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Article *in* Paddy and Water Environment · January 2014

DOI: 10.1007/s10333-013-0376-0

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Paddy and Water Environment

ISSN 1611-2490

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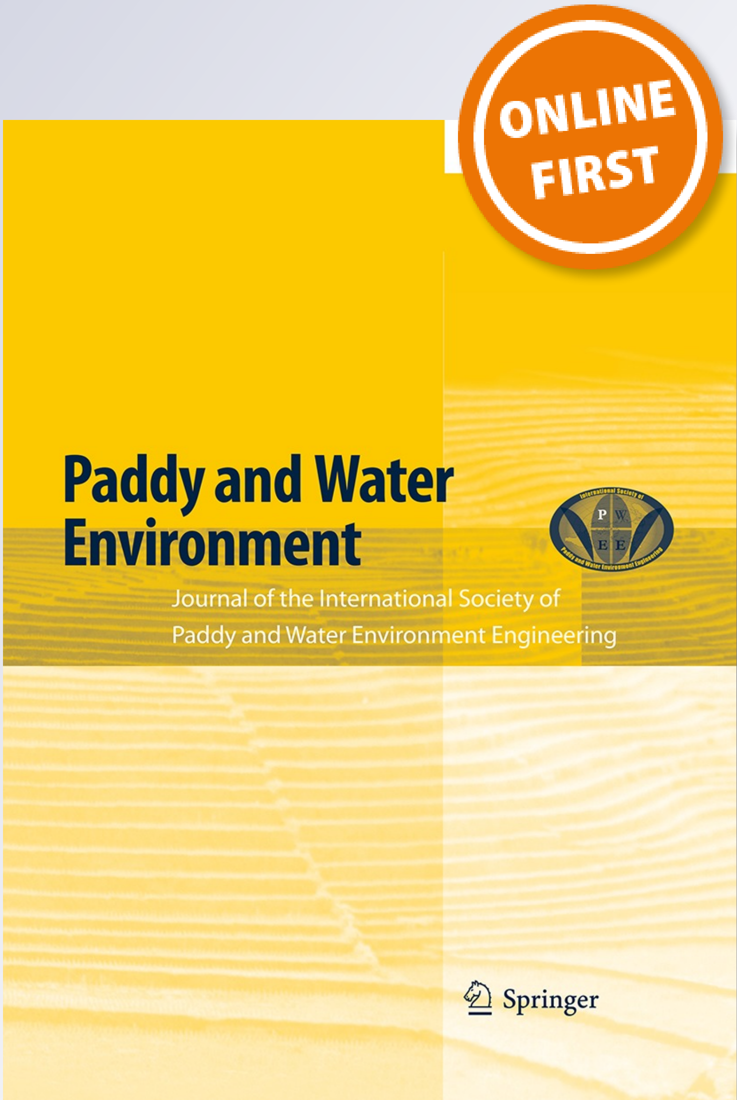

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ARTICLE

In-situ water conservation in upland paddy field to improve productivity in north-west Himalayan region of India

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Received: 23 October 2012 / Revised: 30 April 2013 / Accepted: 8 May 2013

Abstract The hill and mountain agro-ecosystem of NW Himalaya is primarily characterized by limited land under irrigation. Due to farming on terraces, large scale water resource development to store water for supplemental irrigation is not feasible in this region. Construction of trenches may be a good option to hold the runoff and enrich the soil moisture profile. The present study was undertaken to determine the optimal size of the trench through field experimentation, and also to determine the scope of on-farm water management and improvement in soil moisture regime. Four sizes (namely TR1, TR2, TR3 and TR4) of trenches were constructed using 25, 20, 17 and 12 % of the terrace area, respectively. It was observed that all the trenches provided higher average soil moisture and gave 32.9, 50.3 63.6 and 58.4 % higher yield than the control, respectively. However, the yield was statistically at par for TR2, TR3 and TR4. After economical evaluation it is concluded that the trenches may be used as to increase the soil moisture in terraced land, and consequently productivity of upland rice economically, but the area of such trenches must be limited to 12–17 %.

Keywords Trench · In situ water storage · Hill and mountain agro-ecosystem · Upland rice

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Introduction

The Himalayan region of India accounts 14 % land area that supports only 6 % of national population. Despite low population density, the hill farmers face difficulties in raising crops and produces only 5–8 months of food for sustenance from their cultivated terrace (Prakash and Kumar 2006). The major ecological and economical factors which make the agriculture low productive and non remunerative includes rainfed cultivation (82.6 % of the total area), small and fractured land holdings distributed over rugged terrain and limited scope to adopt intensive agriculture (Negi and Dhar 2006). Rice is one of the major staple food crop of the Northwest Himalayan region and cultivated in 0.60 million ha area. The rice productivity in the region is 15 % less than the national average productivity of 1.87 t/ha.

The region receives sufficient rainfall (1,029 mm/year) out of which 629 mm received during monsoon season (June–September). The temporal distribution of the rain is highly skewed, and about 50 % of the rainfall received from 4 to 5 intense storm. This subjected to high runoff and quick discharge due to the terrain conditions, and provide very less opportunity time to enrich the soil moisture profile from the rain.

The reproductive phase of short duration rice (100–110 days duration) popular in this region, usually has 30 days, typically between mid-August and mid-September. Analysis of long term rainfall data of Research Farm, Hawalbagh, Almora, Uttarakhand state, India representing mid-hill conditions (amsl 1,250 m) by Bhatnagar and

Published online: 18 May 2013

Kundu (1992) revealed that the mean date of onset of effective monsoon[1] in the region is 20th June with variation of 14 days, and monsoon withdraws around 19th September with variation of 11 days. In this region, half of the duration of the reproductive phase experience soil moisture deficit of 20 % below saturation moisture content. The yield of rice is adversely affected when soil moisture content (SMC) depletes by equal to or more than 20 % from the saturation moisture content during the reproductive stage (Dorrenbose and Kassam 1979; Allen et al. 1998). Thus, the provision of supplemental irrigation is necessary for rice to maintain the soil moisture regime at optimal level for higher production. Several studies on supplemental irrigation using on farm water storage system has been carried out in the past (Rathore et al. 1996; Panigrahi et al. 2005). Construction of on farm reservoir of capacity less than 100 m^3 is a good economical alternative for storage of excess rainwater and its reuse, as supplemental irrigation to rice during dry spell of monsoon season and pre-sowing irrigation to the crop of rabi season during November–April (Panigrahi et al. 2005; Guerra et al. 1990; Paul and Tiwari 1994; Syamsiah et al. 1994; Jensen et al. 1993).

