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**Research Paper**

# Energetics, water and crop productivity of wheat (*Triticum aestivum*)–cluster bean (*Cyamopsis tetragonoloba*) sequence under land configuration and irrigation regime in semi-arid agro-ecosystem

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## ABSTRACT

A field experiment was conducted during the rainy and winter seasons of 2012–14 at Hisar, Haryana, to study energetics, water and crop productivity of wheat (*Triticum aestivum* L.)–clusterbean [*Cyamopsis tetragonoloba* (L.) Taub.] sequence as affected by land configurations and irrigation regimes in semi-arid agro-ecosystem. Two years average data showed that the highest yields were achieved with furrow-irrigated raised bed (FIRB). It has increased system yields by 13%, 21.7% and 13.7% over conventional tillage (CT), minimum tillage (MT) and zero tillage (ZT) respectively. This study also indicated that FIRB gave greater system returns (₹58×$10^3$/ha) compared to the other practices. Water-use efficiency (WUE) and irrigation water productivity (IWP) of wheat–clusterbean increased by 26–28% and 25–35% with FIRB planting than CT. The maximum system net energy (355.9 × $10^3$ MJ/ha) was recorded in FIRB with water stress level of 0.90 IW : CPE for wheat and 0.80 IW : CPE for clusterbean ($I_1$) than other combinations. Similarly, energy-use efficiency (22.5) and energy productivity (375.7 g/MJ) were maximum in ZT with water stress level of 0.75 IW : CPE for wheat and 0.70 IW : CPE for clusterbean ($I_2$) compared to the other tillage and irrigation regimes. Wheat–clusterbean under FIRB with water stress level of $I_1$ chronicled considerably greater system net returns (12–75%) than CT, MT and ZT across water stress levels. Among planting systems, FIRB under $I_1$ was found to be a better option to enhance productivity and profitability, while greater energy use efficiency and energy productivity in ZT.

***Key words:*** Clusterbean, Energy, FIRB, IW : CPE, System water productivity, Wheat, ZT

Land degradation, dwindling soil and water resources and climate change are the major drivers that influence Indian agriculture (Pathak *et al*., 2012). Continuous rice–wheat cropping system in Northern India (~12.5 m ha) triggered number of ecological problems like development of soil hard pan, low input-use efficiency, decline in groundwater table and water quality, declining soil organic matter leading to increased nutrient deficiencies and salinity due to poor management practices (Sarkar, 2015; Rana *et al*., 2018). Faulty farming practices like imbalanced use of water and fertilizers greatly implies on decreased agricultural production and reduced factor productivity in semi-arid regions. The increased temperature due to change in climate scenarios would result in more water shortage and the demand for irrigation water would rise (Pathak *et al*., 2012; Rana *et al*., 2018) due to more water loss through non-process beneficial evapotranspiration. Accordingly, minimizing the water losses by developing and implementing efficient technologies and strategies will substantially enhance the water productivity in semi-arid areas (Rajanna *et al*., 2016). Hence, road ahead is to enhance the efficient use of water through improved tillage management along with diversification and advanced irrigation technologies.

Furrow-irrigated raised bed (FIRB) planting has been found effective in saving water in crop production by reducing amount of water by ~18–35% (Hobbs and Gupta, 2003) in wheat while ~25% in clusterbean (Dhindwal *et al*., 2006) which enhances productivity of other inputs as well. Moisture stress given at irrigation regime is highly location-specific and climatological approach such as irrigation water : cumulative pan evaporation (IW : CPE) integrate all weather parameters have natural weightage in a given climate–plant continuum. However, water supplied as IW : CPE basis was more economical and convenient

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than other criteria for better crop yields and water-use efficiency (WUE).

