Converting Rain into Grain: Opportunities for Realizing the Potential of Rain-fed Agriculture in India

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Introduction

India ranks first among the rain-fed agriculture practicing countries of the world both in terms of extent (86 M ha) and value of the produce. Due to low opportunities and higher population of landless households and agricultural laborers as well as low land and labor productivity, poverty is concentrated in rain-fed regions (Singh 2001). Yield gap analyses, undertaken by Comprehensive Assessment of Water in Agriculture (CA 2007) for major rain-fed crops found farmer's yield being a factor 2-4 times lower than achievable yields for major rain-fed crops. Grain yield oscillates around 1-2 t/ha compared with attainable yields of over 4-5 t/ha (Falkenmark and Rockstrom1993). The large yield gap between attainable yields and farmers' practice as well as between attainable and potential yields shows that a large potential of rain-fed agriculture remains to be tapped.

Rainfall is a truly random factor in the rain-fed production system and its variation and intensity is high in areas of low rainfall. Semi-arid regions, however, may receive enough annual rainfall to support crops but it is distributed so unevenly in time or space that rain-fed agriculture becomes unviable (Reij et al. 1988). Rockstrom and Falkenmark 2000 note that due to the high rainfall variation, a decrease of one standard deviation from the mean annual rainfall often leads to the complete loss of crop. Agricultural droughts, where primarily a skewed distribution of rainfall causes drought in the root zone, are more frequent than the real meteorological droughts. Dry spells (or monsoon breaks), which generally are 2-4 weeks of no rainfall during critical stages of plant growth causing partial or complete crop failures, often occur every cropping season. Therefore, besides several other factors related to agriculture sector as a whole, adverse meteorological conditions resulting in long dry spells and droughts, unseasonal rains and extended moisture stress periods with no mechanisms for storing and conserving the surplus rain to tide over the scarcity/ deficit periods were identified as the major cause for non-remunerative yields and heightened distress in rain-fed regions (Kanwar 1999).

Supplemental (or deficit) irrigation is a key strategy, so far underutilized on a regional basis, to unlock rain-fed yield potentials. Supplemental irrigation to bridge dry spells in rain-fed agriculture has the potential of increasing yields and minimizing risks for rain induced yield loss.

The existing evidence indicates that supplemental irrigation ranging from 50-200 mm/ season (500-2,000 m3/ha) is sufficient to mediate yield reducing dry spells in most years and rain-fed systems, and thereby stabilize and optimize yield levels (Wani and Ramakishna 2005). Since irrigation water productivity is much higher when used conjunctively with rainwater (supplemental), it is logical that under limited water resources priority in water allocation may be given to supplementary irrigation (Agarwal 2000; Joshi et al. 2005). Collecting small amounts using limited macro-catchments, water harvesting during rainy season in the potential regions/ districts can achieve this. Under the 'Strategic Analyses of India's National River Linking Project', a study was, therefore, made to estimate the available runoff in the potential regions to mitigate the terminal drought in the dominant rain-fed districts of India. The study developed a criterion and identified the dominant rain-fed districts for major rain-fed crops in India, made an assessment of the surplus runoff available for water harvesting and supplemental irrigation in these districts, estimated the regional water use efficiency and increase in production due to supplemental irrigation for different crops across the dominant districts and made a preliminary estimate of the economics of the proposed intervention. The next sections of the paper describe in brief the methodology and assumptions; and results and conclusions of the study.

