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Integrated crop management technology for enhanced productivity, resource-use efficiency and soil health in legumes – A review

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ABSTRACTS

Under impeding production–and resource–vulnerabilities in India, our approach to agriculture needs to be redefined with inclination towards climate resilient integrated crop and resource management (ICRM) having low risk vulnerability, high factor productivity and sustained farm profitability with safe food and environmental quality. In above context, integrated crop management (ICM) practices hold great potential which take into account economic, social and environment sustainability. In irrigated agro-ecosystem of Indo-Gangetic Plains Region (IGPR), continuous cultivation of rice-wheat cropping system (RWCS) with intensive input use has caused a serious threat to agricultural sustainability with numerous production constraints. In order to diversify the IGPR production systems, pulses and other legumes like soybean and pigeonpea etc. hold great promises. Thus, legume-based cropping systems coupled with ICM practices may bring overall sustainability in IGPR. As per FAO, ICM is a recent concept in agriculture. ICM practices are the integrated technology package of appropriate site-specific crop management, integrated nutrient management, crop residue recycling, tillage management, water management, crop diversification/legume intervention, varietal selection, crop protection, energy saving and post-harvest management. Overall, this review paper highlights sufficient research findings which establish the superiority of ICM practices; in addition, it invokes for further strengthening of this research area for improving agricultural productivity, resource use efficiency and soil health with special reference to legume crops.

Key words: Carbon sequestration, Integrated crop management, Productivity, Resource vulnerability, Soil health

According to Food and Agriculture Organization (FAO), integrated crop management (ICM) has been adopted recently in agriculture and is of much significance and relevance than the individual approach of crop, soil, water, nutrients, weeds, diseases, pests and energy management (Varatharajan *et al.* 2019a, b, c).It integrates suitable agronomic management practices for raising a good crop including tillage and crop establishment methods, integrated nutrient management (INM), integrated weed management (IWM), integrated water management (IWrM), integrated disease management (IDM) and integrated pest management (IPM) and integrated energy management (IEM), etc.

Fig 1 Components of integrated crop management.

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(Choudhary *et al*. 2018). ICM is particularly beneficial for small and marginal farmers because it aims to minimize dependence on the purchased inputs while utilizing *on-farm* resources. Thus, ICM is a holistic and site-specific approach of sustainable agriculture which considers the production factors across the whole farm, including on-farm resources, socio-economic and environmental factors; to deliver the most suitable and safe approach for long-term benefits (Choudhary *et al*. 2018).

In irrigated agro-ecosystem of Indo-Gangetic Plains Region (IGPR), the rice-wheat cropping system (RWCS) is the dominant food production system mostly relying upon the indiscriminate use of high analysis chemical fertilizers only on same piece of farm-land year after year which poses a threat to its sustainability characterized with numerous production vulnerabilities besides high energy demand and production costs. In order to diversify the IGPR production systems, legume crops hold great promises. Thus, legume-based cropping systems need to be popularized in IGPR coupled with ICM practices for overall sustainability of production domain of irrigated IGPR. Thus, ICM is an innovative production technology to cope up above production vulnerabilities besides enhancing productivity and profitability over conventional farming.

