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RESEARCH ARTICLE

Effects of Resource Conservation Practices on Productivity, Profitability and Energy Budgeting in Maize–Wheat Cropping System of Indian Sub-Himalayas

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Abstract Resource conservation issues have drawn the attention of scientists to devise innovative tillage and crop establishment techniques for higher productivity in small holder farming systems in the tropics but relatively less attention has been given in rainfed sloping lands of the Indian sub-Himalayan (sub-temperate) regions. To investigate these issues, an experiment was conducted on resource conservation practices under rainfed conditions for 5 years (June 2007–May 2012) at Dehradun, Uttarakhand in the Indian Himalayan region. Four treatments, 1. 100:60:40 kg $N:P_2O_5:K_2O$ + conventional tillage (CT) + chemical weeding + PANICUM vegetation strip (T_1); 2. FYM (5 t ha^{-1}) + minimum tillage (MT) + 1 weed mulch (30 DAS) @ 0.52 t ha^{-1} + PALMAROSA vegetation strip (T_2); 3. FYM (5 t ha^{-1}) + vermi-compost (1.0 t ha^{-1}) + MT + 2 weed mulch (25 and 50 DAS) @ 1.47 t ha^{-1} + PALMAROSA vegetation strip (T_3) and 4. FYM (5 t ha^{-1}) + vermi-compost (1.0 t ha^{-1}) + poultry manure (2.5 t ha^{-1}) + MT + 3 weed mulch (20, 40 and 60 DAS) @ 2.18 t ha^{-1} + PALMAROSA vegetation strip (T_4). The results showed that resource conservation treatments (T_4, T_3 and T_2) had significant ($P \leq 0.05$) multiple benefits as compared to traditional agriculture treatments (T_1). T_1 gives the highest yield of maize whereas T_4 gives highest yield of wheat. For the maize–wheat cropping system, mean wheat equivalent yield (WEY) was ~16 % higher in T_4 than T_1. Mean runoff was ~30 % lesser and mean soil loss was ~34 % lesser in T_4 as compared with T_1. Similarly, mean soil moisture conservation for rainfed wheat was ~31 % higher in T_4 than T_1. Mean carbon retention potential increased by ~53 % which subsequently increased mean soil quality index (SQI) by ~25 %. Mean energy productivity increased by ~70 % and mean energy intensiveness decreased by ~56 % in T_4 than T_1. Treatment T_1 (2,560 MJ^{-1}) emerged to be the most energy intensive system as compared to T_4 (1,113 MJ $Rs.^{-1}$). On an average, T_4 had 7 % higher net returns than T_1 and in terms of net returns per tonne of soil loss, T_4 was the best treatment (Rs. 4,907). Therefore, resource conservation system (PALMAROSA as a vegetation strip along with organic amendments, FYM, vermi-compost, poultry manure and weed mulch under minimum tillage) had significant positive impact on yield, resource conservation and energy saving and may be introduced as a substitute of conventional system in the Indian sub-Himalayas and under similar climatic and edaphic conditions.

Keywords Manure · Mulch · Soil quality index · Tillage · Vegetative barrier

Introduction

Resource conservation issues have drawn the attention of scientists to devise innovative tillage and crop establishment techniques for higher productivity. In the conventional systems involving intensive tillage, there is gradual decline in soil organic matter through accelerated oxidation [1]. Aggressive seed-bed preparation leads to declining soil fertility and biodiversity through higher soil erosion. When crop residues are retained in soil surface or mulched in combination with reduced tillage, it initiated processes that lead to reduced soil erosion to improve soil quality and overall resource enhancement. Therefore, resource

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conservation practices may lead to sustainable improvements in the efficient use of water and nutrients, infiltration and retention by soils and reducing water loss due to less run off and evaporation and improving the quality and availability of ground and surface water [2].

High input intensive agriculture not only degrades soil resources but also creates environmental problems in a sensitive ecosystem of the Himalayan region. India looses about 13.4 million tonnes of food grain worth 162.8 billion (2008–2009) due to soil erosion by water in rainfed areas [3] and of maize, a rainfed crop, loss in productivity is to the tune of 8.0–10.3 kg ha^{-1} for loss of each mm of top soil [4]. In terms of energy consumption, the national share of agriculture has been rising consistently over the last three decades. Yield and economical parameters increase linearly as the level of fertility increases, while the reverse trend is observed with energy use efficiency, energy production and energy intensiveness. Yield of different crops can be increased up to 30 % by using an optimal level of energy input [5]. When vegetation strips integrate with reduced tillage, nutrient management (bio-resources like FYM, vermi-compost and poultry manure) and weed management, it can lead to a sustainable production system in Indian sub-Himalayas where ~82 % of the population lives in rural areas and is chiefly dependent upon crop farming [5]. Minimum tillage is recommended for soils of the Indian Himalayan region due to reduced cost of cultivation, more retention of soil water and physical protection of soil organic carbon (SOC) in the aggregates [6]. Bio-resource in situ (weed live mulch) and ex situ (FYM, vermi-compost, poultry manure) recycling not only fulfils nutrient requirement of a crop cycle but also increases soil water storage. In addition, weed live mulching reduces cost of weeding, increases annual nutrient cycling and organic matter content, and conserves moisture while another component as grass vegetation strips, reduce runoff and soil loss from agricultural fields, thereby improving soil quality [7]. The authors hypothesized that bio-resource recycling can fulfil nutrient requirements of cropping cycles under resource conservation farming, and increase nutrient, water and energy use efficiencies, as chemical fertilizers are not only becoming costlier annually but also highly energy intensive.

