Indian Journal of Agronomy **58** (1): 42–47 (March 2013)

Research Paper

Effect of tillage, residue management and crop establishment techniques on energetics, water use efficiency and economics in soybean (*Glycine max*)–wheat (*Triticum aestivum*) cropping system

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Received : October 2011; accepted : February 2013

ABSTRACT

In Indo-Gangetic plains of India, the returns from crop cultivation are shrinking gradually owing to escalation of input costs. Under such situation, conservation agriculture systems have gained importance to make farming profitable by cutting down the variable cost and enhancing resource-use efficiency. The studies were conducted during 2009-10 to 2010-11on energy relations and irrigation water use efficiency (IWUE) involving sequential tillage (i.e to skip the tillage either in *kharif* to soybean or in *rabi* to wheat) in soybean (*Glycine max* (L.) Merr.)–wheat (*Triticum aestivum* L. emend. Fiori and Paol) system in order to evaluate the performance under sequential tillage. The energy relations *viz.* input energy, output energy, net energy and energy use efficiency were statistically similar in most of the cases except energy-use efficiency for both soybean and wheat due to different sequential tillage and crop establishment techniques. Residue management treatments significantly influenced the energy relations in both the crops. Wheat + soybean residue recorded highest gross energy (235.9 and 269.9 × 10^3 MJ/ha), while the reverse with net energy and energy use efficiency where the no residue (control) obtained 189.0 and 206.4 × 10^3 MJ/ha; 8.69 and 10.4 ×10^3 MJ/ha respectively during the year 2009-10 and 2010-11 in the soybean-wheat system. IWUE in wheat recorded significantly higher with bed system of crop establishment either adopting conventional tillage-bed (CT-Bed) (209.1 kg/ha-cm) or skipping CT-Bed with zero tillage-bed (ZT-Bed) (312.6 kg/ha-cm) in *rabi* season during the year 2009-10 and 2010-11, respectively.

Key words: Bed and flat planting, Energy, Sequential tillage, Soybean–wheat cropping system

Efficient use of energy is one of the most important indicators of crop performance. Yield of different crop can be increased up to 30 % by using optimal level of energy input (Chaudhary *et al*., 2006). Thus, it becomes imperative to sustain the productivity of agricultural systems concomitant with friendly environment and efficient utilization of production resources. Continuous rice – wheat cropping sequence in the Indo-Gangetic Plains has resulted in a number of ecological and other disorders like development of hardpan, low input use efficiency, lowering of water table, more pests etc. besides environmental pollution through emission of gases. There is need for diversification of rice wheat sequence for higher sustainability of agriculture. Soybean is a potential *kharif* crop to replace rice. However, in soybean based rainfed cropping system, hardly 10–15 days time is available between harvesting of soybean and timely sowing of winter crops. Moreover, delayed sowing adversely affects germination owing to moisture depletion, which results in lower yield. In recent years, conservation agriculture systems have gained importance due to reduced cultivation cost. Zero tillage (ZT) and furrow irrigated raised bed (FIRB) planting are found to be the potential resource conservation technologies (RCTs) which can play a big role in saving the scarce natural resource like water. ZT technique is an ecological approach for soil surface management and seed bed preparation resulting in less energy requirement, less weed problem, better crop residue management and higher or equal yield (Jain *et al*., 2007). It is energy efficient and beneficial to environment as compared to conventional practices of sowing (Filipovic *et al*., 2006). FIRB planting is a method of planting a crop on raised beds. The FIRB planting systems have number of advantages like better irrigation management, better crop establishment, better weed management and less soil compac-

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tion (Dhillon *et al*., 2004). Further, the permanent bed (PB) planting allows the bed to be re-used for succeeding crop and thus has the potential to minimize the cost of cultivation similar to ZT. The present study was therefore conducted to study the energy relations and irrigation water use efficiency (IWUE) in conventional tillage in soybean / wheat followed by zero tillage / conventional tillage in wheat in flat or raised bed planting in soybean-wheat system.