Rationale and principles of ICM concept

In past 5 decades, tremendous gains in the crop productivity have reduced the food insecurity and greatly contributed to the economic growth globally in general and India in particular (Singh *et al*. 2011). But, increased efforts to produce more and more food within discriminate use of input and resource have resulted in many problems and challenges, *viz*. decline in ground water table (Mahajan *et al*. 2012), decline in soil health; low resource-use efficiency (Prasad 2005; Singh *et al*. 2011); imbalanced use of inorganic nutrients; excessive nutrient mining and emerging multiple-nutrient deficiencies (Bana and Shivay 2012; Singh 2012). Besides this, the rising problems of insect-pests and diseases; shifting of weed flora and emerging herbicide resistances; contamination and pollution in water-bodies and soils causing health hazards; greenhouse gas emissions; degradation and deterioration of natural resource base etc. have further led to various threats to agricultural sustainability (Cassman *et al*. 1998; Aggarwal *et al*. 2004; Prasad 2005). Therefore, there is urgent need to frame appropriate resource-management strategies in crop production like ICM. Under ICM, the farmers should make better use of *on-farm* resources leading to a reduced dependency on external inputs while integrating the best crop management practices. There are five major principals of ICM, viz. food security, environmental safety, economic viability, social acceptability, and food safety and quality. ICM also takes care of cultivation practices, cropping systems, type and size of machinery, tillage operations, soil and water management, land configuration, use of manures and fertilizers, crop residue management and finally inherent soil fertility to maintain or improve soil health. In nutshell, conventional farming practices needs to be replaced by location–specific ICM practices to sustain the farm productivity and profitability, enhance farm employment and farm livelihoods, conserve natural resource-base, and reduce farm and environmental risks.

ICM practices for legume husbandry

Basic components of ICM are tillage and crop establishment methods, integrated nutrient management (INM), integrated weed management (IWM), integrated water management (IWrM), integrated disease management (IDM) and integrated pest management (IPM), efficient farm machinery management, energy management. This review article includes the relevant components/practices of ICM concept related to legume cultivation hereunder.

Tillage management in legumes

Tillage management has a significant impact on crop growth and productivity because of its influence on soil properties and environment. Tillage optimizes soil temperature and moisture, accelerates seed germination, improves seedling establishment, enhances root development and minimizes weed competition as a result of short-term effects; while maintenance of soil productivity and sustainable management of soil and water resources are the long-term effects of tillage (Prasad *et al*. 2016; Bamboriya *et al.* 2017; Choudhary *et al*. 2018). Suitability of a tillage system in production systems depends upon their effectiveness in soil and water conservation (Baker *et al*. 2005). No-till system/reduced tillage system also intensifies the frequency of cropping (Halvorson *et al*. 2001). Pikul *et al.* (1993) reported higher green pea yield in no-tillage relative to conventional tillage (CT). Garry *et al*. (2000) found that CT has an important effect on different soil processes right from soil physico-chemical and biological properties. Franzluebbers (2005) gave an account of sequestration rate of 250 kg C ha^{-1} when using cover crops compared to bare-fallow in south-eastern United States. As well, SOC sequestration potential at the 0-20 cm soil depth increased around 20% while using cover crops under conservation tillage systems. ZT combined with crop residue retention (CRR) on soil surface also reduce soil erosion and enhance water use efficiency (Fischer *et al.* 2002; Varatharajan *et al*. 2019c). Conservation tillage also leads to higher macro-porosity, thus, improving soil quality. Munoz *et al*. (2007) found more soil moisture content under no-till than under conventional tillage in 0-15 cm soil depth because of crop residues left on soil which protect against evaporation losses more effectively. Benbi and Senapati (2010) reported ZT with or without crop residues resulted in 46.5% higher water stable macro aggregates in surface as compared to CT. Chaghazardia *et al*. (2016) reported that reduced tillage was the most efficient soil management practice for obtaining higher chickpea yield and conservation of soil moisture in rainfed Mediterranean climate besides maintaining better soil physical properties. Gathala *et al.* (2011) reported that tillage practices had a strong impact on SOC sequestration,

