Influence of integrated crop management practices on yield, PAR interception, resource-use-efficiency and energetics in pigeonpea in North Indian Plains

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Abstract

Aim : The aim of the present study was to assess the influence of different integrated crop management (ICM) practices on productivity, resource-use efficiency and energetics of pigeonpea crop so as to overcome various production- and climatic-vulnerabilities in Indo-Gangetic Plains Region (IGPR).

Methodology : A study was conducted during *Kharif* 2017 in pigeonpea under pigeonpea-wheat cropping system at IARI, New Delhi, India to assess the influence of nine different ICM modules [Conventional tillage (CT) based: 04 (ICM₁-ICM₄); Conservation agriculture (CA) based: 04 (ICM₅-ICM₈); Organic agriculture based: 01 (ICM₉)] on productivity, PAR interception, resource-use-efficiency and energetics in pigeonpea in randomized block design replicated thrice.

Results : Pigeonpea seed yield was significantly higher in ICM₇ (1.92 t ha⁻¹) – a CA-based ICM module which was followed by ICM₅, ICM₈ and ICM₆. In general, the CA based ICM modules showed an edge over CT based ICM modules with reference to growth, yield and PAR interception. The resource-use-efficiency indices like total water-use-efficiency (TWUE), irrigation water-use-efficiency (IWUE), economic water-productivity (WPE), partial factor productivity of applied nutrients (NPK) also exhibited same trend as that of seed yield with highest TWUE (2.96 kg ha-mm⁻¹) and WP_e (104.5 INR ha-mm⁻¹) in ICM₇ module. The energy output was highest in ICM₇ (2, 23, 664 MJ ha⁻¹) followed by ICM₅, ICM₈ and ICM₆. The trend of energy-use-efficiency was ICM₄>ICM₂>ICM₁>ICM₃>ICM₅>ICM₇>ICM₆>ICM₈, respectively.

Interpretation : Conservation agriculture (CA) based modules like ICM₇ can be recommended to the farmers for enhancing the plant growth, PAR interception, crop productivity, resource-use efficiency and energetics in pigeonpea alone or on pigeonpea-wheat cropping system basis in semi-arid Indo-Gangetic plains region (IGPR).

Key words: Energy dynamics, Integrated crop management, Pigeonpea, PAR interception, Resource use efficiency

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Introduction

It is important to increase the global agricultural production by 70% to meet the needs of an estimated world population of ~9.2 billion by 2050 (FAO, 2006). Also, an additional 100 m ha area is required by 2050 to feed this population, which is practically not feasible (FAO, 2017). Thus, food security, food safety and environmental sustainability are the major concerns to be addressed in current agricultural scenario (Choudhary and Suri, 2019). Currently, Indian agriculture is facing acute problems like degradation of soil, reduction in soil organic matter (Paul et al., 2014) and ground water table (Pandey, 2014). The decline in factor productivity and input-use efficiency (Singh et al., 2011; Jat et al., 2013), emerging multiple-nutrient deficiencies (Pooniya et al., 2015), degradation of natural resource base and changing climate (Choudhary and Suri, 2019) are other major issues which need utter attention of agronomists and policy planners for agricultural sustainability, especially under rice-wheat cropping system (RWCS) in Indo-Gangetic plains region (IGPR). Contamination and pollution of water-bodies resulting in health hazards (Paul et al., 2014), herbicide resistance (Dass et al., 2017), increasing problem of insect-pests and disease complexes and more dependence on agro-chemicals for pest management are another second generation issues affecting biodiversity and also humans, animals, plants and soil health (Pooniya et al., 2015).

To overcome the above challenges with climate-resilient and eco-friendly farm practices, the integrated crop management (ICM) practices may prove as a key strategy in present day crop production systems to cope-up these production vulnerabilities with high resource-use efficiency besides enhancing productivity and profitability over conventional farming (Choudhary et al., 2018; Das et al., 2018). ICM approach emphasize on using suitable agronomic management practices for raising a good crop, including crop diversification, integrated nutrient management (INM), integrated weed management (IWM), integrated water management (IWRM), integrated disease management (IDM) and integrated pest management (IPM), integrated energy management (IEM), etc. (Choudhary et al., 2018).