MATERIALS AND METHODS

The field experiments were conducted during *kharif* and *rabi* 2009-10 and 2010-11 at the research farm of Division of Agronomy, Indian Agricultural Research Institute, New Delhi, situated at 28.4°N latitude and 77.1°E longitude and at an altitude of 228.6 meters above mean sea level. The soil of the experimental field was a sandy clay loam in texture, neutral in reaction (pH 7.6), low in organic carbon (0.38 %), low in available N (150 kg/ha), medium in available P (11.2 kg/ha) and available K (245 kg/ha). The experiment was conducted in split plot design with three replications in a fixed lay out. The main plot treatments consisted of four sequential tillage and crop establishment techniques to soybean and wheat *viz*. conventional tillage-flat–zero tillage-flat (CT-F–ZT - F); zero tillage-flat–conventional tillage-flat (ZT-F–CT - F); conventional tillage-bed–zero tillage-bed (CT- B–ZT- B) and zero tillage-bed–conventional tillage-bed (ZT - B– CT-B) while the sub plot treatments were four residue management practices *viz*. control, wheat residue (3 t/ha), soybean residue (3 t/ha) and soybean + wheat residue (3 t/ha each). The gross plot size of the sub plot was 15 m^2, while the gross size of the main plot was 60 m^2. The soybean variety DS 9814 during *kharif* (June to October) and wheat variety PBW 550 during *rabi* (November to April) were grown at row to row spacing of 35 cm and 20 cm, respectively. Well dried crop residues of wheat and soybean of previous season were applied @ 3 t/ha to soybean and wheat crop, respectively, by spreading the material uniformly a week before preparation of the field for sowing. In conventional tillage–flat: After the harvest of previous crop the plots were ploughed with a disc harrow twice. Further cultivator was run twice followed by planking before sowing of soybean. In conventional tillage–bed: Soybean was sown with the help of bed planter after the land preparation. The beds were formed at a distance of 67.5 cm from bed to bed. In zero tillage–flat: No tillage operation was carried out after harvest of previous crop, soybean was sown with the help of zero-till seed drill. In zero tillage–bed: Soybean was sown with the help of bed planter without any tillage operation. The recommended practice of fertilizers application was followed to both the crops. The N, P and K were given in the form of urea, single super phosphate and muriate of potash, respectively in soybean @ 20:60:40 N, P_2O_5 and K_2O kg/ha and in wheat @ 120:60:40 N, P_2O_5 and K_2O kg /ha. In soybean Pendimethalin @ 0.75 kg a.i/ha was applied as pre-emergence followed by two hand weeding at 20 DAS and 40 DAS and in wheat one blanket spray of Paraquat was made before sowing of the crop only in zero tillage plots followed by application of Isoproturon and 2,4-D at 30-35 DAS to ZT and CT plots. The depth of each irrigation was 7 and 5 cm in flat and bed system of planting in both crops. Irrigation water was measured with the help of a Parshall flume. Energy efficiency was calculated using the formula suggested by Mittal and Dhawan (1988). Irrigation water use efficiency (kg/ha-cm) was calculated as the grain yield (kg) divided by the irrigation water applied (ha-cm) (Ibragimov *et al*., 2011).

RESULTS AND DISCUSSION

Energy relations

Energy consumption (both renewable and non-renewable) for production of soybean as influenced by sequential tillage and crop establishment and residue management practices in both soybean and wheat is presented in Table 1. The input energy requirement for soybean was maximum 27.61 × 10^3 MJ/ha for CT-Flat (S) – ZT-Flat (W) and 26.03 × 10^3 MJ/ha for CT-Bed (S) – ZT-Bed (W) during the years 2009 and 2010, respectively. The input energy requirement for wheat was maximum with ZT-Flat (S) – CT-Flat (W) (34.19 and 33.61 × 10^3 MJ/ha) during both the years of study while the minimum was recorded in the CT-Bed (S) – ZT-Bed (W) treatment for wheat during both the years. The input energy requirement of soybean for different residue management practices varied from 7.60 × 10 ^{3} MJ/ha in no residue treatment to 45.12 × 10^3 MJ/ha in wheat residue receiving treatments in 2009. Similarly in 2010 the input energy requirement varied from 6.10 × 10^3 MJ/ha for 43.63 × 10^3 MJ/ha between no residue and wheat + soybean receiving treatment. The increase in energy requirement with residue was 493.7 and 615.2% than control during the year 2009 and 2010, respectively. Input energy requirement for wheat varied with residue management treatments from 14.16 to 51.68 × 10^3 MJ/ha and 13.66 to 51.18 × 10^3 MJ/ha during the year 2009-10 and 2010-11, respectively. The maximum input energy in wheat was recorded with soybean residue involving treatments while the minimum was recorded with no residue and wheat residue treatments during both the years of study and the difference was 37.52 × 10^3 MJ/ha between them. During both the years the maximum energy input was recorded with flat system of crop establishment techniques in soybean-wheat cropping system (Table

2). Whereas, the bed system of crop establishment techniques registered less energy input to the system. In the soybean-wheat system considerably higher energy input was required with wheat + soybean residue treatment to the tune of 96.80 and 94.80 x 10^3 MJ/ha during the year 2009-10 and 2010-11, respectively which was 345 and 380 % higher than control (no residue) treatment.

