NJAS - Wageningen Journal of Life Sciences 70–71 (2014) 71–77

Contents lists available at ScienceDirect

NJAS - Wageningen Journal of Life Sciences

journal homepage: www.elsevier.com/locate/njas

Science-led interventions in integrated watersheds to improve smallholders' livelihoods

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ARTICLE INFO

Article history:
Received 13 September 2013
Received in revised form 7 May 2014
Accepted 23 July 2014
Available online 19 August 2014

Keywords:
Bridging yield gaps
Community watershed
Dryland agriculture
Integrated resource management
Participatory action.

ABSTRACT

Existing large crop yield gaps between farmers' fields in rainfed areas and the achievable yields are abridged through integrated watershed management during 2002-2007, while improving farmers' livelihoods also. In addition to water shortages, emerging widespread deficiencies of multiple micro- and secondary nutrients such as sulphur (S), boron (B) and zinc (Zn) along with nitrogen (N) and phosphorus (P) are holding back the productivity potential through inefficient utilization of limited available water. Soil test-based balanced nutrient application of deficient SBZn plus NP in fields in watersheds recorded 70 to 119% (2100 kg ha^{-1} in maize, 660 kg ha^{-1} in groundnut, 640 kg ha^{-1} in mungbean and 1070 kg ha^{-1} in sorghum) improvement in crop productivity along with additional returns varying from Rs 16,050/- to Rs 28,160/- ha^{-1} over the farmers' practice (only NP). Landform management to alleviate waterlogging proved effective intervention to manage high clay Vertisols for higher soybean and groundnut productivity by 13 to 27% (340 to 350 kg ha^{-1} in soybean and 160 to 250 kg ha^{-1} in groundnut) over the farmers' practice. However, the integrated approach of balanced nutrition and landform management plus improved cultivar was the best option in increasing sunflower productivity by 182% (1600 kg ha^{-1} in sunflower) over farmers' management (control). Adoption of these soil-water-crop interventions in target watersheds abridged yield gaps by 12 to 96% in groundnut (160 to 1280 kg ha^{-1}), 29 to 100% (240 to 1130 kg ha^{-1}) in pigeonpea and 0 to 100% (0 to 1175 kg ha^{-1}) in chickpea. The impact of watershed interventions was seen in farm-based activities like improved milk production and incomes. The watershed programs alleviated migration in the catchments by improving the five capitals viz. human, financial, social, physical and natural.

1. Introduction

1.1. Rain-fed regions, our hope to future food security

World population of 9.2 billion by 2050 mostly in developing countries in Asia and Africa (5.3 and 1.7 billion, respectively) would need increased water withdrawal from 2500 km^3 in 2000 to 3200 km^3 by 2025 by agriculture to achieve needed food production [1,2]. One third of the world's population (especially in the developing countries) is expected to face severe water scarcity by 2025 [3]. To achieve food security, minimize the water conflicts and reduce poverty, it has become essential to harness potential of rainfed systems [4], as globally 80% of agriculture is rainfed and current productivity on farmer' fields is lower by two to four folds than achievable potential [5–9].

In India, rainfed agriculture constitutes 67% of the net cultivated area [10] and is the hot spot of poverty and malnutrition as it was bypassed during the green revolution era in 1960's. Researchers and policy makers have now realized importance of rainfed agriculture to meet the demand for food which would continue to rise with the growing population expected to reach 1.6 billion by 2050 and also to uplift socioeconomic conditions of the farmers [11,12].

1.2. Harnessing the potential of rainfed agriculture

A long-term study since 1976 at ICRISAT center at Patancheru, India demonstrated a virtuous cycle of persistent yield increases with an average annual productivity of 5.1 t ha^{-1} through improved watershed management (land, water and crop management etc.) in rainfed agriculture as compared with 1.1 t ha^{-1} (Fig. 1) in the farmers' practice [4,13]. Both management practices are sustainable

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http://dx.doi.org/10.1016/j.njas.2014.07.001
1573-5214/