Energy is one of the most important indicators of crop performance. The net energy of a cropping system can be quantified for sound planning of sustainable cropping systems [8]. In developing countries, the primary objectives of mechanizing crop production are to reduce human drudgery and to raise farm output by either increasing crop yield or area under cultivation. This can only be done by supplementing traditional energy input i.e. human labour with substantial investments in farm machinery, irrigation equipments, fertilizers, soil and water conservation and weed management, etc. These inputs and methods need to be evaluated in the form of energies to ascertain their effectiveness and to know how to conserve them. Energy budgeting, therefore, is necessary for efficient management of scarce resources for improved agricultural production. It would identify production practices that are economical and effective. Information on energy use in different cropping systems under resource conservation practices and its relationship with productivity is very limited in the study area. Therefore, in order to identify energy efficient resource conservation practice and for satisfactory energy output and net return, the present study has been undertaken with maize–wheat cropping system.

Material and Methods

Description of Field Experiment

A fixed plot field study was conducted from June 2007 to May 2012 at the Research Farm of the ICAR—Indian Institute of Soil & Water Conservation (Erstwhile Central Soil and Water Conservation Research and Training Institute), Selakui, Dehradun, India (30°20′40″N latitude, 77°52′12′E longitude) at 516.5 m above mean sea level (Arabian Sea) on 2 % land slope. Climate of the region is sub-temperate and the climatic data for last 50 years are presented in Fig. 1. The mean annual rainfall for the last 55 year (1956–2011) is 1,625 mm with ~80 % occurring during the rainy season (June–September). The experimental plot was previously used for soil erosion studies with single winter crop since 1985. The soils at the experimental site are fine mixed hyperthermic Typic Udorthents. Experimental initial soil physico-chemical properties and details of establishments of grass vegetation strips (VS) were reported by Ghosh et al. [9]. The experiment was laid out in a randomized complete block design with five replications, each measuring 100 × 20 m (2,000 m^2) with four treatments.

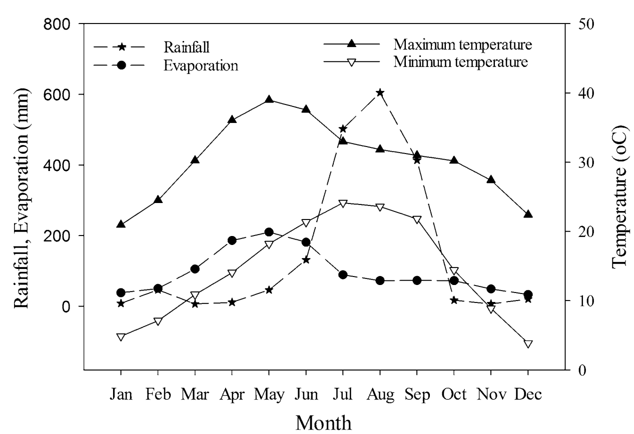

Fig. 1 Mean (1956–2011) rainfall, evaporation, maximum and minimum temperatures of the experimental site

T_1: 100:60:40 kg N:P_2O_5:K_2O + conventional tillage (CT) + chemical weeding + PANICUM VS

T_2: FYM (5 t ha^{-1}) + minimum tillage (MT) + 1 weed mulch (30 DAS) @ 0.52 t ha^{-1} + PALMAROSA VS

T_3: FYM (5 t ha^{-1}) + vermi-compost (1.0 t ha^{-1}) + MT + 2 weed mulch (25 and 50 DAS) @ 1.47 t ha^{-1} + PALMAROSA VS

T_4: FYM (5 t ha^{-1}) + vermi-compost (1.0 t ha^{-1}) + poultry manure (2.5 t ha^{-1}) + MT + 3 weed mulch (20, 40 and 60 DAS) @ 2.18 t ha^{-1} + PALMAROSA VS

Tillage, Manuring and Mulching

In CT plots, tillage was done four times with tractor drawn tillers, whereas in MT plots, two tillage periods retained 30 % maize and wheat crop residues. The machine is nine tines tillers (5R/4F) with duck font shovel and tines are spring loaded curved with the size of height 3, width 7 and length 3 feet, respectively having a working depth of 5.90 inch. The recommended nitrogen, phosphorus and potassium (NPK) dose of 100:60:40 kg ha^{-1} without VS was applied with half of the N and all the P and K applied at the time of sowing. The remaining N was top-dressed at knee height and tassel initiation stages of the maize crop. In treatments T_2, farm yard manure (FYM) @ 5 t ha^{-1}, in T_3 FYM @ 5 t ha^{-1} and vermi-compost (VC) @ 1.0 t ha^{-1}; and in T_4, FYM @ 5 t ha^{-1}, vermi-compost (VC) @ 1.0 t ha^{-1} and poultry manure (PM) @ 2.5 t ha^{-1} were applied at the final land preparation stage before sowing *kharif* (summer) crops. Organic manures were calculated based on N:P:K content of manures so that T_4 treatment received approximately equivalent dose of NPK i.e. 100:60:40 kg ha^{-1} as T_1. While in T_2 and T_3 treatments, manure doses were approximately one-fourth and half, respectively, to T_1. On dry weight basis FYM had N:P:K content of 0.5:0.2:0.4 %, VC had N:P:K content of 1.3:0.8:1.2 % and PM had N:P:K content of 2.3:1.6:1.2 %. Weed mulching was done at 25 DAS in T_2, 20 and 50 DAS in T_3 and 20, 40 and 60 DAS in treatment T_4. The maize–wheat crop rotation was followed in all the years. Maize composite 'Kanchan' was sown using maize planter by second fortnight of June to first fortnight of July during experimentation period as per commencement of monsoon season rains, at 90 × 20 cm and harvested in the second fortnight of September. Wheat cv. 'UP-2572' was sown by second fortnight of November using seed drill at 23 cm row spacing. Wheat was cultivated with residual fertility in soil and one hand weeding in T_2, T_3 and T_4 treated plots. Like maize, conventional tillage (CT) was applied for T_1 treatment whereas, minimum tillage for T_2, T_3 and T_4 treatments. Atrazine for maize as pre-emergence and isoproturon for wheat at 35 days after sowing @ of 1.5 kg active ingredient ha^{-1} were applied to control weeds in treatments T_1. Hand weeding in wheat was done after 30–35 days of sowing. Grain yield of crops was determined at harvest from 2 × 8 m^2 areas with three replicates per plot. Wheat equivalent yield (WEY) was estimated to compare performance of cropping systems by converting the economic yield of each crop into equivalent wheat yield on price basis, using the following formula:

