

## Estimation of Water Consumption and Crop Water Productivity of Wheat Crop in Farmer's Field of North Bihar

Ravish Chandra, S. K. Jain, A. K. Singh

Received 17 June 2016; Accepted 25 July 2016; Published online 6 August 2016

**Abstract** A study was conducted in the farmer's field for estimating gross water productivity, irrigation water productivity and process depletion for HD 2733 variety of wheat crop. The water accounting methodology developed by International Water Management Institute was taken for this study. Ten fields of farmers were selected for detailed data collection in Harpur village of Pusa block of Samastipur district. The value of gross water productivity ranges from 0.67 kg/m<sup>3</sup> to 0.90 kg/m<sup>3</sup> for HD 2733 variety of wheat with an average value of 0.79 kg/m<sup>3</sup>. The irrigation water productivity for HD 2733 variety of wheat ranges from 0.75 kg/m<sup>3</sup> to 1.09 kg/m<sup>3</sup> with an average value of 0.91 kg/

m<sup>3</sup>. The value of process depletion varied between 0.98 kg/m<sup>3</sup> to 1.32 kg/m<sup>3</sup> with an average value of 1.16 kg/m<sup>3</sup>. The water balance component indicated average gross inflow of 47.60 cm for HD 2733 variety of wheat crop against the crop demand of 32.09 cm. The irrigation inflow constituted about 87% of gross inflow for HD 2733 variety of wheat. The total depth of irrigation water application varied between 31 cm to 52 cm with an average value of 42 cm. The deep percolation loss ranges from 11 to 46% with an average value of 31%, which shows low water use efficiency.

**Keywords** Process depletion, Irrigation water productivity, Deep percolation.

### Introduction

In India, wheat is the most important cereal crop after rice, which is cultivated in an area of about 30 m ha with a production of 95 m tones and the average yield is 3.1 t ha<sup>-1</sup> [1]. Rice-wheat is a major cropping system for sustaining food security in the region and millions of farmers and agricultural workers depend on this system for employment and livelihoods. The agricultural sector in India in general and Bihar in particular, continues to occupy the center-stage in the overall economic progress and development.

Inappropriate use of applied inputs and over exploitation of resources, principally water, is leading

---

R. Chandra\*, S. K. Jain, A. K. Singh  
Department of Irrigation and Drainage Engineering,  
College of Agricultural Engineering,  
Rajendra Agricultural University,  
Bihar, Pusa (Samastipur 848125), India  
e-mail : ravish.cae@gmail.com

\*Correspondence

to secondary salinization in low quality aquifer zones, ground water table recession in fresh water aquifer zones and physical and chemical deterioration of soil and water quality [2]. Water shortage is an important factor limiting grain production in many parts of the world [3, 4]. During the wheat growing season (from mid November to mid April of the following year), the mean precipitation is about 50 mm, while the evaporation which can reach up to 400 mm. Therefore irrigation is required to satisfy the consumptive use of the crop. Growing water scarcity has further constrained attainment of goals of food security and sustainable natural resource management. The irrigation sector will have less water in future as the competition and demand from the domestic, industrial and environmental sectors keep increasing. The challenge for irrigated agriculture will be to grow more food with less water. The cost of abstraction of ground water is increasing with increasing fuel prices. The focus from improving land productivity needs to be shifted to improving water productivity. The water productivity for different crops needs to be estimated for suggesting best possible options for this region. Keeping the above things in mind a study was conducted in the farmers' field of North Bihar for estimating gross water productivity, irrigation water productivity and process depletion for wheat crop.

## Materials and Methods

### Study area and climate

Harpur village is located very close to Rajendra Agricultural University and 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°46' N latitude and 86°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% 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°C and minimum from 5.7 to 8.8°C. Rice 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.

Figure 1 shows the rainfall received at Pusa from the year 2000-2010. The data shows that maximum rainfall (2430.9 mm) was received in the year 2007 and minimum rainfall (636.7 mm) in the year 2003.