Identification of Dominant Rain-fed Districts

A district (with an average size of ~ 0.5 M ha) is identified as the administrative and planning unit in India and all data sets pertaining to agriculture, water resources, climate, human development and related parameters are available for the district; so, 'district' was considered as unit of analysis for this research. Rain-fed crops in varying proportions are cultivated throughout the rural landscape of the country. The earlier classifications of rain-fed areas were based on fixed or variable percentages of irrigated area (Kerr et al. 1996) in the district irrespective of the area under major rain-fed crops. An improved criterion for the identification of rain-fed districts for a given crop was based on the total rain-fed area under the crop in the district (CRIDA 1998). For the present analysis, districts in the descending order of area coverage limiting to cumulative 85 % of total rain-fed area for each crop were identified and termed as 'dominant rain-fed districts' for a given crop. Crops covered were sunflower, soybean, rapeseed mustard, groundnut, castor, cotton, sorghum, pearl millet, maize and pigeon peas in *kharif* (rainy season) and linseed and chickpeas in *rabi* (winter season). The 5-year averages (1995-2000) of the irrigated area, production and the total cropped area were prepared on district basis. Crop-specific dominant rain-fed districts helped to delineate the major region for the given crop. Details on total districts in rain-fed states and 'dominant districts' covering 85 % of the rain-fed crop area are given in Table 1.

Such identification shows that each of the rain-fed crops has a particular agro-climatic niche and its cultivation is concentrated in certain selected districts. Productivity and other development activities related to a specific crop should be taken up first in these identified districts to ensure a major impact on productivity.

Table 1. Total and 'dominant districts' for the important rain-fed crops in India.

Crop	Rain-fed states	Districts covering cumulative 85 % of rain-fed area (dominant districts)
Sunflower	224	11
Soybean	202	21
Rapeseed mustard	265	29
Groundnut	316	50
Castor	202	12
Cotton	296	30
Sorghum	346	71
Pearlmillet	346	43
Maize	346	67
Pigeon pea	266	83
Chickpea	346	85

Assessment of Available Surplus Runoff for Water Harvesting and Supplemental Irrigation

The total rainfall in India is spread over few rainy days and fewer rain events (about 100 hours in the season) with high intensity resulting in large surface runoff and erosion and temporary stagnation. In either of the cases this 'green water' is not available for plant growth and has very low productivity. Local harvesting of a small part of this water and utilizing the same for supplementary/ protective irrigation to mitigate the impacts of devastating dry spells offers a good opportunity in the fragile rain-fed systems (Rockstrom 2001; Sharma et al. 2005; Wani et al. 2003). For national/ regional level planning on supplementary irrigation, one needs to make an assessment of the total and available surplus runoff and potential for its gainful utilization. In the present study, both crop season-wise and annual water balance analyses were done for each of the selected crops cultivated in the identified districts. Whereas, annual water balance analysis assessed the surplus and/or deficit during the year to estimate the water availability and losses through evaporation, the seasonal crop water balance analysis assessed changes in the temporal availability of rainfall and plant water requirements. Water requirement satisfaction index was used for assessing the sufficiency of rainfall vis-à-vis the crop water requirements.

The total surplus from a district is obtained by the multiplication of seasonal surplus with the rain-fed area under the given crop .The total surplus available from a cropped region is obtained by adding the surplus from individual dominant districts identified for each crop. An estimated amount of 11.5 M ha-m runoff is generated through 39 M ha of the prioritized rain-fed area. Out of the surplus of 11.5 M ha-m, 4.1 M ha-m is generated by about 6.5 M ha of rain-fed rice alone. Another 1.32 and 1.30 M ha-m of runoff is generated from soybeans (2.8 M ha) and chickpea (3.35 M ha), respectively. Total rain-fed coarse cereals (10.7 M ha) generate about 2.1M ha-m of runoff. Spatial distribution of runoff on agro-ecological sub- region river basin wise is shown in Figure 1. However, based on experiences from watershed management research and large-scale development efforts, practical harvesting of runoff is possible only when the harvestable amount is greater than 50 mm or greater than 10 % of the seasonal rainfall (minimum utilizable runoff, CRIDA 2001). This constitutes about 10.5 M ha of rain-fed area which generates a seasonal runoff of less than 50 mm (10.25 M ha) or less than 10 % of the seasonal rainfall (0.25 M ha). Thus, the total estimated runoff surplus for various rain-fed crops is about 11.4 million ha-m (114.02 billion cubic meters, BCM) from about 28.5 million ha which could be considered for water harvesting (Table 2). Among individual crops, rain-fed rice contributes a higher surplus (4.12 M ha-m from an area of 6.33 M ha) followed by soybeans (1.30 M ha-m from 2.8 M ha). The deficit of rainfall for meeting crop water requirement is also visible for crops like groundnut, cotton, chickpea and pigeon pea.