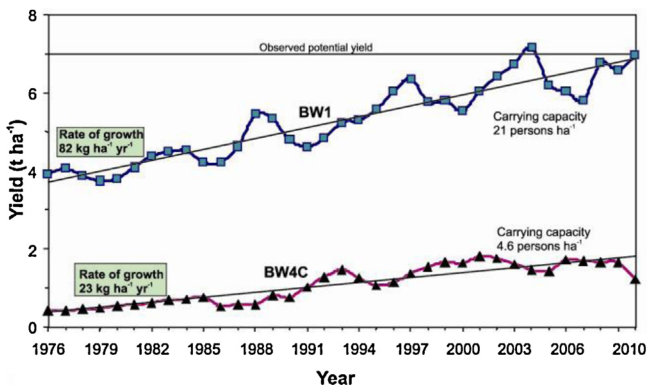

Fig. 1. Three-year moving average of crop yields in improved (BW1) and traditional (BW4 C) management systems *during 1976-2010 at ICRISAT, Patancheru, India.* Source: Wani et al. [10].

in the long run, but have different carrying capacities - farmers' practice having a low carrying capacity of 5 persons ha^{-1}, while improved watershed management can support 21 persons ha^{-1}. Currently, rainfed agriculture suffers from a number of biophysical and socioeconomic constraints, which limit the productivity of crops. There is an urgent need to understand and break the unholy nexus of drought, land degradation and poverty for improving livelihoods, food security through sustainable intensification of natural resources using science-led, holistic watershed scale development approach (5, 13, 14, 15).

1.3. Watershed programs in India–key learning

A meta-analysis of watershed projects in India [14,15], showed a benefit to cost (B:C) ratio of 2 and internal rate of return (IRR) of 27% with rural incomes enhanced by 58%, agricultural productivity increased by 35% and additional environmental and social benefits. However, 68% of projects performed below average in terms of economic, production and social indicators pointing out a large scope for improvement [14,15].

Watershed programs were conspicuously more remunerative and impact oriented in the low income regions with higher B:C ratio of 2.25:1 and 164 person days employment generated per year per ha as compared to the high income regions with 1.75:1 B:C ratio and 91 person days employment generated per year per ha (Table 1). Moreover, returns on investment in inputs as well as research were higher for dryland areas than for irrigated areas [16].

Integrated watershed development is a community approach [17,18] with a positive relationship between people's participation and benefits from watershed program (Table 2). The B:C ratio was greater (2.63) in watersheds where people's participation was higher in comparison to the watersheds with lower participation (1.42). The prominent drivers of success were integrating the needs of all stakeholders particularly women, landless laborers and other vulnerable groups through targeted activities [19,20], knowledge-based entry point activities to build rapport with the community [21,22], tangible economic benefits to individual farmers [23,24], agroecoregion specific technologies [20], consortium (of multiple institutions) approach to harness multidisciplinary strength [25], capacity strengthening of the stakeholders [4,18], and making watersheds a business case by transforming subsistence farming in to marketable surplus farming.

In rainfed areas, management at watershed scale is one of the most trusted approaches to manage rainwater and other natural resources for increasing food production, improving livelihoods, protecting environment, addressing gender and equity issues along with biodiversity concerns [4,13,17,18,24,26–29]. Therefore, integrated watershed management is recognized as a potential engine for agricultural growth and development in fragile and marginal rain-fed areas in India [17,22,26,28].

2. Materials and Methods

2.1. Details of case study watershed sites

The present study was conducted in the selected watersheds in 5 states in India implemented by ICRISAT-led consortia in the areas of soil, water, crop and nutrient management (Table 3). The

Table 1
Summary of benefits from the sample watersheds in India according to income status of the region.

