Subsurface Drip Irrigation for Wet Season Rice Production under Climate Variability in India

Y A Rajwade, D K Swain and K N Tiwari

Agricultural and Food Engineering Department, Indian Institute of Technology Kharagpur,
Kharagpur, Medinipore (W), West Bengal, INDIA

ABSTRACT

The present investigation was carried out to analyze the rainfall variability at Kharagpur, India and to assess the application of drip irrigation to improve rice yield under the climatic variability. Meteorological analysis was carried out on past years' data using a first order Markov chain. For assessment of drip irrigation, the rice variety 'Annada' was grown during wet season (June-September) of the year 2012 and 2013 at Kharagpur using four nitrogen fertilizer levels and two drip lateral spacings in a strip-plot design. Probability of occurrence of dry spell length of 3 and 5 days was found to be $p \geq 0.9$ and $p \geq 0.5$, respectively during the wet season. Among the drip irrigated rice (DIR) treatments, the 40 cm lateral spacing with 75 kg Nha^{-1} through drip fertigation recorded highest grain yield of 4108kgha^{-1}. Grain yield of DIR was higher by 8.48% and lower by 11% as compared to the rain-fed direct seeded rice (RFR) and irrigated puddle transplanted rice (PTR), respectively under similar N application level. Also, the N uptake of the DIR increased by 12.5 and 16.2% compared to RFR and PTR, respectively. The drip irrigation was effective in improving grain yield and N use efficiency of rainfed rice.

Keywords: Climate variability, dry spell, drip irrigation, N uptake, Rice yield

1. INTRODUCTION

Climate change or variability is a threat to food security of the world in general and of the developing countries located in tropical and sub-tropical latitude in particular. Warming of the climate system in recent decades is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, rising sea level, and change in precipitation pattern. The precipitation over last 30-40 years of the 20th century has decreased between 10°S to 30°N, the tropical and sub-tropical belt (Bates et al., 2008). Generally, the frequency of occurrence of extreme events such as flood and drought has increased with increasing high intensity rainfall events and long dry spell, leading to food insecurity in the world. Rice is the second most important food crop after wheat in the world, which is grown in about 145 million hectares with an annual production of 696 million tonnes (FAO, 2010). More than 90% of the global rice is produced and consumed in Asia. In India, rice is grown in 44 million ha area, which is 28% of world rice area and contributes 22% of rice grain production (FAI, 2008).

Coupling with the weather information, water and nutrient management are the key inputs for improving rice productivity and resource use efficiency. The seepage and percolation account for about 50-80% of the water input (Bouman et al., 2005). The recent introduction of water saving irrigation technique such as reducing the depth of ponding water, System of Rice Intensification (SRI), Alternate Wetting and Drying (AWD), and keeping the soil just saturated are precision water management options to minimize the seepage and percolation loss of water from rice fields. Among the nutrient management, nitrogen plays key role in improving yield of rain-fed as well as irrigated rice. The greatest nitrogen loss in a rice field is in the range 20-45% through the process of volatilization and denitrification and 30-49% through leaching into ground water (Kyuma, 2004). The Nitrogen management technologies for increasing the use efficiency and uptake comprises adjusting application rates based on crop needs, time of application, placement, and using slow or controlled-release fertilizer forms or nitrification inhibitors (IPCC, 2007). Precision N management through fertigation with drip irrigation can reduce overall fertilizer application rates and minimize adverse environmental impact. Researchers have demonstrated drip-irrigated crop response to N fertilizer with higher water use efficiency (Hanson and May, 2004; Wang et al., 2009).

No information is available on use of drip irrigation on improvement of rice production and resource use efficiency. The present study was carried out at Kharagpur, India with two objectives:(i) To analyze the probability of occurrence of dry spells during growing season of a crop using Markov chain and (ii) To assess the application of drip irrigation as water saving precise irrigation technology to improve rice yield, water productivity and N use efficiency under the climatic variability.