Long- and short-term agricultural droughts and more pronounced meteorological droughts are a common and recurrent phenomenon in the rain-fed areas served by monsoons. Though there is a good amount of surplus available as runoff in a season, all the runoff is not available at one time during the season. For the southwest Indian monsoon, usually there are two peaks of rainfall, the first occurring immediately after the onset of monsoon and the second during its withdrawal phase. During these two periods, there is a likely certainty of overflows (Ramakrishna et al. 1998) which can be harvested in suitable structures to mediate the randomness and enhance the structured supply of rainwater.

Figure 1. Spatial distribution of surplus runoff (ha-m) across dominant rain-fed districts and river basins.

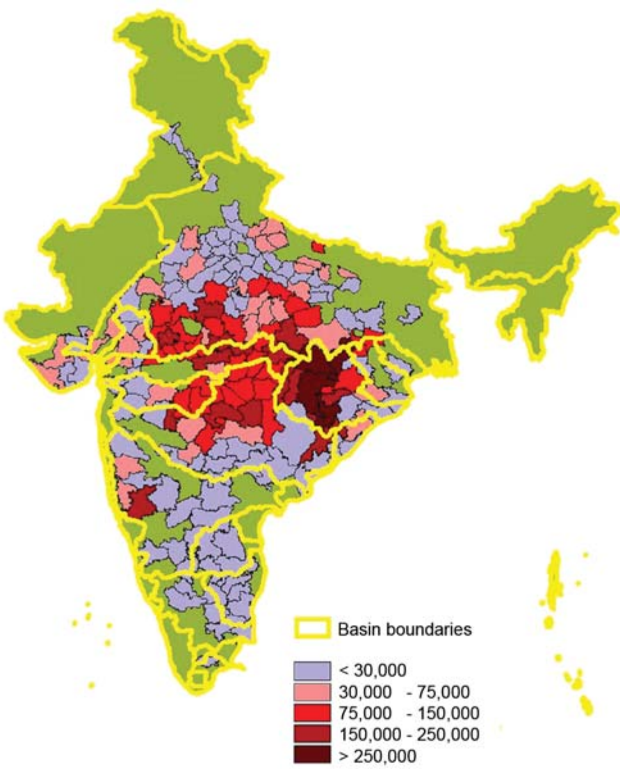

Table 2. Potentially harvestable surplus runoff available for supplemental irrigation under different rain-fed crops of India.

Crop group	Crop	Rain-fed crop area ('000 ha)	Surplus (ha-m)	Deficit (ha-m)
Cereals	Rice	6,329	4,121,851	0
Coarse cereals	Finger millet	303	153,852	0
	Maize	2,443	771,890	0
	Pearl millet	1,818	359,991	0
	Sorghum	2,938	771,660	0
Total (coarse cereals)		7,502	2,057,393	0
Fiber	Cotton	3,177	757,575	8,848
Oilseeds	Castor	28	14,489	0
	Groundnut	1,663	342,673	1,646
	Linseed	590	306,360	0
	Sesame	1,052	416,638	0
	Soybeans	2,843	1,329,251	0
	Sunflower	98	11811	0
Total (oilseeds)		6,273	2,421,222	1,646
Pulses	Chickpea	3,006	1,304,6829,166	
	Green gram	458	80135	0
	Pigeon pea	1,823	659,328	238
Total (pulses)		5,288	2,044,145	9,404
Grand total		28,568	11,402,186	19,898

