Nepal Journal of Science and Technology Vol. 15, No.2 (2014) 1-10

Effects of Tillage and Crop Establishment Methods, Crop Residues, and Nitrogen Levels on Wheat Productivity, Energy-savings and Greenhouse Gas Emission under Rice -Wheat Cropping System

G. Sah[1*], S.C. Shah[2], S.K. Sah[3], R.B. Thapa[2], A. McDonald[4], H.S. Sidhu[5], R.K. Gupta[5], B.P. Tripathi[6], S.E. Justice[4]

[1]Nepal Agricultural Research Council, Kathmandu, Nepal

[2]Institute of Agriculture and Animal Science, Tribhuvan University, Chitwan, Nepal

[3]University of Agriculture and Forestry, Chitwan, Nepal

[4]CIMMYT, South Asian Regional Office, Nepal

[5]Borlaug Institute for South Asia, India

[6]International Rice Research Institute-Nepal Office

e-mail: sahganesh35@yahoo.com

Abstract

Field experiments were conducted to evaluate conventional tillage (CT), permanent raised bed (PRB), and zero tillage (ZT) with residue retention and removal at three nitrogen levels (0, 100, and 120 kg N ha^{-1}) on wheat productivity, energy input and energy output, energy use efficiency, specific energy, and CO_2 emission from 2010 to 2012 under rice-wheat system at Pheta V.D.C, Bara, Nepal. The experiments were carried out in strip split plot designs with three replications. Zero tillage wheat produced significantly higher grain yield (2616.5 kg ha^{-1}), saved 10.4 % energy input, increased energy output (12.4 %), enhancing energy use efficiency by 25.2 % and reducing specific energy by 23.6 %, as compared to conventional tillage. Diesel consumption on crop establishment and irrigations were the lowest for ZT (48.6 liter ha^{-1}) and the highest for CT (86.3 liter ha^{-1}). PRB consumed the lowest quantity of diesel on two irrigations (34.6 liter ha^{-1}) with higher energy use efficiency (3.4 %) and lower specific energy (8.76 MJ kg^{-1}) over CT. The CO_2 emission from CT was the highest (224.32 kg ha^{-1}) over ZT (126.4 kg ha^{-1}) and PRB (146.11 kg ha^{-1}). Residue retention increased 4 % grain yield over residue removal. Without nitrogen application, energy output was the lowest (34192 MJ ha^{-1}) with the highest specific energy (12.6 MJ kg^{-1}). Thus, zero-till wheat with 40-cm residue retention and 100 kg N ha^{-1} application was suggested for mass scale adoption in the Tarai region of Nepal.

Key words: CO_2 emission, climate change, energy input/output, fossil fuel, specific energy

Introduction

Wheat (*Triticum aestivum*) is a major crop supporting food security in South Asia. Around 42 % of the wheat in this region is grown following rice (*Oryza sativa*) covering 13.5 million hectares of land. In Nepal, wheat is the third important cereal after rice and maize. It occupies 20 % of total cereal area and contributes about 19 % of the total cereal production in the country. The area under wheat is 0.75 million ha with the productivity of 2290 kg ha^{-1} (MoAD, 2012/13) following rice occupying 0.56 million ha (Tripathi *et al.* 2002).

The rice-wheat system supports more than 450 million people and contributes more than 80 % of the total cereal production in Bangladesh, India, Nepal, and Pakistan (Ladha *et al.* 2003). The system produces staple food for more than one billion people or about 15 % of the world's population. Where, resource conserving technologies, grown on 4.0 million ha of land in the Indo-Gangetic Plains (Ladha *et al.* 2003), increase input use efficiency, cuts costs, provides various environmental benefits, and ultimately improves farmers' livelihoods and helps to reduce poverty (Hobbs & Gupta 2003).

Rice and wheat are the fertility exhaustive crops and need more water, labor, time, heavy farm machineries, costs, and non-renewable energy for their successful cultivation (Jha *et al.* 2011). Conventional tillage for wheat establishment requires repeated soil tilling, 6-8 times (Hobbs & Gupta 2003) and planking (5 times) causing delayed planting, soil health, and higher production cost. Late wheat planting causes 30-50 kg day^{-1} ha^{-1} yield reduction which could not be reversed with better crop management and application of inputs. However, wheat sowing can be accomplished efficiently with the use of conservation-based machineries, i.e. zero-till seed drill, rotary seed drill, and bed planter etc. to save time, fossil fuel, cost, and energy (Grace *et al.* 2003, Jha *et al.* 2007). Zero-till wheat uses reduced water requirements by about 10 cm or approximately one million liter ha^{-1} (Hobbs & Gupta 2003). Also, bed planted wheat saves 35 % irrigation water as compared to flat-planted wheat (Sayre & Ramos 1997, Sayre 2000, Malik *et al.* 2002).