Several researchers in the past attempted the optimal design of runoff recycling based systems for crop production (Palmer et al. 1981; Srivastava 1996 and Sanchez-Cohen et al. 1997). Mishra et al. (1998) demonstrated the conservation of rainwater using different weir heights in diked rice field of eastern India. Chang et al. (2007) suggested deep-water management practice in wet land rice field to increase the water storage capacity, and thus productivity. Ambast et al. (1998) recommended that 20 % of the watershed area can be diverted to the water harvesting system based on the results from the soil water balance model for rice field. Islam et al. (1998) based on his studies in low rainfall areas of Bangladesh, recommended 8 % of the farm area if put under water harvesting system, is economically feasible and reported 20 % increase in rice yield. Panigrahi et al. (2005) recommended 12 % area under water harvesting system for the eastern region of India.

Pandey et al. (2008) studied the rice yield as affected by tillage and irrigation in north-west Himalayan region of India. Kumar et al. (2009) studied the scope for water resource development in small pond lined with low density poly ethylene film and its integration with gravity based micro-irrigation system for limited scale vegetable production. However, in terraced land of hilly region, where provision of on-farm-reservoir water storage system for surface irrigation is usually not feasible because of several reasons that include, the area of most of the individual terraces is limited to 200 m^2, width usually less than 10 m and average soil depth is limited to 1.0 m. The land modification can be done to enhance the sub-surface flow of water in the soil that can improve the soil moisture regime. Construction of trenches can help to hold the runoff and enrich the soil moisture profile by means of horizontal seepage. Response of soil moisture to the crop yield under the rainfed farming system is highly site specific, depending on the climate, soil and availability of water. It is essential to determine the optimal size of trenches, since excessively large trenches are wastage of precious land resources with high cost of construction and very small trenches can not meet the crop water requirement. The purpose of the present study is to determine the optimal size of trenches, its functional evaluation along with economic analysis of investment. Field experiment of short duration direct seeded rice was conducted to determine technically viable and economically feasible land modification.

[1] A spell of 7 days satisfying the three criteria of: 1. The first day rain is not less than evaporation, 'e'; 2. Total rain in the spell is at least equal to 5e+10 mm; and 3. At least four out of seven days are rainy days with a minimum of 2.5 mm rain each day.

Materials and method

Climatic characteristics of the region

The agro-climatic condition in the region changes from sub-tropical to temperate and humid-temperate to sub-alpine type climates in mid hills (900–1,600 m amsl). The study area is situated at Hawalbagh block (29°36′ latitude and 79°40′E longitude and elevation of 1,250 m) of Almora district in Uttarakhand state of India representing the mid-hill condition, where cultivation is usually done on bench terraces. Figure 1 presents the location of the experimental site. The region receives enough rainfall during the year. Singh et al. (2001) analyzed the rainfall data of 33 years (1964–1996) prevailing the mid-hill condition and found annual average rainfall of 1,029 mm with 20.8 % as coefficient of variation. However, higher variation in the rainfall distribution over months persists in the region. Forty-six percent of total annual rainfall is received during July and August only. However, 85 % of the rainfall (at 80 % probability) is expected during monsoon months. The reference evapotranspiration (ETo) using Penman–Monteith method was analyzed for 6 years daily data, and observed to vary from 17 mm/week (during winter) to 32 mm/week (during summer). During monsoon months, the ETo is considerably reduced because of higher relative humidity, and increases after the recession of monsoon. The annual estimate of potential evapotranspiration (PET) in the region is 1204 mm with 5.29 % as coefficient of variation.

Fig. 1 Picture shows the experimental site

Site selection

Five terraces at different slopes were selected such that there is minimum variation in the physical and soil properties (Table 1). The trenches (TR1, TR2, TR3 and TR4) were constructed at these sites as per the specification mentioned in Table 2. One terrace was used as control where no trench was constructed. The soil type of the terraces was sandy loam, where infiltration rate varies from 3.63 to 3.83 mm/h. The soil properties including bulk density, field capacity (soil moisture at 0.33 bar suction pressure), permanent wilting point, PWP (soil moisture at 15 bar suction pressure), pH, organic carbon, available N, P and K were quantified using standard methods and presented in Table 1. The bulk density was varied from 1.32 to 1.49. The available moisture content (difference between field capacity and PWP) varied from 14.77 to 18.90 cm/m. The quantified soil pH, OC, and available N, P, K suggested that the soil had good native fertility. The average soil depths were 1.0 and 2.1 m at the riser end and shoulder bund end of the terrace, respectively (Fig. 2a). The trenches were constructed at the riser end of the terrace. The TR1, TR2, TR3 and TR4 were spread over the 25, 20, 17 and 12 % of the respective terrace area, and 0.5 m deep below the terrace level (Fig. 2b).

