Int.J.Curr.Microbiol.App.Sci (2017) *6*(7): 2043-2052

International Journal of Current Microbiology and Applied Sciences
ISSN: 2319-7706 **Volume 6 Number 7 (2017) pp. 2043-2052**
Journal homepage: http://www.ijcmas.com

Original Research Article https://doi.org/10.20546/ijcmas.2017.607.242

Crop Water Requirement, Water Productivity and Comparative Advantage of Crop Production in Different Regions of Uttar Pradesh, India

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Keywords

Crop water requirement, Water productivity and Comparative advantage.

Article Info

Accepted:
21 June 2017
Available Online:
10 July 2017

A B S T R A C T

The growing physical water scarcity would further hamper the food security. Over the past few years, the concept of water productivity in agriculture has gained ground with a shift from land productivity to water productivity due to increasing shortage of irrigation water productivity. The objective of the study was to estimate consumptive water use and agronomic water productivity for different crops grown in different regions of Uttar Pradesh and to identify the regions for comparative advantage of crop production based on water productivity and crop yield. The study was based on the secondary data and it was collected from different sources. The Crop Wat model was used for estimation of consumptive water requirement for crop production. The results showed that among kharif crops, highest crop water requirement was found for paddy crop in Bundelkhand region, whereas minimum crop water requirement was observed for jowar in Western region. In rabi season, highest crop water requirement was estimated for wheat crop in Bundelkhand region and minimum water requirement was estimated for barley crop in Western region. Almost all kharif crops were depicting comparative advantage from water productivity point of view in Eastern region, while among these crops most of the crops were depicting comparative advantage from yield point of view in Central region. Gram and sesamum has comparative advantage in Eastern region, soybean in central region, moong (k) in Bundelkhand region and maize (k), wheat, barley, pea and beans, lentil, rapeseed-mustard, maize (z) and sugarcane in western region from both water productivity and crop yield point of view.

Introduction

Water is the most critical resource for agriculture, gaining primacy even over soil. It is essential for sustaining all forms of life, food production, economic development, and for general wellbeing. Water availability within the country varies widely from region to region as a result of rainfall, groundwater reserve and proximity to river basins, which will have its own effect on water use efficiency and water allocation. The average annual rainfall in the country is about 1170 mm with extremely irregular with respect to time and area.

Agriculture is largest user of water resources accounting for about 80 per cent of the total water withdrawal. Among the different sources of irrigation water, groundwater is

playing an important role in the India's irrigated farming, which contributes about 60 per cent of the net cultivated area is irrigated by groundwater (Shah *et al.*, 2006). Water is a finite resource the availability of which is declining with each passing day. The per capita water availability in 2001 was 1820 m^3 per year and it is projected that by 2025, the per capita water availability will further reduce significantly to 1341 m^3 and to 1140 m^3 in 2050 (Bhattacharyya *et al.*, 2015). Going by Falkenmark criteria, most of the Indian states will have reached the water stress condition by 2025 and almost water scarcity condition by 2050. A total renewable water resource of Uttar Pradesh was 77.19 BCM in 2011 and it is varying from region to region. The highest total renewable water resource was found in western region (28.93 BCM) followed by eastern region (27.60 BCM), central region (15.86 BCM) and lowest in Bundelkhand region (4.80 BCM) (Anonymous, 2014). The scarcity of water would further hamper the food security, as the scarcity of water will directly suppress agricultural production. Growing physical shortage of water on the one hand, and scarcity of economically accessible water owing to increasing cost of production and supply of the resource on the other, had preoccupied researchers with increasing productivity of water use in agriculture in order to get maximum production or value from every unit of water used.

The water productivity is relevant to economists and engineers who are interested in evaluate the sustainability and efficiency of agricultural water management in terms of "produced yields per unit of water used", often referred to as "crop per drop". Its help to identify disproportionate water use or water limited yield gaps and thereby support improvements in agricultural water management. The term crop-water productivity used in the literature as physical water productivity expressed in kilogram of crop produce from one cubic meter of water used or diverted (kg/m^3) and combined physical and economic water productivity of water expressed as net or gross present value of crop produce per cubic meter of water ($Rs./m^3$) (Kumar *et al.*, 2008).