Sequential tillage and crop establishment techniques did not influence significantly the gross energy output of soybean crop during the year 2009 (Table 1) Contrary to this in the year 2010, the gross energy output was influenced significantly by the sequential tillage and crop establishment treatments. The maximum energy output was recorded in CT-Flat (S) – ZT-Flat (W) (70.28 × 10^3 MJ/ha) and ZT-Flat (S) – CT-Flat (W) (88.03 × 10^3 MJ/ha) in soybean during 2009 and 2010 respectively. The minimum output energy was recorded in the ZT-Bed (S) – CT-Bed (W) treatment in soybean during both the years. The energy output was residue found to have influenced significantly by management treatments. The higher energy in soybean output was recorded in wheat + soybean residue receiving treatments (71.84 and 93.89 × 10^3 MJ/ha) which was 7.54 and 22.9 % higher than no residue treatment during 2009 and 2010, respectively and the minimum output energy was reported in the no residue treatment during both the years. Sequential tillage and crop establishment techniques were non-significant for gross energy output of wheat crop during both the year 2009-10 and 2010-11 (Table 1). However, the maximum energy output was obtained with ZT-Flat (S) – CT-Flat (W) (157.1 and 164.4 × 10^3 MJ/ha) while the minimum was obtained with ZT-Bed (S) – CT-Bed (W) (140.4 and 153.6 × 10^3 MJ/ha) during both the year. The residue management practices significantly influenced the energy output of wheat crop during both the years. The combined application of wheat + soybean residue has yielded significantly higher energy output than rest of the treatments (no residue, wheat residue and soybean residue) during the year 2009-10 whereas, this was at par with the soybean residue treatment and significantly higher than other two treatments (no residue and wheat residue) during the year 2010-11. In soybean-wheat cropping system the energy output among the sequential tillage and crop establishment techniques was non-significant during both the years of study (Table 2). However, the maximum gross energy output was obtained with ZT-Flat (S) – CT-Flat (W) (232.1 and 257.8 × 10^3 MJ/ha) while the minimum was obtained with ZT-Bed (S) – CT-Bed (W) (213.4 and 239.3 × 10^3 MJ/ha) during both the year. The no residue treatment recorded the lower gross energy output while the maximum was obtained with the combined application of wheat + soybean residue respectively during both the years.

Table 1. Effect of sequential tillage and crop establishment techniques, and residue management on energy relations in soybean and wheat

Treatment	Soybean						Wheat					
	Input energy (× 10^3 MJ/ha)		Gross output energy (× 10^3 MJ/ha)		EUE(output/ input ratio)		Input energy (× 10^3 MJ/ha)		Gross output energy (× 10^3 MJ/ha)		EUE (output/ input ratio)	
	2009	2010	2009	2010	2009	2010	2009-10	2010-11	2009-10	2010-11	2009-10	2010-11
Tillage and crop establishment												
CT–Flat (S) – ZT–Flat (W)	27.61	25.86	70.28	86.58	4.60	6.83	32.15	31.57	151.9	158.8	151.9	158.8
ZT–Flat (S) – CT–Flat (W)	25.61	23.86	70.13	88.03	5.83	9.22	34.19	33.61	157.1	164.4	157.1	164.4
CT–Bed (S) – ZT–Bed (W)	27.28	26.03	69.19	82.21	4.73	6.45	31.48	31.06	146.0	160.5	146.0	160.5
ZT–Bed (S) – CT–Bed (W)	24.93	23.69	67.81	80.45	6.13	8.89	33.86	33.44	140.4	153.6	140.4	153.6
SEm±			0.659	1.324	0.05	0.13			4.525	4.750	4.525	4.750
CD (P=0.05)			NS	4.581	0.18	0.44			NS	NS	NS	NS
Residue management												
No residue	7.60	6.10	66.80	76.38	8.99	12.9	14.16	13.66	139.4	144.9	139.4	144.9
Wheat residue	45.12	43.63	70.79	81.59	1.57	1.87	14.16	13.66	147.3	158.8	147.3	158.8
Soybean residue	7.60	6.10	67.98	85.43	9.13	14.5	51.68	51.18	149.8	163.4	149.8	163.4
Wheat + soybean residue*	45.12	43.62	71.84	93.89	1.59	2.15	51.68	51.18	158.8	170.2	158.8	170.2
SEm±			0.642	0.939	0.05	0.12			3.330	4.050	3.330	4.050
CD (P=0.05)			1.875	2.741	0.15	0.34			9.720	11.82	9.720	11.82

