Indian Journal of Agricultural Sciences **91** (8): 1117–21, August 2021/Article
https://doi.org/10.56093/ijas.v91i8.115779

Research Articles

Sustainable intensification of water guzzling crops: Identifying suitable cropping districts of India

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Received: 12 November 2019; Accepted: 04 February 2021

ABSTRACT

With food sufficiency being achieved, emphasis of policy makers is now on to sustainable intensification in line with the objectives of Sustainable Development Goals (SDGs). Widening discrepancy between the water-resource supply and demand necessitates relook into the cropping pattern of the country. Based on district-level secondary data of area, productivity and level of groundwater extraction, this study aims to identify critical and potential area for cultivation of three major water-intensive crops, i.e. rice, wheat and sugarcane. Study found that 1.93 million ha of area under rice, mainly in north-western and western India, need a gradual shift. Nearly 43% of the rice cultivated area in eastern and north-eastern states of West Bengal, Odisha, Chhattisgarh and Assam has potential for further intensification of rice cultivation. In case of wheat, around 0.65 million ha of area, mostly in Rajasthan, is critical in terms of sustainability. Livestock is an integral part of agriculture in this region and hence diversification of wheat would require mixed strategy of shifting to alternative dual-purpose crops and wheat cultivation with water conservation technologies. Study further found that around 13543 ha of sugarcane in mainly in western Uttar Pradesh and Tamil Nadu is deterring the groundwater resources. Recommendations emanating from the study include differentiates agricultural price policy, payment for ecosystem services and greater focus on productivity enhancement in eastern India.

Keywords: Diversification**,** Groundwater development, Relative yield index, Relative spread index, Sustainability

Ensuring food security by feeding the growing population, meeting their rising demands has been a major challenge to the Indian agricultural systems. However, agricultural production in India is constrained by limited inputs and aggravated discrepancies between demand and supply of these inputs. Water is the most critical among these input discrepancies with almost 89% of groundwater being extracted for irrigation (ADB 2016). On the contrary, cropping pattern and consumption orientation in India is highly skewed towards water intensive food grains. Studies by Hoekstra and Chapagain (2007), Kampman (2007) and Jayaram and Mathur (2015) corroborate the fact based on their estimates on crop water foot prints in Indian agriculture. With an objective to ensure food security and raise the food production henceforth, the policy makers have been incentivising agriculture substantially through subsidies and price assurances cornered to major food grains. Emerging agricultural sustainability issues in various agro-ecologies of India is pointing out towards re-aligning cropping pattern in the country (Rodell *et al*. 2009, MacDonald *et al*. 2016, Roul *et al.* 2020, Chand *et al.* 2020a). The high share of irrigation water use in most of the relatively productive areas of semi-arid region further emphasize the need of cropping pattern realignment and increasing water productivity (Chand *et al.* 2020b). Production-oriented policies like free water and power subsidies alter the farmers' perspective of water to be a free good. This perspective deters development of innovative resource-saving technologies and encourages mono-cropping by the farmers.

Water being the most limiting factor in agriculture; the paper addresses the groundwater resource imbalance across the districts of India. The study apprehends the over-estimation of relative spread index across the districts when estimated as a proportion of the respective states which is a procedural modification over previously used methodologies (NBSS&LUP 2017). By considering the relative spread, relative yield of reference crop and the stage of groundwater development in each district, efforts have been made to develop a road map that identifies critical areas that need immediate focus of the policy makers to substitute the resource harnessing crops and diversify the cropping pattern as per resource endowments.

MATERIALS AND METHODS

The district level data related to area, production

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and productivity and total cropped area of rice, wheat and sugarcane were collected for the TE 2015–16 from the Department of Agriculture Cooperation (DAC). The data related to groundwater draft and recharge, stage of groundwater development stages were obtained from Central Groundwater Development Board (CGWB) for the years 2009, 2011 and 2013.