In India, wheat is grown during *rabi* in an annual system with rice, cotton, pearlmillet or clusterbean as rainy season (*kharif*) crops. Although, it is grown under improved irrigation practices associated with the use of new varieties, increased fertilizer use and conservation tillage, but the individual factor productivity has declined (Chauhan *et al*., 2012). Hence wheat–clusterbean system is intended to provide the farmer with a useful harvest in addition to improving the soil fertility to achieve goals of sustainability in long-run by overcoming aforesaid problems. However, the distribution of water in the soil root zone and its use by the crops is likely to be desperate than the normal tillage practices. Therefore, the present study was designed to develop production technologies such as scheduling irrigation at critical growth stages and planting techniques for maximizing the productivity per unit of water use under wheat–clusterbean system.

## MATERIALS AND METHODS

A field experiment was conducted for 2 consecutive years (2012–2014) during rainy and winter seasons at a fixed site at CCS Haryana Agricultural University, Hisar, (29° 10' N, 75° 46' E and 215.2 m above mean sea-level). The soil of the experimental site was sandy loam (Typic Haplustepts) in texture with 57.5% sand, 24.3% silt and 18.2% clay. The soils having *p*H-8.0, organic carbon 0.58%, bulk density 1.42 Mg/m$^3$, infiltration rate 4.6 mm/h, electrical conductivity 0.23 dS/m and available N, P and K of 133.6, 24.6 and 276.5 kg/ha respectively. The moisture content at –0.03 MPa was 20.5% at (field capacity) and 6.1% at –1.5 MPa. The experiment was laid out in a strip-plot design with 4 tillage practices as main factors and 3 irrigation regimes as sub plot treatments (Table 2) and were replicated thrice. Wheat was sown during winter (4 and 1 December 2012 and 2013) and clusterbean during rainy season (21 and 15 June 2013 and 2014). Wheat 'WH 711' and clusterbean 'HG-2-20' varieties were used at seed rate of 100 and 10 kg/ha respectively. The recommended dose of 150-60-60 kg NPK/ha for wheat and 50-25-25 kg NPK/ha for clusterbean was applied through diammonium phosphate, urea and muriate of potash. For managing weeds, glyphosate @ 1.0 kg/ha was sprayed in ZT plots. However, CT, MT and FIRB application of pendimethalin @ 1.0 kg/ha as basal in wheat and clusterbean crops, while metsulphuron methyl @ 25–30 g/ha application at 25–30 days after seeding of wheat. The IW : CPE ratios were calculated based on depth of irrigation water with the help of current meter and the cumulative pan evaporation during the particular period. The total number of post-sown irrigations applied during both the years under CRI + 0.9, 0.75 and 0.6 IW : CPE moisture regimes were 3, 2 and 2, respectively, in wheat. During *kharif* 2013, the rainfall was well distributed and no irrigation was applied to clusterbean, whereas during *kharif* 2014, four post-sown irrigations each in 0.8 and 0.7 IW : CPE, while in 0.6 IW : CPE three post-sown irrigations were applied.

At maturity, the crops were harvested manually in both the crop seasons. Clusterbean, mature pods were manually picked followed by threshing. The biomass yield of wheat and clusterbean were harvested from 37.8 m$^2$ net area. To compute the system productivity, the yield of clusterbean was converted into wheat-equivalent yield. Total water used by wheat and clusterbean crops were computed and calculated in terms of system water-use efficiency (WUE) and system irrigation water productivity (IWP) by using following expression:

System water use = Total water use of wheat + Total water use of clusterbean

System water use was summarized and represented as $I_1$: CRI+ 0.9 IW : CPE for wheat and 0.8 IW : CPE for clusterbean, $I_2$: CRI + IW : CPE=0.75 for wheat and IW : CPE=0.70 for clusterbean and $I_3$: CRI + IW : CPE=0.60 for wheat and IW : CPE=0.60 for clusterbean. As proposed by Rajanna *et al.* (2016), soil profile moisture depletion in the entire root zone (0–60 cm) was determined gravimetrically at various crop growth stages. Evapo-transpiration (ET) was computed using the field water balance equation as given by Parihar *et al.* (2017). System productivity (t/ha) of wheat–clusterbean system was calculated in terms of wheat-equivalent yield (WEY) as:

$$\text{WEY (t/ha)} = \frac{\text{Clusterbean yield (t/ha)} \times \text{minimum support price of clusterbean (₹/t)}}{\text{Minimum support price of wheat (₹/t)}} \quad .. (2)$$

Profitability/net returns (₹/ha) was calculated by adding yearly net returns of the wheat and clusterbean during both the years.