2. MATERIALS AND METHODS

2.1 Analysis of rainfall data using Markov chain

The use of the Markov chain for the modeling of daily rainfall occurrences has been suggested by many previous studies. The optimum order of Markov chain depends on the threshold levels used and the length of period for the recorded data. Rainfall characteristics and dry spell occurrences were obtained by statistical evaluation of data using a first-order Markov chain process to estimate probability of occurrence of rainfall. It is assumed that rainfall at any given day is a stochastic event only dependent on the probability of the previous day being dry (P (rd)) or rainy (P (rr)), therefore, a first-order process. Rainy day was considered when rainfall amount of the day was 2.5 mm or more, else dry day (Dash et al., 2009). Each year (Yi) of the dataset can be described as a sequence of dry ($x_j = 0$) or wet ($x_j = 1$) days as equation 2.1;

$$Yi = \{x_1, x_2, \ldots, x_{j-1}, x_j\} \text{ for } Yi = \{1, 2, 3, \ldots, i-1, i\}, \qquad (2.1)$$

Where *i* is the number of years and *j*is the day number of year (DoY). The probability for a day being rainy after a dry day and rainy day followed by rainy day can be estimated as equation 2.2;

$$P(rd) = P(X_j = 1 | X_{j-1} = 0) \text{ and } P(rr) = P(X_j = 1 | X_{j-1} = 1) \qquad (2.2)$$

The estimated values of P(rr) and P(rd) were then fitted to a Fourier series to find the modelled values of these probability distributions.Best fit was determined by the F-test of added harmonics to the function. The probabilities of rainfall on any given day after the Fourier fit (f_rr and f_rd) were then used to determine the probabilityof occurrence of dry spells of 3, 5, 10 and 15 days using the software *Instat v 3.36*.

2.2 Field Experiment

A field experiment was conducted at the research farm of Agricultural and Food Engineering Department, Indian Institute of Technology, Kharagpur (22°19'N latitude and 87°19'E longitude), India, to study the effect of different lateral spacings(S) and nitrogen (N) fertigation levels in drip irrigation on growth and yield of rice, and N uptake in the acid lateritic soil of the subtropical India during the wet season (June-November) of the year 2012 and 2013. Variety 'Annada' of duration 100 days was used for the experiment. The experiment of drip irrigated rice (DIR) involved two lateral spacings and four N fertigation levels. The lateral spacings were 40 cm (S_{40}) and 60 cm (S_{60}). The N fertigation levels were0(N_0), 50(N_{50}), 75(N_{75}) and 100(N_{100}) kg ha^{-1}. These eight treatment combinations (lateral spacing [2] × fertigation [4]) were laid in strip-plot design with three replications. There were total 24 sub-plots and each subplot had dimensions of 6 m × 4.8 m.

Since the drip irrigation is considered as precision water and fertilizer application method, the N fertilizer amount as per the fertigation treatment was applied in 5 splits in the form of urea were applied through ventury injector starting at two weeks after emergence at every 15 days interval up to two weeks after heading. In addition to these DIR, two more treatments of conventional rice production technologies were included for comparative assessment of the drip irrigation system. These conventional treatments were (i) rain-fed direct seeded rice (RFR) and (ii) irrigated puddled transplanted rice (PTR). For these conventional treatments, recommended dose of full P_2O_5 and K_2O and 50% N was applied as basal at the time of sowing/transplanting of the crop. The rest N was applied in two equal splits at 25 and 45 days after sowing for direct seeded and 20 and 40 days after transplanting for transplanted rice. Irrigation was applied on the basis of manual observation of hairline crack in the soil in drip irrigated treatments. The water application was carried out to replenish the loss through the evapotranspiration when there was a dry spell of 3 days or more.

2.2.1 Grain yield and N uptake. For grain yield determination, the crop was harvested from an area of 4.5m^{2}in each plot, where plant sampling was not done earlier. Initial grain weight was recorded followed by oven drying of the grain samples to zero moisture content and the yield was converted to standard 12% moisture content. Plant samples were collected at maturity from each treatment and replication and oven dried at 70°C till constant weights wereobtained. The dried leaf, stem and grain samples were powdered and analyzed for N content following standard procedure (Jackson, 1973). The data were analyzed statistically following the standard procedures as described by Gomez and Gomez (1984).

