Mini Review

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Rice and wheat water productivity assessment in India

Abstract

Crop water productivity denotes the amount or value of product (i.e. crop or food) over volume or value of water used or depleted or diverted. It is dependent on water used in various production and agro-eco systems, level and scale of study. Assessment of crop water productivity helps in generating knowledge and information about water used by various users and committed losses. Crop water productivity is influenced by many factors and it can be improved if impact of various interventions on crop water productivity is known. In order to study the impact of various interventions on rice and wheat water productivity, it was computed from published data at different locations in the country and interventions showing higher values of water productivity were identified. The information generated from this study is useful in selecting and prioritizing suitable interventions to improve crop water productivity under prevailing constraints of limited availability of land, water and other input resources.

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Introduction

According to Droogers & Kite[1] water is expected to be one of the most critical natural resources in the twenty-first century. Twenty-six countries are now classified as water deficient, and nearly 230 million people are affected with water shortages. Seckler et al.[2] reported that by 2025, one quarter of the world's population will face severe water shortages. To avoid social and environmental chaos, there is a clear need for better management of the limited amount of water available.

Seckler et al.[2] also reported that irrigated agriculture is the biggest consumer of world's fresh water resources. On a global level, irrigation comprises 72 percent of the average per capita diversions, with industrial and domestic sector accounting for 19 percent and 9 percent, respectively, of the average per capita water diversions. But in future share of water in agriculture sector is expected to reduce due to increased demand of industries, urban and domestic sectors.

Water being one of the most important inputs for crop production, adversely affects crop yield, when applied in excess or deficit at critical crop growth stages. Quality, quantity and time of input application have direct impact on crop yield and it is necessary to measure/ record and analyze the impact of one of the most important inputs i.e. water on yield to plan efficient and effective use of water resource in crop production.

The quantity of water application depends on many factors like size, shape and slope of field, method of irrigation, source and amount of water available, type of soil, type of crop and its' growth stage, socio-economic condition and awareness level of farmer about advanced agronomic and on-farm water management practices. Since time and quantity of water application have direct impact on crop yield it is necessary to record the time and scientifically measure the quantity of water applied (inflow to the field), water used by crop in transpiration, water stored in the root zone and water depleted from system in the form of evaporation, percolation and runoff.

The concept of productivity i.e., production per unit of input, focuses on limiting factors or constraints. In the mid 70s for example the petroleum crisis highlighted the importance of energy in agriculture and the productivity of energy became popular. In areas where labour is constrained, the concept of labour productivity is used. Water is also a limiting resource and water productivity also needs to be estimated for its judicious use.

Crop water productivity varies with location depending on the factors such as cropping pattern, climatic conditions, irrigation technology, field water management, infra structure and on the labour, fertilizer, and machinery inputs. According to Kijne et al.,[3] raising crop water productivity means raising crop yields per unit of water consumed, though with declining crop yield globally, the attention has shifted to potential offered by improved management of water resources. In general water productivity is a function of water applied, which depends on space scale and generally increases from small plots to large domains at basic scale because applied water is recycled and reused.

According to Molden,[4] water productivity can be estimated at three levels: a use level such as an irrigated field or household, a service level such as an irrigation or water supply system, and a water basin level that may include several uses.

At the field level agronomists evaluate the productivity of water through water use efficiency, the ratio of yield to water consumed (kg/m^3) by the crop through evapotranspiration at the field scale or as the yield per unit depth of water per area kg/ha/mm. Biomass yield may also include straw and roots if they have an economic value. It can be estimated for individual crop or for a particular farm. Molden et al.[5] discussed in detail the concept of water productivity and pathways to improve it. Chandra et al.[6] computed crop water productivity in head, middle and tail reaches of RP Channel V under Patna Main canal in the Sone Command and two tube well commands in Vaishali, Bihar. They observed that crop water productivity varied in increasing order between 2.42 and 3.11`/$m^3$ from head to tail reach and 2.81 and 2.39`/m^3 in tube well 2 with land consolidation and tube well 1 with fragmented land holdings. Upadhyaya & Sikka[7] also discussed the concept of water, land and energy productivity in agriculture and pathways for improvement.