The energy inputs consist renewable (seed, manual, crop residue, etc) and non-renewable energy [manual, fuel, machinery, chemical fertilizers (N, P and K) and agro-chemicals etc.]. For estimation of energy consumption used primary data on various inputs and agronomic practices. The energy output from the biomass grain/seed and straw/stover yield was also calculated. For estimation of energy inputs and outputs (MJ/ha) for each item of inputs and management practices, energy equivalents are given in Table 1. The energetic indices were calculated by using the following formulae as suggested by Mittal and Dhawan (1988); Parihar *et al.* (2017); Sudhakara *et al.* (2017).

$$\text{Net energy} = \text{Gross energy output (MJ/ha)} - \text{Energy input (MJ/ha)} \quad .. (3)$$

**Table 1.** Energy equivalents of inputs and outputs in agricultural operations

| Particular | Unit | Energy equivalent (MJ/unit) | References |
|---|---|---|---|
| *Inputs* | | | |
| Human labour | | | |
| Adult man | Man–hour | 1.96 | Mittal and Dhawan (1988) |
| Women | Women–hour | 1.57 | Mittal and Dhawan (1988) |
| Diesel | Litre | 56.31 | Mittal and Dhawan (1988) |
| Electricity | KWh | 11.93 | Mittal and Dhawan (1988) |
| Electric motor | kg | 64.8 | Mittal and Dhawan (1988) |
| Farm machinery | kg | 62.7 | Mittal and Dhawan (1988) |
| Irrigation water | Tone | 1.02 | Khosruzzaman *et al.* (2010) |
| Plough | kg | 180 | Mittal and Dhawan (1988) |
| Disc plough | kg | 149 | Mittal and Dhawan (1988) |
| Planter | kg | 133 | Mittal and Dhawan (1988) |
| Combine | kg | 116 | Mittal and Dhawan (1988) |
| *Chemical fertilizers* | | | |
| Nitrogen | kg | 60.6 | Mittal and Dhawan (1988) |
| Phosphate ($P_2O_5$) | kg | 11.1 | Mittal and Dhawan (1988) |
| Potash ($K_2O$) | kg | 6.7 | Mittal and Dhawan (1988) |
| Herbicide | kg | 288 | Mittal and Dhawan (1988) |
| Fungicide | kg | 196 | Khosruzzaman *et al.* (2010) |
| *Output* | | | |
| Wheat grain | kg | 14.7 | Mittal and Dhawan (1988) |
| Wheat straw | kg | 18.9 | Mittal and Dhawan (1988) |
| Cluster bean seed | kg | 18.0 | Mittal and Dhawan (1988) |
| Cluster bean straw (other residues) | kg | 19.4 | Khosruzzaman *et al.* (2010) |

Energy use efficiency (%) = Gross energy output (MJ/ha)/Total energy input (MJ/ha) .. (4)

Energy productivity (kg/MJ) = Grain and straw yield (kg/ha)/Total energy input (MJ/ha) .. (5)

Specific energy (MJ/kg) = Energy input (MJ/ha)/Grain yield (kg/ha) .. (6)

Economic analysis of the data was done on the basis of prevailing cost of inputs/operations and price of the marketable produce during respective cropping seasons. The data recorded were checked for homogeneity of variance prior to the analyzing the data for different parameters through analysis of variance (ANOVA) technique for a strip plot design. The results are presented at 5% level of significance ($P$=0.05) and difference between treatments were compared.