3. RESULTS AND DISCUSSION

3.1 Conditional probability analysis

Conditional probability analysis of weather data for 32 years (1977-2008) was done with respect to rainfall. The annual estimated probabilities of rainfall for the location at Kharagpur, India are presented in Fig. 1(a). The increase in rainfall probability coincides with the expected duration of rainy seasons, which begins around 150th day and ends around 300th day of the year at Kharagpur. The likelihood to receive today's rainfall is highly dependent on the previous day whether that was rainy or dry. This feature is illustrated in Fig. 1(a)by the higher probability of receiving rain given the previous day being rainy (*P*(rr)) compared to the curve of probability of rain given previous day being dry (*P*(rd)).

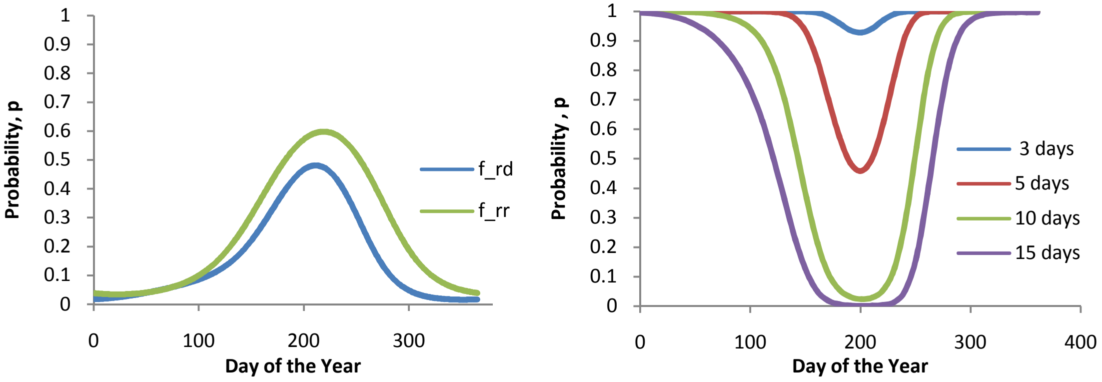

Figure 1. (a) Observed probability of rain if the previous day was dry (f_rd) or rainy (f_rr) dayat Kharagpur, India. (b) Probability of dry spell exceeding 3, 5, 10, or 15 days during the yearat Kharagpur, India

As shown in Fig. 1(b), the probability of exceedence of dry spell of more than three consecutive days was found high during any time of the year ($p \geq 0.9$), although slightly less during the expected rainy seasons. The probability of occurrence of dry spell of 5 days length was also high even in rainy season ($p \geq 0.5$). However, probability of excedence of dry spell length of 10 or 15 days was very less. Hence, it can be said that, there is a high probability of dry spells (3 or 5 days) but very less probability of long dry spells (10 or 15 days). From agriculture production point of view, long dry spells (10 or 15 days and more) are critical which result in crop failure, whereas short dry spells have an impact on soil moisture storage but can be controlled through supplementary irrigation. Many researchers have used Markov chain model for dry spell analysis and for recognizing suitable cropping patterns in different regions (Chattopadhyay and De, 2011).