Overall, the ICM is an alternative system of crop production which conserves and enhances natural resources, beside producing quality food on an economically viable and sustainable foundation (Choudhary et al., 2018). The pigeonpea crop serves as an alternative crop for diversification of RWCS in IGPR. Moreover, majority of earlier studies in pigeonpea has been conducted while integrating one or more components like nutrients and/or weeds and/or water and/or tillage, etc. (Babu et al., 2014; Choudhary et al., 2018). Thus, the present study conspicuously aimed at assessing the influence of different ICM practices as a complete technology package (in module form) on productivity, resource-use efficiency (RUE) and energetics of pigeonpea under pigeonpea–wheat cropping system in IGPR.

Materials and Methods

Experimental set up: Current field investigation was undertaken during *Kharif* 2017 in pigeonpea crop under a pigeonpea–wheat cropping system at Experimental Farm of ICAR–Indian Agricultural Research Institute (IARI), New Delhi. The soil of experimental site was sandy-loam in texture with pH 8.0 and 0.427% soil organic carbon; while it had low available nitrogen (185.5 kg ha^{-1}), medium available phosphorus (13.9 kg ha^{-1}) and high available potassium (287.2 kg ha^{-1}). The treatments were laid-out in randomized block design (RBD) replicated thrice. The gross plot-size was $10.0 \text{ m} \times 4.2 \text{ m}$ (42.0 m^2) while net plot-size was $9.2 \text{ m} \times 2.8 \text{ m}$ (25.76 m^2).

The nine ICM modules of the experiment are: ICM₁: Conventional tillage (CT) + flat-beds (FB) + 100% RDF + pendimethalin (pendi) as pre-emergence (PE) @ $1 \text{ kg a.i. ha}^{-1}$ followed by (fb) imazethapyr (imaz) @ 75 g ha^{-1} as post-emergence (POE) at 25 DAS + 1 hand-weeding and its mulching at 40 DAS (1 HWM) + 3 irrigations (irr) + need based IDM/IPM; ICM₂: CT–FB + 75% RDF + AM fungi (AMF) + NPK-biofertilizers (NPK-bf) + pendi-PE fb imaz-POE + 1 HWM + 3 irr + need based IDM/IPM; ICM₃: CT + raised-beds (RB) + 100% RDF + pendi-PE fb imaz-POE + 1 HWM + 2 irr + need based IDM/IPM; ICM₄: CT–RB + 75% RDF + AMF + NPK-bf + pendi-PE fb imaz-POE + 1 HWM + 2 irr + need based IDM/IPM; ICM₅: Zero-tillage (ZT) + FB + wheat crop residues retention (CRR) @ 3 t ha^{-1} + 100% RDF + glyphosate pre-planting (PP) @ $1 \text{ kg a.i. ha}^{-1}$ 15 days prior to sowing fb pendi-PE fb imaz-POE + 1 HWM + 2 irr + need based IDM/IPM; ICM₆: ZT–FB + CRR @ 3 t ha^{-1} + 75% RDF + AMF + NPK-bf + glypho-PP fb pendi-PE fb imaz-POE + 1 HWM + 2 irr + need based IDM/IPM; ICM₇: ZT + permanent raised-beds (PRB) + CRR @ 3 t ha^{-1} + 100% RDF + glypho-PP fb pendi-PE fb imaz-POE + 1 HWM + 2 irr + need based IDM/IPM; ICM₈: ZT–PRB + CRR @ 3 t ha^{-1} + 75% RDF + AMF + NPK-bf + glypho-PP fb pendi-PE fb imaz-POE + 1 HWM + 2 irr + need based IDM/IPM; ICM₉: CT–FB + CRR @ 3 t ha^{-1} + FYM @ 5 t ha^{-1} + AMF + NPK-bf + 2 HWM at 20 & 40 DAS + 2 irr + need based organic IDM/IPM. For IDM and IPM, the need based use of fungicides and pesticides was done as per treatment plan.

Crop management: The experimental field was ploughed using a tractor drawn disc plough. The disking and harrowing were followed by planking. The field was laid-out for applying treatments under different ICM modules. All cultural operations were carried as per aforesaid treatment details. The pigeonpea variety Pusa-992 was sown in May, 2017 with recommended fertilizer dose of $30:60:40 \text{ kg N:P}_2\text{O}_5:\text{K}_2\text{O ha}^{-1}$ at $70 \times 20 \text{ cm}$ spacing. Thinning was done 15 days after sowing (DAS) to have desired plant population while gap filling was done at 20 DAS. The crop was harvested during November, 2017. Total rainfall received during entire crop growth period was 881.8 mm. The irrigations (60 mm each) and other moisture management practices were imposed as per treatment plan. After harvesting,

the crop was sun-dried, threshed plot-wise, cleaned and grains sun-dried till 10% seed moisture was obtained. Plant height, dry matter accumulation (DMA) and leaf area index (LAI), as well as seed yield were measured following the standard procedures of Rana *et al.* (2014).