## RESULTS AND DISCUSSION

### *Wheat-clusterbean yields*

Wheat planted under FIRB gave significantly higher grain yield and had noticeable edge over CT, MT and ZT during the respective crop seasons. On pooled basis, the grain yield of wheat was significantly higher with FIRB (5.34 t/ha) compared to the other tillage practices (Table 2). In this study, FIRB planted wheat gave significantly higher grain yields by 15–19 % (wheat) and 28–30 % (clusterbean) than the other tillage practices. Each crop row under bed planting acts as a border row hence offered less competition for light, space and nutrition, ascribed to higher dry matter and the conversion of more photosynthates into the reproductive parts resulted in stronger plants, thereby giving higher yield attributes and grain yield (Zhang *et al*., 2007). Rajanna *et al.* (2017) reported that, additional yield advantage by increasing root density, deeper root-system and higher root dry weight occasioned with enhanced water uptake under FIRB. However, clusterbean planted under FIRB performed well and evidently shows that beds well suited to higher rainfall and dry regions owing to better water-holding capacity and better drainage system under FIRB encourages better plant growth (Rajanna *et al*., 2016).

Among moisture stress levels, grain yields increased significantly with increasing IW : CPE from 0.6 to 0.9 (Table 2). The grain yield of wheat was the highest with the application of irrigation at CRI + 0.9 IW : CPE (5.12 t/ha) and decreased significantly with decrease in each moisture regime, i.e. irrigation at CRI + IW : CPE=0.75 and 0.6. Overall, irrigation applied at higher moisture regimes recorded significantly higher wheat grain yield by 4–11% and clusterbean yields by 1–3% as compared to lower moisture regimes. This increase in economic yields might be owing to improved moisture and nutrient availability under higher moisture regimes, resulting in taller plants and enhanced crop growth. However, irrigation regimes did not influence significantly the yield of clusterbean during 2013. While during 2014, clusterbean yields were lower by 50% due to varied climatic conditions. Earlier published papers of Dhindwal *et al*. (2006) indicated that seed yield decrease with decreased in moisture regimes in clusterbean and greengram-based cropping systems.

Interaction effect of tillage and irrigation regimes were differed significantly between tillage and irrigation regimes on wheat–clusterbean productivity (Table 2). System productivity enhanced by 21–32 % under FIRB with $I_1$ over other combinations. The improvement in productivity owing to higher WUE, improved water availability, deeper root growth and better moisture uptake by roots coupled with better growing conditions provided under FIRB. In agreement with the current results the higher system productivity with beds and ZT was also reported by many workers in pulse–cereal-based cropping systems (Singh *et al*., 2010).

### *System productivity and net returns*

Tillage and irrigation regimes had significant effect on system productivity and net returns of wheat–clusterbean system over 2 years study (Table 2). The system productivity in terms of wheat-equivalent yield under FIRB planted wheat–clusterbean was significantly higher (7.80 t/ha) than CT, MT and ZT. Among irrigation regimes, irrigation applied at $I_1$ resulted significantly higher wheat, equivalent yield (WEY), i.e. 7.28 t/ha, as compared to $I_2$ (7.04 t/ha) and $I_3$ (6.66 t/ha). However, system productivity was lower by 13–23% with irrigation applied at $I_3$ levels than $I_1$ might be due to lower clusterbean and wheat productivity in the respective treatments. Among the interaction effects, $I_1$ irrigation regime applied under FIRB resulted in highest system productivity of 8.04 t/ha and the improvement was 21–32% than any other combinations. Application of irrigations at later stages of crop growth than critical stages might have caused scarcity of soil moisture and hence negative impact on productivity and profitability (Patil *et al*., 2014; Rajanna *et al*., 2017).

Planting of wheat–clusterbean in a system, on FIRB (bed) resulted in significantly higher system net returns of ₹58 × 10³/ha as compared to the other tillage practices

**Table 2.** Effect of tillage and irrigation regimes on system productivity (WEY) and system net returns of wheat–clusterbean system (pooled over 2 years)