3.2 Field experiment on rice

*3.2.1 Rice grain yield.*Grain yield of DIR was in the range 2389 to 4108 kgha^{-1} under varying N and water management (Table 1). The grain yield of rice was increased from 2401 kg ha^{-1} under no N application to 3240, 3915, and 4040 kg ha^{-1} with application of N at 50, 75 and 100 kg ha^{-1}, respectively through drip fertigation. The increase in grain yield was significant with increasing N application up to 75 kg ha^{-1}. Further increasing N application up to 100 kg ha^{-1} did not improve the grain yield significantly. Between the drip lateral spacings, S_{40} was better than S_{60} in improving the grain yield, though not significant. The highest grain yield was recorded in $S_{40}N_{75}$ (4108 kg ha^{-1}) followed by $S_{60}N_{100}$ and the $S_{40}N_{100}$.The interaction between lateral spacings and N fertilizer rate was not significant. Grain yield of DIR was higher by 8.48% and lower by 11% as compared to rain-fed direct seeded rice (RFR) and irrigated puddle transplanted rice (PTR), respectively under similar N application level. A study in south India by Kadiyala et al. (2012) the increase in rice grain yields under a flooded method was 39.0% and 15.4% higher over an aerobic method during the first and second years, respectively. Choudhury et al. (2007) observed 27% lower yield of DSR when irrigated at field capacity than in PTR in sandy loam and loam soils. The yield difference between aerobic and flooded rice can be attributed to reduce leaf area and biomass which may have resulted in reduced yields under aerobic rice. In several studies in NW India, yield of RFR was lower than of PTR (Qureshi et al., 2004). Ladha et al. (2009) also reported lower grain yield in reduced or zero till RFR compared with PTR. The variable performance of DSR relative to PTR could be due to many factors like soil properties, water management, weed management, and soil bacteria.

Table 1.Effect of nitrogen application rates (N) with drip lateral spacings (S) on grain yield (kg ha^{-1}) of rice.

TREATMENTS	N_0	N_{50}	N_{75}	N_{100}	Average
S_{40}	2414.45	3381.85	4108.1	4009.69	3478.53
S_{60}	2389.3	3098.33	3722.97	4070.81	3320.35
Average	2401.87	3240.09	3915.54	4040.25	
	S	**N**	**S × N**		
SEm(±)	18.94	175.84	256.18		
LSD(P=0.05)	186.53	781.50	1146.11		

The subscripts of N represents its application rate in kg ha^{-1} and the subscripts of S represent the lateral spacing in cm

3.2.2 Nitrogen uptake. The highest N uptake by the crop under DIR was recorded in $S_{40}N_{75}$ treatment (88.78 kg ha^{-1}) and the lowest in $S_{60}N_0$ (35.8 kg ha^{-1}). The treatments with S_{40} lateral spacing had higher N uptake than S_{60} spacing except at N_{100} application in which N uptake under S_{40} treatment was marginally lower that S_{60} treatment, but they were statistically at par. Averaged over the lateral spacings, the N uptake of crop increased with increasing N application level up to 75 kg ha^{-1}and declined thereafter (Fig. 2). The N uptake was increased from 38.04kg ha^{-1} in no N application treatment to 60.79 and 85.65 kg ha^{-1} with N application of 50 and 75 kg ha^{-1}, respectively. Hence, the apparent recovery of 50 and 75 kg ha^{-1} of N application by the crop were 45.4 and 63.4%, respectively under drip fertigation (Fig. 3). The N uptake was higher by 12.5% in DIR compared to RFRat similar N application rates. Whereas in conventional irrigation, only 30-40% of applied N is utilized by the crop (Patrick and Mahapatra, 1968) and the rest is lost through the process of volatilization and denitrification (20-45%) and leaching into ground water (30-49%) (Kyuma, 2004). In this experiment, the apparent N recovery of applied N increased up to 63% with increasing N application up to 75 kgha^{-1} under DIR. With further increase in N application (100 kg ha^{-1}), the N recovery was reduced to 42.6%, which is possibly due to higher leaching loss under increasing N application.