Since each region of the Uttar Pradesh state has a combination of problems and potentials for water resources, and hence recommendations can be suggested on a region basis. Regional planning of water resources could be achieved, only if we have more precise scientific data about the crop water requirements at different stages, quantity of water needed for producing targeted yields specific to crops.Hence, this study has taken with following objectives: [1] To estimate the consumptive water use for crop production in different regions of Uttar Pradesh; [2] To work out the physical water productivity of different crop grown in different regions of Uttar Pradesh; and [3] To find out the comparative advantage of the crop production based on water productivity, crop yield and both crop yield and water productivity.

Materials and Methods

Several studies are available which deals with water productivity of crops with respect to evapo-transpiration (ET) from crops (Kijne *et al.*, 2002). Yihun (2015) analyzed the water productivity for irrigated teff; Zwart (2010) analyzed water productivity of rain-fed and irrigated wheat and Carr (2016) analyzed water productivity in irrigated corn.

Data and sources

Present study was based on the secondary data and data related to the cropped area, production and yield of major crops etc. were collected from the various sources which

were published by Economic and Statistics Division, Ministry of Agriculture and Farmer Welfare, Government of India, Government of Uttar Pradesh for the year 2013-14.

Estimation of crop water requirement

Crop water requirements of major crops in different regions of state were estimated by using FAO model Crop Wat. It uses the FAO Penman-Monteith method (Equation 2) for calculating the reference crop evapotranspiration (ET_0), and gives values that matches with the actual need of the crop water use data worldwide, also being reproducible (Allen *et al.*, 1998; Allen *et al.*, 2006; Lopez *et al.*, 2012). The crop water requirement (CWR) was measured in m^3/ha was calculated from the accumulated crop evapo-transpiration (ETc) measured in mm/day over the complete crop growing period. The evapo-transpiration (ETc) was calculated by using following formula:

$$ET_c = K_c * ET_0 \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where ET_0 is crop reference evapo-transpiration and Kc is crop coefficients. Reference crop evapo-transpiration was calculated on the basis of following FAO Penman-Monteith:

$$ET_0 = \frac{0.408\ \Delta (R_n - G) + \gamma \frac{900}{273} U_2 (e_a - e_d)}{\Delta + \gamma (1 + 0.34\, U_2)} \quad \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Where, $ET_0$is Reference crop evapo-transpiration (mm/day); R_n is Net radiation at the crop surface (MJ/m^3 /day); G is Soil heat flux (MJ/m^3 /day); T is Average air temperature (^{0}C);U_2 is Wind speed measured at 2 m height (M/S); e_a is Saturation Vapour Pressure Curve (kPa); e_d is Actual Vapour pressure (kPa); e_a-e_d is Vapour pressure deficit (kPa); Δis slope of the vapour pressure curve (kPa/^{0}C) and Γ is Psychometric Constant (kPa/^{0}C).

Estimation of crop water productivity

The physical water productivity for a given crop (kg/m^3) was estimated across the different regions of Uttar Pradesh by using the data on crop yield and the estimated volume of consumptive water used for crop production. The physical productivity of water was estimated by using following equation:

$$WP_{crop} = \frac{Q_{crop\ (main)}}{\theta_{crop}}$$

Where, WP_{crop} is the water productivity (Kg/m^3) for crop; $Q_{crop\ (main)}$ is the average yield of crops in Kg; θ_{crop} is the total volume of water used for crop production.

Results and Discussion

Region-wise consumptive water use

The results of Crop Wat model gives consumptive water use and it does not includes water losses during water supply from source to crop field i.e. evaporation, percolation, seepage loses from conveyance channel. Water requirements for various crop productions are influenced by the various factors viz. area share of different crops, climatic factors (temperature, wind velocity, relative humidity, sunshine and rainfall), crop variety, crop duration and soil structure.. Besides these, agronomic practices and plant physiology also affects the water consumption by the crops. Thus, these factors lead to difference in the consumptive water use for the same crop in different regions

Most of the crops growing during the kharif season are using more green water (rainfall)

and supplemented by blue water (artificial irrigation), whereas crops grown in rabi and zaid seasons were catering water requirement from irrigation water and somewhat fulfilled by off season rainfall for their crop cycle (Table 1). The major crops grown during kharif season were rice, maize, jowar, small millets and wheat, barley in rabi season.