| Treatment | Wheat grain yield (t/ha) | Clusterbean seed yield (t/ha) | System productivity (t/ha) | System net returns (₹×10³/ha) |
|---|---|---|---|---|
| *Tillage* | | | | |
| FIRB | 5.34 | 0.69 | 7.79 | 58.0 |
| CT | 4.65 | 0.63 | 6.90 | 42.6 |
| MT | 4.49 | 0.54 | 6.41 | 39.7 |
| ZT | 5.11 | 0.49 | 6.87 | 50.4 |
| CD (*P*=0.05) | 0.17 | 0.05 | 0.29 | 3.8 |
| *Irrigation regime* | | | | |
| $I_1$ | 5.12 | 0.60 | 7.28 | 50.7 |
| $I_2$ | 4.95 | 0.59 | 7.04 | 49.0 |
| $I_3$ | 4.61 | 0.57 | 6.66 | 43.3 |
| CD (*P*=0.05) | 0.09 | NS | 0.21 | 2.8 |
| *Tillage × Irrigation regime* | | | | |
| FIRB × $I_1$ | 5.48 | 0.71 | 8.04 | 60.4 |
| FIRB × $I_2$ | 5.39 | 0.68 | 7.80 | 58.6 |
| FIRB × $I_3$ | 5.15 | 0.67 | 7.55 | 55.0 |
| CT × $I_1$ | 5.03 | 0.66 | 7.41 | 49.3 |
| CT × $I_2$ | 4.67 | 0.65 | 6.97 | 44.2 |
| CT × $I_3$ | 4.24 | 0.58 | 6.32 | 34.3 |
| MT × $I_1$ | 4.87 | 0.54 | 6.82 | 44.1 |
| MT × $I_2$ | 4.45 | 0.52 | 6.33 | 39.4 |
| MT × $I_3$ | 4.14 | 0.55 | 6.10 | 35.6 |
| ZT × $I_1$ | 5.11 | 0.48 | 6.85 | 49.1 |
| ZT × $I_2$ | 5.29 | 0.50 | 7.08 | 53.8 |
| ZT × $I_3$ | 4.92 | 0.49 | 6.67 | 48.2 |
| CD (P=0.05) | 0.19 | NS | 0.37 | 4.8 |

FIRB, $I_1$, CRI + IW : CPE, 0.90 for wheat and IW : CPE, 0.80 for clusterbean; CT, $I_2$, CRI + IW : CPE, 0.75 for wheat and IW: CPE, 0.70 for clusterbean; MT, and $I_3$, CRI + IW : CPE, 0.60 for wheat and ZT, IW : CPE, 0.60 for clusterbean; NS, Non-significant.

(Table 2). Overall, there was a reduction of 13–52% net returns under CT, ZT and MT as compared to FIRB. The net returns increased over time by adoption of improved tillage (FIRB and ZT) and irrigation practices compared to CT where 56% reduction in net returns was observed. Study revealed that higher system net returns were consistent and recorded 112–125% higher system net returns in FIRB with $I_1$ compared to CT, might be owing to application of timely and frequent irrigations particularly at higher moisture regimes encourages crop growth by avoiding water stress leads to higher productivity and it reflected on net returns. Interestingly, $I_1$ gave 10–23% highest system profitability over $I_3$, but the difference between $I_1$ and $I_2$ was not marked significantly. The system profitability, in relations to net returns was improved by 31–79% under FIRB in $I_1$ compared to CT, MT and ZT under all the moisture stress levels. However, irrigation applied with both $I_1$ and $I_2$ under either FIRB or ZT exhibited equally higher profitability of wheat–clusterbean system compared with the other treatment combinations. Interestingly, ZT with any moisture stress levels recorded 17–21 % lower system net returns than FIRB.

### *System water use and water productivity*

Total water use by wheat–clusterbean system was lowest with FIRB (91.9 cm) than the other tillage practices. Similarly, the amount of irrigation water applied was the lowest in FIRB (22.4 cm), followed by ZT, MT and the highest with CT (29.2 cm) in the respective crop seasons. The lowest total water use (3–6%) and irrigation water (13–16%) were recorded in the wheat–clusterbean system under FIRB, followed by ZT (3.9% and 3.0%) as compared to CT and MT (Fig. 1). The lower water use in FIRB might be due to changed land configuration, wherein least quantity of water was applied and it irrigates the crop by lateral movement of water and hence lower depletion from soil resulted lower ET through furrows (Rajanna *et al.*, 2017; Rajanna *et al.,* 2018). Among the irrigation regimes, the highest system water use and irrigation water applied was observed with $I_1$ (96.9 cm) irrigation regime, followed by $I_2$ (94.7 cm) and $I_3$ (93.1 cm). Overall, about 3–5% greater water used by wheat–clusterbean under $I_1$ might be due to availability of more moisture under the respective plots due to a greater number of irrigations were applied.