Parameter	Particulars	Unit	Per capita income of the region		
			High*	Medium**	Low***
Efficiency	Benefit to cost (B:C)	Ratio	1.75 (15.3)	1.96 (28.2)	2.25 (9.36)
	Internal rate of return (IRR)	Per cent	24.6 (7.23)	27.9 (6.89)	30.6 (6.02)
Equity	Employment	Persons days ha^{-1} $year^{-1}$	91.1 (7.23)	159.7 (9.16)	164.3 (6.76)
Sustainability	Increase in irrigated area	Per cent	48.5 (12.5)	45.8 (8.09)	76.0 (6.71)
	Increase in cropping intensity	Per cent	31.4 (10.8)	34.1 (14.4)	43.8 (10.3)
	Runoff reduced	Per cent	43.2 (9.32)	43.3 (6.81)	49.3 (5.28)
	Soil loss saved	t ha^{-1} $year^{-1}$	1.18 (36.2)	1.10 (41.1)	0.87 (12.3)

Figures in parentheses indicate t-values; *, **, and *** include the states having per capita Ag GDP greater than Rs. 4000, between Rs. 2000 to Rs. 4000, and below Rs. 2000 per annum, as in Joshi et al., 2005. Source: Joshi et al. [14]

Table 2
Summary of benefits from the sample watersheds in India according to people's participation.

Parameter	Particulars	Unit	People's participation		
			High	Medium	Low
Efficiency	Benefit to cost (B:C)	Ratio	2.63 (16.0)	1.60 (29.7)	1.42 (16.4)
	Internal rate of return (IRR)	Per cent	38.3 (10.2)	22.3 (4.74)	17.3 (8.21)
Equity	Employment	Persons days ha^{-1} $year^{-1}$	165.2 (5.29)	118.7 (4.31)	105.4 (9.97)
Sustainability	Increase in irrigated area	Per cent	77.4 (8.23)	56.2 (8.07)	29.4 (10.3)
	Increase in cropping intensity	Per cent	44.6 (9.37)	25.0 (10.2)	32.0 (14.2)
	Runoff reduced	Per cent	43.2 (6.03)	40.4 (4.22)	69.0 (7.19)
	Soil loss saved	t ha^{-1} $year^{-1}$	1.18 (43.2)	1.10 (18.2)	0.87 (22.3)

Source: Joshi et al. [14]

Table 3
Detail of case study watersheds sites in different states in India.

State	District	Nucleus watershed
Andhra Pradesh	Mahabubnagar	Malleboinpally; Mentapally; Appayapally; Sripuram
	Nalgonda	Nemmikal; Thirumalapuram; Kacharam
	Kurnool	Karivemula; Kangulavanka; Nandavaram
	Rangareddy	Kothapally
Karnataka	Kolar	Belaganahalli; T. Peddanahalli; Pulasanivaddu
	Tumkur	Kanakapura; Begur
	Chitradurga	Maradihalli; Toparamalige
	Haveri	Aremallapur; Chikkalingadahalli
	Dharwad	Anchatgiri
Maharashtra	Ahmednagar	Shekta
Rajasthan	Bundi	Thana; Govardhanpura; Gokulpura
Madhya Pradesh	Guna	Kailaspura

nucleus watershed served as the sites of learning where farmers conducted experiments with technical backstopping from the consortium partners. Action research for development, monitoring, collective action was implemented and established participatory processes. The farmers from nucleus watersheds were empowered to became trainers to fellow farmers in both nucleus and satellite watersheds. The nucleus watersheds in Andhra Pradesh were surrounded by 40 satellite watersheds while the nucleus watersheds in Karnataka were surrounded by 33 satellite watersheds. All the watersheds were chosen based on the criteria such as representative typology, extent of rainfed area, productivity levels and willingness of farmers to participate in the project activities. The baseline data collected through participatory rural appraisal (PRA) and rapid rural appraisal (RRA) techniques revealed that farmers' crop yields were lower by two to four folds as compared to the achievable crop yields. Main constraints identified were increased land degradation, low rainwater use efficiency, increased mining of nutrients from soils.