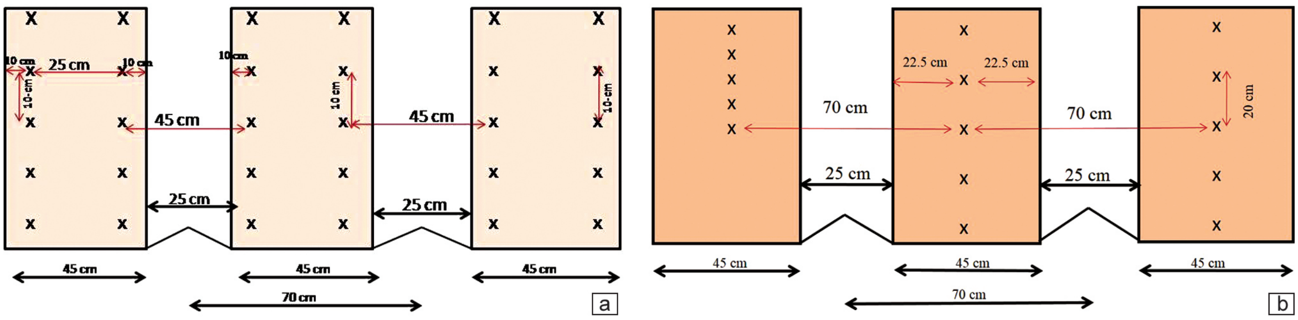

Fig 2 Raised-bed land configuration and planting geometry for (a) soybean and (b) pigeonpea.

GHGs emissions and ecosystem services. Varatharajan *et al.* (2018, 2019b, c) also found that conservation agriculture (CA) based ICM modules exhibited higher vegetative growth and yield in pigeonpea over conventional tillage based ICM modules as a result of less initial stage temperature stress due to temperature modulation and weed suppression owing to residue retention.

Land configuration in legumes

Appropriate land configuration and soil management aims to maintain and improve the soil productivity by improving the availability and plant uptake of water and nutrients through enhancing soil biological activity, replenishing soil organic matter and soil moisture, and minimizing losses of nutrients (Choudhary *et al.* 2015; Choudhary *et al.* 2018; Varatharajan *et al*. 2019a, c). Soil water and temperature are interrelated due to changes in thermal conductivity and heat capacity with water content and also movement of water due to thermal gradients. Warming of the soil is delayed under very wet conditions because more energy is used for evaporation and less for heating the soil and air. Ridges speed up the drying process because of gravitational effects on the water and the increased solar flux. Stone *et al*. (1989) observed that before planting, ridge-tillage resulted in higher temperature within the seed zone than the flat-plots. This increase was because of ~10% greater surface area of raised-beds (RB) than the flat-beds (FB) absorbing more solar radiations. Grewal and Abrol (1990) found more soil water content in ridge system as against the flat-planting. Pathak *et al*. (1991) found significantly lower soil bulk density (SBD) of 0–15 cm soil layer in RB than the FB system in chickpea. Chiroma *et al.* (2006) reported that land configuration practices coupled with mulching improved the soil porosity, SBD and soil strength. Varatharajan *et al.* (2019a, c) observed beneficial effect of land configuration on yield and quality of pigeonpea. Overall, land configuration has great bearing on plant growth, productivity and soil quality. For IGPR, Choudhary *et al.* (2018) and Varatharajan *et al.* (2019a, c) have also suggested some planting geometries/ land configurations (Fig 2) as well as tillage systems for higher productivity and resource-use efficiency in soybean and pigeonpea crops. For example, in soybean, the raised-beds (RB)/permanent raised-beds (PRB) with bed width of 70 cm should be made. Soybean seeds should be sown on plain platform (45 cm) of each bed in two rows having row to row distance of 25 cm while leaving 10 cm space on the edges of each plain platform from both these plant rows of the beds besides maintaining 10 cm plant to plant distance (Fig 2). Thus, row to row distance of 25 cm on the plain platform is maintained while on the inter-platform row to row distance of 45 cm is maintained (Fig 2). For medium to tall statured pigeonpea varieties, RB/PRB with bed width of 70 cm should be maintained where pigeonpea seeds are sown on centre of each bed in single row having row to row distance of 70 cm and plant to plant distance of 20 cm (Fig 2). Varatharajan *et al.* (2018, 2019c) reported that by adoption of land configurations and tillage systems, the pigeonpea yield was considerably higher in raised-beds under conservation agriculture (1.92 t ha^{-1}) while FBs under conventional tillage (CT) produced least grain yield (1.71 t ha^{-1}) (Fig 3). CA based raised-bed sowing performed well over CT based flat-beds as well as raised-beds in terms of productivity due to better growth and yield owing to less trafficking (Paul *et al*. 2014) and better nutrient dynamics (Varatharajan *et al.* 2019a, c) 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 span.

