through promotion of root growth.

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How to cite this article:

Ravish Chandra, S.K. Jain, Mukesh Kumar, A.K. Singh and Vinod Kumar. 2018. Comparative Effects of Deficit Irrigation and Partial Root Zone Drying (PRD) on Growth, Yield and Wateruse Efficiency of *Rabi* Maize. *Int.J.Curr.Microbiol.App.Sci.* 7(02): 1073-1080.
doi: https://doi.org/10.20546/ijcmas.2018.702.133