Water productivity is influenced by many factors. Some of the important factors are:

a. Source of water like rainfall, surface and ground water along with its' availability, accessibility and affordability
b. Water supply system like canal net work, ground water pumping and conveyance through pipes
c. Water application systems or irrigation methods i.e. surface irrigation like border, check basin or furrow irrigation or pressurized irrigation like sprinkler, micro sprinkler or trickle irrigation and various irrigation scheduling approaches
d. Social and economic conditions of water users/farmers
e. Land slope, leveling and drainage characteristics
f. Water losses as runoff, seepage or evaporation/evapotranspiration
g. Shape, size and slope of field
h. Infrastructure, labour, fertilizer, adoption level of farm mechanization, other on farm water management technologies, their cost effectiveness and sustainability, economics and policy interventions
i. Relationship between water suppliers and water users in canal command which helps in making water available to crop in time
j. Frequency, intensity, duration and distribution of rainfall and floods/drought or other climatic conditions
k. Type of soil, soil moisture level, infiltration, soil conservation and other soil health management practices,
l. crops, genetic material, various crop production, protection, improvement and management practices/ technologies
m. Indigenous technical knowledge and superstitions of farmers
n. Training and awareness level of farmers to recent on farm water management technologies
o. Farmers' participation. In addition to these factors, application of quality inputs in appropriate quantity at right time with proper care/management throughout the process of farming, produced output, its' processing, value addition and linkage with suitable market to get appropriate price of produce also help in enhancing water productivity.

Water Productivity may be used as a quite effective management tool in

i. Benchmarking
ii. Identifying gaps and analyzing best ways to use water
iii. Identifying opportunities to reduce non-beneficial outflows from the domain
iv. Comparing productivity of water in different parts of the production system or basin, and
v. Deciding best possible multiple use combinations.

In the present paper rice and wheat water productivity has been estimated at different locations under different technical interventions to understand the variation of water productivity as influenced by various technologies/ practices/interventions.

Materials and methods

Published data from Annual Report (2014-15)[8] about type of soil, depth of water table (m), annual rainfall (mm), source of irrigation and irrigation water quality at 21 water management centers located in major and medium irrigation commands and 4 water management centers located in hilly and high rainfall areas (Figure 1) under All India Coordinated Research Project on Water Management funded by Indian Council of Agricultural Research (ICAR) was collected and given in Table 1.

Table 1 Locality characteristics of AICRP centres in India

Centre name	Soil type	Depth of water table (m)	Annual rainfall (mm)	Source of Irrigation	Irrigation water quality
Belvatagi	Sandy loam to clay	Very deep	556	Canal	Good
Bhavanisagar	Red sandy loam to clay loam	3-10m	702	Canal	Good
Bilaspur	Sandy loam to clay	>2m	1249	Canal	Good
Chalakudy	Loamy sand to sandy loam slightly acidic	>2m	3146	Canal	Good
Chiplima	Sandy loam to sandy clay loam	0.2-5m	1349	Canal	Good
Faizabad	Silty loam to silty clay loam	3-4m	1163	Canal Tubewell	Good
Hisar	Loamy sand to sandy loam	0.4-1m	430	Canal Tubewell	Good
Jammu	Sandy loam to silty loam	>4m	1175	Canal	Good
Jorhat	Sandy loam to sandy clay loam, slightly acidic	0-15m	1985	Canal Tubewel	Good
Bathinda	Loamy sand to sandy loam	1.0-4m	400	Canal Tubewell	Good
Kota	Clay loam to clay	0.7-2m	777	Canal	Good
Madurai	Sandy loam to clay loam	0.5-2m	858	Canal	Good
Gayeshpur	Sandy loam to clay loam	0.2-2m	1315	Canal Tubewell	Good
Morena	Sandy loam to sandy clay loam	5-15m	875	Canal Tubewell	Good

Table Continued....