Estimation of relative spread index (RSI): Relative spread index was calculated as (Ramamurthy *et al.* (2018));

$$RSI = \left(\frac{RCA_{id}}{GCA_d} \Big/ \frac{RCA_{in}}{GCA_n} \right) \times 100$$

where, RCA_{in} is area under crop 'i' in district 'd'; GCA_d is gross cropped area in d^{th} district; RCA_{in} and GCA_n denote area under i^{th} crop and gross cropped area, respectively at national level.

Subsequently, the RSI was categorised in to two categories low spread (RSI<1) and high spread (RSI>1).

Estimation of relative yield index (RYI): Relative yield index is defined as the ratio of district productivity ($Yield_{id}$) (to national productivity for reference crop ($Yield_{in}$) and worked out as;

$$RYI = \frac{Yiled_{id}}{Yield_{in}} \times 100$$

RYI and RSI are graded in terms of high spread-high productivity (RSI and RYI>1), low spread-high productivity RSI<1 and RYI>1), high spread–low productivity (RSI>1 and RYI<1) and low spread-low productivity (RSI and RYI <1).

Stage of groundwater extraction: The stage of ground water extraction (SGWE) is defined as gross groundwater extraction for all uses as percentage of annual extractable ground water resources (CGWB 2019). The Central Groundwater Development Board provides the districts-level data on SGWE and categorises the assessment units into four categories, viz. over-exploited (SGWE >100%), critical (90% < SGWE ≤100%), semi-critical (70% < SGWE ≤ 90%) and safe (SGWE<70%). However, in this study the semi-critical category was merged with critical category.

Identification of efficient cropping areas: The above mentioned three dimensions help in identifying the districts not only of potentially efficient reference crop growing, but also the districts which need an immediate focus in substituting with less water intensive crops. Among the three factors selected for the analysis, two (RSI and RYI) have two levels each (low and high) in comparison to the national scenario as defined by Ramamurthy *et al.* (2017), while the third factor (SGWE) had three levels as explained above. Based on the permutations and combinations of each of the factors and their levels, 12 combinations are possible (Table 1). Among these 12, the study pertains to six major combinations (LLO, HLC and HLO as critical areas, and HHS, HHC and LHS as potential areas) which the authors deliberately highlight to understand both the source as well as solution of the problem. A major emphasis was given to the groundwater scenario.

The district which are either over-exploited or critical in groundwater extraction combined with low yield were categorised as 'critical areas' irrespective of extent of area spread. The rationale behind this was that the additional unit of groundwater use will not only be relatively less efficient but also further lead to depletion of natural resources. Theoretically, this category denotes the third stage of classical production function. Contrary to this, districts with high yield potential together with safe or critical level of groundwater extraction were categories as 'potential areas' for sustainable intensification being efficient in term of production and within the permissible level of groundwater extraction.

RESULTS AND DISCUSSION

The imbalance in resource endowments could be addressed by shifting the crops from resource degraded areas (Table 2). Critical areas that need immediate attention accounts around 1925.52, 652.8 and 32.8 thousand ha in rice, wheat and sugarcane respectively. Perusal of the critical and potential areas (Table 3) also points to the yield gaps in both the areas with potentially safe areas having substantially higher yield in all the three crops. Rice yield in these districts is more than 50% lower than the potential districts implying that a shift of reference crops from resource degraded critical areas to resource endowed potential areas not only reduce the burden on natural resources but also substantially improves

Table 1 Possible combinations of RSI, RYI and SGWE

Category	Description
HHS	High spread, high yield and safe level of groundwater extraction
HHC	High spread, high yield and critical level of groundwater extraction
HLS	High spread, low yield and safe level of groundwater extraction
HLC	High spread, low yield and critical level of groundwater extraction
LHS	Low spread, high yield and safe level of groundwater extraction
LHC	Low spread, high yield and critical level of groundwater extraction
LLS	Low spread, low yield and safe level of groundwater extraction
LLC	Low spread, low yield and critical level of groundwater extraction
HHO	High spread, high yield and over-exploitation level of groundwater extraction
HLO	High spread, low yield and over-exploitation level of groundwater extraction
LHO	Low spread, high yield and over-exploitation level of groundwater extraction
LLO	Low spread, high yield and over-exploitation level of groundwater extraction