Integrated nutrient management in legumes

Adequate plant nutrient supply holds the key to better

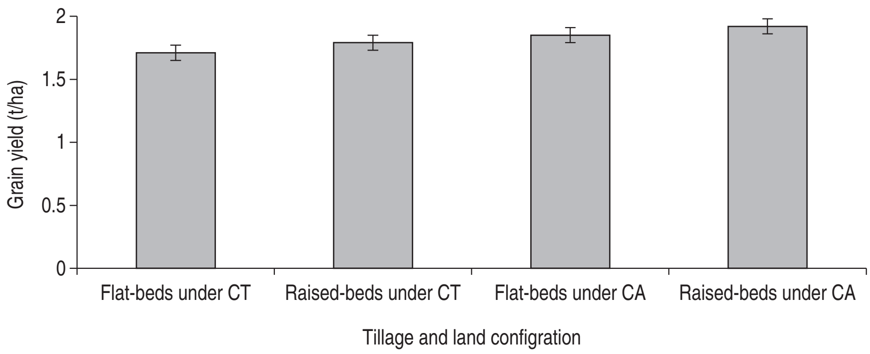

Fig 3 Influence of tillage and land configurations on pigeonpea productivity.

Table 1 General recommendation of chemical fertilizers in legumes in India

Crop	Fertilizer management
Blackgram (*Vigna mungo*)	NPK @ 20:60:40 kg/ha
Kidneybean (*Phaseolus vulgaris*)	NPK @ 20:60:40 kg/ha
Pigeonpea (*Cajanus cajan*)	NPK @ 30:80:60 kg/ha
Cowpea (*Vigna sinensis*)	NPK @ 20:60:40 kg/ha
Chickpea (*Cicer arietinum*)	NPK @ 20:60:20-30 kg/ha
Lentil (*Lens culinaris*)	NPK @ 20-25:50-60:0 kg/ha
Mungbean (*Phaseolus radiatus*)	NPK @ 20:50:40 kg/ha
Clusterbean (*Cyamopsis tetragonoloba*)	NPK @ 20:60:20 kg/ha
Horsegram/Kulthi (*Macrotyloma uniflorum*)	NPK @ 15:45:0 kg/ha
Soybean (*Glycine max*)	
In high rainfall areas	NPK @ 20:60:40 kg/ha
In low rainfall areas	NPK @ 20:30:30 kg/ha

(*Source:* Choudhary *et al.* 2015)

foodgrain production for sustaining livelihoods. In general, for producing one tonne of biomass, pulse crops remove about 30-50 kg N, 2-7 kg P_2O_5, 12-30 kg K_2O, 3-10 kg Ca, 1-5 kg Mg, 1-3 kg S, 200-500 g Mn, 5g B, 1g Cu and 0.5 g Mo from soil (Ahlawat and Ali 1993). The imbalanced application of nutrients leads to loss of productivity due to exhaustion of nutrients and overall soil health (Bhandari *et al*. 2002). Therefore, special emphasis is needed for fertilizer management in legumes as per the recommendations (Table 1). In general, there are ample nutrient management recommendations for agricultural crops across the world, but most of the farmers do not apply fertilizers at recommended rates due to higher costs and non-affordability (Kumar *et al*. 2014). Hence, integrated nutrient management (INM) may play an important role with judicious use of organics, crop residues, bio-fertilizers, legume inclusion etc. in combination with inorganic fertilizers to supplement crop nutrition.