Centre name	Soil type	Depth of water table (m)	Annual rainfall (mm)	Source of Irrigation	Irrigation water quality
Navsari	Clayey	1-5m	1418	Canal	Good
Pantnagar	Sandy loam to clay loam	0.5-3m	1370	Canal	Good
				Tubewell	
Parbhani	Medium to deep black clayey	>3m	879	Canal	Good
Powarkheda	Clay loam to clayey	1-5m	1285	Canal	Good
Pusa	Sandy loam	2-6m	1200	Canal	Good
				Tubewell	
Rahuri	Deep black clayey	2-5m	523	Canal	Good
Sriganganagar	Loam to silty clay loam	>10m	276	Canal	Good
				Tubewell	
Almora	Brown forest and Podzolic soils, slightly acidic	-	1152	-	-
Dapoli	Lateritic and alluvium derived soils-sandy clay loam, slightly acidic	-	3600	-	-
Palampur	Brown forest and podzolic acidic soils-silty clay loam, slightly	-	2605	-	-
Shillong	Red and lateritic soils-sandy loam, slightly acidic	-	2100	-	-

Crop water productivity computation

Crop water productivity is the ratio of amount or value of product (i.e. crop) and the volume of water used or diverted or depleted. Increasing the productivity of water means, in its real sense, getting more benefit from every unit of water used for various crops. From farmers' view point, it means getting more production per unit of irrigation water. It is expressed in terms of kg/m^3 or kg/ha-cm or `/m^3.

Rice water productivity assessment

Total water used by Rice under different resource conservation techniques and at various critical crop growth stages at Almora is given below in Table 2.

Table 2 Rice water productivity under different treatments at Almora

Treatment details	Total water used(mm)	Yield (t/ha)	Water productivity (kg/m^3)
Zero tillage	707.4	2.8	0.396
Conventional tillage	737.9	3.02	0.409
PSI + Tillering	694.7	3.1	0.446
PSI + Tillering + Panicle initiation	743.9	3.14	0.422
PSI + Tillering + Panicle initiation + Grain formation	779.6	3.07	0.394

Rice water productivity varies between 0.394 to 0.446 kg/m^3 under various crop establishment and water application treatments at Almora. Two irrigations at Pre sowing and tillering stages give maximum water productivity. It indicates that PSI and tillering stages are very sensitive stages and under the situation of limited water availability irrigation should be provided at these stages of crop growth. When four irrigations at Pre sowing, tillering, Panicle initiation and Grain formation stages are applied, it gives the minimum water productivity because amount of water applied is more but yield is less. Water productivity is marginally lower in zero tillage treatment compared to conventional tillage method. It indicates that under limited water availability, zero tillage method should be preferred over conventional tillage method.

Rice water productivity was computed at Kurukshetra, Haryana considering total water used in rice production under bed planting and conventional tillage method and is given below in Table 3.

Table 3 Rice water productivity at Kurukshetra, Haryana under bed planting and conventional tillage

Treatment details	Total water used(mm)	Yield(t/ha)	Water productivity(kg/m^3)
Bed Planting	1268.5	5.04	0.397
Conventional tillage	1817.2	5.53	0.3

It is observed that Rice water productivity is more under Bed Planting method of crop establishment as compared to conventional tillage. Though yield is more in conventional tillage but water used is much less in bed planting method leading to higher water productivity under the treatment of bed planting.

Rice water productivity under various soil moisture regimes analyzed at Kanpur is presented below in Table 4.

