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Integrated crop management practices for enhancing productivity, profitability, production-efficiency and monetary-efficiency of pigeonpea (*Cajanus cajan*) in Indo-Gangetic plains region

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Pigeonpea [*Cajanus cajan* (L.) Millsp] is one of the most important pulse crops of India, grown on 5.4 million ha area producing 4.8 million tonnes grains with an average yield of 0.89 t/ha (Choudhary *et al.* 2015). It is fifth most prominent pulse crop in world and second most important crop after chickpea in India (Choudhary *et al*. 2015). Pigeonpea has deep root system which helps in bio-recycling of nutrients from deeper layers and also has the ability to bear the moisture stress in rainfed ecologies and requires less irrigation water when grown under irrigated conditions. It being a highly elastic crop shows adaptation to a wide range of spacing, thus, it can amply cover the ground area and suppress the weeds as well (Babu *et al.* 2013, Choudhary *et al*. 2015). It also contributes an ample quantity of leaf-litter which acts as soil cover reducing weeds and soil erosion, improving infiltration and soil fertility (Dass and Sudhishri 2010, Varatharajan 2018). Due to all these merits, pigeonpea crop is an important alternate option for diversification of rice-wheat cropping system in Indo-Gangetic plains region (IGPR) to curtail the resource-and production-vulnerabilities in the region. However, the productivity of pigeonpea is very low due to poor adoption of improved cultivars and farm technology, early seedling mortality due to water stagnation, severe weed infestation due to wider spacing and disease and pest infestation (Choudhary *et al*. 2015). So, the conventional pigeonpea production practices need redesigning to harness its production potential in IGPR which is already suffering from various production and resource constraints (Choudhary *et al*. 2018). In this direction, integrated crop management (ICM) an innovative crop management concept, may cope-up these production vulnerabilities with high resource-use efficiency (RUE) besides enhancing productivity and profitability over conventional farming (Babu *et al.* 2016, Choudhary *et al*. 2018). It suggests using suitable agronomic management practices for raising a good crop including 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. Thus, ICM is an alternative system of crop production which conserves and enhances natural resources while producing quality food on an economically viable and sustainable foundation (Rohullah 2016, Choudhary *et al*. 2018). Most of the earlier studies in pigeonpea were conducted with integration of two or three components like nutrients and/or weeds and/or water and/or tillage, etc. None of the earlier studies were conducted with integration of all the above said management components. Thus, present study aims to assess the effect of different ICM modules as a complete technology package on productivity, profitability and RUE of pigeonpea in IGPR.

A field experiment was initiated in the year 2015 in pigeonpea-wheat cropping system while current study was undertaken after two years of experimentation in pigeonpea during *kharif* 2017 at the Experimental Farm of ICAR–Indian Agricultural Research Institute (IARI), New Delhi, India (28º63' N latitude; 77º15' E longitude; 228.6 m altitude). The experimental site is located in semi-arid sub-tropics having sandy-loam soil belonging to Typic *Ustochrepts*. The climate of experimental site is semi-arid with dry hot summers and cold winters with average annual rainfall of 650 mm, 80% of which is received through 'South–West Monsoons' during July–September, and the rest is received during the 'Western Disturbances' from December–February. The mean annual evaporation is ~850 mm. The hottest months are May and June with mean daily maximum temperature varying from 40–46°C, whereas December–January are the coldest months with mean daily minimum temperature ranging from 5–8°C. The physico-chemical analysis of composite soil samples done at the initiation of the experiment using standard procedures (Rana *et al*. 2014), revealed that the soil had

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pH 8.0, oxidizable-soil organic C 0.427%, alkaline $KMnO_4$ oxidizable-N 185.5 kg/ha, 0.5 M $NaHCO_3$ extractable-P 13.9 kg/ha and 1 N NH_4OAc extractable-K 287.2 kg/ha. The experiment was laid-out in a randomized block design with three replications.