The ICM principles also promote the INM practices with overall strategy to enhance crop yields and sustain them at a higher level with minimal ill-effects on soil, environment and human health (Choudhary *et al.* 2015). Legume-based cropping systems are important for sustaining agricultural production and maintain the soil fertility due to biological N fixation ability (Prasad 2005; Bana *et al.* 2013; Suri *et al.* 2013, Suri and Choudhary 2013a, b, c, 2014). Boddey *et al*. (2010) also reported an increase in SOC from 5000–8000 kg ha^{-1} while using no-tillage in three long-term rotations (15–26 years) containing intercropped cover-crop legumes over conventional tillage. Likewise, organic manures greatly improve the biological activity of soil microbes, soil structure, water holding capacity and SOC (Choudhary and Suri 2013; Bana *et al.* 2016). Moreover, the use of chemical fertilizers with biofertilizers is highly essential for harnessing higher yields with enhanced soil health (Bana *et al.* 2012; Pooniya *et al.* 2015). *Rhizobium*, is asymbiotic biological N fixer for legumes (Bai *et al*. 2015; Kumar *et al*. 2016). Thus, *Rhizobium* should be an integral component of INM in legumes. Likewise, fertilizer P along with PSB and AM fungi are crucial in meeting nutrient demands of legumes (Harrier and Watson 2003; Kumar *et al*. 2014; Bai *et al*. 2015). Tripartite AMF–*Glycine*–*Rhizobium* symbiosis further have synergetic effect on enhanced pulse yield, nutrient acquisition and soil fertility (Harrier and Watson 2003; Suri *et al*. 2013; Kumar *et al*. 2014). Overall, the location–specific INM practices imbedded in ICM mode may have great potential in sustaining the farm productivity, livelihoods and soil health with reduced farm and environmental risks.

Integrated weed management in legumes

Integrated weed management (IWM) means maintaining weed population below economic threshold level (ETL), which may not cause substantial economic damage to crops (Das *et al.* 2017; Dass *et al.* 2017). IWM uses several weed management techniques such as mechanical and manual methods, cultural/ecological approaches, biological methods and chemical methods etc. ICM concept also uses a variety of IWM technologies with the objective to produce optimum yield at a minimum cost considering ecological and socio-economic constraints. Since, weed menace causes yield losses to the tune of ~10–35% in most of legumes depending upon weed flora and crop canopy (Das 2008) (Table 2).

Critical period of weed competition (CPWC) is also a good determinant for efficient weed management in legumes (Jawahar *et al*. 2012) (Table 3).To reduce weed population

Table 2 Crop yield reductions (%) due to season-long weed infestation in India

Crop	Yield reduction (%)*
Chickpea	10-15
Lentil	10-15
Greengram/blackgram	15-20 (some cases more than 80%)
Cowpea	15-20 (some cases more than 80%)
Groundnut	50 (erect varieties); 25 (spreading varieties)
Peas	10-35

* Yield loss values are mean across locations. (Source: Das 2008)

Table 3 The critical period of weed competition in legume crops

Legume	Critical period
Soybean	First 60 days
Groundnut	42-56 DAS
Greengram	15-30 DAS
Blackgram	15-30 DAS
Cowpea	First 30 days
Pigeonpea	15–65 DAS
Peas	30-45 DAS
Chickpea	30–60 DAS
Lentil	30–60 DAS

(*Source:* Jawahar *et al*. 2012; Das *et al*. 2017).

Table 4 Promising herbicides for chemical weed management in legumes

Crop	Herbicide	Dose (kg/ha)	Time of application
Pigeonpea	Pendimethalin	1.0	Pre-em (1-2 DAS)
Urdbean/ Mungbean	Pendimethalin followed by (fb) imazethapyr	1.0 & 0.075 (resp.)	Pendi as pre-em (1-2 DAS) fb Imazetha post-em (20-25 DAS)
Soybean	Pendimethalin	0.75-1.0	Pre-em (1-2 DAS)
	Metribuzin	0.400	Pre-em (1-2 DAS)
	Pendimethalin + imazethapyr (Tank-mix)	0.75 + 0.075	Pre-em (1-2 DAS)
	Pendimethalin fb imazethapyr	0.75 & 0.075 (resp.)	Pendi as pre-em (1-2 DAS) fb Imazetha post-em (15-20 DAS)
Groundnut	Pendimethalin	1.0	Pre-em (1-2 DAS)
Chickpea/Lentil/Peas	Pendimethalin	1.0	Pre-em (1-2 DAS)