Table 4 Rice water productivity under various soil moisture regimes at Kanpur

Irrigation regime	Relative grain yield (%)	Irrigation requirement (%)	Water productivity enhancement
Continuous submergence	100	100	1
Continuous saturation	92	56	1.64
Saturation during early crop growth stage and submergence thereafter	100	88	1.13
Submergence during active tillering upto flowering and saturation during rest of the crop growth period	104	66	1.58
Saturation during active tillering upto flowering and submergence during rest of the crop growth period	80	75	1.07

Rice Water productivity enhancement is found maximum under continuous saturation followed by submergence during active tillering upto flowering and saturation during rest of crop growth period. In these two methods, water saving is observed without reduction in yields so Rice water productivity is higher. The other two irrigation regimes better than continuous submergence from the view point of Rice water productivity are (i) saturation during early crop growth stage and submergence thereafter followed by (ii) saturation during active tillering upto flowering and submergence during rest of the crop growth period.

Results of another study on Rice water productivity under deficit irrigation at Kanpur are presented below in Table 5.

Table 5 Rice water productivity under deficit irrigation at Kanpur

Soil moisture regime	Grain yield (t/ha)	Irrigation requirement (cm)	Water Productivity (Kg/m^3)
Saturation	5.6	144	0.39
Field capacity (FC)	5.29	114	0.46
80% FC	4.52	66	0.69
60% FC	4.06	48	0.85

Analysis indicates that Rice water productivity depends on soil moisture status and its utilization. Though irrigation at 60% of field capacity yields only 4.06 t/ha and continuous saturation yields 5.60t/ha but Rice water productivity is higher 0.85kg/m^3 in case of irrigation at 60% of field capacity as compared to 0.39kg/m^3 in case of continuous saturation.

Rice water productivity under different depth of submergence and levels of nitrogen at West Bengal was computed and presented in Table 6 below.

It may be observed that shallow water submergence and increasing level of nitrogen gives better rice water productivity. 120kg/ha level of Nitrogen and 5cm depth of submergence gives Rice Water Productivity of 0.46kg/m^3.

Rice water productivity values under continuous submergence and irrigation after 1, 3, and 5 days of drainage period at various locations were computed and given in Table 7.

Table 6 Rice water productivity at different levels of soil submergence and nitrogen levels in West Bengal

Depth of submergence (cm)	Rice Water Productivity (Kg/m3) for different levels of Nitrogen (Kg/ha)				
	0	40	80	120	160
5	0.36	0.41	0.42	0.46	0.46
10	0.24	0.28	0.31	0.31	0.29
15	0.2	0.19	0.2	0.2	0.21
20	0.13	0.15	0.16	0.15	0.17

Table 7 Rice water productivity under continuous submergence and different drainage periods

Location	Irrigation water saving with 3 days drainage v/s continuous submergence (%)	Rice Water Productivity (Kg/m³) under			
		Continuous Submergence	Irrigation after 1-day drainage period	Irrigation after 3-days drainage period	Irrigation after 5-days drainage period
Pusa (Bihar)	43	0.443	0.578	0.707	0.814
Chiplima (Odisha)	23	0.728	0.74	0.851	0.86
Kharagpur (West Bengal)	34	0.31	0.399	0.457	0.462
Bilaspur (M.P.)	29	0.598	0.726	0.733	0.825
Pantnagar (Uttaranchal)	44	0.669	0.68	0.82	1.153
Ludhiana (Punjab)	40	0.291	0.375	0.453	0.542
Hisar (Haryana)	43	0.257	0.263	0.372	-
Kota (Rajasthan)	53	0.373	0.62	0.743	-
Madurai (Tamil Nadu)	36	0.515	0.64	0.754	-
Bhavanisagar (Tamil Nadu)	41	0.336	0.463	0.619	0.756
Chalakudy (Kerala)	55	0.248	0.546	0.704	-

Figure 1 Location of All India Coordinated Research Project on Water Management (AICRPWM) Centres in India (http://www.iiwm.res.in/aicrp.php).