$$\mathrm{WEY}(\text{of crop}\,x) = Y_x(P_x/P_w)$$

where, Y_x is the yield of crop x (maize) in tonnes economic harvest product ha^{-1}, P_x is the price of crop x (maize) and P_w is the price of wheat.

Data Collection of Runoff and Soil Loss

Runoff data were recorded at 08 am using a stage level recorder after each rainfall event from 15 June to 15 September in all the years (2007–2011) by measuring the hydrograph connected with a Coshocton wheel. Runoff coefficient was calculated as the percentage of daily runoff to daily rainfall. The latter was recorded daily at 08 am using a rain gauge. The collected runoff water was thoroughly stirred and 1 L was taken from each tank to determine the accumulated sediment in the runoff tank of each plot. The resultant suspensions were filtered using Whatman 42 filter paper with a pore size of 2.5 µm. The sediment in the filter paper was oven-dried for 24 h at 105 °C and weighed to obtain soil loss data.

Soil, Plant Sampling and Analysis

In May 2012, after the harvest of wheat crop, plot-wise triplicate soil samples were collected from the surface layer (0–15 cm). A representative portion of each soil sample was air dried, powdered and passed through a 0.2 mm sieve for determination of electrical conductivity (EC) and pH in a 1:2.5 soil:water suspension, organic carbon (OC) by Walkley and Black [10], available soil N by Subbaiah and Asija [11] available P by Olsen et al. [12], and available K by Hanway and Heidel [13] method. Zn, Fe, Cu and Mn were determined using the DTPA (diethylene triamine penta acetic acid) extraction method developed by Lindsay and Norvell [14] using atomic absorption spectrophotometer (Analytical Jena Model). Microbial biomass carbon (MBC) determinations were made using chloroform fumigation technique as described by Jenkinson and Ladd [15]. Dehydrogenase activity was estimated using TTC (Triphenyl Tetrazolium Chloride) method of Casida et al. [16]. For plant sample analysis, 1 g samples of dried ground grain, and straw of maize and wheat were digested in HNO_3 and $HClO_4$ mixture for measurement of mean N, P and K contents. N, P and K uptake was estimated using mean N, P and K contents and dry matter yields of maize and wheat, respectively. Nutrient use efficiency was calculated as nutrient uptake divided by nutrient applied. Carbon retention potential was calculated from initial soil organic carbon and organic carbon after 5 years of cultivation using bulk density and soil depth. Soil quality index (SQI) was determined by following formula [17]:

$$\mathrm{SQI} = \sum_{i=1}^{n} W_i S_i$$

where, S is the score for the subscripted variable and W_i is the weighing factor derived from the principal component analysis (PCA).

Water Use and Water Use Efficiency

Soil moisture was determined gravimetrically using a core sampler. Bulk density was determined through core sampler. Soil samples for moisture content determination were collected from each plot in all the replications up to soil depth of 75 cm at intervals of 0–15, 15–30, 30–45 and 45–75 cm. Soil samples for moisture content were taken at the time of sowing and harvesting of wheat crop for profile moisture extraction. Soil samples were also taken before each rainfall event to determine soil moisture deficit for estimating the effective rainfall. Water use by a crop was estimated by following formula described by Jin et al. [18]:

$$\text{Water use (mm)} = [\text{Soil moisture (mm) at the time of crop sowing} - \text{Soil moisture (mm) at the time of crop harvest}] + \text{Effective rainfall (mm)}$$

Water use efficiency (WUE) of the crop was computed using the following equation:

$$\text{Water use efficiency } (\text{kg ha}^{-1}\text{mm}^{-1}) = \frac{\text{Seed yield } (\text{kg ha}^{-1})}{\text{Water use (mm)}}$$

Methods of Energy Calculation

Inputs and outputs were converted from physical to energy unit measures through published conversion coefficients (Table 1).

Input energy (MJ ha^{-1}) = Energy equivalents for all inputs summed to provide an estimate for total energy input.

Output energy (MJ ha^{-1}) = Energy equivalents of biomass crop yield as sum of yields of grain and by-product (straw).

Energy output from the product (grain) was calculated by multiplying the amount of production and its corresponding energy equivalent. Energy output from the by-product was estimated by multiplying the amount of by-product and its corresponding equivalent. Calculation of various energy parameters is given in Table 2. The total manual labour was recorded in each operation with working hours, which was converted in man-hour. All other factors affecting manual energy were neglected.