Like other crops, wheat requires application of both animate (bullock, human power) and inanimate (tractors, tillers, pump-sets, seed drill etc.) forms of energy at different stages. Zero tillage has a direct mitigation effect as it converts the GHG, like CO_2 into O_2 and carbon in the atmosphere, and enriches soil organic matter. Adopting zero tillage on even one million ha of rice-wheat area, a reduction in diesel use of 60 million liter and CO_2 emission of more than 156,000 Mg yr^{-1} would be obtained, using a conversion factor of 2.6 kg CO_2 produced per liter of diesel burned (Hobbs & Gupta 2003).

Climate change can increase potential soil erosion rates, which lower agricultural productivity by 10 to 20 %, or more in extreme cases, (Jorge *et al.* 2011). By growing nitrogen fertilizer use and increased livestock production, methane and nitrous oxide emissions are projected to further increase from 35 to 60 % by 2030 (Varshneya 2009, Venkateswaralu & Shanker 2009). During the last 150 years, the rate of increase of temperature was 0.045 ^{0}C, for last 100 years 0.074 ^{0}C, for the last 50 years 0.128 ^{0}C, and for the last 25 years 0.177 ^{0}C per decade, indicating that the recent rate of increase of temperature was the highest compared to that of previous years (Manning 2007). Increase in temperature in Nepalese context is 0.06 ^{0}C yr^{-1}, 0.04 ^{0}C in the Tarai and 0.08 ^{0}C yr^{-1}in high mountain. The main source of CO_2 emission to the atmosphere in the rice-wheat system is through tillage. Two onsite tillage sources exist: the biological decomposition of soil organic matter and the production of CO_2 as a byproduct of machinery fuel usage. During tillage soil aggregates are broken, surface area exposure of organic material is increased thus increasing oxygen supply and promoting the decomposition of organic matter. Assuming that 150 liter ha^{-1} yr^{-1} of fuel are used for tractor usage and irrigation pumping in conventional systems, this would amount to nearly 400 kg of CO_2 being emitted (Grace *et al.* 2003). Therefore, diesel is a greatly underestimated source of GHGs. Thus, the experiments were conducted with the objectives to evaluate eco-friendly and energy-effective wheat establishment options for long-term production sustainability.

Methodology

The experiments were carried out on farmer's field at Pheta VDC, Bara district, Nepal for consecutive two years (2010/11 and 2011/12). The soil of the experimental field was silty loam and slightly acidic in reaction (pH 5.7), high in organic matter (4.98 %), high in total N (0.241%), very high in P_2O_5 (379 kg ha^{-1}), and medium in exchangeable K_2O (118 kg ha^{-1}) contents. The experiments consisted of three factors: (a) tillage and crop establishment methods, (b) residue management, and (c) nitrogen levels for both the crops under rice-wheat system and were conducted in strip-split plot design with three replications. The size of each plot was 37.8 m^2 (7 m x 5.4 m), as the seeding widths of the zero-till (ZT) drill and the furrow irrigated raised bed (FIRB) drill were 1.8 m and 1.35 m, respectively. The tillage and crop establishment methods comprised of (i) conventional tillage (CT): plots were ploughed twice (double passes each time) using tractor-drawn cultivator followed by wooden planking. Seed and basal fertilizers were manually broadcast on the tilled soil surface followed by shallow seed and soil manipulation with the cultivator and light planking; (ii) permanent raised bed (PRB): seeds were drilled, 5 cm deep, over rice harvested bed tops, in two rows, after superficial reshaping using (FIRB) drill; and (iii) zero tillage (ZT): seeds were drilled, 5cm deep, on untilled rice harvested plots using inclined plate zero-till seed drill. The residue management consisted of (i) residue retention (R_R): 40 cm stubbles of preceding crop were left at harvest and (ii) residue removal (R_O): preceding crop was harvested from ground level leaving about 5 cm stubbles. The nitrogen levels were: (i) zero nitrogen (N_O): 0 kg N ha^{-1}; (ii) Farmers' nitrogen (N_{100}): 100 kg N ha^{-1}; and (iii) Abundant nitrogen (N_{120}): 120 kg N ha^{-1}. Of the nitrogen levels, half N was applied as basal at sowing time and the remaining N in two equal split dozes applied on crown root initiation stage (23 DAS) and maximum tillering stage (54 DAS). Phosphorus (P_2O_5) and potassium (K_2O) were applied @ 60 kg ha^{-1} and 40 kg ha^{-1}, respectively, as basal at sowing. The sources of fertilizers were urea, triple super phosphate, and muriate of potash. Wheat variety 'Gautam' with seed @ 120 kg ha^{-1}for CT and ZT and 80 kg ha^{-1} for PRB, was sown on Dec. 10, 2010 and Dec. 11, 2011. Pre-sowing irrigation was applied to ensure optimum soil moisture a week before sowing to all the plots. Two irrigations were applied on 22 and 53 days after sowing (DAS) during the crop cycles. Irrigation water was lifted from a shallow tube-well and was conveyed to the individual plots through a 10-cm diameter poly-vinyl chloride (PVC) pipe, using a diesel pump-set. The depth of irrigation water applied was 5 cm for CT and ZT and 5 cm below from bed-top in the furrows for PRB. For weed control, a mixture of Isoproturon + 2, 4-D @ 900 g ha^{-1} each in 700 liters water was sprayed using a knap-sack sprayer, at 35 DAS. The rainfalls at the site during 1st and 2nd year were 33.6 mm and 43.5 mm in 3 and 6 spells, respectively. Human labor used for all operations and management practice, amounts of all inputs and outputs, pump set used for irrigation, and machinery usage were recorded for each plot. Grain and straw yields were determined by manually harvesting five random samples (2 m^2 each for CT and ZT and 2.7 m^2 for PRB) from each plot, leaving border rows, at physiological maturity. The samples were weighed, threshed, and cleaned. The cleaned grains were weighed and their moisture contents were observed with the help of a digital moisture meter (Wile 35). The grain yields (kg ha^{-1}) were computed at 12 % moisture content, using equation (I) and (II) and the data were analyzed using Genstat 5 (Sec. edition):