Among the kharif crops, highest crop water requirement was estimated to be 9130 m^3/ha for rice crop in Bundelkhand region, whereas minimum crop water requirement was observed for jowar in Western region with 3565 m^3/ha. While, in rabi season highest crop water requirement was estimated for wheat crop in Bundelkhand region (8286 m^3/ha) and minimum for barley crop with2219 m^3/hain Western region.

The major pulse crops grown by the farmers in different regions of Uttar Pradesh were arhar, moong and urd in kharif season, whereas, gram, pea, peas and beans and lentil inrabi season. The upper most crop water requirement for kharif pulses was in Western region, while bottom most was in Central region with an amount of 4142 m^3/ha and 3765 m^3/ha, respectively.

Among oilseeds, sesame, groundnut and soybean were grown during kharif season, whereas, rapeseed-mustard, linseed and castor grown in rabi season across different regions of Uttar Pradesh. It was found that among the kharif oilseed crops groundnut was devouring highest crop water requirement in Bundelkhand region (4681 m^3/ha). In contrast, soybean was minimum water required crop with 4596m^3/ha in Eastern region. The cash crop includes potato (r), tobacco (r), sugarcane (k) and cotton (k) also grown in state. Among these crops, sugarcane crop in Bundelkhand region was registered highest crop water requirement with 18492 m^3/ha and tobacco crop have minimum water requirement in Western region of Uttar Pradesh with 2278 m^3/ha.

In Uttar Pradesh, crops also grown in zaid season and the crops are rice, maize, moong, urd and sunflower. Among these crops, area share of rice and sunflower was very small as compared to urd, moong and maize. Zaid cereal embraces maize and rice and zaid pulses comprises of moong and urd while there was only one crop grown in zaid oilseed i.e. sunflower (Table 1). Among zaid cereal rice have highest crop water requirement in Central region with 11461m^3/ha. While, minimum water required was maize in Western region with quantum of 6719m^3/ha. In zaid pulse category, highest crop water requirement was noted in Central region with 6387m^3/ha and minimum crop water requirement in Western region with 5878 m^3/ha.

Region-wise physical water productivity

The results of region-wise physical water productivity for different crops grown in Uttar Pradesh is presented in table 2. Among the kharif cereal crops grown in the state, the highest water productivity was found for bajra crops with 1.749, 1.248 and 0.796 kg/m^3 in Eastern, Central and Bundelkhand region, respectively and in Western region it was found highest for maize crop (1.67 kg/m^3) and followed by the bajra crop. Whereas minimum water productivity was found for rice crop with 0.709, 0.708 and 0.313 kg/m^3in Eastern, Central and Bundelkhand region, respectively. In the case of kharif pulses the maximum agronomic water productivity was observed in arhar crop and minimum in moong crop across all regions of the state. However, water productivity of all kharif pulses was found minimum ranging from 0.099 to 0.404 kg/m^3 in Western region as compared to other regions.

Table.1 Region-wise consumptive water use for different crop (m^3/ha)