Economics

For working out the economics of different treatments, all inputs and outputs were converted into their respective monetary value to express them in a common unit. For this, average price of each input/output over the period of study (2007–08 to 2011–12) was calculated to account for yearly price fluctuations. Government prices were utilized, whatever available. Otherwise, local farm-gate prices were used. By this, year wise total cost and total returns per hectare from each crop were calculated for each treatment. Net returns from a crop in each treatment were calculated by deducting total cost from total returns of the year. In addition to the total cost (cost of cultivation), cost of production i.e. cost of producing one tonne of maize or wheat grain was also calculated for each treatment. Soil loss incurred as an environmental cost cannot be included in cost of cultivation as such due to complexity in expressing it in monetary terms. Hence, as a proxy, soil loss incidental to net returns earned i.e. net returns per tonne of soil loss were estimated on an average basis for each treatment by dividing the net return amount by the soil loss quantity. Further, trade off between net returns and soil loss consequent to converting from T_4 treatment to another treatment was estimated from their average values. The T_4 treatment was taken as a benchmark, since soil loss from this treatment was lowest among all the treatments. The estimation was done by dividing the difference in net returns by the difference in soil loss of T_4 and the other treatment, as per following formula:

$$\text{Trade off} = (NR_{Ti} - NR_{T4})/(SL_{Ti} - SL_{T4})$$

where, NR_{Ti} is net return of treatment Ti (i = 1, 2 or 3), NR_{T4} is net return of treatment T_4, SL_{Ti} is soil loss of treatment Ti (i = 1, 2 or 3), and SL_{T4} is soil loss of treatment T_4.

Statistical Analysis

Data were analyzed using the SAS 9.3 software and the standard error of treatment means was used for separation of means. Comparison of means was carried out by Tukey tests at $P < 0.05$.

Table 1 Energy equivalents of inputs and outputs in agricultural production

Particular	Inputs	Unit	Energy equivalent (MJ $unit^{-1}$)
Seed	Seed	kg	14.70
Human labour	Men	h	1.96
Chemical fertilizer	Urea (N)	kg	60.60
	MOP (K_2O)	kg	6.70
	DAP (P_2O_5)	kg	11.10
Organic inputs	FYM	kg (dry mass)	0.30
	Vermi-compost	kg (dry mass)	0.30
	Poultry manure	kg (dry mass)	0.30
Chemicals	Superior	kg	120.00
Farm machinery	Diesel	L	56.31
Outputs	Fodder	kg	18.00
	Seed (grain)	kg	14.70
	Maize and wheat straw	kg	12.50

Source [5]

Table 2 Calculation of various energy parameters

Particulars	Calculation
Net energy return (MJ ha^{-1})	*Gross output energy produced − Gross input energy required*
Energy use efficiency (EUE)	*Energy output (MJ ha^{-1})/ Energy input (MJ ha^{-1})*
Energy ratio	*Output energy (MJ ha^{-1})/Input energy (MJ ha^{-1})*
Energy profitability (MJ ha^{-1})	*Net energy return (MJ ha^{-1})/Input energy (MJ ha^{-1})*
Energy productivity (kg MJ^{-1})	*Crop economic yield(kg ha^{-1})/Input energy (MJ ha^{-1})*
Energy intensiveness (MJ Rs^{-1})	*Input energy (MJ ha^{-1})/Cost of cultivation(Rs ha^{-1})*

Results and Discussion

Productivity

Year wise grain yields of both crops were significantly ($P \leq 0.05$) affected by different treatments (Table 3). In maize crop, up to 2009, increasing yield trend was observed in treatments T_1, T_3 and T_4, but the decreasing trend in T_2 during the period. In 2010, it decreased in all the treatments. In 2011, however, the decreasing trend was observed in only conventional T_1 whereas increasing trend of maize yield was observed in T_2, T_3, and T_4 treatments [all conservation agriculture (CA) treatments]. Wheat yield showed an increasing trend in the resource conservation systems (T_2, T_3 and T_4 treatments) from the very first year, whereas in conventional system (T_1 treatment), an exact opposite trend to that of maize was observed. Year and treatment interaction effects were found to be non-significant. Mean grain yield of both crops were also significantly ($P \leq 0.05$) affected by different treatments (Fig. 2). Mean highest maize yield was observed in T_1 treatment i.e. conventional system of maize cultivation and was observed to produce ~10 % higher than T_4 treatment i.e. resource conservation method of maize cultivation. Mean maize yield followed the order of $T_1 > T_4 > T_3 > T_2$ treatments. But the reverse trend was observed in case of wheat yield where highest yield was observed in T_4 treatment, which was ~57 % higher as compared to T_1 treatment. Mean wheat yield followed the order of $T_4 > T_3 > T_2 > T_1$. The present results indicated that resource conservation practices had a significant effect on crop yield enhancement. The highest mean yield of maize was observed in T_1 treatment (conventional agriculture), which can be attributed to higher nutrient supplying capacity of soil with the application of soluble NPK fertilizers. The present results show that in resource conservation systems (T_3 and T_4), maize crop yields increased over the years due to the cumulative effects of soil and water conservation in the sloping lands as supply of nutrients from organic sources (FYM, vermi-compost and poultry manure) in resource conservation systems (including T_2) did not show synchrony with nutrient demands

Table 3 Year wise maize and wheat yield (t ha^{-1}) as affected by different treatments