### Water productivity

Water productivity (WP) refers to benefits derived from use of irrigation water. The productivity of water is expressed in terms of kg/m<sup>3</sup> of water or Rs/m<sup>3</sup> of water. The water accounting methodology developed by IWMI [5, 6] is taken for the present study. The definitions of terms adopted are expressed as under:

$$\begin{aligned} \text{WP gross inflow} &= (\text{Yield, kg/ha}) / (\text{Gross inflow, m}^3/\text{ha}) \\ &\text{or} \\ &= (\text{Gross income, INR/ha}) / (\text{Gross inflow, m}^3/\text{ha}) \quad \dots(1) \end{aligned}$$

$$\begin{aligned} \text{WP irrigation inflow} &= (\text{Yield in kg/ha}) / (\text{Irrigation inflow in m}^3/\text{ha}) \\ &\text{or} \\ &= (\text{Gross income, INR/ha}) / (\text{Irrigation inflow in m}^3/\text{ha}) \quad \dots(2) \end{aligned}$$

$$\begin{aligned} \text{WP process depletion} &= (\text{Yield in kg/ha}) / (\text{Evapotranspiration, m}^3/\text{ha}) \\ &\text{or} \\ &= (\text{Gross income, INR/ha}) / (\text{Evapotranspiration, m}^3/\text{ha}) \quad \dots(3) \end{aligned}$$

The term gross inflow represents the water from canal, ground water pumped from tube wells and rainfall whereas irrigation inflow includes only the canal water supplies and ground water abstractions through tube wells. Thus, the precipitation received in the area is not included calculating irrigation in-flow.

### Evapotranspiration

The evapotranspiration for the crop was calculated using CROPWATT-8 software [7] which is based upon Penman-Monteith equation [8]. The FAO Penman-Monteith method is maintained as the sole stan-

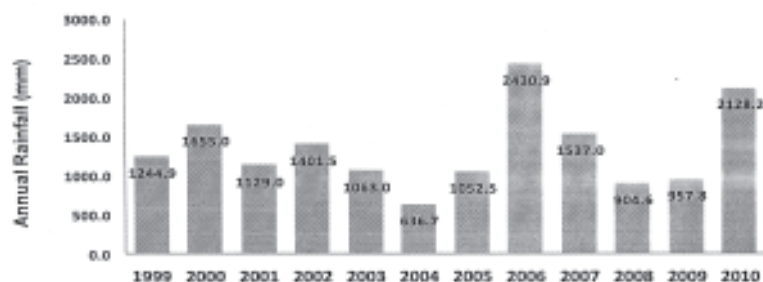


Fig. 1. Annual rainfall (mm) received at Pusa farm (2000–2010).

standard method for the computation of  $ET_0$  from meteorological data. The Penman-Monteith equation is presented below.

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T + 273} u_2 (e_s - e_a)}{\Delta + \gamma (1 + 0.34u_2)} \quad \dots(4)$$

where,  $ET_0$  – is reference evapotranspiration [ $\text{mm day}^{-1}$ ],  $R_n$  – is net radiation at the crop surface [ $\text{MJ m}^{-2} \text{day}^{-1}$ ],  $G$  – is soil heat flux density [ $\text{MJ m}^{-2} \text{day}^{-1}$ ],  $T$  – is air temperature at 2 m height [ $^{\circ}\text{C}$ ],  $u_2$  – is wind speed at 2 m height [ $\text{m s}^{-1}$ ],  $e_s$  – is saturation vapor pressure [kPa],  $e_a$  – is actual vapor pressure [kPa],  $e_s - e_a$  – is saturation vapor pressure deficit [kPa],  $D$  – is slope of vapor pressure curve [ $\text{kPa } ^{\circ}\text{C}^{-1}$ ] and  $\gamma$  – is psychrometric constant [ $\text{kPa } ^{\circ}\text{C}^{-1}$ ].

The FAO Penman-Monteith equation determines the evapotranspiration from the hypothetical grass reference surface and provides a standard to which evapotranspiration in different periods of the year or in other regions can be compared and to which the evapotranspiration from other crops can be related.

#### Calculation procedure

#### Reference evapotranspiration

The calculation procedure consists of the following steps:

1. Derivation of some climatic parameters from the daily maximum ( $T_{\max}$ ) and minimum ( $T_{\min}$ ) air tempera-

ture, altitude ( $z$ ) and mean wind speed ( $u_2$ ).

2. Calculation of the vapor pressure deficit ( $e_s - e_a$ ). The saturation vapor pressure ( $e_s$ ) is derived from  $T_{\max}$  and  $T_{\min}$ , while the actual vapor pressure ( $e_a$ ) can be derived from the dewpoint temperature ( $T_{\text{dew}}$ ) from maximum ( $\text{RH}_{\max}$ ) and minimum ( $\text{RH}_{\min}$ ) relative humidity from the maximum ( $\text{RH}_{\max}$ ) or from mean relative humidity ( $\text{RH}_{\text{mean}}$ ).