Construction of trench

The traditional terraces in this region are provided with shoulder bund in order to conserve the rain water to some extent. The prevailing terrace system of the region is used for the present study as well. The shoulder bund of 15 cm height was provided in the terrace chosen for present study. These shoulder bunds are provided to check the sheet erosion from the terraces. The terrace system in this region is slightly outwards with 1–2 % slope, in order to drain excess runoff caused from rainfall to avoid impounding unlike N-E Himalayan region of India, where runoff are meant to conserve for intensive transplanted paddy. The trenches were constructed along the length of the terrace at riser end. The size of the trenches was selected such that it represents a fraction of the terrace area (Fig. 2a). The trenches TR1, TR2, TR3 and TR4 were constructed so that it spread over 1/4th (25 %), 1/5th (20 %), 1/6th (17 %) and 1/8th (12.5 %) of the terrace area. Thus, the width of these trenches (W_T) was determined by specific percent of individual terrace width. Soil moisture access tube was installed such that it represents one-third of the remaining width, such as W_A, W_B and W_C (Fig. 2b). The various dimensions pertaining to different trenches are presented in Table 2. The capacity of the trenches was 23.1, 14.5, 12.9 and 9.9 m^3, respectively for TR1, TR2, TR3 and TR4. The runoff volume was calculated using runoff ratio method (Samra et al. 2002). The runoff coefficient, 'K' was taken as 0.4, because the terrace risers were completely covered with grass (*Cynadon dactylon*).

Field experiment

The rice variety, *Vivek Dhan 154* developed by Vivekananda Institute of Hill Agriculture, (VPKAS), Indian Council of Agricultural Research, Almora, Uttarakhand, India was selected for the field experiments. The variety

Table 1 Characterization of terraces where seepage trenches were constructed

Parameters	TR1	TR2	TR3	TR4	Control
Physical					
Terrace area (m^2)	186.4	145.4	152.5	160.7	87.6
Terrace length (m)	17.1	15.3	19.8	16.4	12.7
Terrace width (m)	10.9	9.5	7.7	9.8	6.9
Width of trench[a] (m)	2.7 (25)	1.90 (20)	1.3 (17)	1.2 (12)	–
Micro-catchment area[b] (m^2)	34.2	33.7	37.6	36.8	–
Vegetation[c]	Grass	Grass	Grass	Grass	Grass
'K' value[d]	0.40	0.40	0.40	0.40	0.40
Capacity of trench (m^3)	23.1	14.5	12.9	9.9	–
Soil property					
Soil type	Sandy loam	Sandy loam	Sandy loam	Sandy loam	Sandy loam
Infiltration rate (mm/h)	3.83	3.63	3.77	3.81	3.67
Bulk density	1.42	1.36	1.49	1.48	1.32
Field capacity (cm/m)	27.95	25.66	28.34	26.55	27.19
PWP (cm/m)	11.16	10.89	11.64	10.80	8.29
pH	6.93	7.07	6.89	7.02	6.97
Organic carbon (OC) (%)	0.75	0.60	0.74	0.63	0.67
Avl. N (kg/ha)	378.6	423.8	388.9	379.1	410.5
Avl. P (kg/ha)	15.49	21.78	19.40	18.69	17.25
Avl. K (kg/ha)	190.0	211.6	203.1	212.7	217.5

[a] Figure in parenthesis represents the % area used in trenches

[b] Micro-catchment area is the slope area of the riser end from where the runoff generates and stored in the trench. Slope varied between 75 and 100 %

[c] The slopes are fully covered with grass (*Cynadon dactylon*)

[d] Values represent the runoff coefficient (runoff to rainfall ratio)

Table 2 Experimental detail of trenches

Trench	Length (m)	Width				
		[a]W_{Ca}	W_T	W_A	W_B	W_C
TR1	17.1	2.0	2.7	4.8	4.8	4.8
TR2	15.3	2.2	1.9	4.5	4.5	4.5
TR3	19.8	1.9	1.3	6.2	6.2	6.2
TR4	16.4	2.3	1.2	5.1	5.1	5.1

[a] Width was measured on sloping surface

was chosen because it is recommended for the rainfed conditions of Uttarakhand hills of India by the state varietals release committee. The length of growing period of this variety is 100–110 days. The agronomic practices such as sowing method, seed rate, fertilizer application, interculture operation and harvesting was done as standardized by VPKAS 2004, a manual on package of practices of the varieties developed by the Institute, for the prevailing mid-hill conditions. The field was subdivided into three, first third being nearest to the trench (Fig. 2b). Weekly soil moisture data were recorded from each plot using neutron probe method. The experiment was carried out in each terrace in small plots of size 3 m × 2 m and with three replications. Thus, each terrace had 9 such plots.

Water balance model of rice

Considering the effective root zone of rice as a single layer, the generalized water balance model under unsaturated condition is given as

$$\mathrm{SMC}_i = \mathrm{SMC}_{i-1} + P_i + \mathrm{SI}_i - \mathrm{AET}_i - \mathrm{SP}_i - \mathrm{SR}_i \quad (1)$$

where SMC_i is soil moisture content in the root zone of rice (mm), P is rainfall (mm), SI is supplemental irrigation, AET is actual ETo, SP is seepage and percolation from the root zone, SR is surface runoff from the cropped field and i is time index. In the present study, SI is zero since the crop is completely rainfed.

The AET is determined from the reference ETo after moderation using crop coefficient, Kc and soil moisture stress factor, Ks. The AET is estimated using the following equation.

$$\mathrm{AET}_i = \mathrm{Kc}_i \cdot \mathrm{Ks}_i \cdot \mathrm{ETo}_i \quad (2)$$

where ETo is reference crop evapotranspiration (mm).