Observed grain yield (kg ha^{-1}) = Observed grain yield (kg m^{-2}) X 10,000 ———— (I)

Grain yield at 12 % moisture content (kg ha^{-1}) = Observed grain yield (kg ha^{-1}) X (100 - observed moisture content, %)/(100 -12, %) ———— (II)

Straw yields were calculated on sun- dry weight basis using equation (III):

Observed straw yield (kg ha^{-1}) = Observed straw yield (kg m^{-2}) X 10,000 ———— (III)

The variable input energy sources included were human labor, machinery (tractor, cultivator, seed drills, pump-set, and thresher), fossil fuel and the inputs of production (seed, fertilizers, and chemicals). The energy input, energy output, and energy use efficiency were calculated using energy coefficients (Table 5) given by Mittal *et al.* 1985 and procedures given by Devasenapathy *et al.* 2009. Following assumptions were made for input energy calculations:

CT land preparation time- 8.25 (hr ha^{-1})
Tractor plowing (double pass) with cultivator- 1st plowing- 3; 2nd plowing- 2.5; planking-1; seed + soil manipulation-1; light planking- 0.75 (hr ha^{-1})

PRB planting time- 6.17 (hr ha^{-1})
Reshaping with tractor + bed former- 2.68; seed drilling time-3.49 (hr ha^{-1})

ZT planting time- 2.61 (hr ha^{-1})

The energy input was calculated using equation (IV) used by Devasenapathy *et al.* (2009):

Energy input (MJ ha^{-1}) = Tractor, cultivator, seed drill, and/or pump set weight (kg) X energy coefficient (MJ unit^{-1}) X operation (hr)/life span (hr)———(IV)

Where, tractor, cultivator, seed drill, and pump set weight were 2500, 400, 400, and 50 kg with their life span of 12000, 6000, 2400, and 10500 hr, respectively. Diesel consumption for tractor and pump set were 3.5 and 0.8 (liter hr^{-1}). Pump set operation duration (in two irrigations) for CT, PRB, and ZT were 71.75, 43.25, and 49.35 hr ha^{-1}, respectively. Irrigation water applications for CT, PRB, and ZT were 1145, 678, and 777 m^3 ha^{-1}, respectively. Harvesting charge@ 180 man-hr ha^{-1}.Threshing and cleaning charge @ 10 % of threshed grains.

Specific energy was calculated using equation (V) used by Laik *et al.* (2014):

Specific energy (MJ kg^{-1}) = Energy input (MJ ha^{-1})/ Economic yield (kg ha^{-1}) ———————— (V)

Results and Discussion

Grain yield

The grain yields, over the years, were significantly influenced by the tillage and crop establishment (TCE) methods. The highest grain yield (2616.5 kg ha^{-1}) was recorded from zero tillage (ZT) followed by CT (2231.5 kg ha^{-1}) and the lowest by PRB (2163 kg ha^{-1}). Zero tillage produced significantly higher grain yield than CT and PRB by 17.3 % and 21.0 %, respectively, while, CT and PRB were at par (Table 1). The higher grain yield from ZT is attributed to minimum soil disturbance, prolonged soil moisture conservation, uniform seed distribution, proper seeding depth, and higher nutrient efficiency. The results were in accordance with the findings of Hobbs *et al.* (1997), Gupta *et al.* (2000), and Gupta *et al.* (2003). Melha *et al.* (2000) also reported 6 % higher yield in timely sown zero tillage wheat than the timely sown conventionally tilled wheat crop. Residue retention produced slightly higher grain yield (93 kg ha^{-1}) than residue removal. Grain yields varied with increased nitrogen doze. Grain yield at N_0 was 60 % lower than farmers' N (100 kg ha^{-1}). The higher grain yields from increased N doze attributed to more plant chlorophyll, plant vigor, more tillers, more leaf area index, more grains per spike and specific grain weight. The results were similar to the findings of other researchers (Ram 2000, Balasubramanian *et al.* 2000).