Normally, farmers (depending on the method of irrigation) apply an irrigation to a depth of 30 to 50 mm as supplemental/ deficit irrigation in rain-fed areas. Actually the objective of supplemental irrigation is to adequately recharge the upper dry soil profile and connect it with the moist profile prevailing in the deeper soil layers so as to provide continuity to the flow process. In the present study, an amount of 100 mm was considered per irrigation including the conveyance and other losses. This quantity of irrigation may appear to be high but was forced due to a vast number of untrained water managers, uneven farm lands and the lack of suitable irrigation infrastructure available with rain-fed farmers.

Based on this available surplus, the irrigable area was estimated for a single supplemental irrigation of 100 mm at the reproductive stage of the crop. This was estimated for both normal rainfall and drought years. Runoff during a drought year is assumed to be 50 % of the runoff/ surplus during a normal rainfall year (based on authors' estimates for selected districts and rain-fed crops in Andhra Pradesh). The potential irrigable area (through supplementary irrigation) for both scenarios is given below (Table 3). Out of 114 billion cubic meters available as surplus, about 28 billion cubic meters (19.4 %) is needed for supplemental irrigation to irrigate an area of 25 million ha during a normal monsoon year thus leaving about 86 M ha-m (80.6 %) to meet

Table 3. Irrigable area ('000 ha) through supplemental irrigation (100 mm per irrigation) during normal and drought years under different rain-fed crops.

Crop group	Crop	Rain-fed crop area ('000 ha)	Irrigable area ('000 ha) during normal monsoon	Irrigable area ('000 ha) during drought season
Cereals	Rice	6,329	6,329	6,215
Coarse cereals	Finger millet	303	266	224
	Maize	2,443	2,251	1,684
	Pearl millet	1,818	1,370	837
	Sorghum	2,938	2,628	1,856
Total (coarse cereals)		7,502	6,515	4,601
Fiber	Cotton	3,177	2,656	1,725
Oilseeds	Castor	28	25	22
	Groundnut	1,663	1,096	710
	Sesame	1,052	919	741
	Soya beans	2,843	2,843	2,667
	Sunflower	98	59	30
Total (cilseeds)		5,684	4,942	4,171
Pulses	Chickpea	3,006	2,925	2,560
	Pigeon pea	1,823	1,710	1,374
Total (pulses)		4,829	4,634	3,934
Grand total		27,520	25,076	20,647

river/environmental flow and other requirements. During drought years also about 31 billion cubic meters is still available even after making provision for irrigating 20.6 million ha. Thus it can be seen that water harvesting and supplemental irrigation may not seriously jeopardize the available flows in rivers even during drought years or cause significant downstream effects in the normal years.

Rainwater Use Efficiency and Production Potential of Rain-fed Crops

Water use efficiency (WUE), is normally defined as grain yield (or value of the produce) per unit of water used/ transpired, measured in kilograms (or monetary units) per hectare per millimeter of water (kg/ha/mm, $/ha/mm) applied/ used (Molden 2001). At a regional scale, the estimation of rainwater use efficiency (RWUE) could be obtained by aggregating the rainwater use efficiency available at field scale. However, it is not a viable practical solution as the data requirement is quite large (in terms of productivity values from each parcel of land, inflow/outflow as surface/ sub-surface flow from cultivated fields etc.). Thus, a simple method to estimate RWUE at regional scale is to utilize the existing database of productivity statistics (available at district level) and to derive the estimate of rainfall utilized for production purposes (i.e., rain water use efficiency as a ratio of productivity at district level to the effective rainfall).Water use efficiency under rain-fed agriculture is not a consistent value as evidenced in irrigated agriculture. In rain-fed areas, the WUE varies from district to district and from year to year based on the pattern of rainfall occurrence with drought years giving a higher value of water use efficiency. The present study aggregates water use efficiency at district level for major rain-fed crops. At the field level, the effective rainfall was estimated by the procedure developed under CROPWAT and water productivity was estimated as the ratio of crop productivity at district level (5-year average) to the effective rainfall received at the district. This analysis was carried out for various rain-fed crops in respective dominant rain-fed districts. Achievable yields from on-farm trials and long-term average rainfall for each dominant rain-fed district and for different rain-fed crops were used for estimating the 'achievable' water use efficiency (Table 4).