2.2. *Stratified soil sampling as knowledge-based entry point activity*

In addition to water shortage, soils in rainfed agriculture are degraded which are apparently holding back the realization of productivity potential and leading to inefficient utilization of even existing water. Therefore, to diagnose soil related constraints, the soil samples were collected from farmers' fields in the target states in India during the period 2002 to 2007 by participatory stratified soil sampling method [30]. Soil sampling was used as knowledge-based entry point activity to build rapport with the farmers. Farmers themselves collected the soil samples with required hand holding support. The samples were collected from 11 districts in Andhra Pradesh (Adilabad, Ananthapuram, Kadapa, Khammam, Kurnool, Mahabubnagar, Medak, Nalgonda, Prakasam, Rangareddy and Warangal), 10 districts in Karnataka (Bengaluru Rural, Bijapur, Chamrajnagar, Chikkabalapur, Chitradurga, Dharwad, Haveri, Kolar, Raichur and Tumkur), one district in Gujarat (Junagarh), nine districts in Rajasthan (Alwar, Banswara, Bhilwara, Bundi, Dungarpur, Jhalawar, Sawai Madhopur, Tonk and Udaipur) and 12 districts in Madhya Pradesh (Barwani, Dewas, Guna, Indore, Jhabua, Mandla, Raisen, Rajgarh, Sagar, Sehore, Shajapur and Vidisha). The collected samples were air dried, ground and passed through 2 mm sieve. For organic carbon, the soil samples were ground to pass through 0.25 mm sieve. The processed samples were analyzed for pH, organic carbon (OC), available - sulphur (S), boron (B), zinc (Zn), phosphorus (P) and potassium (K) in analytical laboratory at ICRISAT. Soil reaction (pH) was measured with the help of glass electrode using soil to water ratio of 1:2. Organic carbon was determined using the Walkley-Black method [31], available P using the sodium bicarbonate (NaHCO3) method [32], exchangeable K using the ammonium acetate method [33], and available S using 0.15% calcium chloride ($CaCl_2$) as an extractant [34]. Available Zn was extracted by diethylene triamine pentaacetic acid (DTPA) reagent [35], and available B by hot water [36].

2.3. *Participatory on-farm trials*

2.3.1. *Soil test-based balanced nutrition trials*

The farmer participatory research trials for development (PR&D) were conducted during 2003 to 2007 within the watershed boundaries to evaluate suitable technologies for currently existing constraints. The trials evaluated the effect of soil test-based balanced nutrition on crop productivity. The effects of individual applications of deficient S, B or Zn as well as conjoint application of S, B and Zn along with farmers' practice (of adding sub-optimal N and P) were evaluated in the watersheds. As farmers in target watersheds add sub-optimal amounts of N and P fertilizers, therefore another treatment comprised of deficient S, B and Zn plus state recommended N and P. Recommended N and P for non-legume study crops were - 60 to 100 kg N, 20 kg P in Andhra Pradesh and 50 kg N, 10 kg P in Karnataka. Similarly, in legume study crops recommended N and P were - 20 kg N, 20 kg P in Andhra Pradesh, 30 kg N, 25 kg P in Karnataka, 10 to 20 kg N, 10 to 25 kg P in Rajasthan and 20 kg N, 25 kg P in Madhya Pradesh. In view of no mention of secondary and micro-nutrients in state recommendation, but widespread observed deficiencies, S, B and Zn were added at the rate of 30, 0.5 and 10 kg ha^{-1} (once in two years), respectively in all study crops. The treatments were imposed on plots, side by side and uniform crop management practices were ensured in all the treatments. Application of all the nutrients except N was made as basal. Fifty per cent of N dose to non-legumes was added as basal and the remaining in two equal splits at one month interval. The fertilizer sources for nutrients were urea for N, DAP (diammonium phosphate) for P and N, MOP (muriate of potash) for K, gypsum for S, zinc sulphate for Zn and agribor (20% B) for B. To evaluate the benefits of soil test based fertilization, additional cost on fertilizer application under BN was worked out on current (year 2013) average market prices of fertilizers used viz. 33 Rs kg^{-1} zinc sulphate, 40 Rs kg^{-1} borax and 2.20 Rs kg^{-1} gypsum. Additional returns were calculated for crops based on farm gate price of 12 Rs kg^{-1} maize, 37 Rs kg^{-1} groundnut, 44 Rs kg^{-1} mungbean, and 15 Rs kg^{-1} sorghum. The currency conversion factor is 1 Rs = 0.014 USD.