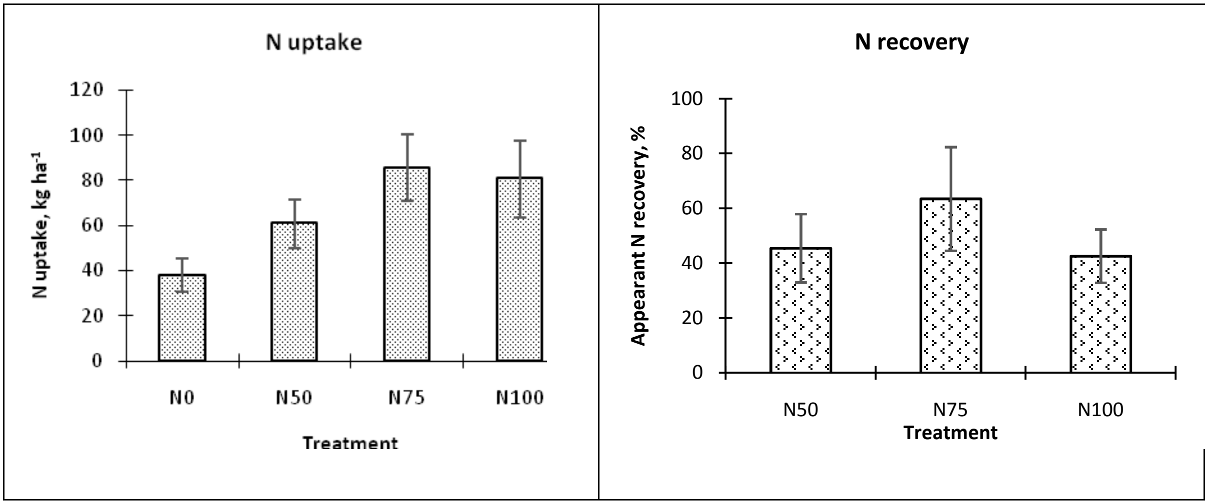

Figure 2.Nitrogen uptake (kg ha^{-1}) and apparent N recovery (%) under varying nitrogen (N) application rates as averaged over the lateral lateral spacings in drip irrigation.

Since, N is one of the major nutrients for cereal crops; the yield of rice is regulated by the N uptake pattern and its quantity by the plants. A significant positive correlation was obtained between grain yield and N uptake (r=0.818** at p=0.01), apparent N recovery (r=0.396** at p=0.01). Earlier studies on N deficiency revealed that the yield components, specially, panicle number per plant and per unit area decreased with lower N application (Eagle et al, 2000; Slaton et al, 2003). In this study, the N uptake in PTR was 69.4 kg $ha^{-1}$with N_{100}, whereas in DIR, the N uptake was 85.68 and 80.66 kg ha^{-1} in N_{75} and N_{100} treatments, respectively. This results stated that under the similar N application rate (100 kg ha^{-1}), DIR will have 11.3 kg higher N uptake (16.22%) as compared to the PTR, which shows increasing resource use efficiency with the use of drip fertigation.

4. CONCLUSION(S)

The study was carried out to determine the probability of occurrence of dry spells during the wet season (June-October) and to understand the feasibility of water saving irrigation technology to mitigate the adverse effect of dry spell on rain-fed rice yield. The probability of exceedense of 3 and 5 days dry spells was very high during the wet season, which is critical for rice growth and development. To compensate the yield loss of rice due to the occurrence of such dry spell, lifesaving irrigation is essential. From this experiment, it is evident that through drip irrigation 78% water could be saved as compared to the irrigated puddle transplanted rice, with slight yield penalty. Moreover application of N fertilizer through drip irrigation increased the crop N uptake by 16.2% as compared to the puddle transplanted rice, hence the apparent N recovery. Additionally, the fertilizer requirement in drip irrigation was reduced by 25% with a marginal yield reduction over the conventional transplanting.

REFERENCES

[1] A J Eagle, J A Bird, W R Horwath, B A Linquist, S M Brouder, J E HillandK C Van (2000), Rice yield and nitrogen utilization efficiency under alternative straw management practices. *Agronomy Journal*, **92,** pp. 1096–1103.

[2] A S Qureshi, I Masih, and H Turral (2004), Comparing land and water productivities of transplanted and direct dry seeded rice for Pakistani Punjab, *J. Appl. Irrig. Sci.***41**, pp. 47–60.