Straw yield

The tillage and crop establishment methods did not show significant effect on straw yields despite difference in grain yield. However, zero tillage produced higher straw yields by 7.7 % and 12.8 % than CT and PRB, respectively. Residue removal (R_O) showed significantly higher straw yield by 29.2 % compared to residue retention (R_R), over the years. In R_R, 40 cm residues were left in situ, while, in R_0 all the residues were collected increasing straw yields. The increased N applications significantly increased straw yields over the years (Table 1).

Table 1. Wheat yields, energy input/output, energy use efficiency, and specific energy as influenced by tillage methods, residue management, and nitrogen levels at Pheta, Bara, Nepal, 2010/11 and 2011/12

Treatments	Yields (kg ha^{-1})		Energy			
	Grain	Straw	Input (MJ ha^{-1})	Output (MJ ha^{-1})	Use efficiency (%)	Specific (MJ kg^{-1})
Tillage methods:						
Conventional tillage (CT)	2231.5	2728.5	22164.8	66908	3.02	9.93
Permanent raised bed (PRB)	2163.0	2606.0	18948.5	64361	3.40	8.76
Zero-tillage (ZT)	2616.5	2939.0	19861.9	75191	3.78	7.59
LSD $_{(0.05)}$	125.3	305.5	-	4688.2	-	-
F-test $_{(0.05)}$	**	NS	-	**	-	-
Residue management:						
Residue retention (R_R)	2384.5	2406.0	24785.7	65096	2.63	10.39
Residue removal (R_O)	2291.5	3109.0	15864.5	72544	4.57	6.92
LSD $_{(0.05)}$	102.3	249.5	-	3827.9	-	-
F-test $_{(0.05)}$	NS	**	-	**	-	-
Nitrogen level:						
Control N doze (N_0)	1122.5	1415.5	14095.9	34192	2.42	12.56
Farmer's N doze (N_{100})	2854.0	3347.5	22701.1	83795	3.69	7.95
Abundant N doze (N_{120})	3034.0	3510.0	24178.3	88473	3.66	7.97
LSD $_{(0.05)}$	125.3	305.5	-	4688.2	-	-
F-test $_{(0.05)}$	**	**	-	**	-	-
C.V. (%)	7.9	16.4	-	10.1	-	-

*= significant at 5% level of significance, **=significant at 1% level of significance, NS=not significant

Energy-savings

The comparison of energy use pattern (Table 1) from different crop establishment methods of wheat revealed that the highest input energy consumption was (22164.8 MJ ha^{-1}) for CT and the lowest (18948.5 MJ ha^{-1}) was for PRB which was closely followed by ZT (19861.9 MJ ha^{-1}). The results were similar to the findings of other researchers (Jain *et al.* 2007, Jha *et al.* 2011, Singh *et al.* 2011). The higher energy consumption under CT than ZT, attributed to more tillage operation. Residue retention proved 56% higher energy consuming than residue removal. The reason for higher energy use for R_R attributed to 40-cm residues left in situ. Compared to zero N, the energy inputs were higher by 71% and 61% for 120 kg N ha^{-1} and 100 kg N ha^{-1}, respectively. The energy outputs for the TCE methods varied significantly. However, the highest energy output (75191 MJ ha^{-1}) was obtained from ZT followed by CT (66908 MJ ha^{-1}) and the lowest from PRB (64361 MJ ha^{-1}). Residue removal proved more energy output (7448 MJ ha^{-1}) than residue retention as residues added more to energy output. The abundant N (120 kg ha^{-1}) produced the highest energy output (88473 MJ ha^{-1}) followed by farmers' N (100 kg ha^{-1}) of 83795 MJ ha^{-1} and the lowest (34192 MJ ha^{-1}) from zero N application. The energy use efficiency was 3.78, 3.4 and 3.02 % for ZT, PRB, and CT, respectively. The higher energy use efficiency under ZT was mainly attributed to higher energy production with the use of relatively lesser energy utilization. The results were similar to the findings of several researchers (Jha *et al.* 2011, Sharma *et al.* 2008, Singh *et al.* 2011). Abundant N and farmers' N showed similar efficiencies. To produce a kg of wheat grain, CT, PRB, and ZT consumed 9.93, 8.76, and 7.59 MJ energy input, respectively. The results indicated that wheat productivity for CT < PRB < ZT per unit energy consumed. Residue retention utilized 10.39 MJ for a kg of wheat grain production when compared to 6.92 MJ for residue removal. The maximum energy (12.56 MJ) was utilized to produce a kg of wheat grain without N application, while, it was minimum (7.95 MJ) by farmers' N and abundant N (7.97 MJ). Application of farmers' N was more beneficial.