Year wise Tukey grouping of mean

	Treatment*	2007	2008	2009	2010	2011
Maize	T1	1.76^{a}	2.25^{a}	2.88^{a}	2.45^{a}	1.85^{b}
	T2	1.13^{c}	1.06^{c}	1.06^{d}	0.96^{d}	1.44^{c}
	T3	1.36^{b}	1.65^{b}	2.16^{c}	1.68^{c}	1.96^{b}
	T4	1.48^{b}	1.80^{b}	2.56^{b}	1.98^{b}	2.25^{a}
		2007–2008	2008–2009	2009–2010	2010–2011	2011–2012
Wheat	T1	1.38^{a}	1.25^{ab}	0.94^{c}	1.08^{c}	1.19^{c}
	T2	0.78^{c}	1.12^{b}	1.22^{b}	1.67^{b}	1.44^{b}
	T3	0.84^{c}	1.45^{a}	1.66^{a}	1.84^{b}	1.56^{ab}
	T4	1.02^{b}	1.66^{a}	1.88^{a}	2.24^{a}	1.78^{a}

Similar letter among different treatments within a year are not significantly different at P ≤ 0.05 level of significance according to Tukey's mean separation test

* Year × treatments effects were found non-significant

of crops in the active growth stages, as also supported by findings of Ghosh et al. [19] during the initial years up to 2009. Maize yield decreased in 2010 in all the treatments because of unprecedented rainfall of higher total volume (2,680 mm for the crop growth period as against 1,656 mm average rainfall) as well as intensity (80–110 mm h^{-1} of 6 rainfall events). Contrary to the case of maize, all the resource conservation treatments (T_2, T_3 and T_4) produced higher yields of wheat than conventional system (T_1). It was the highest of T_4 treatment in all the years resulting into highest mean yield from the treatment. The maize yield started showing a decreasing trend in T_1 treatment from 2010 and wheat yield in the same treatment showed decreasing trend in the initial years (up to 2009–2010) and then increasing trend. The maize yield decrease in T_1 treatment is ascribed to soil quality deterioration due to the depletion of nutrients with more runoff and soil loss, whereas wheat yield trend is mostly dependent upon winter rainfall pattern and residual fertility [20]. Increase in maize yield in T_2, T_3 and T_4 (all CA treatments) after 2010 was because of interaction effect of minimum tillage soil erosion control through VS [9] and bio-resource recycling through FYM, VC, poultry manure and weed mulch, which contributes significantly to the addition of carbon input that increases nutrient supplying capacity and soil water storage [21].

Mean WEY differed significantly (P ≤ 0.05) between treatments (Fig. 2). Highest and significant (P ≤ 0.05) WEY was observed in T_4 to the tune of ~57 % higher than T_1 (conventional treatment) and the WEY followed the trend of $T_4 > T_1 > T_3 > T_2$. Effects of resource conservation system on crop yield were clearly visualized when the WEY of the maize–wheat cropping system was compared across the treatments. It was observed that WEY was

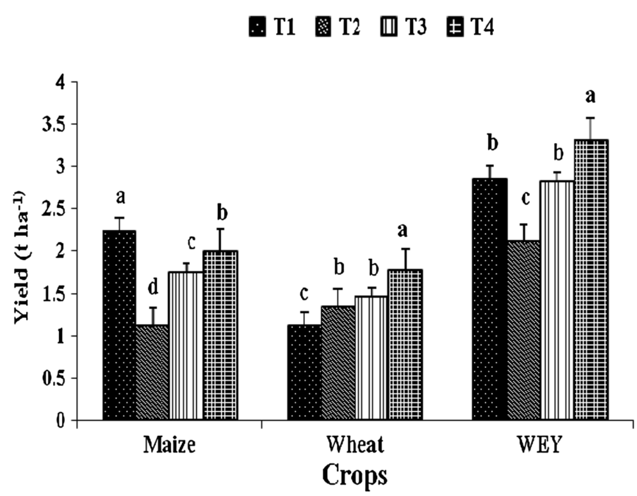

Fig. 2 Effect of different treatments on mean yield (mean data of 5 years) of crops. *Error bars* indicate standard error of the mean and the bars with *same letters* indicate that they are not significant (P ≤ 0.05)

continuously high over the years in the T_4 treatment (CA system) and the importance of resource conservation system implantation is called upon more specifically in sloping land [22]. It is pertinent to mention here that the present results of WEY yield in the CA system (T_2, T_3 and T_4) were the combined effect of MT plus bio-resource recycling and VS imposition as Sur and Santhu [23] have independently reported that MT, bio-resource cycling and VS have a significant effect on crop yields.

The mean biomass yields of grass (PANICUM and PALMAROSA) were affected significantly (P ≤ 0.05) and the dry biomass yield of PANICUM grass was one and a half times greater than PALMAROSA. The mean weed biomass, which was used three times for mulch in T_4

Table 4 Mean (2007–2011) biomass yield (t ha^{-1}) of vegetation strips (VS) and weed mulch (t ha^{-1}) as affected by treatments

Treatment	Vegetation strips		Weed mulch	
	Fresh	Dry	Fresh	Dry
T_1	3.10^{a}	1.00^{a}	–	–
T_2	1.46^{c}	0.48^{c}	1.65^{c}	0.52^{c}
T_3	1.62^{bc}	0.57^{bc}	4.43^{b}	1.47^{b}
T_4	1.82^{b}	0.61^{b}	6.99^{a}	2.18^{a}

Similar letter between treatments are not significantly different at $P \leq 0.05$ level of significance according to Tukey's mean separation test

treatments, was 2.18 t ha^{-1} (Table 4). Biomass yield of VS of PANICUM is higher than that of PALMAROSA VS because of higher root density of the former for better uptake of water and nutrients. The increase in biomass yield of PALMAROSA grass in different CA system treatments was also attributed to the nutrient management level and varying levels of silt deposition behind the VS to form vegetative bunds [24], which provided more nutrient and moisture for the PALMAROSA grass.