Table 4. Estimated water use efficiency values based on 'achievable yields' (improved technologies) for different rain-fed crops*.

Crop group	Crop	Water use efficiency (kg/ha/mm)		
		Average	Maximum	Minimum
Cereals	Rice	9.40	7.34	11.29
Coarse cereals	Finger millet	6.80	6.30	8.01
	Maize	10.97	8.44	13.70
	Pearl millet	8.67	6.96	11.31
	Sorghum	13.51	11.22	17.72
Fiber	Cotton	1.60	1.23	1.97
Oilseeds	Castor	3.50	3.18	3.67
	Groundnut	3.75	2.88	4.69
	Sesame	3.11	2.48	3.68
	Soybean	7.11	5.38	8.15
	Sunflower	3.05	2.97	3.13
Pulses	Chickpea	5.19	3.90	6.25
	Pigeon pea	2.44	1.86	2.96

Note: * Based on long-term on-farm data from the national network on rain-fed agriculture.

Production projections were made for different crops in the respective rain-fed districts using the information on regional rainwater use efficiency from both scenarios, namely; district averages and on farm trials hereafter referred to as 'traditional practices' and 'improved technologies', respectively and supplemental irrigation of 100 mm at reproductive stage. Secured crop water supply (though of a limited amount) during critical drought spells reduces the risks for crop failure, thereby increasing farmers' incentives to invest in farm inputs, such as fertilizers, improved seeds, crop protection and diversification (Falkenmark et al. 2001). Trials of water harvesting and its strategic application (supplementary irrigation) in Burkina Faso, Kenya, Niger, Sudan and Tanzania have also shown increased yields of 2-3 times of those achieved in dryland farming (FAO 2002). The improved technologies involve the adoption of improved varieties, application of recommended doses of fertilizers, better management and follow-up on recommended package of practices etc. The estimated production projections for each crop and district and aggregates based on individual crop with improved practices and over two types of seasons (normal and drought) summarized for crops and groups of crops are given in Table 5. Additional production was a product of irrigable area, water use efficiency and the amount of irrigation. The irrigable area through supplemental irrigation (at 100 mm) for different crops during drought season varies between 50-98 % (98 % for rice crop to 50 % for sunflower districts) of the irrigable area during normal season.

Improved technologies, along with water, play an important part to harness the potential benefits. Under improved management practices an average of 50 % increase in total production cutting across drought and normal seasons is realizable with supplemental irrigation from rain-fed area of 27.5 M ha (Table 5). Production enhancement in drought season in case of rice crop is high due to higher water application efficiency and due to the sufficient surplus to

Table 5. Yield increases with supplemental irrigation (SI) in normal and drought seasons at two irrigation efficiencies (based on WUE of improved technologies).