2.3.2. *Land form evaluation trials*

Vertisols with high clay content are the predominant soils in the watersheds and their structure is distorted with falling raindrops and subsequent flooding which negatively affect crop yields and also water infiltration and soil moisture. Farmer participatory trials were conducted to evaluate the effects of landform management on bridging the yield gaps through increased infiltration of rainwater via intact soil surface and alleviate waterlogging through safe and guided disposal of excess rainwater. Two landform management practices viz. broadbed and furrow (BBF) and/or conservation furrow (CF) were evaluated against the farmers' practice of cultivation on flat bed. BBF system consisted of making raised beds of 105 cm width followed by furrows/channel (45 cm), while CF comprised of making a furrow/channel in the field every 3–4 m width, with a purpose to safely drain excess rainwater, while preserving good soil structure on the raised bed.

2.3.3. *Farmer participatory evaluation of cultivars*

Many farmers in watersheds still use low-yielding cultivars which results in lower crop yields. Farmer participatory trials were

Table 4
Nutrient mining in farmers fields' in rainfed regions in India.

State	No of	% deficiency (Range of available nutrients)					
	Farmers	Org-C	P	K	S	B	Zn
*Andhra Pradesh	3650	76 (0.08-3.00)	38 (0.0-248)	12 (0-1263)	79 (0.0-801)	85 (0.02-4.58)	69 (0.08-35.6)
Karnataka	17712	70 (0.01-3.60)	46 (0.0-480)	21 (4-3750)	84 (0.1-4647)	67 (0.02-26.2)	55 (0.06-235)
Gujarat	82	12 (0.21-1.90)	60 (0.4-42.0)	10 (30-635)	46 (1.1-150)	100 (0.06-0.49)	85 (0.18-2.45)
*Rajasthan	421	38 (0.09-2.37)	45 (0.2-44)	15 (14-1358)	71 (1.9-274)	56 (0.08-2.46)	46 (0.06-28.6)
*Madhya Pradesh	341	22 (0.28-2.19)	74 (0.1-68)	1 (46-716)	74 (1.8-134)	79 (0.06-2.20)	66 (0.10-3.82)

Notes: Org-C stands for organic carbon and P, K, S, B and Zn for available phosphorus, potassium, sulphur, boron and zinc, respectively; the figures in the parentheses indicate the range of nutrients % for Org-C and mg kg^{-1} for P, K, S, B and Zn; *Source: Wani et al. [44]

Table 5
Effects of application of sulphur (S), boron (B) and zinc (Zn) on crop yields in watersheds in Andhra Pradesh, rainy season 2003.

Crop	FP	FP + S	FP + B	FP + Zn	FP + SBZn	NP + SBZn	SE +	CV (%)
Maize	2790	3510 (26)	3710 (33)	3710 (33)	4140 (49)	4890 (75)	466	12
Groundnut	830	930 (12)	1000 (20)	1060 (27)	1230 (48)	1490 (78)	134	12
Mungbean	900	1210 (33)	1130 (24)	1320 (46)	1390 (54)	1540 (70)	114	9
Sorghum	900	1190 (32)	1160 (29)	1330 (47)	1460 (62)	1970 (119)	190	14

Notes: FP = farmers' practice, S = sulphur, B = boron, Zn = zinc, N = nitrogen, P = phosphorus; the figures in the parentheses indicate the % increase over the FP.

conducted to evaluate the benefits of adopting improved cultivar with or without improved management (balanced nutrition plus landform management) in improving the productivity in watersheds.

In all the trials, the yields were recorded at maturity by harvesting crop at three spots in a treatment measuring 3X3 m^2 and the average of three was used to compute yield in kg ha^{-1}.

2.4. Analysis of yield gaps abridged

In order to find the extent of yield gaps bridged through watershed implementation programs, average yields were recorded in the watershed catchments, and compared with those in experimental stations (achievable potential) and the average district yield (without watershed interventions) with groundnut and pigeonpea crops in Andhra Pradesh watersheds and chickpea crop in Madhya Pradesh and Rajasthan watersheds.