Runoff and Soil Loss

Mean runoff (as % of rainfall) and soil loss also significantly varied between the treatments. Highest runoff and soil loss was observed in T_1 treatments and lowest in T_4 treatments. In T_4 treatments, the runoff and soil loss reduced to the tune of ~30 and ~34 %, respectively as compared to T_1 treatments (Table 5). Soil loss followed the runoff trend. Among the treatments, runoff and soil loss follow the order of $T_4 < T_3 < T_2 < T_1$. Full CA system (T_4) exhibited superiority in reducing runoff and soil loss not only to conventional system (T_1) but also to partial CA systems (T_3 and T_2). The resource conservation treatments caused reduction of runoff and soil loss. MT favourably affects pore and pore size distribution that increases infiltration rate, which reduces runoff and thereby soil loss [21]. The VS reduces runoff and soil loss by deposition of sediments carried by runoff water behind the strips to form vegetative bund over the years [20, 24], whereas weed mulch reduces rainfall's erosion potential by preventing breaking down of large water stable aggregates that reduces soil erosion [24]. Reduction of runoff and soil through bio-resources (FYM, VC and PM) recycling is expected as carbon input from organic sources helps in formation of more water stable macro-aggregates [6]. As independent components of CA reduce runoff and soil loss, therefore, interaction effect of the components obviously reduces runoff and soil loss by higher quantity.

Soil Moisture Storage and Water Use Efficiency (WUE)

Mean soil moisture storage at critical growth stages of maize and wheat were significantly ($P \leq 0.05$) affected by the treatments. Moisture storage up to a depth of 75 cm for maize and wheat crops at grain filling stage were observed to be highest in T_4 treatments and lowest in T_1 treatments. In treatment T_4, moisture storage at critical growth stages increased by ~7 % for maize and ~27 % for wheat crops, respectively as compared to T_1 treatment. The moisture

Table 5 Average (2007–2008 to 2011–2012) conservation efficiencies of different treatments

Particulars	T_1	T_2	T_3	T_4
Runoff loss (% of rain)	32.8^{a}	33.5^{a}	30.6^{a}	22.8^{b}
Soil loss (t ha^{-1} $year^{-1}$)	5.24^{ab}	5.72^{a}	4.31^{b}	3.47^{c}
Soil moisture storage at grain filling of maize (mm)	622^{bc}	580^{c}	640^{ab}	664^{a}
Soil moisture storage at grain filling of wheat (mm)	235^{c}	255^{bc}	290^{ab}	321^{a}
Moisture conservation (mm) for wheat before sowing	47.3^{c}	52.0^{bc}	57.0^{ab}	62.0^{a}
Water use efficiency for maize (kg ha-mm^{-1})	5.57^{b}	5.87^{b}	6.84^{a}	7.29^{a}
Water use efficiency for wheat (kg ha-mm^{-1})	4.72^{c}	5.28^{bc}	5.83^{ab}	6.61^{a}
Nutrient (NPK) use efficiency for maize (kg ha^{-1} $year^{-1}$)	64.8^{b}	74.8^{ab}	75.6^{a}	77.0^{a}
Nutrient (NPK) use efficiency for crop (maize + wheat) cycle (kg ha^{-1} $year^{-1}$)	89.3^{b}	101.9^{ab}	110.7^{a}	116.0^{a}
Carbon retention potential (t ha^{-1} $year^{-1}$)	0.57^{c}	0.52^{c}	0.65^{b}	0.87^{a}
Soil quality index (SQI)	0.58^{c}	0.68^{c}	0.72^{b}	0.86^{a}

Similar letter between treatments are not significantly different at $P \leq 0.05$ level of significance according to Tukey's mean separation test storage pattern followed the sequence of $T_4 > T_3 > T_2 > T_1$. Soil moisture conservation for wheat before sowing was higher by ~31 % in T_4 than T_1 treatment. WUE also significantly differed among the treatments, and T_4 exhibited maximum, whereas T_1 minimum (Table 5). The increase in WUE was observed to be ~31 and ~40 % higher in maize and wheat crops, respectively in T_4 treatment as compared to T_1 treatments. Similar trend of WUE was observed in case of soil moisture storage among the treatments. Soil moisture storage at critical growth stages of both the crops increases in resource conservation system because of less evaporation through mulching, more microporosity volume in soil through MT and conservation of rainwater in upper slope of VS. Soil moisture conservation for the succeeding rainfed wheat crops is important as germination gets affected due to less moisture at the time of sowing (second fortnight of November). The present results showed higher soil moisture conservation for wheat crops because of combined effect of MT, weed biomass and bio-resource recycling. Higher carbon input of resource conservation system might have increased the labile carbon pool and carbon management index which increased the soil moisture storage at critical growth stages and during sowing of wheat crops [4]. As higher soil moisture conservation helps in more water uptake, the present results also influenced higher water use in resource conservation treatments in both the crops with highest in T_4 treatment. Higher WUE is expected and observed in resource conservation system as dry matter yield was water production function of water use [24].

Nutrient Use Efficiency (NPKUE) and Carbon Retention Potential (CRP)

Mean NPKUE by the crops was significantly affected by the treatments (Table 5). Highest NPKUE was observed in T_4 treatment and lowest in T_1 treatment. NPKUE increased to the tune of ~19 % for maize and ~30 % for maize + wheat (as wheat was grown on residual fertility) in T_4 treatment as compared to T_1 treatment. The trend of NPKUE followed the sequence of WUE (Table 5).