The WUE of wheat–clusterbean system was found greater (18–28%) than CT and MT, but it was 12–20% higher with FIRB planting (Fig. 1). Similarly, the irrigation water productivity (IWP) of the wheat–clusterbean was higher (25–35%) with FIRBs followed by ZT>MT>CT. Considerably higher WUE and IWP were obtained under FIRB owing to relatively better system productivity and lower system water use. Out results conform the findings

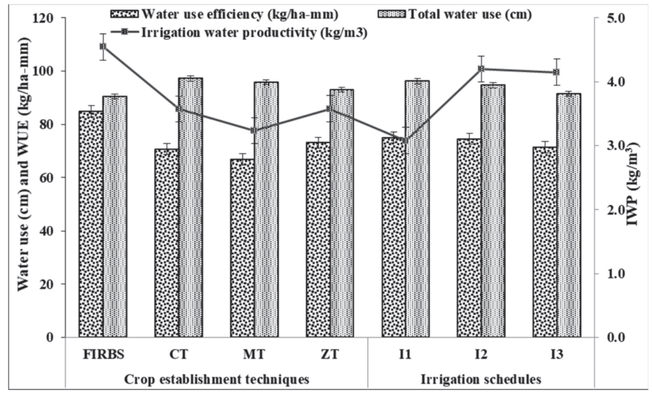


**Fig. 1.** System water-use, water-use efficiency (WUE) and irrigation water productivity (IWP) in wheat–clusterbean sequence.

of Karunakaran and Behera (2013) in soybean–wheat system under bed system either adopting conventional tillage-bed or skipping CT-bed with zero tillage-bed. Among the irrigation regimes, irrigation applied at $I_1$ resulted in the higher WUE (72.8 kg/ha–cm), followed by $I_2$ and least in $I_3$. The WUE was 2–6% higher with higher moisture regimes than that with lower moisture regimes during both the crop seasons. Likely, application of irrigation at $I_2$ recorded 18–47% higher IWP compared to $I_1$. During 2014, IWP in the second year was lowered by 60–70% as compared to 2013. Since no irrigation was applied in clusterbean during 2013 due to well-distributed rainfall, the WP could not be calculated.

### *Energy-use efficiency and productivity*

The current study analyzed the positive effects of tillage and irrigation regimes on mean net energy, energy productivity and energy-use efficiency of wheat–clusterbean system. The total operational energy input was the maximum in FIRB under $I_1$ in wheat–clusterbean system and the minimum in ZT with $I_3$ compared to the other treatment combinations (Tables 3, 4). Input energy requirement under ZT was minimum (18,298 MJ/ha) and maximum under beds (21,818 MJ/ha) for wheat. The respective value for clusterbean varies from 6,685 and 9,928 MJ/ha under ZT and FIRB respectively. Similarly, input energy requirement was the maximum under irrigation regime of IW : CPE=0.9 for wheat compared to IW : CPE=0.75 while it was minimum under IW: CPE=0.6. However, in clusterbean, input energy requirement followed the same trend as that of wheat irrigation regimes during the respective seasons. However, FIRB with all the irrigation regimes produced considerably maximum pooled net energy than CT, MT and ZT under irrigation regimes. Likewise, FIRB enumerated significantly higher pooled system net energy (347.5 × $10^3$ MJ/ha) compared to ZT and CT. The lowest pooled system net energy was obtained with minimum tillage