3. Results and Discussion

3.1. Diagnosis of soil constraints

The analysis of soil samples from the farmers' fields revealed large scale mining of soil nutrients in rainfed agricultural systems across many states in India (Table 4). Soil carbon (C) status an indicator of general soil health showed that majority of farmers' fields were severely degraded particularly in Andhra Pradesh and Karnataka indicating critical deficiency in 70% to 76% farmers' fields. Soil C ranged in rainfed farming systems in India from very low levels of 0.01% to high levels of 3.60%. Low levels of C in soils also indicate specifically the deficiencies of available nitrogen (N). Phosphorus (P) deficiencies were serious in Madhya Pradesh (74% farms) and Gujarat (60% farms) where majority farms had low levels of it. Majority farmers' fields' across all the states, however, had sufficient levels of potassium (K) which varied from traces to as high as 3750 mg kg^{-1} soil. But very surprisingly, the analysis results revealed acute and widespread deficiencies of multiple nutrients such as sulphur (S), boron (B) and (Zn). The deficiencies were widespread across all states; 46 to 84% farms were deficient in S, 56 to 100% farms were deficient in B, while 46 to 85% farms were deficient in Zn. Earlier works have also shown rain-fed dryland soils critically deficient in micro and macro nutrients [37–41]. Moreover, there is little awareness about such deficiencies amongst the farmers, extension staff as well as policy makers. In view of essentiality of nutrients, we understand these nutrient deficiencies are apparently holding back the realization of achievable yields in the watersheds and therefore due focus was given on adoption of soil test based balanced nutrition in addition to other water and soil interventions.

3.2. Improving farm productivity and livelihoods

3.2.1. Evaluation of soil test-based balanced nutrition

The farmer participatory trials with maize, groundnut, mungbean and sorghum in watersheds in Andhra Pradesh showed that the application of S over the farmers' practices increased crop productivity by 12 to 33%, the application of B increased it by 20 to 33%, while the application of Zn increased by 27 to 47% (Table 5). The conjoint application of S, B and Zn along with farmers' practice increased productivity by 48 to 62%. However, the application of S, B and Zn along with the recommended levels of N and P recorded the highest productivity improvement (70 to 119%) over the farmers' practice of sub optimal N and P.

In economic terms (Table 6), the application of S alone through gypsum brought additional per ha net returns of Rs 3700/- to Rs 13640/-. Similarly, individual applications of B through borax or

Table 6
Economic gross returns through application of micro and secondary nutrients to different crops in watersheds in Andhra Pradesh, rainy season 2003.

Crop	Gross returns (Rs ha^{-1})					
	FP	FP + S	FP + B	FP + Zn	FP + SBZn	NP + SBZn
Maize	33480	42120	44520	44520	49680	58680
Groundnut	30710	34410	37000	39220	45510	55130
Mungbean	39600	53240	49720	58080	61160	67760
Sorghum	13500	17850	17400	19950	21900	29550

Notes: FP = farmers' practice, S = sulphur, B = boron, Zn = zinc, N = nitrogen, P = phosphorus.

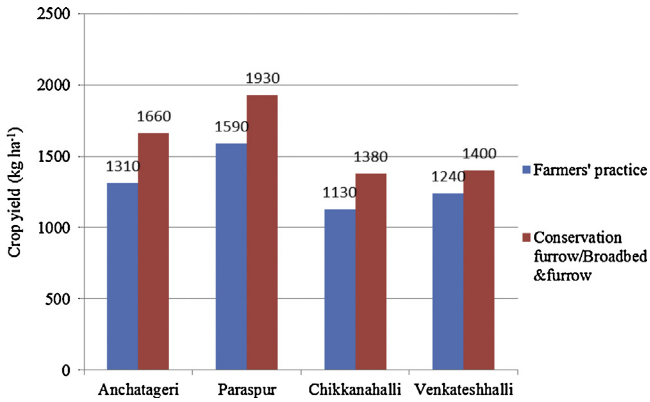

Fig. 2. Effects of landform management on soybean yield in Dharwad district (Anchatageri, Paraspur) watersheds and groundnut yield in Kolar district (Chikkanahalli, Venkateshhalli) watersheds in Karnataka, 2007.