CRP was also significantly affected by the treatments. Highest CRP was observed to be in T_4 treatment and lowest in T_2 treatment. Effect of FYM + MT + one weed mulch (T_2) was not significantly different from NPK + CT (T_1). CRP increased to the tune of ~53 % in T_4 treatment as compared to T_1 treatment. The trend of CRP followed the sequence of $T_4 > T_3 > T_1 > T_2$ (Table 5). It is worthwhile to mention that the authors did not measure the different pools of carbon and only the oxidizable SOC [10] was utilized to estimate CRP. Higher carbon input of resource conservation system might have increased the labile carbon pool and carbon management index which increased the soil moisture storage at critical growth stages and during sowing of wheat crops [6, 25, 26]. As higher soil moisture conservation helps in more water uptake, the present results also influenced higher water use in resource conservation treatments in both the crops with highest in T_4 treatment. Higher WUE is expected and observed in resource conservation system as dry matter yield is water production function of water use [27]. Resource conservation system also exhibited higher NPKUE as loss of nutrients through runoff water, sediment and leaching through soil profile was less [19]. Dass et al. [24] have supported by the assertion that nutrient synchrony (demand and supply) is higher in resource conservation system, which ultimately increases the nutrient uptake and thereby NPKUE.

Soil Quality Index (SQI)

SQI was also significantly affected by the treatments. Highest SQI was observed to be in T_4 treatments and lowest in T_2 treatments. Similar to CRP, in SQI estimation, effect of FYM + MT + one weed live mulch (T_2) was not significantly different from NPK +CT (T_1) ($P > 0.05$). SQI increased to the tune of ~41 % in T_4 treatment as compared to T_1 treatment. The trend of SQI followed the sequence of CRP (Table 5).

On the other hand, in conventional treatment (T_1), frequent tillage decreases macro-aggregates, which further decrease when chemical sources of nutrient (NPK) are applied resulting into less quantity of carbon input addition. The present results also observed higher carbon retention potential (CRP) in resource conservation system because of higher carbon input received by these treatments. Higher CRP in resource conservation system is also justified by the fact that loss of labile carbon pool is less through runoff water and sediments. Soil quality index (SQI), which is the expression of all soil functional properties, improves in resource conservation system because of the combined effect of MT, VS and bio-resource cycling [9]. On the other hand in the conventional system, application of frequent tillage and chemical NPK decreases SQI from an initial value (0.69) because of depletion of available N, K, Zn, MBC, dehydrogenase activity, increase in bulk density, and decrease in mean weight diameter (MWD). NPK application as the only nutrient management (without addition of FYM, VC, PM and weed mulch) and cultivation of succeeding wheat crops on residual fertility failed to maintain the soil functional properties [20].

Energy Input–Output Relationship

The different energy input–output parameters were also significantly ($P \leq 0.05$) affected by the treatments (Table 6). In T_4 (CA system) energy input as well as

Table 6 Energy input–output relationship of different treatments (mean data of 5 years)

Particulars	T_1	T_2	T_3	T_4
Energy input (MJ ha^{-1})	$11{,}529^{a}$	$5{,}265^{c}$	$6{,}127^{bc}$	$7{,}426^{b}$
Energy output (MJ ha^{-1})	$98{,}070^{a}$	$56{,}815^{c}$	$73{,}375^{b}$	$86{,}906^{ab}$
Net energy return (MJ ha^{-1})	$86{,}541^{a}$	$51{,}549^{d}$	$67{,}248^{c}$	$79{,}480^{b}$
Energy ratio	8.5^{a}	10.8^{a}	12.0^{a}	11.7^{a}
Energy profitability (MJ ha^{-1})	7.5^{b}	9.8^{a}	11.0^{a}	10.7^{a}
Energy productivity or EUE (kg MJ^{-1})	0.0070^{c}	0.0108^{a}	0.0127^{b}	0.0122^{b}
Energy intensiveness (MJ $Rs.^{-1}$)	0.50^{a}	0.24^{b}	0.21^{b}	0.22^{b}

Similar letter between treatments are not significantly different at $P \leq 0.05$ level of significance according to Tukey's mean separation test

energy output is less, so the net energy return is also less as compared to T_1 (conventional system). Highest net energy return was observed to be in T_1 and lowest in T_2. Net energy return followed the sequence of $T_1 > T_4 > T_3 > T_2$. But it is interesting to note that other energy parameters like energy ratio, energy profitability and energy productivity (as indicator of energy use efficiency) were maximum in T_4 and minimum in T_1. Energy ratio, energy profitability and energy productivity increased to the tune of ~38, ~43 and ~70 %, respectively in T_4 than in T_1. Energy intensiveness was observed to be maximum in T_1 and minimum in T_4. Energy intensity was reduced by ~56 % in T_4 (CA system) than in T_1 system (conventional system).