**Table 3.** Wheat and clusterbean energetics, productivity and energy-use efficiency under tillage and irrigation regimes (pooled over 2 years)

| Treatment | Wheat | | | | | Clusterbean | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Energy input (MJ/ha) | Net energy ($10^3$MJ/ha) | Energy-use efficiency | Energy productivity (g/MJ) | Specific energy (MJ/kg) | Energy input (MJ/ha) | Net energy ($10^3$ MJ/ha) | Energy-use efficiency | Energy productivity (g/MJ) | Specific energy (MJ/kg) |
| ***Ti****llage* | | | | | | | | | | |
| FIRB | 21,818 | 283.4 | 14.2 | 247.4 | 4.05 | 9,928 | 64.1 | 8.01 | 75.2 | 16.8 |
| CT | 21,568 | 252.2 | 12.6 | 213.1 | 4.74 | 9,836 | 61.8 | 7.66 | 67.8 | 18.4 |
| MT | 19,807 | 250.7 | 13.7 | 226.4 | 4.46 | 8,328 | 53.2 | 7.96 | 69.9 | 18.0 |
| ZT | 18,298 | 275.8 | 16.1 | 279.0 | 3.60 | 6,685 | 52.2 | 9.71 | 81.2 | 15.9 |
| CD (*P*=0.05) | - | 8.0 | 0.40 | 8.6 | 0.16 | - | 3.87 | 0.49 | 7.0 | 1.9 |
| *Irrigation regime* | | | | | | | | | | |
| $I_1$ | 20,937 | 275.7 | 14.2 | 245.6 | 4.11 | 8,784 | 58.9 | 8.41 | 74.3 | 16.7 |
| $I_2$ | 20,094 | 268.0 | 14.5 | 247.9 | 4.11 | 8,803 | 57.7 | 8.29 | 73.2 | 17.6 |
| $I_3$ | 20,086 | 253.0 | 13.7 | 231.0 | 4.42 | 8,496 | 56.9 | 8.32 | 73.1 | 17.4 |
| CD (*P*=0.05) | - | 4.6 | 0.21 | 4.6 | 0.12 | - | 1.84 | 0.27 | 5.4 | NS |

FIRB, $I_1$, CRI + IW : CPE, 0.90 for wheat and IW : CPE, 0.80 for clusterbean; CT, $I_2$, CRI + IW : CPE, 0.75 for wheat and IW: CPE, 0.70 for clusterbean; MT, and $I_3$, CRI + IW : CPE, 0.60 for wheat and ZT, IW : CPE, 0.60 for clusterbean; NS, Non-significant.

**Table 4.** Total energetics, productivity and energy-use efficiency of wheat–clusterbean system under tillage and irrigation regimes (pooled over 2 years)

| Treatment | System energy input (MJ/ha) | System net energy ($10^3$MJ/ha) | System energy-use efficiency (Output : input ratio) | System energy productivity (g/MJ) | System specific energy (MJ/kg) |
|---|---|---|---|---|---|
| *Tillage* | | | | | |
| FIRB | 31,745 | 347.5 | 22.2 | 322.6 | 20.8 |
| CT | 31,404 | 314.0 | 20.2 | 280.9 | 23.1 |
| MT | 28,135 | 304.0 | 21.6 | 296.2 | 22.5 |
| ZT | 24,983 | 328.0 | 25.8 | 360.2 | 19.5 |
| CD (*P*=0.05) | - | 7.47 | 0.53 | 13.4 | 2.0 |
| *Irrigation regime* | | | | | |
| $I_1$ | 29,721 | 334.5 | 22.6 | 319.9 | 20.8 |
| $I_2$ | 28,897 | 325.7 | 22.7 | 320.9 | 21.8 |
| $I_3$ | 28,582 | 309.9 | 22.0 | 304.1 | 21.9 |
| CD (*P*=0.05) | - | 5.67 | 0.45 | 8.5 | NS |
| *Tillage × Irrigation regime* | | | | | |
| FIRB × $I_1$ | 32,350 | 355.9 | 22.2 | 324.8 | 20.1 |
| FIRB × $I_2$ | 31,592 | 348.8 | 22.3 | 326.4 | 21.2 |
| FIRB × $I_3$ | 31,295 | 337.9 | 21.9 | 316.6 | 21.3 |
| CT × $I_1$ | 32,090 | 333.7 | 20.9 | 296.5 | 21.7 |
| CT × $I_2$ | 31,216 | 316.3 | 20.5 | 286.0 | 23.0 |
| CT × $I_3$ | 30,906 | 292.3 | 19.4 | 260.2 | 24.7 |
| MT × $I_1$ | 28,805 | 319.0 | 22.1 | 308.6 | 21.9 |
| MT × $I_2$ | 27,965 | 303.5 | 21.7 | 295.7 | 23.5 |
| MT × $I_3$ | 27,635 | 289.3 | 21.1 | 284.2 | 22.1 |
| ZT × $I_1$ | 25,641 | 329.6 | 25.4 | 349.6 | 19.6 |
| ZT × $I_2$ | 24,815 | 334.4 | 26.4 | 375.8 | 19.4 |
| ZT × $I_3$ | 24,491 | 319.9 | 25.6 | 355.3 | 19.5 |
| CD (*P*=0.05) | - | 10.3 | 0.51 | 14.1 | NS |