Table 2 Potential and critical areas of rice, wheat and sugarcane in India ('000 ha)

Category	Crops parameter	Rice	Wheat	Sugarcane
Critical areas	LLO	99.95	274.0	13.2
	HLC	1717.3	378.8	
	HLO	108.3		
Potential areas	HHS	5626.1	2893.0	851.5
	HHC	1526.3	432.6	1783.5
	LHS	905.0	5014.5	430.6

the yield. The foremost sustainable intensification strategy should be to diversify the potential rice from high spread-low yield-overexploited/critical SGWE (HLO/HLC) areas to low speed-high yield-safe SGWE (LHS) areas. Another strategy should be the halting of area under the category of low spread, low yield and over-exploited SGWE (LLO).

Potential and critical areas of rice in India: In case of rice production, critical areas where the crop-resource imbalance is prevalent and an immediate shift of rice crop is necessary. It accounts to about 1.00 lakh ha accounting for 0.35% of the total rice area in the country. The districts that fall under LLO category are Hisar, Haryana (42070 ha); Amroha, Uttar Pradesh (14761 ha); Kota, Rajasthan (12904 ha); Agra, Uttar Pradesh (5612 ha); Gandhi Nagar, Gujarat (5455 ha) among other rice growing districts in Rajasthan and Karnataka. Another 8.07 lakh ha of area under rice is under the category LLC; standing just behind critically over-exploited areas needing shift to relatively suitable/resource endowed region. Pune (80600 ha), Satara (51433 ha), Ahmadnagar (8000 ha), Latur (7233 ha), Amravathi (4600 ha) in Maharashtra state; Hardoi (72655 ha), Unnao (59434 ha), Mathura, Budaun, Moradabad, Sambal, Kanpur Nagar, Bijnor, Etah, Hathras, Kasganj districts of Uttar Pradesh (4.28 lakh ha) are notable districts that are less productive with low spread and yet critical groundwater exploited regions. Some districts of Gujarat, Madhya Pradesh, Rajasthan and Karnataka also demand for immediate shift from the presently cultivated districts. Perusal of the critical rice producing areas indicates the adverse effects of resource intensive cultivation and rice mono-cropping in the major rice belts. Crop-resource suitability is the key in sustainable intensification of agriculture in these regions. The declining groundwater level demands efficient management strategies and use of water saving technology. Drip irrigation reduces water requirement in aerobic rice by 48% (Hsiao *et al.* 2007). Resource conserving technologies like Direct Seeded Rice (DSR) avoids operations like puddling, transplanting and maintaining standing water thereby saving 30-55% of water (Bhushan *et al*. 2007).

Potential areas for rice cultivation with safe groundwater development (<70% degradation) along with high yield and high spread are spread across Chhattisgarh, West Bengal, Bihar, Assam, some parts of Andhra, Telangana, Karnataka and Tamil Nadu. Pathankot is the only district in Punjab which has the potential for rice cultivation. Other districts of Punjab, viz. Mukhtsar, Bhatinda, Fazilka and Hoshiarpur with higher yield than the national average and higher spread can also sustain the rice cultivation if convened by resource saving technologies to address the critical groundwater issue. Around 5.33% of the total rice area is suitable for rice cultivation assisted with water saving technologies. With an area scope of one million ha, few districts across the states of Kerala, Karnataka, Tamil Nadu and Madhya Pradesh have yield advantage as well as safe limits of water resource exploitation with a lower area spread. This makes them potential rice cultivation zones if assisted with appropriate policy measures. Rice from low productive areas with seemingly degraded water resource (2 million ha) could be shifted to reduce the burden on water resource from these producing areas. On the other hand, 17.17% of total rice area has scope for increasing rice productivity through yield enhancing technologies. Precision farming technology assists substantial yield improvement with minimal external input use (Aurenhammer 2001). Notable example of successful yield improving technologies is System of Rice Intensification (SRI), a system of rice cultivation with a package of various synergetic technologies in different parts of the country. Yield improvement of 7–20% due to SRI over the traditional irrigated transplanted rice (Kumar *et al.* 2009). Laser land levelling in rice is an excellent resource conserving technology with an extent of 36.19 cm/ha of water saving in Punjab (Sidhu *et al.* 2010). The scope of shifting rice from critical areas to potential areas with higher yield and spread within safe groundwater limits is depicted by total area of 56 lakh ha that accounts