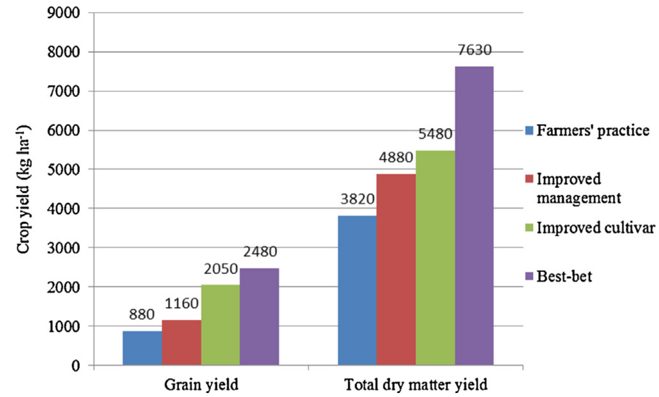

Fig. 3. Effects of integrated management practices on sunflower yield in watershed in Chitradurga district, Karnataka, 2006.

Zn through zinc sulphate recorded per ha additional net returns of Rs 3900 to Rs 11040/- and Rs 6450 to Rs 18480/-, respectively depending on the crop. The conjoint application of S, B and Zn over the farmers' practice resulted additional net returns of Rs 8400/- to Rs 21560/-. Farmers used to apply sub-optimal amounts of N and P in the watersheds, and thus another practice of application of S, B and Zn along with the recommended levels of N and P resulted the highest increase in net returns over the farmers practice by Rs 16050/- to Rs 28160/-.

Similarly, scaling up balanced nutrient management part in Sujala-ICRISAT watershed initiative through innovative “Bhoochetana” initiative in Karnataka [42,43] and other states like Rajasthan, Madhya Pradesh, Andhra Pradesh [37,38,41] have also revealed that balanced nutrient application treatment based on the soil test results increased yields of various crops compared to the farmer's input treatment and improved farmers' incomes and livelihoods.

3.2.2. *Evaluation of landform management practices*

The on-farm trials in watersheds in Karnataka showed clearly the benefits of cultivation across the slope with landform management of BBF and CF as compared with farmers' practice of cultivation on flat beds. The improved landform management practice increased soybean yields by 21 to 27% and groundnut yields by 13 to 22% (Fig. 2). The benefits are apparently accrued due to safe disposal of excess water alleviating waterlogging in soil, ensuring aeration and better infiltration of water.

3.2.3. *Evaluation of integrated management practices (best bet)*

In watersheds in Chitradurga district in Karnataka results (Fig. 3) showed a significant increase in sunflower yield with improved cultivar (KBSH 44) as compared with farmers' local cultivar. However, the improved cultivar alone was not sufficient to harness achievable yields in the depleted soils. Improved management also improved productivity over farmers' practice by 32%, but it is also not enough to bridge yield gaps with low responsive crops. The best bet comprising improved cultivar, landform and soil test-based balanced nutrition recorded highest yield (182%) improvement, and thus is the way forward to bridge the yield gaps in the watersheds.

3.2.4. *Quantification of yield gaps bridged in watersheds*

An analysis of actual crop yields in selected districts and the achievable potential (Researcher plots yields) showed large yield gaps in groundnut (1330 kg ha^{-1}), pigeonpea (820 to 1520 kg ha^{-1}) and chickpea (880 to 980 kg ha^{-1}) crops in the states of Andhra Pradesh, Rajasthan and Madhya Pradesh (Table 7). The on-farm crop yields improved significantly in the watershed catchments which are on expected lines due to improved soil and water resources due to different interventions and adoption of other best-bet practices. The implementation of watershed programs bridged yield gaps by 12 to 96% in groundnut (160 to 1280 kg ha^{-1}), by 29 to 100% (240 to 1130 kg ha^{-1}) in pigeonpea and 0 to 100% (0 to 1175 kg ha^{-1}) in chickpea.