In *kharif* soybean residue @ 3 t/ha and in *rabi* wheat residue @ 3 t/ha were applied

The energy use efficiency was significantly influenced by the sequential tillage and crop establishment treatments during both the years (Table 1). The highest energy use efficiency (output/input energy) was recorded in ZT-Bed (S) – CT-Bed (W) (6.13) and ZT-Flat (S) – CT-Flat (W) (9.22) during 2009 and 2010, respectively in soybean and this was 29.6 and 35.0% higher than their corresponding tillage treatments. Apparently the energy use efficiency was higher with control/soybean residue while the minimum was obtained with the wheat residue and wheat + soybean residue treatments in soybean during both the years. The sequential tillage and crop establishment techniques significantly influenced the energy use efficiency of wheat crop during both the years of study (Table 1). The maximum energy use efficiency in wheat was recorded with the zero tillage treatments CT-Bed (S) – ZT-Bed (W) (7.03 and 8.00) during both the years. The energy use efficiency of wheat crop was significantly influenced by the residue management practices which followed the order: wheat residue (10.45 and 11.17) > no residue (9.92 and 10.7) > wheat + soybean residue (3.07 and 3.33) > soybean residue (3.07 and 3.33) during both the years of study. Energy-use efficiency of the soybean-wheat cropping system was non-significant with sequential tillage and crop establishment treatments (Table 2). However, the maximum energy-use efficiency was recorded with ZT-Flat (S)–CT-Flat (W) (3.99 and 4.90) while the low efficiency was recorded with ZT-Bed (S)–CT-Bed (W) (3.81 and 4.60) during both the years of study.

Irrigation water use efficiency

In wheat the IWUE was significantly influenced due to sequential tillage and crop establishment practices during both the years (Table 3). Depth of irrigation water of 7 and 5 cm was applied for flat and bed system of crop establishment, respectively. The highest IWUE was obtained with bed system of crop establishment ZT-bed and CT-bed in *rabi* season during both the years. An average of 38.24 and 36.70 % improvement in IWUE by ZT-bed over ZT-flat and CT-bed over CT-flat and saving of irrigation wa-

Table 2. Effect of sequential tillage and crop establishment techniques, and residue management on energy relations in soybean – wheat cropping system

Treatment	Input energy ($\times 10^3$ MJ/ha)		Gross output energy ($\times 10^3$ MJ/ha)		Energy use efficiency (output/ input ratio)	
	2009-10	2010-11	2009-10	2010-11	2009-10	2010-11
Tillage and crop establishment						
CT–Flat (S) – ZT–Flat (W)	59.76	57.43	227.2	250.8	3.92	4.65
ZT–Flat (S) – CT–Flat (W)	59.80	57.47	232.1	257.8	3.99	4.90
CT–Bed (S) – ZT–Bed (W)	58.76	57.10	220.0	247.8	3.92	4.87
ZT–Bed (S) – CT–Bed (W)	58.79	57.13	213.4	239.3	3.81	4.60
SEm ±			4.089	5.427	0.09	0.15
CD (P=0.05)			NS	NS	NS	NS
Residue management						
No residue	21.75	19.76	210.8	226.2	8.69	10.4
Wheat residue	59.28	57.28	223.6	245.5	2.77	3.29
Soybean residue	59.28	57.28	222.4	254.2	2.75	3.44
Wheat + soybean residue*	96.80	94.80	235.9	269.9	1.44	1.85
SEm±			3.339	4.210	0.07	0.14
CD (P=0.05)			9.746	12.29	0.20	0.40

In *kharif* soybean residue @ 3 t/ha and in *rabi* wheat residue @ 3 t/ha were applied

Table 3. Effect of sequential tillage and crop establishment techniques on IWUE of wheat

Tillage and crop establishment	2009-10			2010-11		
	Grain yield (t/ha)	Irrigation water (cm)	IWUE (kg/ha-cm)	Grain yield (t/ha)	Irrigation water (cm)	IWUE (kg/ha-cm)
CT–F(S) – ZT–F(W)	4.22	28	150.8	4.76	21	226.5
ZT–F(S) – CT–F(W)	4.31	28	154.0	4.75	21	226.4
CT–B(S) – ZT–B(W)	4.18	20	208.8	4.69	15	312.6
ZT–B(S) – CT–B(W)	4.18	20	209.1	4.68	15	311.6
SEm±	0.11	-	4.28	0.207	-	13.89
CD (P=0.05)	NS	-	14.8	NS	-	48.09

Table 4. Economics and average yield of soybean and wheat in soybean-wheat cropping system as influenced by sequential tillage and crop establishment practices