Table 3 Area, production and yield of rice, wheat and sugarcane in critical and potential areas

Category	Crops parameter	Rice		Wheat		Sugarcane	
		P	Y	P	Y	P	Y
Critical areas	LLO	229.5	20.9	537.5	16.28	673.8	439.9
	HLC	3666.3	21.4	824.4	21.88		
	HLO	264.7	24.5				
Potential areas	HHS	17680.5	31.5	9038.4	31.18	62327.2	747.2
	HHC	5317.6	35.0	14203.8	32.36	146070.9	798.3
	HHS	2764.6	30.6	14640.3	29.24	34199.3	798.8

A- Area in ‘000 ha; P- production in ‘000 t; Y-yield (q/ha) for around 40% of the total rice area in the country.

Prospective areas of wheat: Wheat cultivation in India is mainly concentrated in the irrigated northern belts of Uttar Pradesh, Punjab, Haryana, Rajasthan and Madhya Pradesh. It was estimated that there is possibility of reallocation of area under wheat in the country. Around 2.73 lakh ha of wheat area in the country found to be cultivated in the resource degraded region with low productivity. This area falls in Bikaner, Barmer, Jodhpur and Jaisalmer of Rajasthan and Mahoba district of the Bundelkhand region of Uttar Pradesh. Furthermore, 9.2 lakh ha of wheat in the country is cultivated in crop-resource imbalance conditions and have opportunity to be shifted to a resource endowed region. Wheat producing districts of Maharashtra (Pune, Buldana, Ahmednagar, Amravathi, Latur, Satara, Solapur, Jalgaon and Sangli); Rajasthan (Dungarpur, Jalore, Churu); Chhattisgarh (Bemetra, Durg) and Bundelkhand region across Madhya Pradesh and Uttar Pradesh are critical areas of wheat cultivation that needs an immediate shift.

The scope of sustainable intensification of wheat could be understood through the statistics in which 3.85% of the wheat area is critical while 27% of the wheat area is potentially suitable for wheat. This implies that the burden on critical wheat producing areas can be shifted to potentially suitable areas without affecting the aggregate national wheat production since wheat is immiscible from the Indian consumption basket. Notable potential areas for expansion of wheat cultivation are Shajahanpur, Azamgarh, Sitapur, Gorakhpur, Kheri, Barabanki, Bahraich (Uttar Pradesh); Ganga Nagar (Rajasthan), Raisen, Hoshangabad, Sehore, Rewa, Harda (Madhya Pradesh). There is certain highly productive wheat producing areas with high spread with critical groundwater. Wheat cultivation from low productive areas could be shifted to these areas with resource saving-technology assisted cultivation. Promising areas in this category are traditional wheat belts like Bhatinda, Muktsar, Fazilka of Punjab; Hardoi, Budaun, Unnao, Aligarh, Jaunpur, Bareilly, Mathura, Bulandshahr, Ghazipur, Fatehpur and Deoria of Uttar Pradesh. Since an immediate shift of the crop from traditional areas would be unacceptable from the farmer-producer point of view, promoting water-saving technologies through incentivization should be suitable approach in these areas. Evidences suggest that conservation agriculture technologies save substantial resources without reducing yield of wheat crop (Erenstein 2009, Sidhu *et al.* 2010).