It may be observed from the above Table that compared to continuous submergence, saving in irrigation water with 3 days de-saturation/drainage period, varies in the range of 23 to 55% at various locations in India. As compared to continuous submergence, rice water productivity is higher under the cases when irrigation is applied after different days of drainage period and rice water productivity value increases when drainage period increases from 1 to 5 days. It is very evident from the above Table that continuous submergence in Rice doesn't enhance water productivity and water is not efficiently utilized by the crop leading to more water losses. So this practice should be discouraged.

Wheat water productivity assessment

Water productivity and wheat yield analysis under various resource conservation techniques such as Furrow irrigation raised bed (FIRB) planting, zero tillage and conventional tillage at Patna is presented below in Figure 2.

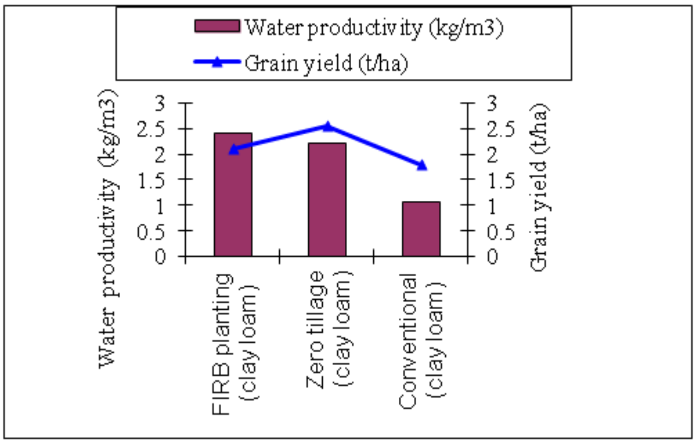

Figure 2 Water Productivity and Grain Yield of Wheat under different sowing methods.

Analysis indicates that though wheat yield is more in zero tillage method followed by FIRB planting method as compared to conventional tillage method but water productivity is higher in FIRB followed by zero tillage method as compared to conventional tillage method.

Six field demonstrations conducted in Hisar on Outlet No. 14920L on FIRBS sowing and irrigation in wheat during 2014-15. The average grain yield was 4001kg/ha which was higher by 78kg (2.01 %) over conventional sowing and surface irrigation. Under FIRBS, the amount of irrigation water applied was 2.1cm (10.5 %) less as compared to surface flood methods. Water productivity at the six farmers' fields varied between 145.5 to 212.7kg/ha-cm with surface flood method while it varied between 210.7 to 242.9 kg/ha-cm with FIRBS and thus the increase in water productivity varied from 12.9 to 15.6 %. The average increase in water productivity was calculated to be 14.0kg/ha-cm with FIRB.

The wheat water productivity computation at various locations in the country under different interventions based on input data collected from Annual Report (2003-04)[9] was done considering total water used and is presented in Table 8.

The computed water productivity of wheat at various locations as shown in Table 8 indicate that it varied in the range of 0.715kg/m^3 (only pre-sowing irrigation of 5cm) to 1.511kg/m^3 (irrigation at CRI stage). Results also indicate that irrigation at most critical crop growth stages gives better water productivity compared to irrigation at all the stages or less sensitive stages. Resource conservation techniques indicate that bed planting method of wheat crop establishment yields marginally better water productivity values compared to zero tillage and conventional tillage method.

Yadav etal.[10] reported yield of wheat and total water used by wheat crop at optimum schedule of irrigation (based on IW/CPE ratio*) at different locations in India. Wheat water productivity was computed employing this data and is presented below in Table 9.