FIRB, $I_1$, CRI + IW : CPE, 0.90 for wheat and IW : CPE, 0.80 for clusterbean; CT, $I_2$, CRI + IW : CPE, 0.75 for wheat and IW : CPE, 0.70 for clusterbean; MT, and $I_3$, CRI + IW : CPE, 0.60 for wheat and ZT, IW : CPE, 0.60 for clusterbean; NS, Non-significant.

(MT) compared to the others. While higher energy-use efficiency (25.8%) and energy productivity (360.2 g/MJ) recorded under ZT in comparison with other tillage practices. Among irrigation regimes, irrigation applied at higher moisture regime ($I_1$) resulted in significantly higher system pooled net energy ($334.5 \times 10^3$ MJ/ha) than lower moisture regimes ($I_2$ and $I_3$). Lower moisture regime of $I_2$ resulted in significantly higher system energy-use efficiency (22.7%) and energy productivity (320.9 g/MJ) than other higher and lower moisture regimes.

Tillage and irrigation regimes interaction effects were significant ($P < 0.05$) on system net energy, energy-use efficiency and energy productivity (Table 4). Significantly greater pooled system net energy ($355.9 \times 10^3$ MJ/ha) perceived under FIRB with $I_1$ over the other combinations. The ZT with $I_2$ attained the maximum system energy productivity than FIRB, MT and CT, which were higher by 11.6%, 21.6 % and 28.4% respectively. Similar trend was observed in system output: input ratio and it was increased to the tune of 16.7, 19.4 and 27.7% respectively. Though energy efficiencies were lower, system pooled specific energy was maximum with CT (23.1 MJ/kg) but at par with MT (22.5 MJ/kg) and least in ZT (19.5 MJ/kg). The specific energy use was lower by 18.8, 11.1 and 3.0% in ZT, FIRB and MT respectively. It shows higher energy accumulation capacity in ZT due to better environment for crop growth in terms of higher nutrient availability, better root growth and modulation of micro-climatic conditions with better water retention. The results demonstrated that ZT wheat seeding technology can play an important role in saving inputs, turnaround time, reducing energy usage, and environmental pollution, and improving farmers income (Kumar *et al*., 2013; Sudhakara *et al.,* 2017). Parihar *et al.* (2017) also reported higher energy indices under conservation agriculture (ZT plots) in semi-arid agro-ecologies of India. However, interaction effects and irrigation regimes did not influence significantly on specific energy during both the crop seasons.

In the present study, wheat and clusterbean planted in FIRB was found effective and emerging resource conservation technique under semi-arid climatic situation of IGP. Beds and ZT had improved yields, system productivity, system net returns, WUE, IWP, net energy outputs, energy productivity and efficiency. Besides, the total system water use was reduced by 3–4 % from the 4 crop seasons with overall saving of irrigated water by 11–16%. At all the growing conditions like high rainfall and water scarcity areas, bed planting offered set of circumstances of crop diversification by improving the system profitability and 60–70% of irrigation water productivity. Significant knowledge gaps have existed still with the efficiency and suitability of ZT and MT under varied climatic condition especially *kharif* where legume crops were grown.

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