3.3. *Socio-economic impact of watershed implementation*

Watershed implementation also boosted animal-based livelihoods through increased fodder from byproduct stover/straw yields. Among different categories of farmers in Shekta watershed in Maharashtra, the incomes through sale of milk increased after watershed interventions by 76 to 99% as compared with before watershed interventions (Table 8). The watershed program put to an end all pre-watershed seasonal and permanent migration of skilled and unskilled workers from medium and large category of farmers. Among small and marginal farmers, permanent migration of skilled workers reduced to 14 to 17% of pre-watershed levels; and of unskilled workers to 21 to 43%. Similarly seasonal migration of skilled workers from small and marginal category of farmers

Table 7
Potential and actual crop yields and the impact of watershed interventions in bridging the yield gaps in Andhra Pradesh, Rajasthan and Madhya Pradesh watersheds.

Parameter	Yield (kg ha^{-1})				
	Groundnut	Pigeonpea	Chickpea		
	Kurnool	Kothapally	Kurnool	Bundi	Guna
Max. rainfed potential	4950	3460	2130	2900	2780
Mean rainfed potential	2200	1870	1220	1580	1990
District yield	870	350	400	700	1010
Yield gap	1330	1520	820	880	980
Yields in watersheds	1030-2150	815	640-1530	1630	860-2185
% yield gap abridged	12-96	31	29-100	42	0-66

Table 8
Impact of watershed implementation on livestock productivity, and migration in low-rainfall Shekta watershed, Maharashtra.

	Before watershed				After watershed			
	Marginal (< 1 ha)	Small (< 2 ha)	Medium (2-4 ha)	Large (> 4 ha)	Marginal (< 1 ha)	Small (< 2 ha)	Medium (2-4 ha)	Large (> 4 ha)
Income from Milk (Rs $month^{-1}$ $family^{-1}$)	1563	626	626	1044	2795	1246	1246	1838
Seasonal migration								
Skilled (No.)	15	5	0	0	5	0	0	0
Unskilled (No.)	165	105	10	52	105	57	0	0
Permanent migration								
Skilled (No.)	18	7	2	0	3	1	0	0
Unskilled (No.)	24	7	1	0	5	3	0	0

reduced to 0 to 33% of pre-watershed levels and of unskilled workers to 54 to 64% of pre-watershed levels of migration.

4. Conclusions

In context of ensuring food security for burgeoning population, and irrigated regions in India having reached productivity plateau, rainfed regions with large yield gaps between farmers' yields and potential yields have come in the centre stage. In such regions, management at watershed scale is one of the most trusted approaches to manage rainwater and other natural resources. In addition to water, deficiencies of multiple nutrients like sulphur, boron and zinc along with nitrogen and phosphorus are holding back the realization of achievable yields. Farmer participatory trials in watersheds showed huge benefits in crop productivity by 70 to 119% through adopting soil test-based fertilizer management. Other on-farm trials showed landform management in Vertisols a suitable strategy in watersheds to improve crop productivity by 13 to 27%. However, integrated strategy of balanced nutrition and landform management plus improved cultivar recorded highest productivity improvement (182%). As such, science-led interventions in watersheds abridged yield gaps by 12 to 100%. Improvements in straw yield also boosted animal-based activities leading to improved milk production and incomes. Improved productivity and incomes also brought social stability as evident from alleviation of migration in the watershed regions. So, desired policy orientation to support poor farmers to implement science-led watershed interventions to upgrade rainfed agriculture is need of the hour.

Acknowledgement

We greatly acknowledge the support from Andhra Pradesh Rural Livelihoods Program (APRLP) Hyderabad, India; Department for International Development (DFID), New Delhi, India; Commissioner, Watershed Development Department, Sujala Watershed Project, Government of Karnataka; Sir Dorabji Tata Trust, Mumbai; Indian Council of Agricultural Research, New Delhi; Ministry of Rural Development and Ministry of Agriculture, Government of India; Watershed Organization Trust (WOTR), Ahmednagar, Maharashtra; Asian Development Bank for undertaking the watershed interventions in target regions. Efforts of watershed team(s) are duly acknowledged.

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