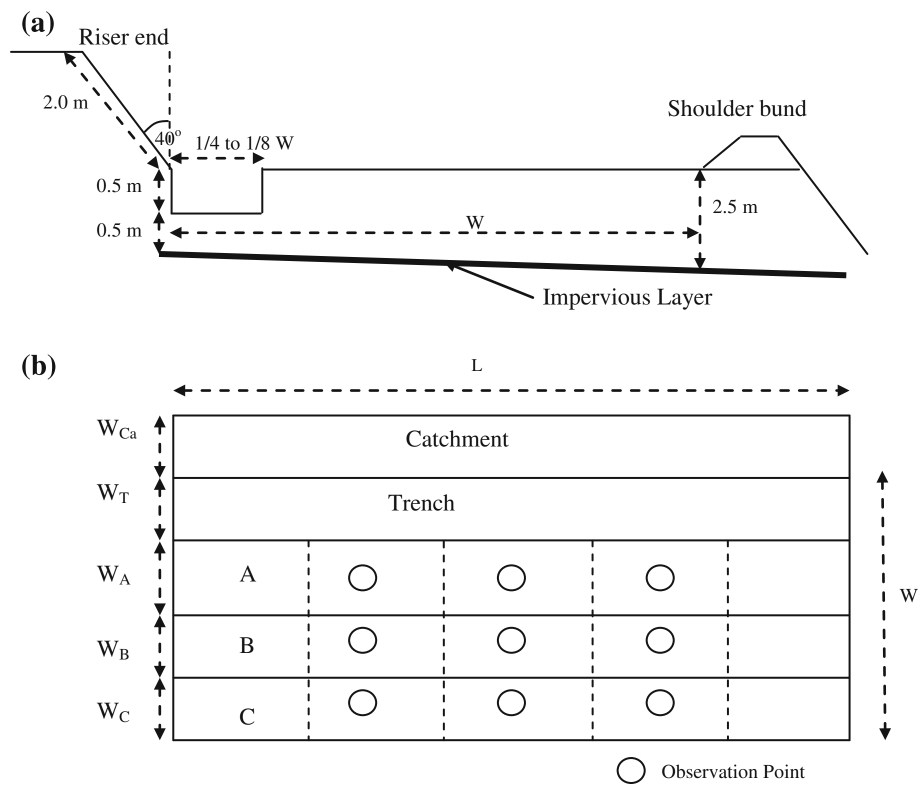

Fig. 2 **a** Cross sectional view. **b** Plan of experimental setup

The ETo is estimated on daily basis using FAO-56 Penman–Monteith method (Allen et al. 1998). All the requisite input data were collected from the meteorological station situated in the study area. The input data included weekly data of maximum and minimum temperature, maximum and minimum relative humidity, sunshine hours, average wind speed (kmph) and rainfall (mm) for the rice growing season from meteorological week of 24–41. The data quality check was performed using the procedure outlined by Allen et al. (1998) in the computation of ETo. The crop coefficient (Kc) of rice is taken as 1.10, 1.10, 1.05 and 0.95, respectively, during crop establishment, crop development, reproductive and maturity stages from standard table (Doorenbos and Pruitt 1977) since no such local study was carried out in the past.

Under the saturated conditions the soil moisture stress factor, Ks, is 1.0 and hence AET equals ET_{crop}. The stress occurs when the soil moisture depletes from the saturation SMC and consequently decreases the actual ETo and yield (Allen et al. 1998). The level of depletion in the soil moisture is represented by the soil moisture adequacy index, S_f. For simplicity, the value of S_f was assumed to vary linearly (at $S_f = 1$; no stress and $S_f = 0$; maximum stress) with the relative available soil moisture (SMC/SAT) in rice field under unsaturated condition (Panigrahi and Panda 2001; Panigrahi et al. 2005) and given as

$$S_f = \frac{SMC_i}{SAT} \quad (3)$$

where SAT is the saturation moisture content (mm). The value of SAT was assumed as the quantum of soil moisture storage in 50 cm effective root zone of rice and was estimated as 190 mm. Thus, the values of S_f used as Ks for calculating actual ETo.

Water balance model for trench

The trenches received water as runoff from the micro-catchment of the terrace riser and direct rain, as well as subsurface flow contributed by preceding terrace. However, contribution from subsurface flow is minimal due to the inherent characteristics of prevailing terrace system in the region. Also, due to difficulty in measuring in situ subsurface flow occurring from preceding terraces, surface runoff and direct rainfall were considered for water balance model for trench.

The seepage and percolation are non-separable, and so both the terms are considered as a single component (Wickham and Singh 1978). The seepage volume that contributes to soil moisture was calculated form the following equation given by Frevert and Ribbens 1988.

$$S = WL(d_1 - d_2) - (EWL) + I + R \quad (4)$$

where S is seepage volume (m^3), w is the width of the trench (m) varied from 1/4th to 1/8th of the terrace width, W, and L are the width and length of the trench (m) identical to length of the terrace, E evaporation (m), I is surface runoff (m^3) and R is direct rainfall (m^3), d_1 and d_2 are the level of water in the trench (m).

Water balance modeling

The theoretical framework of soil water balance model was used to determine soil moisture availability index. Different sizes of trenches (25, 20, 17 and 13 % area of the terrace land), which stores the runoff generated from riser end of the terrace were evaluated for soil moisture availability through experimentation. The initial boundary condition of soil moisture regime in the root zone of rice was considered as PWP, which was 113 mm/m. 50 cm effective root zone of rice was considered for soil moisture storage, which was found to be 190 mm. It was assumed that whenever soil moisture storage reaches to 190 mm, surface runoff generated and discharged from the paddy on terrace. Thus, the runoff due to in excess of saturated moisture content of terrace soil has no effect on paddy growth.

Economic analysis

The present worth analysis was performed to account for the interest and inflation factor on the investment. The different cost involved in the construction of trenches and returns from increased yield of crop were considered as (i) initial investment; (ii) trench maintenance cost; and (iii) annual return from the investment. All the cost and returns were worked out using scheduled rate and minimum support price of the commodity as fixed by the government during 2007–08, which was Rs. 1,000 per quintal. The price of straw was worked out using the prevailing price of local market (Rs 150 per quintal).

Initial investment in the construction of trenches was considered as construction cost only. The dimensions and volume of the excavated earth were different for various trenches, which caused variation in the total construction cost (Rs 40/m^3 of the excavated volume; Abbreviation 'Rs.' is stands for 'rupees' as Indian currency and US\$ 1 ≈ Rs. 52.50).