Overviewing sugarcane production in India: In this line, we identified critical areas from which an immediate shift is needed to potential areas where there is crop-resource balance for cultivating the water guzzling crop. Around 13543 ha of sugarcane area in India is deterring the groundwater resources as it is been cultivated in groundwater over-exploited areas. Few districts to highlight are Jind, Palwal, Bhiwani, Hisar, Sirsa and Fatehabad in Haryana; Mahoba, Agra, Firozabad districts in Uttar Pradesh; Shajapur and Indore in Madhya Pradesh, and Alwar in Rajasthan. Uttar Pradesh is considered to be a major producer of sugarcane. However, it is interesting to note that few districts of Uttar Pradesh such as Jaunpur, Ghazipur, Kasganj, Mau, Ballia, Varanasi, Mathura, Mainpuri and Kanpur Nagar; Satna, Bharwani, Shivpuri, Dhar, Tikamgarh and Bhopal of Madhya Pradesh are suitable for sugarcane cultivation. The crop-resource mismatch in the area could be an opportunity if bio-physically suitable crop is recommended in the region integrating with suitable post-harvest infrastructural and marketing facilities.

On the other hand, districts like Kheri, Shajahanpur, Sitapur, Kolhapur, Parbhani, Bijapur, Gulbarga, Bidar and Cuddalore are relatively sustainable being highly productive and in the safe zones of groundwater development zones. Around 8.5 lakh ha is potentially safe for sugarcane cultivation and another 17.83 lakh ha is potential areas for sugarcane cultivation with technology assistance for water saving. Around 12.55% of the sugarcane area in India is prospective, if assisted with yield improving technologies. Irrigation water saving techniques in sugarcane developed by the Indian Institute of Sugarcane Research, Lucknow include skip furrow irrigation, irrigation at critical growth stages, trash mulching and ring pit planting, which can enhance irrigation water use efficiency by 1.5 to 2.5 times (Srivastava *et al.* 2011). Other resource conserving technologies successfully adopted in states like Tamil Nadu is Sustainable Sugarcane Initiative (SSI), an innovative method of sugarcane production using less seeds, less water and optimum utilization of fertilizers and land to achieve more yields. Drip irrigation is yet another resource saving technique which reduces water requirement in sugarcane by 56% (Hsiao *et al.* 2007). Areas that need focus in terms of such technology assistance for sugarcane cultivation are Bijor, Meerut, Bareilly, Baghpat, Bulandshahr, Moradabad, Basti, Hardoi, Sambhal, Budaun and Rampur (Uttar Pradesh); Solapur, Pune, Ahmed Nagar, Sangli, Satara, Latur (Maharashtra); Belgaun and Bagalkot (Karanataka) besides Chittoor, Andhra Pradesh and Villupuram, Erode of Tamil Nadu.

Study found that 1.93 million ha of area under rice, mainly in north-western and western India, need a gradual shift. Nearly 43% of the rice cultivated area in eastern and north-eastern states of West Bengal, Odisha, Chhattisgarh and Assam has potential for further intensification of rice cultivation. In case of wheat, around 0.65 million ha of area, mostly in Rajasthan, is critical in terms of sustainability. Productivity enhancement through best management practices, high yielding varieties should be the major focus as there is a huge yield gap and to irrigate at critical stages irrigation potential need to be created in these states. The north-western belts are critical that demand an immediate shift from this region. Precision farming, SRI and laser land levelling are resource conserving technologies in rice through which water can be saved in potential areas. The critical areas in wheat are concentrated in the western states while the Indo-gangetic plains are potential wheat growing areas. Permanent raised-bed planting, happy seeders (not till seed drill) are resource conserving technologies in wheat.

Potential areas of sugarcane are identified in Maharashtra and Uttar Pradesh besides the southern districts in Tamil Nadu. Sustainable sugarcane initiative, drip irrigation and skip furrow irrigation are resource saving technologies in potential area for sugarcane cultivation. The study recommends a gradual cross-sectional diversification for rice, wheat and sugarcane from the over-exploited regions and strengthening the technology assisted cultivation in potential areas for sustainable intensification. The shifting of area requires policy interventions in the form of regional price support policies.

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