3. Determination of the net radiation ( $R_n$ ) as the difference between the net shortwave radiation ( $R_{\text{ns}}$ ) and the net longwave radiation ( $R_{\text{nl}}$ ). In the calculation sheet, the effect of soil heat flux ( $G$ ) is ignored for daily calculations as the magnitude of the flux in this case is relatively small. The net radiation, expressed in  $\text{MJ m}^{-2} \text{day}^{-1}$ , is converted to  $\text{mm/day}$  (equivalent evaporation) in the FAO Penman-Monteith equation by using 0.408 as the conversion factor within the equation.

4.  $ET_0$  is obtained by combining the results of the

Table 1. Crop yield and no. of irrigations applied in the field of selected farmers of Harpur village (rabi 2010-11).

Sl. No.	Farmers (F)	Crop	Variety	No. of irrigation	Crop yield (t/ha)
1.	F <sub>1</sub>	Wheat	HD2733	2	3.9
2.	F <sub>2</sub>	Wheat	HD2733	2	3.7
3.	F <sub>3</sub>	Wheat	HD2733	2	3.3
4.	F <sub>4</sub>	Wheat	HD2733	3	3.6
5.	F <sub>5</sub>	Wheat	HD2733	3	4.1
6.	F <sub>6</sub>	Wheat	HD2733	2	3.7
7.	F <sub>7</sub>	Wheat	HD2733	4	4.2
8.	F <sub>8</sub>	Wheat	HD2733	3	3.8
9.	F <sub>9</sub>	Wheat	HD2733	3	3.5
10.	F <sub>10</sub>	Wheat	HD2733	3	3.3
Average				2.70	3.70

**Table 2.** Water productivity of wheat crop for selected fields (*rabi* 2010-11).

Sl. No.	Farmers (F)	Variety-HD-2733		
		Irrigation WP (kg/m <sup>3</sup> )	Total WP (kg/m <sup>3</sup> )	Yield/ET process depletion (kg/m <sup>3</sup> )
1.	F <sub>1</sub>	1.05	0.90	1.21
2.	F <sub>2</sub>	0.81	0.71	1.20
3.	F <sub>3</sub>	1.07	0.89	0.98
4.	F <sub>4</sub>	0.85	0.75	1.08
5.	F <sub>5</sub>	0.85	0.76	1.32
6.	F <sub>6</sub>	0.91	0.79	1.23
7.	F <sub>7</sub>	0.81	0.72	1.25
8.	F <sub>8</sub>	0.75	0.67	1.23
9.	F <sub>9</sub>	0.96	0.82	1.09
10.	F <sub>10</sub>	1.09	0.91	1.02
	Average	0.91	0.79	1.16

previous steps.

#### *Crop evapotranspiration*

In the crop coefficient approach the crop evapotranspiration  $ET_c$  is calculated by multiplying the reference crop evapotranspiration  $ET_o$  by a crop coefficient  $K_c$ :

$$ET_c = K_c ET_o \quad \dots(5)$$

Where,  $ET_c$  = crop evapotranspiration [mm d<sup>-1</sup>],  $K_c$  = crop coefficient [dimensionless] and  $ET_o$  = reference crop evapotranspiration [mm d<sup>-1</sup>].

### Results and Discussion

#### Number of irrigation and crop yield

The fields of ten farmers were selected for detailed data collection in Harpur village of Pusa Block (dist Samastipur). The crop selected for the study was wheat. The source of irrigation was only ground water. Information related to different agricultural practices done by the farmers in their fields and data collected are presented in Table 1.

The number of irrigations applied by different farmers for HD-2733 variety of wheat crop varied from

2 to 4. The average number of irrigation for ten selected farmers was found to be 2.70. The table also shows the impact of number of irrigation on yield of wheat crop. The highest yield of 4.2 t/ha for HD-2733 variety was obtained with 4 irrigations. The crop yield of HD-2733 variety of wheat varied between 3.3 t/ha to 4.2 t/ha with an average of 3.70 t/ha.

#### Water productivity

The productivity of irrigation water depends on the amount of irrigation water and crop yield. Table 2 shows water productivity for HD-2733 variety of wheat crop for *rabi*-2010-11. The water productivity values for gross inflow range from 0.67 kg/m<sup>3</sup> to 0.90 kg/m<sup>3</sup> for HD-2733 variety of wheat with an average value of 0.79 kg/m<sup>3</sup>. This indicates that 1266 liter water was used to produce one kilogram of HD-2733 variety of wheat. The water productivity determined, based on irrigation inflow was higher than that of gross inflow. The value of irrigation water productivity ranges from 0.75 kg/m<sup>3</sup> to 1.09 kg/m<sup>3</sup> for HD-2733 variety of wheat crop with an average value of 0.91 kg/m<sup>3</sup>. Process depletion is defined as yield divided by crop evapotranspiration. The value of process depletion varied between 0.98 kg/m<sup>3</sup> to 1.32 kg/m<sup>3</sup> with an average value of 1.16 kg/m<sup>3</sup>. The higher value of process depletion compared to irrigation water productivity is showing the losses incurred in the system. The water productivity values are very low compared with the other countries in the world. These values are also low in comparison to the developed states of India. The analysis suggests that there is significant scope for increasing water productivity by increasing yield through both better water and other input management.