Chlorophyll index, NDVI and PAR interception: Chlorophyll index (SPAD) was measured with soil and plant analysis department (SPAD) meter. Three plants from each experimental plot were selected. From each plant, three readings, *i.e.*, bottom, middle and top leaf, were taken by holding the leaf in between the sensors of chlorophyll meter. These readings were averaged to get a single value per plant, which was used for analysis. The normalized difference vegetation index (NDVI) values were measured with green seeker—hand held crop sensor by holding the instrument 45 cm above the crop canopy by holding the switch key in the green seeker and walking along the row of plants. Automatically, the instrument gave the NDVI values in its digital display. The photo synthetically active radiation (PAR) interception was measured by canopy analyser LP-80 AccuPAR. Three readings were taken in each experimental plot. Incident solar radiation was measured by holding the knob like structure under direct solar radiation. Transmitted solar radiation was measured by holding the lengthy tube like structure under the plant canopy inside the experimental plot. Thus, the intercepted solar radiation was calculated by the formula :

PAR interception = Incident solar radiation - transmitted solar radiation

Resource-use-efficiency indices: The partial factor productivity of applied nutrients ($PFP_N/PFP_P/PFP_K$) was calculated by computing the total applied nutrient (N/P/K) through inorganic fertilizers and/or through wheat crop residues retained and/or FYM in pigeonpea crop after precise estimations following standard analytical procedures (Rana *et al.*, 2014). The respective NPK content in wheat stalk (used as residue retention) were 0.51, 0.12 and 1.29%. Similarly, NPK content in FYM was estimated as 0.55, 0.28, and 0.51%, respectively. The pigeonpea seed yield (kg ha^{-1}) so obtained in each treatments/plot was divided by the total applied nutrients (through fertilizers and/or wheat crop residues and/or FYM) to estimate partial factor productivity of applied nutrients ($PFP_N/PFP_P/PFP_K$) as $\text{kg ha}^{-1} \text{kg}^{-1}$ of applied nutrients.

The total water use (TWU) was calculated by taking into consideration the total number of irrigations and depth of water applied (60 mm each irrigation) and effective rainfall during crop growth period. Total rainfall received during the pigeonpea crop season was 881.8 mm. During the crop period, 2 to 3 irrigations (each of 60 mm) were applied to the crop under different ICM modules. Effective rainfall was calculated by multiplying the total rainfall received during the entire period with the factor 0.60 for IARI soils. Thus, the total water use (effective rainfall + irrigation water) varied from 649.08 mm to 709.08 mm under different ICM modules. The total water-use efficiency (TWUE) was estimated

using standard procedure suggested by Choudhary and Suri (2019). The irrigation water-use efficiency (IWUE) was estimated using standard procedure suggested by Adeboye *et al.* (2015). Since, 2 to 3 irrigations (each of 60 mm) were applied to crops under different ICM modules. Thus, the irrigational water use varied from 120 mm to 180 mm under different ICM modules. The economic water productivity (WPE) was determined following the standard procedure of Igbadun *et al.* (2006).

Estimation of energy dynamics: In order to assess the energy dynamics and energy-use-efficiency of pigeonpea crop, each and every input used in pigeonpea production and respective output was converted into the form of energy, using standard energy equivalents. The energy equivalents and different energy efficiency indices were calculated using standard formulas as suggested by ISA (2014).

Statistical analyses: The data recorded on various parameters were subjected to statistical analyses following variance ANOVA as described by Gomez and Gomez (2010) and were tested at 5% level of significance ($P = 0.05$) to interpret the significant differences.

Results and Discussion

The ICM₇ module resulted in the tallest plants with largest dry matter accumulation (DMA) and leaf area index (LAI) which was, however, similar to ICM₅ (Table 1). Pigeonpea crop in modules with conventional tillage (CT) with and without residue retention exhibited lower LAI owing to poor growth as a result of initial high temperature stress followed by weed competition and water stagnation stress compared to CA-based ICM modules (Babu *et al.*, 2014). The LAI values in modules ICM₇, ICM₅, ICM₈ and ICM₆ exceeded 5.0 at later stages of growth; however it was maximum in ICM₇. This led to more efficient photosynthesis and dry matter accumulation in these modules with efficient weed suppression (Varatharajan and Choudhary, 2018). The crop in ICM₇ module was the earliest to attain branching stage followed by that in ICM₈, ICM₅ and ICM₆ (Table 2).