The treatments consisted of nine ICM modules [Conventional tillage (CT) based: 04 (ICM_1–ICM_4); Conservation agriculture (CA) based: 04 (ICM_5–ICM_8); and Organic agriculture based: 01 (ICM_9)]. For integrated nutrient management (INM), the crop was supplied with nutrients through urea, single super phosphate and muriate of potash in CT and CA based ICM modules (ICM_1–ICM_8) besides NPK-biofertilizer (NPK-*bf*) and arbuscular mycorrhizal fungi (AMF) as per treatment plan (Table 1). In case of organic module (ICM_9), the nutrients were supplied through farmyard manure (FYM), NPK-*bf* and AMF (Table 1). The FYM contained 0.55, 0.28, and 0.51% N, P_2O_5 and K_2O, respectively on oven-dry weight basis. In CA and organic agriculture based ICM modules, the wheat crop residue retention (CRR) @ 3 t/ha was also done as a component of nutrient/weed/moisture management. Thus, accordingly the weeds were managed through pendimethalin @ 1.0 kg a.i./ha as pre-emergence followed by imazethapyr @ 75 g/ha as post-emergence in CT and CA based ICM modules (ICM_1–ICM_8) besides one hand-weeding (HW). In case of CA based ICM modules, a pre-planting spray of glyphosate @ 1.0 kg a.i./ha was also done. In organic module (ICM_9), two hand-weedings were done for weed management as per the treatment plan (Table 1). For integrated disease management (IDM) and integrated pest management (IPM), the need based use of fungicides and pesticides was also done as per the treatment plan (Table 1). The seed-bed was prepared with double-disc and harrowing in CT based ICM modules while there was a pre-plant spray of glyphosate in CA based ICM modules. The pigeonpea variety Pusa-992 was sown on 23rd May, 2017 at a spacing of 70 × 30 cm and harvested on 8th November, 2017. The NPK fertilizers were applied basally through seed drill/behind the plough while seed sowing as per the treatment plan in Table 1. 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 the treatment plan. After harvesting, the crop was sun-dried, threshed plot-wise, cleaned and grains sun-dried till 10% seed moisture was obtained. The seed and stalk yields as well economics were determined using standard procedures suggested by Rana *et al.* (2014). Production-efficiency (kg/ha/day) and monetary-efficiency (`/ha/day) of each treatment was calculated as per the standard formula (Kumar *et al.* 2015). The statistical analysis was done following standard procedure suggested by Rana *et al.* (2014).

The seed (1.92 t/ha) and stalk yield (10.86 t/ha) were found to be significantly higher in ICM_7 – a conservation agriculture(CA) based ICM module [zero tillage (ZT)–permanent raised bed (PRB) + crop residue retention (CRR) @ 3 t/ha + 100% recommended dose of fertilizer (100% RDF) + (glyphosate-pre-plant followed by (fb) pendimethalin-pre emergence (Pend-PE) fb imazethapyr-

Table 1 Detailed description of nine integrated crop management (ICM) modules followed in pigeonpea crop

ICM modules	Details of the ICM modules
ICM_1	[{Conventional tillage (CT)} + {Flat-beds (FB)} + {100% of recommended dose of fertilizers-RDF @ 30:60:40 kg $N:P_2O_5:K_2O$ ha^{-1} (RDF)} + {pendimethalin as pre-emergence (PE) @ 1 kg a.i. ha^{-1} followed by (fb) imazethapyr @ 75 g ha^{-1}as post-emergence (POE) at 25 DAS + 1 hand-weeding and its mulching at 40 DAS (1 HW-mulch)} + {3 irrigations (irr)} + {need based IDM/IPM*}]
ICM_2	[{CT–FB} + {(75% RDF + AM fungi (AMF) + NPK-biofertilizer formulation (NPK-*bf*)} + {Pendi-PE fb Imaz-POE + 1 HW-mulch} + {3 irr} + {Need based IDM/IPM}]
ICM_3	[{Conventional tillage (CT)} + {Raised-beds (RB)} + {100% RDF} + {Pendi-PE fb Imaz-POE + 1 HW-mulch} + {2 irrigations} + {need based IDM/IPM}]
ICM_4	[{CT–RB} + {75% RDF + AMF + NPK-*bf*} + {Pendi-PE fb Imaz-POE + 1 HW-mulch} + {2 irr} + {need based IDM/IPM}]
ICM_5	[{Zero-tillage (ZT)} + {FB} + {Wheat crop residues retention (CRR) @ 3 t ha^{-1}} + {100% RDF} + {Glyphosate pre-planting (PP) @ 1 kg a.i. ha^{-1} 15 days prior to sowing fb Pendi-PE fb Imaz-POE + 1 HW-mulch} + {2 irr} + {need based IDM/IPM}]
ICM_6	[{ZT–FB} + {CRR @ 3 t ha^{-1}} + {75% RDF + AMF + NPK-*bf*} + {Glypho-PP fb Pendi-PE fb Imaz-POE + 1 HW-mulch} + {2 irr} + {need based IDM/IPM}]
ICM_7	[{ZT} + {Permanent raised-beds (PRB)} + {CRR @ 3 t ha^{-1}} + {100% RDF} + {Glypho-PP fb Pendi-PE fb Imaz-POE + 1 HW-mulch} + {2 irr} + {need based IDM/IPM}]
ICM_8	[{ZT–PRB + CRR @ 3 t ha^{-1}} + {75% RDF + AMF + NPK-*bf*} + {Glypho-PP fb Pendi-PE fb Imaz-POE + 1 HW-mulch} + {2 irr} + {need based IDM/IPM}]
ICM_9	[{CT–FB} + {(CRR) @ 3 t ha^{-1} + FYM @ 5 t ha^{-1} + AMF + NPK-*bf*}+ {2 HW-mulch at 20 & 40 DAS} + {2 irr} + {need based organic IDM/IPM}]

*IPM: Integrated pest management; IDM: Integrated disease management; Recommended dose of fertilizers (RDF): 30: 60: 40 kg N: P_2O_5: K_2O/ha.