The maintenance of trenches that include desilting was assumed constant as 5 % of the initial investment in the trenches. Higher side of maintenance cost was considered because of the hilly terrain. The initial investment was different in the various trenches hence, maintenance cost was different. Land lease cost was not considered because agriculture on leased land is not popular in the region.

Economic analysis based on 3 years data was carried out to work out the benefits from investment in trenches by improving soil moisture conditions and scope of sustaining the benefits. Cost of the construction of trenches was worked out under the heads—(i) initial investment (construction cost), and (ii) annual additional operational cost (maintenance cost).

The costs and returns were worked out by using scheduled rates of inputs and minimum support price of paddy as fixed by government of India, which is presently Rs. 1000 per quintal. In the economic analysis, interest rate for agricultural loan of 12 % was used. The economic life of the trenches was assumed as 10 years.

Net present value (NPV) and benefit to cost ratio (BCR) were worked out using following formulae:

$$\mathrm{NPV} = \left[\sum_{t=0}^{n} \frac{(B_t - C_t)}{(1+r)^t}\right] - C_0 \tag{5}$$

$$\mathrm{BCR} = \frac{\sum_{t=0}^{n} \left[(B_t)/(1+r)^t\right]}{\sum_{t=0}^{n} \left[(C_t)/(1+r)^t\right]} \tag{6}$$

where B_t is the income from paddy produce, C_t operational cost including cost of cultivation and trench maintenance cost, C_0 is initial investment, r is the rate of interest and t is the time period.

Internal rate of return (IRR) was obtained by solving the following equation:

$$\sum_{t=0}^{n} \left[\frac{(B_t - C_t)}{(1+\mathrm{IRR})^t}\right] = 0 \tag{7}$$

Payback period was worked out as the length of time required to recover initial investment through cash flows ($B_t - C_t$) generated by investment.

Results and discussion

Water balance

The soil moisture adequacy index was estimated between meteorological weeks of 24–41 that coincides with the onset and recession of monsoon, respectively in the region. Duration for four critical crop stages namely, germination, tillering, panicle initiation and reproduction were taken as 3, 3, 3 and 4 weeks respectively. It was observed that as the size of trench increase from 12.5 to 25 % of terrace area, average adequacy index increases 0.67–0.79 during germination stage. In the control condition (where trench does not exist), the soil moisture adequacy index was found as 0.57 during the germination which causes the poor germination and thus lower productivity. The result also suggested that the presence of trenches substantially reduced the stress, and thus ensured adequate germination. The result suggested that the field has adequate soil moisture during panicle initiation and reproduction stage (Fig. 3). Hence, the trench has the major role in providing adequate soil moisture at different critical stages of rice growth.

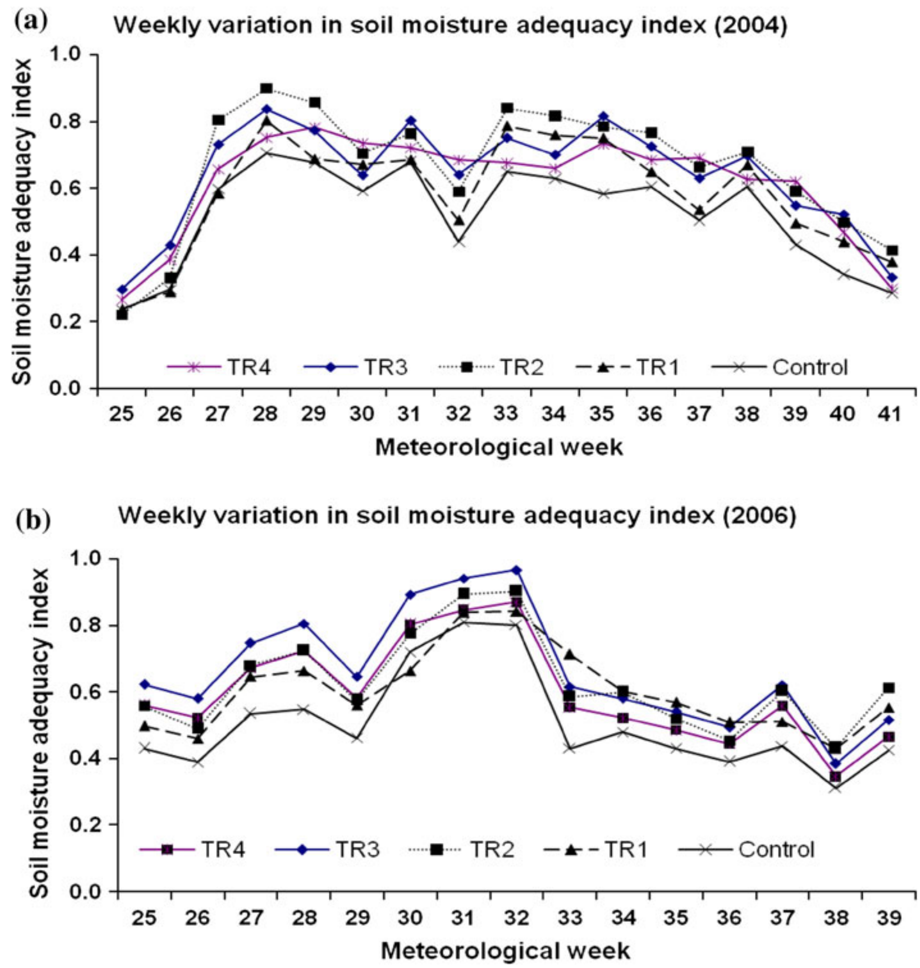

Fig. 3 Weekly variations in soil moisture adequacy index, S_f. **a** 2004, **b** 2006