The ICM modules also differed significantly for days to flower initiation, 50% flowering and 50% pod filling. The number of days taken to maximum branching stage, flower initiation, 50% flowering and 50% pod filling occurred in advance in CA-based modules (ICM₅ – ICM₈) owing to better plant establishment and vigorous growth due to temperature modulation, no water-stagnation, and meagre weed and nutrient stress under CA-based modules compared to other ICM modules (Jakhar *et al.*, 2018; Choudhary *et al.*, 2018). However, physiological maturity was delayed by three days in CA-based ICM plots when compared with CT plots due to synchronous N supply under CA-based ICM plots (Babu *et al.*, 2014). The normalized differentiation vegetation index (NDVI) at 60 and 120 DAS was highest in ICM₇ module, due to even crop canopy with ample leaf growth in CA-based ICM modules (Table 3). SPAD (chlorophyll

Table 1: Effect of different ICM modules on growth and yield of pigeonpea

Treatment	Growth parameters (150 DAS)			Seed yield (t ha ⁻¹)
	Plant height (cm)	DMA (g plant ⁻¹)	LAI	
ICM ₁	222	197	3.77	1.71
ICM ₂	213	185	3.60	1.64
ICM ₃	235	208	4.22	1.79
ICM ₄	222	198	3.96	1.74
ICM ₅	253	249	5.80	1.85
ICM ₆	243	219	5.60	1.80
ICM ₇	258	261	5.93	1.92
ICM ₈	247	235	5.80	1.82
ICM ₉	212	182	3.37	1.54
SEm±	4	5	0.05	0.02
CD (P=0.05)	12	14	0.16	0.06

meter) have been shown to positively correlate with leaf greenness, leaf NO₃ status, photosynthesis and CO₂ assimilation (Papasavvas *et al.*, 2008). In this study, the SPAD values did not differ significantly among ICM modules. However, the photosynthetically active radiation (PAR) interception values at 75 DAS significantly differed among ICM modules. ICM₇ module showed the highest PAR [1472.1 µmol (photon) m⁻² s⁻¹] (Table 3). The PAR interception stood in the order of ICM₇ > ICM₅ > ICM₈ > ICM₆ > ICM₃ > ICM₄ > ICM₁ > ICM₂ > ICM₉. Significantly higher PAR interception in ICM₇ module resulted from higher LAI and consequent higher photosynthesis. Also, altered planting geometry (raised-bed planting) had influence in harnessing more solar energy due to good canopy development and crop growth (Ram *et al.*, 2013), ultimately leading to more plant photosynthesis and higher yield over flat-bed sowing (Choudhary and Suri, 2014; Poonyia *et al.*, 2015). Pigeonpea seed yield was

significantly higher in ICM₇ (1.92 t ha⁻¹) followed by ICM₅, ICM₈ and ICM₆ (Table 1). The ICM₃, ICM₄, ICM₁ and ICM₂ were in intermediate trend while ICM₉ produced minimum seed yield (1.54 t ha⁻¹). Seed yield of pigeonpea was higher under ICM₇ module due to moisture conservation in rainless span (Choudhary *et al.*, 2018). The CA based ICM modules with raised-bed sowing performed well over CT-based modules both under flat-beds and raised-bed in terms of productivity due to better growth and yield owing to less machine trafficking (Paul *et al.*, 2014); higher soil organic matter and better nutrient dynamics (Ram *et al.*, 2013), better soil physico-chemical and biological properties over CT plots (Babu *et al.*, 2014; Choudhary and Rahi, 2018), less weed stress (Dass *et al.*, 2017) and better moisture conservation in stress periods vis-a-vis less water stagnation in rainy period (Ram *et al.*, 2013); thus, leading to higher productivity over CT-based ICM modules.