Table 2 Effect of different ICM modules on crop productivity and profitability in pigeonpea crop

Treatment	Crop productivity			Economic analysis			
	Seed yield (t/ha)	Stover yield (t/ha)	Harvest index (%)	Cost of cultivation (₹/ha)	Gross returns (₹/ha)	Net returns (₹/ha)	B: C ratio
ICM_1	1.71	9.91	14.7	30,868	1,02,830	71,962	3.33
ICM_2	1.64	9.60	14.6	30,580	99,166	68,586	3.24
ICM_3	1.79	10.27	14.9	31,795	1,08,005	76,211	3.40
ICM_4	1.74	10.09	14.7	31,507	1,04,919	73,411	3.33
ICM_5	1.85	10.64	14.9	32,001	1,11,645	79,645	3.49
ICM_6	1.80	10.29	14.9	31,404	1,08,207	76,803	3.45
ICM_7	1.92	10.86	15.1	32,722	1,15,498	82,776	3.53
ICM_8	1.82	10.39	14.9	32,434	1,09,584	77,150	3.38
ICM_9	1.54	8.80	14.9	35,504	92,730	57,226	2.61
SEm±	0.02	0.38	0.5		1,092	1,092	0.03
CD (P = 0.05)	0.06	1.13	NS		3,274	3,274	0.10

post emergence (Imaz-PoE) + 1 hand-weeding (HW)-mulch) + 2 irrigations + need based IDM/IPM] which was followed by ICM_5, ICM_8 and ICM_6, respectively (Table 2). While the organic module ICM_9 [conventional tillage-flat bed + CRR @ 3 t/ha + (FYM @ 5 t/ha + AMF + NPK-*bf*) + 2 HW-mulch + 2 irrigations + need based organic IDM/IPM] produced lowest seed (1.54 t/ha) and stalk yield (8.80 t/ha). The trend of seed and stalk yield was ICM_7>ICM_5>ICM_8>ICM_6>ICM_3>ICM_4>ICM_1>ICM_2>ICM_9, respectively (Table 2). Harvest index was higher in ICM_7 (15.1%) followed by ICM_5, ICM_6, ICM_8, ICM_9 and ICM_3 while ICM_2 exhibited least harvest index (14.6%). It indicates the ability of the plants having efficient source-sink relationships (Choudhary *et al*. 2010). Generally, CA based ICM modules with raised-bed sowing performed well in terms of seed and stalk yield which might be due to less machine trafficking (Paul *et al*. 2014 Choudhary 2016), less water stagnation (Ram *et al.* 2013) and more moisture conservation in rainless span (Dass *et al.* 2017). Higher soil organic matter and better nutrient dynamics and soil physico-chemical and microbiological properties are other reasons for higher productivity of CA based ICM modules (Choudhary 2016 Rohullah 2016 Prasad *et al*. 2016). The ZT based ICM modules also conserved more moisture in soil over CT plots (Babu *et al*. 2014, Paul *et al*. 2014), leading to better crop growth, yield attributes and yield in pigeonpea (Rohullah 2016). In addition to this, ZT based ICM modules added ~1.5 t/ha of pigeonpea leaf fall which had positive effect on physical, chemical and biological parameters of soil which is conducive for better plant growth, yield attributes and yield. The ICM_7 module was performing better than other modules since beginning. Thus, crop sown on raised-bed with residue retention in CA might have increased root aeration, enhanced root growth, higher dry matter accumulation, higher chlorophyll content altogether led to higher seed and stalk yield (Rohullah 2016).