Field experiments

The seepage volume was estimated using the water balance method for different trenches. The seepage volume that enriched the SMC of plot was found highest in TR3 in both the year 2004 and 2006. In TR3, surface area was almost half of the TR1. This resulted into less area exposed to evaporation as well as more depth of water in the trench, and hence increased the wetted perimeter. During the season, TR3 and TR4 enriched the soil moisture at the maximum extent though its storage capacity was lowest. The average SMC during the crop season was highest in TR3. All the treatment gave higher average soil moisture than the control in both the years. 32.8, 42.0 50.0 and 33.8 % improvement in SMC was observed in TR1, TR2, TR3 and TR4, respectively, as compared to control (12.01 cm/m) during 2006 (Table 3). Similarly in year 2004, the improvement was 12.4, 24.5, 27.2 and 14.7 %, respectively. Though the year 2004 and 2006 received almost similar rainfall during paddy season, 493.6 and 462.5 mm, respectively, but the temporal distribution of rainfall in 2006 was highly skewed as compared to 2004 (Fig. 4). The rainfall distribution in the year 2004 was more uniform, there was less moisture gradient between trench and the plot, and so the relative improvement in the soil moisture was less.

The water enters in the soil in two phase namely (i) horizontal infiltration of stored water into the soil and (ii) redistribution of infiltered water in the soil profile. The water infiltrate horizontally from trench to the soil profile through matric suction force. After infiltration process, redistribution starts and the nearest plot to the trench which is wetted to near saturation, begins to transmit water to the successive portion horizontally. After certain length, however, the soil first wets during redistribution and then transmits. Hence, the wetness gradually decreases as the length increase and thus the SMC decrease gradually towards the far end (shoulder bund end) of the terrace. In all the cases, the moisture distribution in the soil was higher near to the trench and gradually decreased to the far end. The phenomenon however, was observed more frequent in case of TR3 and TR4 during both the year, and is shown in Figs. 5 and 6. The soil moisture was observed at three locations, first third nearest to the trench and last third

Table 3 Performance of different trenches—yield and effective productivity

Seepage trench size	Runoff volume stored during crop season (m^3)	Evaporation loss (EL) (m^3)	% EL of runoff volume	Average soil moisture content (cm/m)	Rice yield (t/ha)	Effective productivity[a] (t/ha)
2004						
TR1	26.85	15.42	57.43	15.95	2.82	2.12
TR2	20.73	9.71	46.80	17.06	3.07	2.46
TR3	19.55	8.12	41.53	18.26	3.24	2.70
TR4	18.38	7.93	43.14	16.07	2.77	2.43
Control	–	–	–	12.01	1.69	1.69
CD ($\alpha = 5$ %)	–	–	–	–	0.34	–
2006						
TR1	30.14	12.09	40.10	16.13	3.31	2.48
TR2	23.54	8.63	36.66	17.87	3.42	2.74
TR3	22.29	7.71	34.59	18.10	3.55	2.96
TR4	21.34	7.63	35.75	16.46	3.04	2.64
Control	–	–	–	14.35	1.77	1.77
CD ($\alpha = 5$ %)	–	–	–	–	0.49	–

Note The crop was damaged in 2005 due to severe white grub (*Anomala elimidiata*) attack and hence was not considered in the analysis

[a] Effective productivity was calculated after moderating the area under trench

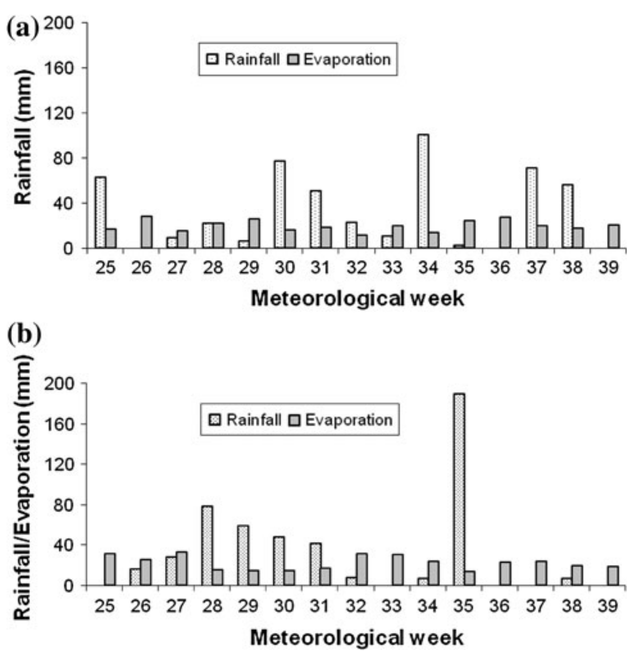

Fig. 4 Weekly distribution of rainfall and evaporation. **a** Year 2004 and **b** year 2006

nearest to the shoulder bund end of the terrace. Figures 5 and 6 suggested that the TR1, TR2 and TR3 provided higher soil moisture availability than the control terrace during both the year 2004 and 2006.

The short duration direct seeded rice has four critical stages namely germination, tillering, panicle initiation and reproduction of duration 3, 3, 3 and 4 weeks, respectively. The soil moisture stress at this critical duration adversely affects the yield. The treatment was found effecting in mitigating the soil moisture stress. In the year 2004, initially during the germination stage, crop experienced soil moisture stress, and later due to sufficient rain, the trenches helped in reducing the moisture stress, and thus minimized the adverse effect of in-season dry spell. The soil moisture adequacy index, S_f, was lowest in TR1 among the treatment though it was higher than the control. The evaporation loss in TR1 was higher due to more spread area (Table 3), thus less water infiltrated into the soil. This resulted in lower level of moisture availability among the treatments. Thus, the actual ETo was lower. The weekly variation in the S_f value in various terraces having different trenches is presented in Fig. 3.

Yield response

Rice crop experienced drought during most of the growing season. Though much of the rainfall received during the monsoon season but its temporal distribution is highly skewed. This results into elongated dry spells during the season. The S_f value of soil moisture adequacy index was higher in the terraces with trenches of various sizes. The value indicates availability of soil moisture, and thus actual ETo and that reflected in the rice yield.