[3] B AMBouman, S Peng, A R Castañeda and R M Visperas (2005), Yield and water use of irrigated tropical aerobic rice systems, *Agricultural Water Management*, **74,** *2*, pp. 87-105.

[4] B CBates, Z W Kundzewicz, S Wu, and J P Palutikof (2008), Climate Change and Water.*Technical Paper of the Intergovernmental Panel on Climate Change*, IPCC Secretariat, Geneva, pp. 210.

[5] B R Hansonand D May (2004), Effect of subsurface drip irrigation on processing tomato yield, water table depth, soil salinity and profitability, *Agricultural Water Management*, **68**, pp. 1–17.

[6] B U Choudhury, B A M Boumanand A K Singh (2007), Yield and water productivity of rice–wheat on raised beds—results from a field experiment at New Delhi, India. *Field Crops Research,* **100**, pp. 229–239.

[7] FAI (Fertilizer Association of India) (2008).Area, Production and yield of principal crops. In: TKChanda, K Sati, C Robertson, (Eds.), *Fertilizer Statistics*, pp. 11-44.

[8] FAO (Food and Agriculture Organization of the United Nations), 2010.Electronic on-line database.Online at http://www.fao.org

[9] GChattopadhyay andS SDe (2011), A Markov Chain approach in the prediction of severe pre-monsoon thunderstorms through artificial neural network with daily total ozone as predictor. *XXXth URSI General Assembly and Scientific Symposium*, Istanbul, Turkey, August

[10] IPCC(2007), *Climate change impacts, Adaptation and Vulnerability.* Contribution of working group II to the fourth assessment report of the intergovernmental panel on climate change, Cambridge university press, Cambridge.

[11] J K Ladha, V Kumar, MAlam, S Sharma, M Gathala, P Chandna, and V Balaubramanian (2009), Integrated crop and resource management technology for enhanced productivity, profitability, and sustainability of rice–wheat system in South Asia. In: *Integrated Crop and Resource Management in the Rice–Wheat System of South Asia*(J K Ladha, Yadvinder-Singh, O Erenstein, and B Hardy, (Eds.)) Los Banos. Philippines: International Rice Research Institute, pp. 133–150.

[12] K A Gomez and AAGomez (1984), *Statistical Procedures for Agricultural Research.* 2nd Edn., John Wiley and Sons, UK.

[13] K Kyuma (2004), *Paddy soil science*, Kyoto University Press, Kyoto, Japan 280 pp., 2004.

[14] M D Kadiyala, R S Mylavarapu, Y C Li, G B Reddy, and M D Reddy (2012), Impact of Aerobic Rice Cultivation on Growth, Yield, and Water Productivity of Rice–Maize Rotation in Semiarid Tropics, *Agronomy Journal*, **104,** *6*, pp. 1757-1765.

[15] M L Jackson (1973), *Soil chemical analysis.* Prentice Hall of India Pvt. Ltd, New Delhi.

[16] N ASlaton, R D Cartwright, J Meng, E E JrGbur, andR J Norman (2003), Sheath blight severity and rice yield as affected by nitrogen fertilizer rate: Application method and fungicide. *Agronomy Journal*, **95**: pp. 1489–1496.

[17] S K Dash, M A Kulkarni, UC Mohanty and KPrasad (2009), Changes in the characteristics of rain events in India, *J. Geophy. Res.*, **114**, D10109, doi:10.1029/2008JD010572.

[18] W H Patrick and L C Mahapatra (1968), Transformation and availability to rice of nitrogen and phosphorus in waterlogged soils. *Advances Agronomy*, **20**, pp. 323–359.

[19] Z Wang, L Zuoxin, ZZikunand L Xingbin (2009), Subsurface drip irrigation scheduling for cucumber (Cucumissativus L.) grown in solar greenhouse based on 20 cm standard pan evaporation in Northeast China, *ScientiaHorticulturae*, **123,** *1*, pp. 51-57.