Crop	Eastern			Central			Bundelkhand			Western		
	Blue Water	Green Water	Total Water	Blue Water	Green Water	Total Water	Blue Water	Green Water	Total Water	Blue Water	Green Water	Total Water
Rice (K)	3389	5595	8985	3715	5207	8922	5316	3814	9130	3906	4862	8768
Rice (Z)	9603	1188	10791	10415	1045	11461	10135	1165	11300	9563	1036	10600
Maize (K)	1420	2907	4328	2189	600	2789	1987	2410	4397	1263	3242	4506
Maize (Z)	4967	2143	7110	5474	1804	7278	5204	2022	7226	5166	1552	6719
Jowar (K)	722	2949	3672	1125	2521	3646	1284	2434	3718	1164	2400	3565
Bajra (K)	722	2949	3672	1125	2521	3646	1284	2434	3718	1164	2400	3565
Small millets (K)	755	3025	3781	1156	2595	3751	1319	2505	3824	794	3008	3802
Arhar(K)	540	3269	3809	870	2895	3765	1015	2804	3819	2382	1760	4142
Urd (K)	540	3269	3809	870	2895	3765	1015	2804	3819	2382	1760	4142
Urd (Z)	5084	1114	6198	5501	886	6387	5231	1033	6264	4951	927	5878
Moong (K)	540	3269	3809	870	2895	3765	1015	2804	3819	2382	1760	4142
Moong (Z)	5084	1114	6198	5501	886	6387	5231	1033	6264	4951	927	5878
Moth (K)	540	3269	3809	870	2895	3765	1015	2804	3819	2382	1760	4142
Sesamum (K)	1517	3079	4596	1750	2936	4686	1939	2849	4788	2438	2668	5106
Groundnut (K)	1430	3196	4626	1856	2713	4570	2050	2631	4681	1585	3092	4677
Soybean (K)	1517	3079	4596	1750	2936	4686	1939	2849	4788	2438	2668	5106
Wheat (R)	6959	1176	8136	7256	1018	8275	7357	929	8286	6583	968	7551
Barley (R)	1847	532	2380	1841	537	2378	2041	415	2456	1793	425	2219
Gram (R)	1754	502	2256	1833	464	2297	2043	366	2409	1723	375	2098
Peas and beans (R)	1754	502	2256	1833	464	2297	2043	366	2409	1723	375	2098
Lentil (R)	1754	502	2256	1833	464	2297	2043	366	2409	1723	375	2098
Rapeseed-mustard (R)	5036	1814	6850	5489	1538	7027	5203	1751	6954	2736	2868	5605
Sunflower (Z)	5036	1814	6850	5489	1538	7027	5203	1751	6954	2736	2868	5605
Potato (R)	2297	636	2933	2426	577.5	3004	2737	461	3198	4274	1026	5300
Tobacco(R)	1897	532	2429	2024	464	2488	2247	366	2613	1908	370	2278
Sugarcane (K)	11278	4835	16113	12098	4352	16450	12247	6245	18492	10806	4694	15501
Cotton (K)	2395	4697	7092	2230	5225	7455	2183	5392	7575	3323	3564	6888

Note: K = kharif, R = Rabi and Z = zaid

Table.2 Region-wise physical water productivity (Kg/M^3) for different crops

Crop	Eastern			Central			Bundelkhand			Western		
	Irr. Water (m^3/ha)	Crop Yield (Kg/ha)	Water Productivity (Kg/M^3)	Irr. Water (m^3/ha)	Crop Yield Kg/ha)	Water Productivity (Kg/M^3)	Irr. Water (m^3/ha)	Crop Yield Kg/ha)	Water Productivity (Kg/M^3)	Irr. Water (m^3/ha)	Crop Yield Kg/ha)	Water Productivity (Kg/M^3)
Rice (K)	3390	2402	0.709	3715	2632	0.708	5316	1665	0.313	3906	2353	0.603
Maize (K)	1421	1379	0.971	2189	1874	0.856	1987	1351	0.680	1264	2113	1.672
Jowar(K)	723	961	1.329	1125	1120	0.996	1284	1015	0.790	1165	388	0.333
Bajra (K)	723	1264	1.749	1125	1404	1.248	1284	1022	0.796	1165	1488	1.278
Small Millets (K)	755	784	1.039	1156	544	0.471	1319	824	0.625	-	-	-
Arhar (K)	540	827	1.532	871	1019	1.171	1015	848	0.836	2383	962	0.404
Urd (K)	540	491	0.909	871	509	0.585	1015	372	0.367	2383	546	0.229
Moong (K)	540	237	0.438	871	374	0.430	1015	330	0.325	2383	236	0.099
Sesamum (K)	1430	150	0.105	1857	123	0.066	2050	125	0.061	1585	96	0.061
Groundnut(K)	1430	698	0.488	1857	812	0.437	2050	700	0.341	1585	548	0.346
Soybean(K)	1517	20	0.013	1750	926	0.529	1939	577	0.298	2438	570	0.234
Wheat (R)	6959	2902	0.417	7257	3468	0.478	7357	2124	0.289	6583	3721	0.565
Barley(R)	1848	2609	1.412	1841	2692	1.462	2041	2702	1.324	1794	3184	1.775
Gram (R)	1755	626	0.357	1833	545	0.297	2043	401	0.196	1724	516	0.299
Peas and beans (R)	1755	763	0.435	1833	1262	0.688	2043	867	0.424	1724	1278	0.742
Lentil (R)	1755	713	0.406	1833	701	0.382	2043	392	0.192	1724	1261	0.732
Rapeseed-mustard (R)	5036	753	0.149	5489	908	0.165	5203	360	0.069	2737	1294	0.473
Linseed (R)	5036	306	0.061	5489	478	0.087	5203	478	0.092	2737	409	0.150
Rice (Z)	9603	2405	0.250	10416	2550	0.245	-	-	-	9564	2407	0.252
Maize (Z)	4968	1804	0.363	5474	1837	0.336	-	-	-	5166	1847	0.357
Moong(Z)	5084	628	0.123	5502	564	0.103	5231	676	0.129	4951	543	0.110
Urd (Z)	5084	539	0.106	5502	607	0.110	-	-	-	4951	575	0.116
Sunflower (Z)	5036	150	0.030	5489	1612	0.294	5203	1568	0.301	2737	1536	0.561
Potato(R)	2298	17417	7.580	2427	18184	7.494	2737	21166	7.733	4275	21547	5.040
Tobacco(R)	1898	4884	2.574	2024	5105	2.522	2247	557	0.248	1908	2484	1.302
Sugarcane (K)	11278	59910	5.312	12098	59953	4.956	12247	42736	3.489	10807	63226	5.851
Cotton (K)	2395	214	0.089	2231	167	0.075	-	-	-	3324	234	0.070