The crop yield during 2004 and 2006 was almost similar. The soil moisture stress during the critical growth stages of

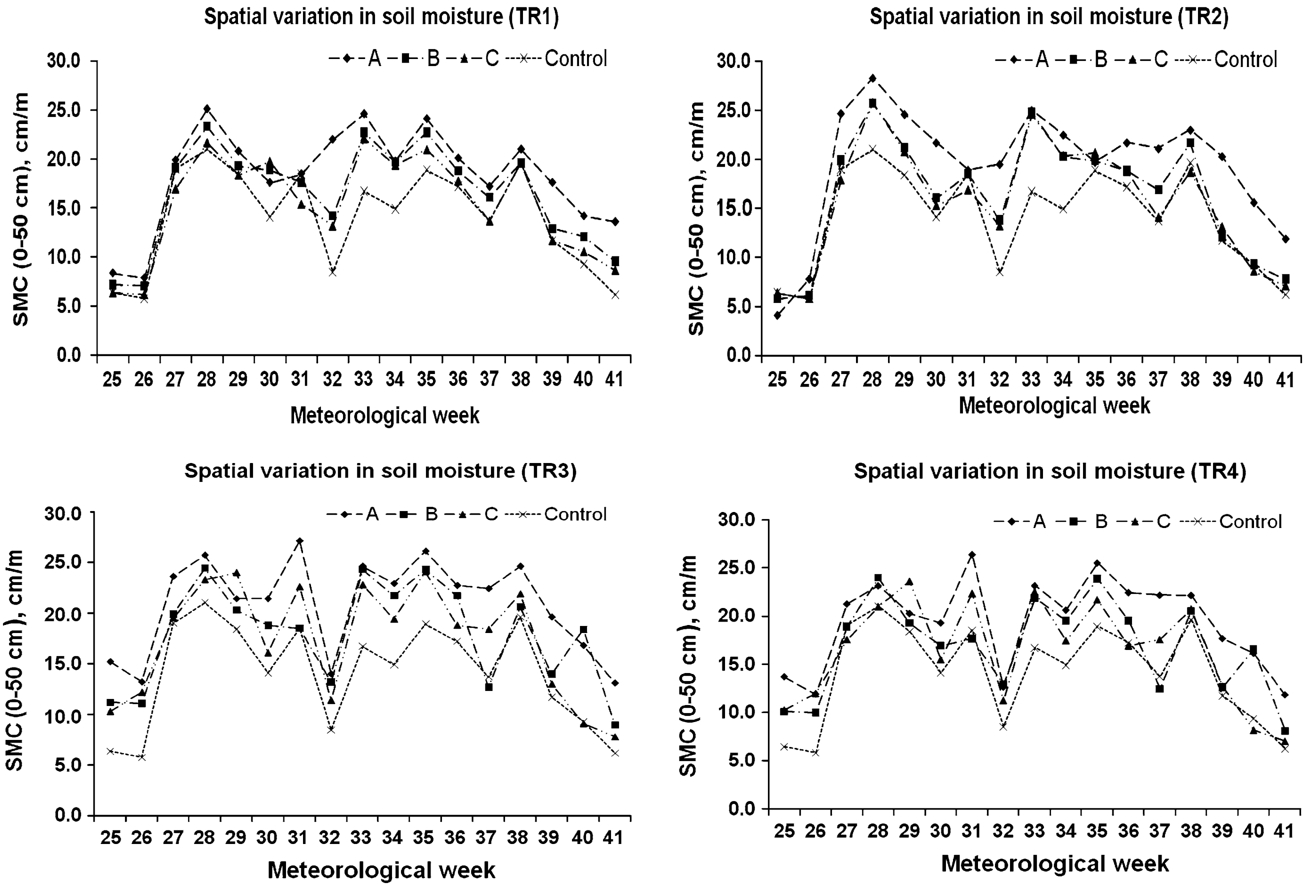

Fig. 5 Temporal and spatial distribution of soil moisture in different trenches (year 2004)

the crop plays a significant role in crop yield. The year 2004 experienced the soil moisture stress during the germination stage of the crop, and year 2006 experience the same during panicle initiation stage. The yield was found at par in both the years despite different time of occurrence of moisture stress. The treatment showed the effect by increasing the yield as compared to control. The average yield increased to 31.2, 50.3, 64.7 and 58.4 % in case of TR1, TR2, TR3 and TR4, respectively. The average yield obtained in all four, TR1, TR2, TR3 and TR4 was significantly higher than the control (Table 3). However, the plot wise yield was found to vary and was higher in the plot nearer to the trench and linearly decreases towards the shoulder bund of the terrace. Overall, among the treatments, the average crop yield was found statistically non-significant.

Economic analysis

The initial investment, annual costs and annual return from different trenches were calculated on per hectare basis. The initial investment was found as Rs. 49573, 39904, 33845 and 24795 per ha, respectively for TR1, TR2, TR3 and TR4. The present worth of initial investment was found as Rs. 83734, 129992, 163484 and 152284, respectively for TR1, TR2, TR3 and TR4.