Crop group	Crop	Rain-fed cropped area ('000 ha)	Traditional production ('000 tonnes)	Irrigable area ('000 ha)		Additional production ('000 tonnes)			
						Normal monsoon		Drought season	
				Normal season[1]	Drought season[1]	60 % SI effi ciency	70 % SI effi ciency	65 % SI effi ciency	75 % SI effi ciency
Cereals	Rice	6,329	7,612	6,329	6,215	3,549	4,141	3,776	4,357
Coarse cereals	Finger millet	303	271	266	224	107	124	97	112
	Maize	2,443	2,996	2,251	1,684	1,495	1,744	1,221	1,408
	Pearl millet	1,818	1,902	1,370	837	717	836	481	555
	Sorghum	2,938	3,131	2,628	1,856	2,091	2,439	1,616	1,864
	Total coarse cereals	7,502	8,300	6,515	4,601	4,409	5,144	3,414	3,939
Fiber	Cotton	3,177	430	2,656	1,725	252	294	178	206
Oilseeds	Castor	28	10	25	22	5	6	5	6
	Groundnut	1,663	1,182	1,096	710	244	284	176	203
	Sesame	1,052	365	919	741	173	202	153	176
	Soya beans	2,843	2,607	2,843	2,667	1,225	1,429	1,250	1,443
	Sunflower	98	49	59	30	11	12	6	7
	Total oilseeds	5,684	4,214	4,942	4,171	1,657	1,933	1,590	1,834
Pulses	Chickpea	3,006	2,367	2,925	2,560	910	1,061	866	1,000
	Pigeon pea	1,823	1,350	1,710	1,374	242	282	212	245
	Total pulses	4,829	3,717	4,635	3,934	1,152	1,344	1,078	1,244
Grand total		27,520	24,272	25,076	20,647	11,020	12,856	10,037	11,581

bring almost the entire rice cultivated area under supplemental irrigation. This would also indicate that large tracts of rain-fed rice cultivated area are covered under high rainfall zones with sufficient surplus for rainwater harvesting. Similar situation could be observed for soybean, which also reflects the concentration of crop growing area in high rainfall zones. In case of other crops, though water application efficiency is higher during the drought scenario, lack of surplus to cover entire area reduces the total production. Significant production improvements can be realized in rice, sorghum, maize, cotton, sesame, soybeans and chickpea.

The success of Green Revolution in irrigated areas is one solid example built upon irrigation and improved technologies. Everyone of the stakeholders from supplier to farmer to market responded with equal enthusiasm. A second Green Revolution is not in the offing for a long time for the reason that this needs to be staged in water scarcity/insufficiency zone. In the absence of stabilized yields, a production system of marketable value could not be put in place unlike in irrigated rice-wheat and other intensive production systems. The various stakeholders from start to end could not be enthused. However, the improved watersheds did to a little extent what irrigation could do to large assured areas. The mechanisms and processes for both scaling-out and scaling-up the impacts generated at the 'bright spots' have still eluded the development planners and implementing agencies in India (Sharma et al. 2005). Still, it has been observed that the input use like hybrid seed, fertilizers, and plant protection are on the increase with watershed activities especially associated with increase in supplemental irrigation and cropping intensity (Joy and Paranjape 2004). Concerted efforts are required through development of the local water resources to stretch the boundaries of these oases to cover the vast drylands.

Economics of Water Harvesting and Supplemental Irrigation

While it appears that supplemental irrigation offers scope for enhancing production from rain-fed crops across different agro-ecologies/districts, it is also essential that the same need to be economically viable. Numerous such structures have been constructed under varying agro-climatic conditions under state sponsored programs, by nongovernmental organizations and even with individual initiatives. The available literature also has good evidence on the technical and financial viability of the construction of such water harvesting structures for the improvement of productivity and diversification of agriculture in the rain-fed areas (Oweis 1997; Kurien 2005). The cost of provision of supplemental irrigation through construction water harvesting structures varies a great deal between states/ regions and locations between the same state (Sharda 2003; Samra 2007, personal communication; Table 6). Hence a simple analysis based on the national average cost for rainwater harvesting structures (INR 18,500 per hectare) was carried out for the provision of supplemental irrigation to rain-fed crops. The crop- wise annualized cost, considering the useful life of lined structures as 20 years, is given in Table 7. It suggests that an estimated INR 50 billion is annually required to provide supplemental irrigation to around 28 million hectares of rain-fed- cultivated land and about half of that amount is required for rice and coarse cereal production only. The benefit is evaluated based on the price of the crop and the yield difference from supplemental irrigation. With the adoption of improved practices in conjunction with supplemental irrigation, net benefits become positive for all crops except pearl millet indicating the need for development/ general adoption of high yielding varieties of pearl millet, which are responsive to irrigation and improved practices (Table 7). Pearl millet, sorghum and maize continue to be the crops with a very low harvest index. However, the data indicate that the net benefits improve by about, three-times for rice, four-times for pulses and six-times for oilseeds. Droughts appear to have very mild impact when farmers are equipped with supplemental irrigation and the net benefits remain stable even when runoff during a drought period gets reduced by 50 %.