Operation-wise energy consumption

With 100 kg N ha^{-1} and residue removal, CT consumed the highest energy input (19642.5 MJ ha^{-1}) followed by ZT (18314.4 MJ ha^{-1}) and the lowest from permanent raised bed (16866.5 MJ ha^{-1}). The maximum energy utilization was through fertilizers application in all the TCE methods (Table 2). Conventionally grown wheat consumed energy on irrigation (24.3 %), threshing and cleaning (18 %) , seeding (9.5 %), tillage and crop establishment (9.1 %), harvesting (1.8 %), and the least (1.6 %) on chemical application, while, PRB wheat consumed energy on threshing and cleaning (22.1%), irrigation (17 %), TCE (8.2 %), seeding (7.2 %), harvesting (2.1 %), and the least (1.8 %) on chemical application. Zero-till wheat utilized energy on threshing and cleaning (27 %), irrigation (17.9 %), seeding (10 %), TCE (3.2 %), harvesting (1.9 %), and the least (1.7 %) on chemical application. Thus, the minimum TCE cost was associated with ZT as seed sowing was accomplished in one tractor-pass. About one-fourth of the total energy consumption was spent on irrigation applications in CT, while, they were 17.9 and 17 % in ZT and PRB, respectively, as more water was required for CT than others.

Table 2. Operation-wise energy consumption in wheat cultivation under different tillage and crop establishment methods at Pheta, Bara, Nepal, 2010/11-2011/12

Particulars of operation	Total energy used (MJ ha^{-1})					
	Conventional tillage	Percent of total energy	Permanent Raised bed	Percent of total energy	Zero tillage	Percent of total energy
Tillage and crop establishment	1780.8	9.1	1375.9	8.2	582.0	3.2
Fertilization	7017.5	35.7	7017.5	41.6	7017.5	38.3
Seed sowing	1871.0	9.5	1216.0	7.2	1824.0	10.0
Herbicide application	310.0	1.6	310.0	1.8	310.0	1.7
Irrigation	4775.0	24.3	2864.9	17.0	3272.7	17.9
Harvesting	352.8	1.8	352.8	2.1	352.8	1.9
Threshing and cleaning	3535.4	18.0	3729.4	22.1	4955.4	27.0
Total	19642.5	100	16866.5	100	18314.4	100

Energy input and energy output

The energy input (Table 3a) and energy output (Table 3b) data revealed that conventional tillage (CT) in association with residue retention and 120 kg N ha^{-1} consumed the maximum energy (30540 MJ ha^{-1}), while, it was minimum (8675.6 MJ ha^{-1}) for zero tillage combined with N_0 and without residues (R_O). Obviously, ZT had produced more energy outputs by 8284 MJ ha^{-1} and 10829 MJ ha^{-1} than CT and PRB, respectively. Likewise, residue removal proved better for energy output (7420 MJ ha^{-1}) than residue retention. Abundant N application produced significantly higher energy output (52810 MJ ha^{-1}) than control, but, was higher (5277 MJ ha^{-1}) than farmers' N. The results indicated that judicious fertilizer application was necessary for improving yields and reducing GHG emissions under high CO_2 levels (Varshneya 2009).

Greenhouse gas emission

The CO_2 emissions (Table 4) revealed that conventionally tilled (CT) wheat emitted the highest amount of CO_2 (224 kg ha^{-1}) followed by PRB (146 kg ha^{-1}) and the lowest from ZT (126 kg ha^{-1}). The highest CO_2 emission through CT attributed to higher tractor usage on land preparation and more pumping-time on irrigation. However, ZT and PBP wheat emitted lower CO_2 to the atmosphere by 43.7 % and 34.9 %, respectively, as compared to CT.