ICM modules varied in their input-use and agronomic operations (Table 2), *viz.* tillage, crop residue management, land configuration, fertilizer doses, weed management and irrigation management operations. Hence, the cost of cultivation varied accordingly among different ICM modules from ₹ 30580 to 35504/ha. Difference in cost of cultivation among ICM modules was due to different combinations of management practices undertaken (Rohullah 2016). ICM_9 organic module had CT

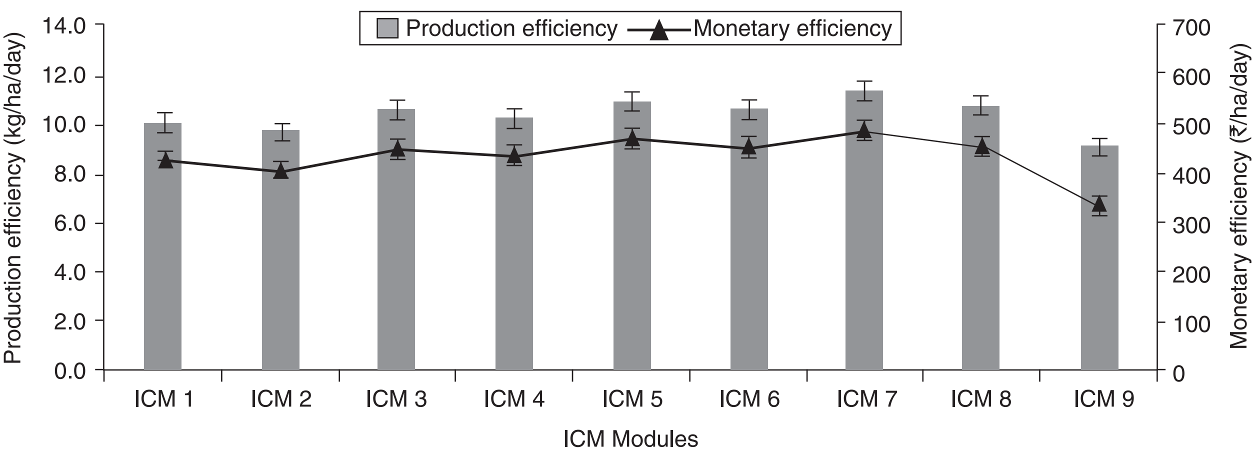

Fig 1 Effect of different ICM modules on production efficiency (kg/ha/day) and monetary efficiency (₹/ha/day) in pigeonpea.

in addition to one extra hand-weeding and wheat-residue retention which spiked its cost of cultivation to be higher among other ICM modules (Choudhary and Rahi 2018). In general, the gross and net returns, and benefit: cost (B: C) ratio were higher under CA based ICM modules than the CT-based ICM modules owing to higher yield (Rohullah 2016). The results revealed that significantly higher gross returns were observed in ICM_7 (` 115498/ha) which was followed by $ICM_5$, $ICM_8$ and $ICM_6$ while $ICM_9$ resulted in lowest gross returns. The gross returns of pigeonpea followed the similar trend as that of seed yield (Table 2). The results revealed that significantly higher net returns were observed in $ICM_7$ (` 82776/ha) which was followed by ICM_5, ICM_8, ICM_6 and ICM_5while ICM_9 resulted in lowest net returns. The ICM_7 reported significantly higher B: C ratio (3.53) which was followed by ICM_5, ICM_6, ICM_3, ICM_8, ICM_4, ICM_1, ICM_2 and ICM_9, respectively owing to higher productivity in ICM_7 module. Generally, the ICM modules with raised-bed/permanent raised-beds had higher B: C ratio compared to other ICM modules with conventional tillage and flat-bed sowing following the similar trend as that of seed yield in different ICM modules, thus, influencing the economic in the same fashion.

The results revealed that CA-based module, ICM_7 recorded significantly higher production-efficiency (PE) (11.3 kg/ha/day) followed by ICM_5, ICM_8, ICM_6 and ICM_3 while organic module ICM_9 exhibited lowest PE (9.1 kg/ha/day). Rest of the modules like ICM_3, ICM_4, ICM_1 and ICM_2 exhibited intermediate trend for PE. The monetary-efficiency (ME) was the highest (486.9 `/ha/day) in ICM_7 followed by ICM_5, ICM_8, ICM_6, respectively (Table 2). Both PE and ME followed the similar trend as that of crop productivity, and gross and net returns (Rohullah 2016, Choudhary and Suri 2018).

SUMMARY

It is concluded that CA-based integrated crop management (ICM) modules imbedded with zero-tillage and residue retention with proper combination of integrated nutrient, water and weed management practices as well as need based crop protection measures had higher crop productivity and profitability in pigeonpea over other conventional agriculture and organic agriculture-based ICM modules. Hence, the CA based module ICM_7 as a complete ICM technology package [zero tillage–permanent raised bed + crop residue retention @ 3 t/ha + 100% RDF + (glyphosate-pre-plant followed by (fb) pendimethalin-pre emergence fb imazethapyr-post emergence + 1 hand-weeding-mulch) + 2 irrigations + need based IPM/IDM] exhibited significantly higher productivity, profitability and resource-use efficiency over other conventional agriculture and organic agriculture based ICM modules in pigeonpea under semi-arid Indo-Gangetic plains region.

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