It is evident from the energy input–output results that higher the energy provided to maize crop, higher is the biomass yield *vis-à-vis* higher energy output at the same level of solar energy, and it had a significant effect among the treatments (Table 6). Among the resource conservation systems, maximum net energy return was observed in T_4 (maximum level of CA) because combined effect of MT, VS and bio-resource cycling more than compensated for the higher user of input energy in the form of higher output energy. It is interesting to note that in wheat crop, with the same energy input level, highest energy output was observed in T_4 followed by T_1, T_3 and T_2. This could be ascribed to the combined residual impact of MT, VS and bio-resource cycling [28, 29]. Though total energy output and net energy output were highest in T_1 treatment, but the highest energy ratio was observed in T_3 treatment closely followed by T_4 and then by T_2 (energy ratio varied from 10.8 to 12.0) having varying levels of resource conservation system (Table 6). T_1 had the lowest energy ratio. This emphasizes the implementation of CA system in a warm temperate climate like the Indian Himalayas where energy dependency in agriculture can be reduced through CA. Again, the highest energy profitability was obtained under T_4 treatment, because of high net energy return generated from low input energy. The higher net energy return in T_1 than T_4 did not commensurate with the utilized higher input energy in T_1. Consequently, the T_4 treatment also produced higher energy productivity (0.0122 kg MJ^{-1}) than T_1 though T_3 treatment (0.0127 kg MJ^{-1}) observed slightly higher value. The efficiency of total (economic yield plus by-product) energy utilization of T_4 treatment was superior to other treatments due to the proportionately higher output energy to the input energy. The T_1 treatment (35.57 MJ^{-1}) emerged to be the most energy intensive system compared to T_2 (17.08 MJ $Rs.^{-1}$), T_4 (15.65 MJ $Rs.^{-1}$) and T_3 (14.94 MJ $Rs.^{-1}$) system. The results regarding energy intensiveness were contrary to energy use efficiency of the treatments. Similar trends in the T_1 treatments were observed by other authors also [28, 29].

Economics

Among the four treatments, T_4 had the highest cost of cultivation (34,209 Rs. ha^{-1}), which was 48 % more than that of T_1 (23,043 Rs. ha^{-1}), though T_2 had the lowest (21,549 Rs. ha^{-1}). However, the cost of production of T_4 was 26 % more than of T_1, which also had the lowest value (1,707 Rs. t^{-1}). Net returns of the treatments varied over the years of study due to variation in crop yields. In the initial year, returns from the three treatments having CA were negative, the worst from T_4, which were 191 % lower than that of T_1. However, in subsequent years it declined to 9 % and then became higher by 7 %, eventually increasing to 111 % in the last year. On an average, T_4 had 7 % higher net returns than T_1. In terms of net returns per tonne of soil loss, T_4 was the best (Rs. 4,907) followed by T_3. However, in terms of tradeoff, T_1 was closest to T_4 as it had lowest value of 569 per tonne of soil loss (Table 7).

Cost of cultivation of treatments having CA, viz. T_4 and T_3 was higher than T_1 indicating that 'conversion' from inorganic to resource conservation is costly. However, by virtue of higher average WEY than T_1, the T_4 treatment recorded cost of production which was comparatively less inferior (26 %) than the cost of cultivation (48 %). Though the resource conservation treatments were observed to have

Table 7 Costs of cultivation and production, net returns, net returns per tonne of soil loss and trade-offs under different treatments

Treatment	Cost of cultivation (Rs. ha^{-1})	Cost of production (Rs. t^{-1})	Net returns (Rs. ha^{-1})						Net returns tonne^{-1} soil loss (Rs.)	Trade-off (Rs. tonne^{-1} soil loss)
			2007–2008	2008–2009	2009–2010	2010–2010	2011–2012	Average		
T_1	23,052	1,708	6,332	15,795	23,052	22,767	12,024	16,008	3,059	−569
T_2	21,558	2,063	−285	10,174	11,882	18,997	18,285	11,811	2,063	−2,348
T_3	28,957	2,134	−4,696	14,230	22,198	21,487	18,356	14,301	3,344	−3,202
T_4	34,222 (48)	2,134 (26)	−5,763 (−191)	14,443 (−9)	24,688 (7)	26,396 (16)	25,400 (111)	17,004 (7)	4,909	–

Figures in parentheses are percent difference of T_4 from T_1

negative as well as lower net returns than T_1 in the initial years of cultivation, better and higher returns were recorded in the subsequent years due to higher yields indicating that the resource conservation can provide positive economic benefits if cultivation is continued over a long period after ‘conversion’, eventually leading to higher returns on an average basis [30]. Further, in terms of net returns for every tonne of soil lost, the T_4 treatment was the best (Rs. 4,907), which indicated that this resource conservation treatment was not only environmentally friendly in terms of soil conservation (incurring lowest soil loss), but also simultaneously provided higher economic benefits. Consequently, replacing this treatment with other treatments would result in loss of net returns (trade-off) ranging from Rs. 569 to 3,200 for every additional tonne of soil loss. Therefore, by the adoption of CA treatment, T_4 would provide higher and sustainable economic and environmental benefits than the practiced high inorganic inputs treatment if adopted for a long period in the Indian sub-Himalayas.

Conclusion

Inclusion of resource conservation system (MT + bio-resource cycling + weed mulch + VS) had a significant positive impact on crop equivalent yield; nutrient, water and energy use efficiencies; SQI; and net returns under maize–wheat cropping system in Entisols of Indian sub-Himalayas., Although maize crop yield, from varying level of bio-resource (FYM, VC and PM) and weed mulch in resource conservation system is less than conventional system but cropping system as a whole is better in nutrient, water and energy use efficiency indicating potential of sustainability of the system in long-run and technology option for the resource poor farmers. In the long run, the technology has the potential to provide higher net returns as well as environmental benefits to the farmers because of higher carbon retention potential and lesser soil loss. Aromatic grass (PALMAROSA) based resource conservation technology can be considered to be the ideal system in terms of controlling soil degradation, and long-term perspective of energy and economic profitability in Entisols of the Indian sub-Himalayas.

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