Table 3a. Energy input as influenced by tillage, residues, and nitrogen levels at Pheta, Bara, Nepal, 2010/11 and 2011/12

Particulars	Energy input (MJ ha^{-1})					
	Residue retention			Residue removal		
	N_0	N_{100}	N_{120}	N_0	N_{100}	N_{120}
	Conventional tillage					
Tillage and crop establishment	1780.76	1780.76	1780.76	1780.76	1780.76	1780.76
Fertilizers	9745.02	15805.02	17017.02	957.52	7017.52	8229.52
Seed and sowing	1871.00	1871.00	1871.00	1871.00	1871.00	1871.00
Herbicide/fertilizer application	310.00	310.00	310.00	310.00	310.00	310.00
Irrigation (two) application	4775.03	4775.03	4775.03	4775.03	4775.03	4775.03
Harvesting	352.80	352.80	352.80	352.80	352.80	352.80
Threshing and cleaning	1654.48	4198.32	4433.52	1755.18	3535.35	4103.05
Total energy input	20489.09	29092.93	30540.13	11802.29	19642.46	21422.16
	Permanent raised bed					
Tillage and crop establishment	1375.88	1375.88	1375.88	1375.88	1375.88	1375.88
Fertilizers	9745.02	15805.02	17017.02	957.52	7017.52	8229.52
Seed and sowing	1216.00	1216.00	1216.00	1216.00	1216.00	1216.00
Herbicide/fertilizer application	310.00	310.00	310.00	310.00	310.00	310.00
Irrigation (two) application	2864.92	2864.92	2864.92	2864.92	2864.92	2864.92
Harvesting	352.80	352.80	352.80	352.80	352.80	352.80
Threshing and cleaning	1833.82	3790.39	4014.57	1654.48	3729.39	4054.32
Total energy input	17698.44	25715.01	27151.19	8731.6	16866.51	18403.44
	Zero-tillage					
Tillage and crop establishment	582	582	582	582	582	582
Fertilizers	9745.02	15805.02	17017.02	957.52	7017.52	8229.52
Seed and sowing	1824.00	1824.00	1824.00	1824.00	1824.00	1824.00
Herbicide/fertilizer application	310.00	310.00	310.00	310.00	310.00	310.00
Irrigation (two) application	3272.67	3272.67	3272.67	3272.67	3272.67	3272.67
Harvesting	352.80	352.80	352.80	352.80	352.80	352.80
Threshing and cleaning	1625.08	4961.98	5006.08	1376.65	4955.37	5150.88
Total energy input	17711.57	27108.47	28364.57	8675.64	18314.36	19721.87

Note: Herbicide/fertilizer application = 310 MJ ha^{-1} same for all TCE; Harvesting = 352.8 MJ ha^{-1} same for all TCE

Table 3b. Energy output as influenced by tillage, residues, and nitrogen levels at Pheta, Bara, Nepal, 2010/11 and 2011/12

Particular	Energy output (MJ ha^{-1})							
	Conventional tillage	Permanent raised bed	Zero tillage	Residue retention (R_R)	Residue removal (R_O)	Control N dose (N_0)	Farmers' N dose (N_{100})	Abundant N dose (N_{120})
Grain yield	32803.05	31796.10	38462.50	35052.10	33685.00	17970.70	41953.80	44599.80
Straw yield	34106.25	32568.70	36731.20	30075.00	38862.50	17693.70	41843.70	43875.00
Total	66909.30	64364.80	75193.70	65127.10	72547.50	35664.40	83197.50	88474.80

Table 4. Carbon dioxide gas emission on diesel combustion in wheat cultivation at Pheta, Bara, Nepal, 2010/11-2011/12

TCE methods	Diesel used (liter ha^{-1})			CO_2 emission	CO_2 change
	Tractor	Pump-set	Total	(kg ha^{-1})	over CT (%)
Conventional tillage	28.87	57.4	86.27	224.32	-
Permanent raised bed	21.59	34.6	56.19	146.11	34.9 (↓)
Zero tillage	9.13	39.48	48.61	126.40	43.7(↓)

Table 5. Equivalents for direct and indirect sources of energy used in wheat production

Particulars	Units	Equivalent Energy (MJ $unit^{-1}$)	Remarks
Inputs			
Human labor: adult man	Man-hr	1.96	
Diesel	Liter	56.31	It included the cost of lubricant
Machinery			
(a) Prime Movers other than electric motors (including self propelled machines)	kg	64.80	Distribution of the weight of the machinery equally over the total life span of the machinery (in hrs).
(b) Farm machineries	kg	62.70	Calculated the use of machinery (hours) for the particular operation in a crop.
Chemical fertilizers			
(i) N	kg	60.60	
(ii) P_2O_5	kg	11.1	Estimated the quantity of nitrogen, P_2O_5 & K_2O in the chemical fertilizer. Then, computed the amount of energy input from chemical fertilizer.
(iii) K_2O	kg	6.7	
Superior chemical/granular pesticides	kg	120	Chemical requiring dilution @ time of application
Seed:			
Output of crop production and not processed	-	-	Same as that of output of crop production
Irrigation water	m^3	1.02	
Outputs			
Main product: cereal (wheat, sorghum)	kg (dry mass)	14.7	The main output was grains
By product : straw, vines	kg (dry mass)	12.5	The by-product was straw