Table 6. Cost of different water harvesting structures per hectare of the service area at different locations in India.

Location	Cost (Indian Rs.*.) of water harvesting structures (2000 price level)		
	Minimum	Maximum	Average
Bagbahrar (Chhatisgarh)	4,100	29,200	11,000
Dindori (Madhya Pradesh)	6,800	25,000	18,000
Keonjhar(Orissa)	19,400	35,000	27,000
Darisai(Jharkhand)	8,300	27,800	18,000
National average	18,500		

Note: *1 USD= Indian Rs. 42

Table 7. Crop-wise net benefits from supplemental irrigation under traditional practices and improved technologies during normal and drought conditions.

Crop/crop group	Rain-fed cropped area('000 ha)	Annual cost (Billion Rupees)	Net benefits under improved technologies(Billion Rs.)	
			With 65 % efficiency of SI during normal monsoon	With 75 % efficiency of SI during drought period
Rice	6,329	11.71	8.52	9.81
Finger millet	303	0.56	1.67	1.46
Maize	2,443	4.52	2.53	1.23
Pearl millet	1,818	3.36	-1.49	-2.10
Sorghum	2,938	5.44	0.95	-0.50
Total cereals	7,502	13.88	3.66	0.08
Cotton	3,177	5.88	8.27	4.12
Castor	28	0.05	0.17	0.16
Groundnut	1,663	3.08	5.79	3.32
Sesame	1,052	1.95	4.87	4.08
Soya beans	2,843	5.26	13.43	13.83
Sunflower	98	0.18	0.18	0.01
Total oil seeds	5,684	10.52	38.59	31.40
Chickpea	3,006	5.56	43.49	41.14
Pigeon pea	1,823	3.37	6.02	4.86
Total pulses	4,829	8.93	49.50	46.00
Grand total	27,520	50.91	94.40	81.42

Conclusion

Rain-fed agriculture is mainly and negatively influenced by the random behavior of rainfall, causing intermittent dry spells during the cropping season and especially, at critical growth stages coinciding with the terminal growth stage. District level analysis for different rain-fed crops in India showed that the difference in the district average yields for rain-fed crops among different rainfall zones was not very high, indicating that the total water availability may not be the major problem in different rainfall zones. Further, for each crop, there were few dominant districts which contributed most to the total rain-fed crop production. The most effective potential strategy to realize the potential of rain-fed agriculture in India (and elsewhere) appears to be harvesting a small part of available surplus runoff and reutilizing it for supplemental irrigation at different critical crop growth stages. The study identified about 27.5 M ha of potential rain-fed area, which accounted for most of the rain-fed production and generated sufficient runoff (114 BCM) for harvesting and reutilization. It was possible to raise the rain-fed production by 50 % over this entire area through application of one supplementary irrigation (28 BCM) and some follow up on the improved practices. Extensive area coverage rather than intensive irrigation needs to be done in regions with higher than 750 mm/ annum rainfall, since there is a larger possibility of alleviating the in-season drought spells and ensuring the second crop with limited water application. This component may be made an integral part of the ongoing and new development schemes in the identified rural districts. The proposed strategy is environmentally benign, equitable, poverty-targeted and financially attractive to realize the untapped potential of rain-fed agriculture in India.

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