Note: K = kharif, R = Rabi and Z = zaid

T**able.3** Comparative advantage of crops production in different regions of Uttar Pradesh

Name of the Region	Comparative Advantage in Respect to		
	Water Productivity	Crop Yield	Crop Yield and Water Productivity
Eastern	Rice (k), Jowar, Bajra, Small millets, Arhar, Urd (k), Moong (k), Groundnut, Tobacco, Cotton		Gram, Sesamum
Central		Rice, Jowar, Arhar, Moong (k), Groundnut, Linseed, Rice (z), Urd (z), Sunflower, Potato, Tobacco	Soybean
Bundelkhand	Potato	Small millets, Linseed	Moong (z)
Western	Linseed, Rice (z), Urd (z), Sunflower,	Bajra, Urd (k), Cotton	Maize (k), Wheat, Barley, Pea and beans, Lentil, Rapeseed - mustard, Maize (z), Sugarcane

Note: K = kharif, R = Rabi and Z = zaid

The water productivity was estimated for the sesamum (k) oilseed crop and it was realized to be 0.105, 0.066, 0.061 and 0.61 kg/m^3 in the Eastern, Central, Bundelkhand and Western region, respectively. In case of groundnut (k), physical water productivity was analyzed and recorded as 0.488, 0.437, 0.341 and 0.346 kg/m^3 in the Eastern, Central, Bundelkhand and Western region, respectively. The water productivity was computed for the soybean (k) crop and maximum water productivity was found in Central region with the 0.529 kg/m^3 and minimum in Eastern region with 0.013 kg/m^3.

During rabi season wheat and barley crops were grown in the state and barley have higher water productivity than wheat crop. Water productivity in wheat crop was found to be 0.417, 0.478, 0.289 and 0.565 kg/m^{3}and similarly in barley crop it was estimated to be 1.412, 1.462, 1.324 and 1.775 kg/m^3 in the Eastern, Central, Bundelkhand and Western region, respectively. The water productivity for gram was affirmed maximum in the Eastern region with 0.357 kg/m^3 and minimum in Bundelkhand region with 0.196 kg/m^3. The water productivity for lentil crop was found maximum in the Western region with 0.732 kg/m^3 and minimum in Bundelkhand region with 0.192 kg/m^3. In case of rabi oilseed crops (rapeseed-mustard and linseed) the water productivity was avowed maximum in Western region and minimum in Bundelkhand region.

Among the crops grown (rice, maize, moong, urd and sunflower) in *zaid* season in the state, the maize crop registered maximum water productivity in Eastern and Central region. In western region, the maximum water productivity found in sunflower and followed by the maize crop. However, only sunflower and moong crops are grown on scant area in Bundelkhand region. The cash crops viz. potato, tobacco, sugarcane and cotton were

also grown in the state. Among these crops, maximum water productivity was found in potato with 7.580, 7.45, 7.733 and 5.040 kg/m^3 in Eastern, Central, Bundelkhand and Western region, respectively. The minimum water productivity was registered in cotton crop in all the regions.