#### Water balance

The water balance components indicated average gross inflow of 47.64 cm for HD-2733 variety of wheat crop against the crop demand of 32.09 cm (Table 3). The irrigation inflow constituted about 87% of gross inflow for HD-2733 variety of wheat. The total depth irrigation water application varied between 30.72 to 51.57 with an average value of 41.54 cm. The rainfall was 6.1 cm during the entire *rabi* season. The change in root zone storage was assumed as zero. The aver-

**Table 3.** Summary of water balance components for wheat (2010-11).

Sl. No.	Far-mers (F)	Irrig. water (cm)	Total rainfall (cm)	Total depth of water (cm)	ET (cm)	( $\Delta S +$ Deep perco.) (cm)	% loss
1.	F <sub>1</sub>	37.13	6.1	43.23	32.29	10.94	25.31
2.	F <sub>2</sub>	46.08	6.1	52.18	31.02	21.16	40.55
3.	F <sub>3</sub>	30.97	6.1	37.07	33.62	3.45	9.31
4.	F <sub>4</sub>	42.24	6.1	48.34	33.32	15.02	31.07
5.	F <sub>5</sub>	48.28	6.1	54.38	31.25	23.13	42.53
6.	F <sub>6</sub>	41.37	6.1	47.47	30.57	16.9	35.60
7.	F <sub>7</sub>	51.57	6.1	57.67	33.34	24.33	42.18
8.	F <sub>8</sub>	50.47	6.1	56.57	30.80	25.77	45.55
9.	F <sub>9</sub>	36.57	6.1	42.67	31.99	10.68	25.03
10.	F <sub>10</sub>	30.72	6.1	36.82	32.72	4.10	11.13
	Average	41.54	6.10	47.64	32.09	15.55	30.83

age seepage and deep percolation losses were high for all selected fields for wheat. The deep percolation loss ranges from 11–46%, which shows low efficiency of water use. The large amount of irrigation water and rainfall was not used beneficially by the wheat crop and goes out of the root zone over the whole growing season. The average value for deep percolation losses was 30.83 cm. This stressed the need for better and efficient use of irrigation and rainwater to improve water use efficiency.

### Conclusion

The analysis suggests that there is significant scope for increasing water productivity by increasing yield through both better water and other input manage-

ment. The lower water productivity is due to inefficient use of irrigation water. The large amount of irrigation water and rainfall was not used beneficially by the wheat crop and goes out of the root zone over the whole growing season. The trade-off between reduced yield and higher water productivity needs to be quantified in economic terms before recommending deficit irrigation (and other water-saving irrigations in rice production).

### References

1. <http://www.indiaagrstat.com/agriculture/2/foodgrains/17180/wheat/17195/stat.aspx>, August 27, 2014.
2. Gupta RK, Naresh RK, Hobbs PR, Jiaguo J, Ladha JK (2003) Sustainability of post green revolution agriculture : The rice wheat cropping systems of the Indo-Gangetic Plains and China. Improving the productivity and sustainability of rice-wheat systems : Issues and Impacts. ASA Special Publication 65, ASA, Madison, WI, USA (Chapter 1:1.125).
3. Khan S, Munir AH, Mu JX (2009) Water management and crop production for food security in China : A review. *Agric Water Manag* 96 : 349–360.
4. Dong BD, Lei S, Shi CH, Quiao YZ, Liu MY, Zhang ZB (2011) Grain yield and water-use efficiency of two types of winter wheat cultivars under different water regimes. *Agric Water Manag* 99 : 103–110.
5. Molden D (1997) Accounting for water use and productivity. SWIM paper 1. Int Water Manag Inst, Colombo, Sri Lanka.
6. Molden D, Sakthivadivel R (1999) Water accounting to assess use and productivity of water. *Water Res Dev* 15 : 55–71.
7. Allen RG, Pereira LS, Raes D, Smith M (1998) Crop evapotranspiration-Guidelines for computing crop water requirements. FAO Irrigation and Drainage Paper 56, FAO. Rome 300 (9), D05109.
8. Smith M (1992) CROPWAT A computer program for irrigation planning and management. Irrigation and Drainage Paper 46. Food and Agric Organ, Rome, Italy.