Sources: Mittal *et al.* (1985)

The higher crop productivity with lower energy uses and reduced CO_2 gas emission is a prime need to meet the basic food demand of increasing population of Nepal, in climate change context. It was concluded that zero-till (ZT) wheat was the most beneficial for increased grain productivity (17.3 %) at lower energy consumption (10.4 %) and reduced specific energy (23.6 %) with enhanced energy use efficiency (25.2 %), as compared to conventionally grown (CT) wheat. Zero-till wheat saved fossil fuel (diesel) burning (37.7 liter ha^{-1}) with reduced CO_2 emission (98 kg ha^{-1}) protecting environment from warming-up. Residue retention showed positive effects on grain productivity. Therefore, zero-till wheat combined with 40-cm residue retention and 100 kg ha^{-1} N application was suggested for mass-scale adoption in the Tarai region of Nepal to ensure long-term production sustainability.

Acknowledgements

The authors express their gratitude to the CIMMYT-CSISA/Nepal Project for the financial support to conduct this study.

References

Balasubramanian, V., A.C. Morales, R.T. Cruz, T.M. Thiyagarajan, R. Nagrajan, M. Babu Abdulrachman and L.H. Hai. 2000. Adaptation of chlorophyll meter (SPAD) technology for real-time nitrogen management in rice: A review. *Intl. Rice Res. Notes.* **25** (1): 4-8.

Devasenapathy, P., G. Senthilkumar and P.M. Shanmugam, 2009. Energy management in crop production. *Ind. J. Agron.* **54** (1): 80-90.

Grace, P.R., L. Harrington, M.C. Jain and G.P. Robertson. 2003. Long-term sustainability of the tropical and subtropical rice-wheat system: An environmental perspective. In: *Improving the productivity and sustainability of rice-wheat systems*: *Issues and impacts* (eds. J.K. Ladha, E.H. James, J.M. Duxbury, R. K. Gupta, and R. J. Buresh). *Amer. Soc. Agron.* Spec. Publ. 65. ASA, CSSA, and SSSA, Madison, Wisconsin, USA. pp. 27-43.

Gupta, R.K., R.K. Naresh, P.R. Hobbs, Z. Jiaguo and J.K. Ladha. 2003. Sustainability of post-green revolution agriculture: The rice-wheat cropping systems of the Indo-Gangetic Plains and China. In: *Improving the productivity and sustainability of rice-wheat systems: Issues and impacts* (eds. J.K. Ladha, E.H. James, J.M. Duxbury, R. K. Gupta, and R. J. Buresh,). *Amer. Soc. Agron*. Spec. Publ. 65. ASA, CSSA, and SSSA, Madison, Wisconsin, USA. pp.1-25.

Gupta, R.K., P.R. Hobbs and J.K. Ladha. 2000. From issue to action. In: *Proceedings of the 6th meeting of the regional steering committee*. Islamabad, Pakistan. 7-8 Mar. 2000. Rice-Wheat Consortium for the Indo-Gangetic Plains, New Delhi, India. pp.1-7.

Hobbs, P.R. and R.K. Gupta. 2003. Resource-conserving technologies for wheat in the rice-wheat system. In: *Improving the productivity and sustainability of rice-wheat systems*: *Issues and impacts* (eds. J.K. Ladha, E.H. James , J.M. Duxbury, R.K. Gupta, and R.J. Buresh). *Amer. Soc. Agron*. Spec. Publ. 65. ASA, CSSA, and SSSA, Madison, Wisconsin, USA. pp.149-171.

Hobbs, P.R., G.S. Giri and P. Grace. 1997. Reduced and zero tillage options for the establishment of wheat after rice in South Asia. RWC-IGP Paper No. 2. Rice-Wheat Consortium for the Indo-Gangetic Plains, New Delhi, India.

Jain, N., V. Jain, J.S. Mishra and M.L. Kewat. 2007. Effect of tillage packages and herbicide on energy and economics of wheat in transplanted rice-wheat system. *Ind. J. Agric. Sci.* **77** (3): 174-176.

Jha, A.K., R.S. Sharma and S.K. Vishwakarma. 2007. Development of resource conservation techniques for tillage and sowing management in rice-wheat cropping system under irrigated production system of Kymore Plateau and Satpura hillzone of Madhya Pradesh. *JNKVV, Res. J.* **41** (1):26-31.

Jha, A.K., M.L. Kewat, V.B. Upadhyay and S.K. Vishwakarma. 2011. Effect of tillage and sowing methods on productivity, economics and energetic of rice *(Oryza sativa)*-wheat *(Triticum aestivum)* cropping system. *Ind. J. Agron*. **56** (1): 35-50.