Treatment	Cost of cultivation (× 10^3 ₹/ha)		Net returns (× 10^3 ₹/ha)		B:C ratio	Soybean yield	Wheat yield
	2009–10	2010–11	2009–10	2010–11		(t/ha)	(t/ha)
Tillage and crop establishment							
CT–Flat (S) – ZT–Flat (W)	35.61	32.12	44.24	64.56	1.62	1.85	4.49
ZT–Flat (S) – CT–Flat (W)	35.39	31.90	45.39	65.58	1.67	1.86	4.53
CT–Bed (S) – ZT–Bed (W)	35.17	32.00	43.21	62.23	1.59	1.78	4.44
ZT–Bed (S) – CT–Bed (W)	34.95	31.78	43.41	61.65	1.59	1.78	4.43
SEm±	-	-	1.28	2.72			
CD (P=0.05)	-	-	NS	NS			
Residue management							
No residue	33.33	30.00	42.84	57.49	1.61	1.68	4.23
Wheat residue	35.43	32.10	44.33	61.38	1.58	1.82	4.41
Soybean residue	35.13	31.80	43.48	65.82	1.66	1.80	4.55
Wheat + soybean residue*	37.23	33.90	45.58	69.33	1.64	1.96	4.71
SEm±	-	-	0.85	1.28			
CD (P=0.05)	-	-	NS	3.73			

In *kharif* soybean residue @ 3 t/ha and in *rabi* wheat residue @ 3 t/ha was applied

ter was 28.57 %. In wheat the highest IWUE was with the bed system of crop establishment during both the year irrespective of CT and ZT. Depth of irrigation water was maintained at 7 and 5 cm for respective flat and bed system of crop establishment, this 2 cm difference in irrigation water is the reason for higher IWUE in bed system of planting. An average of 38.24 and 36.70 % improvement in IWUE by ZT-bed over ZT-flat and CT-bed over CT-flat and saving of irrigation water was 28.57 % which connote the importance of bed planting over flat planting irrespective of CT and ZT. Similarly, higher WUE was also reported in bed planting (Ram *et al*., 2010). Contrary to our findings Ibragimov *et al*. (2011) reported that IWUE was statistically similar with conventional tillage and permanent bed in winter wheat.

Economics

The cost of cultivation varied for sequential tillage and residue management treatments in soybean-wheat cropping system from 34.95 × ₹10^3 and 31.78 × 10^3 ₹/ha to 35.61 × ₹10^3 and 32.12 × ₹10^3 /ha during the year 2009-10 and 2010-11 respectively (Table 4). Similarly the cost of production for residue management treatments was varied from 33.33 × ₹10^3 and 30.00 x 10^3 ₹/ha to 37.23 × ₹10^3 and 33.90 × ₹10^3/ha during the year 2009-10 and 2010-11, respectively. The sequential tillage and crop establishment treatment did not influence significantly the net returns of soybean-wheat cropping system. The highest net return of 45.39 × ₹ 10^3 and 65.58 × ₹10^3/ha was obtained in the ZT-Flat (S) – CT-Flat (W) treatment during both the years while the lowest net returns was obtained with CT-Bed (S) – ZT-Bed (W) (43.41 × ₹10^3/ha) and ZT-Bed (S) – CT-Bed (W) (61.65 × ₹10^3 /ha) during the year 2009-10 and 2010-11. The net returns were non-significant in the year 2009-10 while the same was significantly influenced in the year 2010-11 due to different residue management treatments. The highest net returns was obtained from the combined application wheat + soybean residue (45.58 and 69.33 x 10^3 ₹/ha) while the lowest was obtained with no residue (42.48 and 57.49 × 10^3 ₹/ha) during the year 2009-10 and 2010-11, respectively. Similar trend was also obtained in case of gross returns. The B:C ratio of soybean-wheat cropping system did not influenced significantly by the sequential tillage and residue management practices during both the years of study. The highest B:C ratio was recorded with ZT-Flat (S) – CT-Flat (W) (1.67) while the lowest B:C ratio was recorded with bed system of planting during the year 2009-10 and 2010-11, respectively. The use of ZT significantly reduces energy costs, mainly by reducing tractor costs associated with conventional methods.

It was concluded that the based on the data relating to productivity, water use efficiency, economics and energetics, ZT either flat or bed in sequential tillage either in *kharif* for soybean or in *rabi* for wheat having the possibility of successful adoption in the soybean-wheat in sequence in the Indo-Gangetic plains of India. Bed planting is the important resource conserving technique (RCT's) which saves 28.57 % of irrigation water over flat planting irrespective of CT and ZT.

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