Table 2: Effect of different ICM modules on days taken to various phenological stages of pigeonpea crop

Treatment	Days taken to various phenological stages				
	Branching	Flower initiation	50% flowering	50% pod filling	Physiological maturity
ICM ₁	97.0	121.0	131.7	142.7	168.3
ICM ₂	97.3	121.0	131.3	142.7	167.7
ICM ₃	97.7	120.7	131.0	140.3	168.0
ICM ₄	97.7	121.3	131.0	140.3	168.3
ICM ₅	83.7	115.7	125.0	133.7	171.3
ICM ₆	83.7	114.0	124.0	133.7	170.7
ICM ₇	82.7	114.7	124.3	134.3	171.7
ICM ₈	83.7	113.3	124.3	134.3	170.3
ICM ₉	89.3	120.7	128.0	135.0	172.3
SEm±	2.0	1.8	1.3	1.2	0.7
CD (P=0.05)	6.1	5.3	3.8	3.7	2.2

Table 3: Effect of different ICM modules on NDVI, SPAD and PAR interception of pigeonpea crop

Treatment	NDVI		SPAD		PAR interception [$\mu\text{mol (photon) m}^{-2}\text{ s}^{-1}$]
	60 DAS	120 DAS	60 DAS	120 DAS	75 DAS
ICM ₁	0.65	0.74	45.4	44.3	716.9
ICM ₂	0.65	0.71	45.2	43.4	698.8
ICM ₃	0.64	0.73	47.6	46.6	798.1
ICM ₄	0.64	0.72	46.2	45.0	723.9
ICM ₅	0.76	0.74	47.2	46.7	1218.1
ICM ₆	0.71	0.73	46.2	45.9	1131.9
ICM ₇	0.77	0.75	47.7	46.7	1472.1
ICM ₈	0.71	0.72	47.1	45.6	1143.3
ICM ₉	0.62	0.71	45.2	45.5	698.6
SEm $\pm$	0.03	0.01	1.4	1.1	113.4
CD (P=0.05)	0.08	NS	NS	NS	340.1

The partial factor productivity of applied nitrogen (PFP_N) was significantly higher (77.3 kg ha⁻¹ kg⁻¹ of applied N) in ICM₄ a CT-based ICM module (Table 4). The PFP of applied phosphorus (PFP_P) was significantly higher in ICM₉ (87.5 kg ha⁻¹ kg⁻¹ of applied P₂O₅) while ICM₅ experienced lowest PFP_P. PFP of applied potassium (PFP_K) was significantly higher (60.7 kg ha⁻¹ kg⁻¹ of applied K₂O) in ICM₄. The trend of PFP_N, PFP_P and PFP_K was greatly influenced by differential crop productivity and nutrient addition pattern (Choudhary and Suri, 2019).

Total rainfall obtained during the entire crop season was 881.8 mm. During the crop period, 2 to 3 irrigations (each of 60 mm) were given under different ICM modules. Therefore, the total water-use (effective rainfall + irrigation water) ranged between

649.08 to 709.08 mm among different ICM modules (Table 5). Total water use efficiency (TWUE) (2.96 kg ha-mm⁻¹) and irrigation water-use efficiency (IWUE) (16.0 kg ha-mm⁻¹) were highest in ICM₇. The economic water productivity (104.5 INR ha-mm⁻¹) was also highest in ICM₇ module. Overall, TWUE, IWUE and WP_E followed similar trend as that of pigeonpea seed yield. In general, conservation agriculture improve soil properties and increase soil water storage by decreasing bulk density and increasing porosity (Baker *et al.*, 2005). Crop residue retention acts as soil cover and has significant effect on soil moisture conservation and infiltration (Panachuki *et al.*, 2006) and water holding capacity (Paul *et al.*, 2014). The residue cover reduces the impact of rain drops, reduces soil erosion and acts as filter for sediments (Panachuki *et al.*, 2006). In addition, residue retention

Table 4: Effect of different ICM modules on partial factor productivity (PFP) of applied nutrients in pigeonpea crop

Treatment	Partial factor productivity (kg ha ⁻¹ kg ⁻¹ of applied nutrients)		
	PFP _N	PFP _P	PFP _K
ICM ₁	56.8	28.4	42.6
ICM ₂	73.0	36.5	54.8
ICM ₃	59.8	29.9	44.8
ICM ₄	77.3	38.7	58.0
ICM ₅	40.9	29.1	23.5
ICM ₆	47.5	37.0	26.2
ICM ₇	42.4	30.2	24.4
ICM ₈	48.1	37.4	26.5
ICM ₉	36.0	87.5	24.0
SEm $\pm$	0.6	1.0	0.4
CD (P=0.05)	1.9	2.9	1.3