Table 8 Wheat water productivity at various locations under different interventions

S. No.	Place	Treatment details	Total water used (mm)	Yield (t/ha)	Water Productivity (Kg/m^3)
1	Pantnagar (Uttaranchal)	Irrigation at CRI (Crown Root Initiation Stage)	233	3.52	1.511
		Irrigation at CRI+ Flowering	293	3.53	1.205
		Irrigation at CRI+ boot + milk stage	353	4.55	1.289
2	Almora (Uttaranchal)	Presowing Irrigation of 5 cm	368	2.63	0.715
		Post sowing only	368	2.7	0.734
		Pre sowing + CRI	418	3.03	0.725
		Pre sowing + CRI+ IW/CPE=0.8	468	3.44	0.735
		Rainfed area	421	4.13	0.98
		Rainfed area	455	3.99	0.877
3	Palampur (Himachal Pradesh)	Furrow sowing + Irrigation at CRI	277	2.26	0.816
		Furrow sowing + Irrigation at CRI + boot stage	342	2.93	0.857
		Furrow sowing + mulch + irrigation at CRI	280	3.07	1.096
		Furrow sowing mulch + irrigation at CRI + boot stage	345	3.39	0.983
		Flat sowing + Irrigation at CRI	279	2.13	0.763
		Flat sowing + Irrigation at CRI + boot stage	344	3.07	0.892
		Flat sowing + mulch + irrigation at CRI	283	3.03	1.071
		Flat sowing + mulch + irrigation at CRI + boot stage	346	3.33	0.962
4	Hissar (Haryana)	Zero tillage	410	4.229	1.031
		Conventional	422	4.127	0.978
		Bed planting	414	4.317	1.042
		Conventional	443	4.573	1.032

Table 9 Wheat water productivity at different locations at optimum schedule of irrigations

S. No.	Location	Optimum IW/CPE ratio	Grain yield (t/ha)	Total water use (mm)	Water Productivity (kg/m^3)
1	Belvatagi (Karnataka)	0.9	3.81	390	0.977
2	Bikramganj (Bihar)	0.9	2.64	238	1.109
3	Bilaspur (MP)	0.9	4.01	245	1.637
4	Chiplima (Odisha)	1.05	2.7	240	1.125
5	Faizabad (UP)	1.05	4.01	240	1.671
6	Hisar (Haryana)	1.05	3.85	370	1.041
7	Kharagpur (W.B.)	0.75	2.82	336	0.839
8	Kota (Rajasthan)	0.8	3.98	240	1.658
9	Madhepura (Bihar)	0.6	2.4	120	2
10	Navasari (Gujarat)	1.05	4.6	420	1.095
11	Pantnagar	1.05	4.22	120**	3.517
12	Rahuri (Maharashtra)	1.05	4.1	300	1.367
13	Parbhani (Maharastra)	0.75	2.41	412	0.585
14	Sriganganagar (Rajasthan)	1.05	5.4	240	2.25

*IW/CPE ratio is Irrigation water/Cumulative Pan Evaporation ** shallow water table condition

It may be observed from above that IW/CPE ratio at various locations ranged between 0.60 and 1.05. At 7 locations it was 1.05, at 3 locations 0.90 and at 4 locations below 0.80. Wheat water productivity ranged between as low as 0.585kg/m^3 at Parbhani and as high as 3.517kg/m^3 at Pantnagar. The reason for such variation in water productivity may be mainly attributed to soil type, climatic variation, farmer's awareness level, quality and quantity of inputs used and on-farm water management technologies adopted.

Conclusion

The above study indicates that water productivity may be used as a decision making tool as it considers not only the yield of produce but also the water applied and used. It is influenced by many factors like time, quantity and quality of inputs, methods of inputs application, outputs produced, technologies adopted, and overall management. Crop water productivity can be enhanced either by improving yields without increasing water consumption or sustaining yield and reducing water consumption. In future, diversion of water for agriculture will be reduced due to increased water requirement in other important sectors, so more efficient use of water in agriculture is required, which is possible if water productivity is enhanced. Rice and wheat water productivity can be enhanced by adopting need based, cost effective, identified resource conserving and appropriate on-farm water management technologies.

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Conflicts of interest

Author declares there is no conflict of interest.

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