The quantified values of various economic indicators are given in Table 4. NPV was found minimum for TR1 at Rs. 83,734 and was highest in TR3 (Rs. 163,484). The value of NPV decreases as the size of trench increases from 17 to 25 %. However the NPV value decrease for the trench size 12.5 %. The BCR value was found as 1.49, 1.84, 2.14 and 2.17, respectively for TR1, TR2, TR3 and TR4. NPV of the control was calculated as Rs. 94,691, which provided BCR value of 2.04. The incremental annual return was negative, in case of TR1. TR2, TR3 and TR4 gave positive incremental annual return. Thus, the trench size grater than 20 % of the area may not be justified economically, and hence any trench having size more than 20 % would be wastage of land resources and money. However, TR3 was found as the most economical preposition. Internal rate of return was also found highest for TR4 at 63.1 %, but other economic indicator for TR4 was less as compared to TR3. The payback period of trench size TR3 was calculated as 1.53 years. In the present study, TR3 is found as the best option and it is recommended the optimal size of trench may be 12–17 % in the prevailing mid-hill conditions of

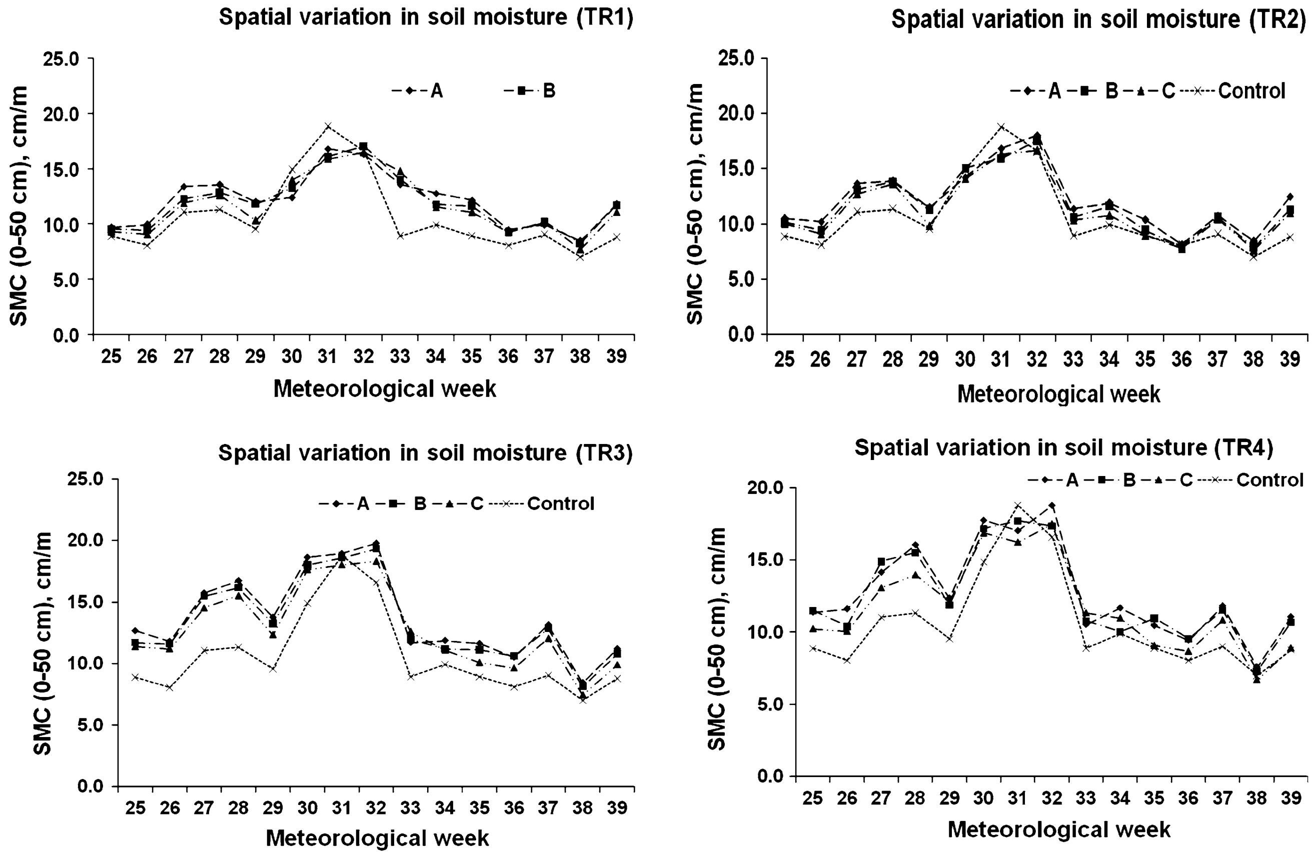

Fig. 6 Temporal and spatial distribution of Soil moisture in different trenches (year 2006)

Table 4 Economic analysis for different trenches

Economic parameters	Trenches				
	TR1	TR2	TR3	TR4	Control
(a) Initial investment (construction cost) (Rs/ha)	49,573	39,904	33,845	24,795	–
(b) Maintenance cost (5 % of a)	2,479	1,995	1,692	1,240	–
(d) Production cost (Rs/ha)	10,000	10,000	10,000	10,000	10,000
(d) Total annual cost (b + c)	12479	11995	11692	11,240	10,000
(e) Annual return[a] (Rs/ha)	27,140	30,680	33,394	29,790	20,414
Economic indicators					
Net present value (Rs)	83,734	122,992	163,484	152,284	94,691
Benefit cost ratio	1.49	1.84	2.14	2.17	2.04
Internal rate of return (%)	27.0	37.9	48.5	63.1	–
Pay back period (years)	2.23	1.77	1.53	1.79	–

[a] Annual return include rice grain and straw

NW Himalaya. In present study, only one crop is considered and so economic indicators may be more positive if multi crop in suitable crop rotation are adopted.

Conclusions

The difficult terrain of the NW Himalaya, water management at the small and fragmented land is the biggest challenge to improvement in the agricultural productivity and profitability. The hill and mountain agro-ecosystem of NW Himalaya is characterized by very low irrigated land. Large scale water resource development is not feasible. The on-farm water management and improvement in soil moisture regime are possible solution. The present study was undertaken to determine the optimal size of the trench through field experimentation. It is concluded that, the trench in 12–17 % area can help in mitigating the adverse effect of soil moisture stress on rice yield. Economically, trenches having size less than the 17 % area of the field was justified with NPV value of Rs. 163,484, BCR value of 2.14 and pay back period less than 2 years. The system also gives IRR value of 48.5 %. The study recommends that the trenches can be used to increase the productivity of rainfed rice in terraced land, but the area under construction of such trenches must be limited to 12–17 % (about 6th to 8th part of the terrace land) for economic viability.

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