Table 5: Effect of different ICM modules on total water use efficiency (TWUE), irrigation water use efficiency (IWUE) and economic water productivity (WPE) of pigeonpea crop

Treatment	Total water use (mm)	TWUE (kg ha-mm ⁻¹)	IWUE (kg ha-mm ⁻¹)	WP _E (INR ha-mm ⁻¹)
ICM ₁	709.08	2.40	9.5	87.5
ICM ₂	709.08	2.32	9.1	84.3
ICM ₃	649.08	2.76	14.9	97.6
ICM ₄	649.08	2.68	14.5	94.7
ICM ₅	649.08	2.86	15.4	100.8
ICM ₆	649.08	2.77	15.0	97.7
ICM ₇	649.08	2.96	16.0	104.5
ICM ₈	649.08	2.80	15.2	99.0
ICM ₉	649.08	2.37	12.8	83.8
SEm±	-	0.03	0.2	1.2
CD (P=0.05)	-	0.10	0.5	3.5

Table 6: Effect of different ICM modules on energy dynamics of pigeonpea crop

Treatment	Energy input (MJ ha ⁻¹)	Energy output (MJ ha ⁻¹)	Energy use efficiency	Energy productivity (kg MJ ⁻¹)	Specific energy (MJ kg ⁻¹)	Net energy (MJ ha ⁻¹)	Energy profitability
ICM ₁	11399	203396	17.84	0.150	6.69	191998	16.84
ICM ₂	10892	197037	18.09	0.151	6.63	186145	17.09
ICM ₃	11943	211196	17.68	0.150	6.66	199253	16.68
ICM ₄	11436	207172	18.12	0.152	6.57	195736	17.12
ICM ₅	35691	218741	6.13	0.052	19.27	183050	5.13
ICM ₆	35185	211614	6.01	0.051	19.59	176429	5.01
ICM ₇	36848	223664	6.07	0.052	19.19	186816	5.07
ICM ₈	36796	213851	5.81	0.049	20.22	177055	4.81
ICM ₉	39102	181032	4.63	0.039	25.45	141930	3.63
SEm±	-	6695	0.41	0.001	0.29	6695	0.41
CD (P=0.05)	-	20071	1.22	0.003	0.88	20071	1.22

in no-till plots has mean weekly temperature modulation of 0°C to 1.5°C lower than mould-plough till plots (Choudhary *et al.*, 2018). Addition of crop residues also increases the mean aggregate diameter. Thus, soils under CA-based ICM modules are able to store more amount of water. All these factors together might have increased the water storage in soil and reduced evaporation, thus, ultimately resulting in increased WUE. It also increased the crop yields with reduced number of irrigations, thus, saving irrigation water (Ram *et al.*, 2013).

Maximum energy input was recorded in ICM₉ (39,102 MJ ha⁻¹), while ICM₂ a CT-based flat-bed ICM module recorded lowest energy input (Table 6), however, the energy output was significantly higher in ICM₁ (2,23,664 MJ ha⁻¹). Generally, CA-based ICM modules had higher energy input than CT based ICM modules. Since, the residues were counted in energy input, thus, CA-based ICM modules resulted in higher energy input. There

was reduction in energy input in zero-till plots due to savings from ploughing and seed-bed preparation, but, this was compensated by energy involved in crop residue retention, as crop residues were also considered in energy input. Energy output was highest in ICM₇ due to higher crop productivity. Raised-bed modules had higher energy input because of energy use in bed-making process. Similarly, ICM modules with 100% RDF had comparatively more energy input than 75% RDF based ICM modules. The energy use efficiency (EUE), energy productivity and energy profitability were significantly higher in ICM₄. However, specific energy was significantly higher in ICM₉ (25.45 MJ kg⁻¹). Likewise, the net energy was significantly higher in ICM₃ (1,99,253 MJ ha⁻¹). In general, higher EUE, energy productivity, net energy and energy profitability were found in CT-based raised-bed modules (ICM₃ and ICM₄) followed by CT-based flat-bed ICM modules (ICM₁ and ICM₂). This was due to better yields with less input of energy in CT-based modules than CA-based ICM modules.

Overall, conservation agriculture based module was the best performer in terms of growth, productivity, resource-use efficiency and energy output over other CT-based and organic-based ICM modules. Hence, the superior ICM modules like ICM₇ can be recommended to farmers in pigeonpea alone or on pigeonpea-wheat cropping system basis in semi-arid regions of Indo-Gangetic plains.

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