Comparative advantage of regions for crop production

The comparative advantage of crops production in different regions of Uttar Pradesh is presented in table 3. All the crops grown by farmers in different regions of Uttar Pradesh was categorized in three groups viz., (a) regions having higher agronomic water productivity; (b) regions having higher crop yield; and (c) regions having higher agronomic water productivity and crop yield. It was found that Eastern region has comparative advantage in respect of agronomic water productivity for rice, jowar, bajra, small millets, arhar, urd (k), moong (k), groundnut, tobacco and cotton, while gram and sesamum was displaying comparative advantage over other regions with respect to both water productivity and crop yield.

In Central region rice, jowar, arhar, moong (k), groundnut, linseed, rice (z), urd (z), sunflower, potato and tobacco cultivation were found to be comparative advantage over other regions of Uttar Pradesh regarding crop yield point of view. Along with this, soybean cultivation in Central region has comparative advantage from both aspects i.e., water productivity and crop yield as compared to other regions of Uttar Pradesh.

With regard to Bundelkhand region, potato cultivation was found to be most attractive crop from the agronomic water productivity point of view, whereas cultivation of small millets and linseed were found comparative advantage over other regions of Uttar Pradesh from crop yield point of view. The moong (z) cultivation in Bundelkhand region has comparative advantage over other regions of Uttar Pradesh in respect of crop yield and agronomic water productivity.

In Western region cultivation of maize (k), wheat, barley, pea and beans, lentil, rapeseed-mustard, maize (z) and sugarcane crops has comparative advantage in respect of crop yield and agronomic water productivity point of view over the other regions of Uttar Pradesh. The region has comparative advantage for bajra, urd (k) and cotton from crop yield point of view, whereas, linseed, rice (z), urd (z) and sunflower cultivation in western region has comparative advantage from agronomic water productivity point of view.

The results showed that among the kharif crops, highest crop water requirement was estimated for paddy crop in Bundelkhand region, whereas minimum crop water requirement was observed for jowar in Western region among all regions of the Uttar Pradesh. In rabi season, highest crop water requirement was estimated for wheat crop in Bundelkhand region and minimum water requirement was found for barley crop in Western region. The upper most crop water requirement for kharif pulses was in Western region while bottom most was in Central region among all regions. Among the kharif oilseed crops, groundnut was devouring highest crop water requirement in Bundelkhand region. In contrast, soybean was minimum water required crop in Eastern region. Among cash crops, sugarcane crop was registered highest crop water requirement in Bundelkhand region and tobacco crop have minimum water requirement in Western region.

The blue water, green water, total water demand and yield of crops across regions of

the state were estimated, which provide the basis for a systematic appraisal of crop-water productivity. Along with other measures, scenario analysis of present study could be used to support the evaluation of the potential improvement in the regional and state water productivity and water use efficiency through regional cropping pattern adjustment and efficient irrigation technologies. The results also provides comprehensive decision support for researcher, policy makers and state development agencies for developing strategies for sustainable and alternative agricultural production systems for better resource use efficiency particularly water and maximizing farm net income. Furthermore, it provides a strong basis for further studies regarding the water and food security and the water resource management strategies in all the regions of Uttar Pradesh. Based on results, the following recommendation can be made for the water policies: [1] Cultivation of rice crop in kharif season and wheat crop in rabi season should be restricted up to a certain level which neither affect the water resources badly nor exert the pressure on stocks and supply of the crop produce; [2] Government should frame policy in such a manner that farmers are encourages to grow those crops which having comparative advantage in particular region to maximize crop production with minimum water use.

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How to cite this article:

Maina Kumari, O.P. Singh and Dinesh Chand Meena. 2017. Crop Water Requirement, Water Productivity and Comparative Advantage of Crop Production in Different Regions of Uttar Pradesh, India. *Int.J.Curr.Microbiol.App.Sci.* 6(7): 2043-2052.
doi: https://doi.org/10.20546/ijcmas.2017.607.242