Jorge, A. Delgado, Petter M. Groffman, Mark A. Nearing, Tom Goddard, Don Reicosky, Rattan Lal, Newell R. Kitchen, Charles W. Rice, Dan Towery and Paul Salson. 2011. Conservation practices to mitigate and adapt to climate change. *J. Soil Water Conservation.* **66** (4): 118-129.

Ladha, J.K., H. Pathak, A.T. Padre, D. Dawe and R.K. Gupta. 2003. Productivity trends in intensive rice-wheat cropping systems in Asia. In. *Improving the productivity and sustainability of rice-wheat systems*: *issues and impacts* (eds. J.K. Ladha, E.H. James, J.M. Duxbury, R. K. Gupta, and R. J. Buresh). *Amer. Soc. Agron*. Spec. Publ. No. 65. Madison, Wis. (USA): ASA, CSSA, and SSSA. pp. 45-76.

Laik, R., S. Sharma, M. Idris, A.K. Singh, S.S. Singh, B.P. Bhatt, Y. Saharawat, E. Humphreys and J.K. Ladha. 2014. Integration of conservation agriculture with best management practices for improving system performance of the rice-wheat rotation in the Eastern Indo-Gangetic Plains of India. *J. Agric. Ecosys. Envi.* **195**: 68-82.

Malik, R.K., A. Yadav, S. Singh, R.S. Malik, R.S. Balyan, R.S. Banga, P.K. Sardana, S. Jaipal, P.R. Hobbs, G. Gill, S. Singh, R.K. Gupta and R. Bellinder. 2002. Herbicide resistance management and evolution of zero tillage: A success story. *Res. Bulle*. Haryana Agricultural University, Hisar, India.

Manning, M. 2007. Climate change 2007: Observations and drivers of climate change. Presentation by Director of IPCC Working Group-I Support Unit, IPCC. pp. 41-73.

Melha, R.S., J.K. Verma, R.K. Gupta and P. R. Hobbs. 2000. Stagnation in the productivity of wheat in the Indo-Gangetic plains: Zero-till-seed-cum-fertilizer drill as an integrated solution. Rice-Wheat Consortium for the Indo-Gangetic Plains, New Delhi, India.

Mittal, V.K., J.P. Mittal and K.C. Dhawan. 1985. *Research digest on energy requirements in agricultural sector.* Co-ordinating Cell, AICP on energy requirements in

Agricultural Sector. Punjab Agricultural University, Ludhiana.

MoAD, 2012/13. *Agricultural diary* (2071 B.S.). Government of Nepal.

Ram, N. 2000. Long-term effects of fertilizers on rice-wheat-cowpea productivity and soil properties in Mollisols. In. *Long-term soil fertility experiments in rice-wheat cropping systems* (eds. I.P. Abrol et al. eds.). *Res. Series No. 6*. Rice-Wheat Consortium, New Delhi, India. pp. 50-55.

Sayre, K.D. 2000. Effects of tillage, crop residue retention and nitrogen management on the performance of bed-planted, furrow-irrigated spring wheat in northwest Mexico. In: *Proc. 15th Conf. Intl. Soil Till. Res. Org.* (CD-ROM), Fort Worth, TX. 2-7 July, 2000.

Sayre, K.D. and O.H. Moreno Ramos. 1997. Applications of raised-bed planting systems to wheat. Wheat Program, Spec. Rep. 31. CIMMYT, Mexico.

Sharma, R.P., S.K. Pathak, K.R. Raman and N. Chattopadhyaya. 2008. Resource conservation in rice (*Oryza sativa*)-wheat (*Triticum aestivum*) for enhancing productivity, profitability, and soil health. In: *Extended summaries, national symposium on new paradigm in agronomic research*, 9 to 11 Nov. 2008, Navasari, Gujrat, India. *Ind. Soc. Agron.* pp. 236-237.

Singh, Veer, S. Ram, A. Bhatnagar and U. S. Savita. 2011. Effect of tillage methods on soil properties and productivity of quality protein maize (*Zea mays*)-wheat (*Triticum aestivum*) system. *Ind. J. Agron.* **56** (2): 83-87.

Tripathi, J., D. Bhandari, S. Justice, N.K. Shakya, T.P. Kharel and R. Sishodia. 2002. Resource conservation technologies for wheat production in rice-wheat system. In: *Proceedings of wheat research papers presented at the 25th National Winter Crops Workshop, Nepal.*

Varshneya, M.C. 2009. Mitigation options for climate change. *Ind. J. Agron.* **54** (2): 231-236.

Venkateswarlu, B. and A. K. Shanker. 2009. Climate change and agriculture: Adaptation and mitigation strategies. *Ind. J. Agron.* **54** (2): 226-230.