(Source: Das *et al.* 2017; Varatharajan *et al.* 2019)

below ETL through weeding at CPWC stages is difficult, time consuming and expensive. Thus, IWM remains the pertinent choice for controlling the weeds. Moreover, pulse crops have generally short stature and slow growth at initial stage, thus weeds compete faster and surpass the growth of crops. Therefore, application of appropriate pre-emergence herbicides followed by 1 hand-weeding (HW) at 30-35 DAS proves quite effective IWM in most winter pulses **(**Table 4**)**. In *kharif* pulses, a greater number of HW are required due to higher weed menace. Under ICM for effective weed management, herbicides are applied in combination with appropriate agronomic practices like soil solarization, HW and mulching, repeated summer cultivation, land configuration, stale seedbed, crop residue retention as well as several non-monetary inputs (suitable variety/geometry/ time, method and rate of sowing/placement and timing of fertilizers, etc.) in order to reduce weed competition in pulses (Das *et al.* 2017; Varatharajan *et al*. 2019a).

In this direction, Malik *et al*. (2006) obtained better control of weeds (50%) with pendimethalin @ 1.0 kg a.i. ha^{-1} + 1 HW at 20 days after sowing (DAS). Patrico *et al*. (2006) also found that soil solarization reduced the infestations of weeds and soil-borne pests without any ill-effects on soil microbes. Kumar *et al*. (2012) reported that soil solarization followed by (fb) glyphosate @ 1.0 kg a.i. ha^{-1} during summer-fallow resulted in significant reduction in *Cyperus rotundus* infestation in succeeding crops. Vijaymahantesh *et al*. (2013) noticed that weed infestation decreased in reduced tillage. Growing crops on raised-beds resulted in many advantages like water saving, reduced weed infestation, enhanced nutrient-use efficiency and reduced operational cost (Connor *et al*. 2003). Singh and Sekhon (2013) reported that pendimethalin @ 0.45 kg ha^{-1} + 1 HW (30 DAS) along with ridging (50 DAS) had higher pigeonpea yield and weed control efficiency as compared to pendimethalin alone. Prachand *et al*. (2015) also found that imazethapyr @ 0.100 kg a.i. ha^{-1} + quizalofop ethyl @ 0.075 kg a.i. ha^{-1} as PoE was found to be more efficient to control weeds in soybean. Varatharajan and Choudhary (2018) also found that raised-bed zero-till sowing followed by pendimethalin @ 1.0 kg a.i. ha^{-1} as Pre-em fb imazethapyr @ 0.075 kg a.i. ha^{-1} at 20-25 DAS + 1 HW at 40 DAS and weed-mulching proved more effective in weed management in pigeonpea. Thus, IWM may hold great promises for efficient weed management as a component of ICM with less chemical herbicide use and minimal environmental risks.

Integrated water management in legumes

Water is one the most critical resource for sustainable development globally. Today, 40% of the world's food comes from ~18% of the cropland that is irrigated. On the other hand, 8–15% of fresh water supplies will be diverted from agriculture to meet increased demand of domestic use and industry. The efficiency of irrigation is very low, only 55% of the water is used by the crop. To overcome water shortage in agriculture, it is essential to increase the water-use efficiency (WUE) using integrated water management (IW_rM) practices. Since, most of thepulses are grown in rainfed situations (Pooniya *et al.,* 2015).Hence, for proper growth and yield both efficient irrigation and moisture management are essential in pulses. In case of less water availability for legumes, the irrigation water must be applied at critical growth stages using simple irrigation scheduling approaches like IW/CPE ratio as mentioned in Table 5 (Rana *et al*. 2014).

Table 5 Irrigation scheduling and critical stages for irrigation in important legume crops

Crop	Irrigation				Critical stages
	IW/ CPE	Depth (cm)	Number	Requirement (cm)	
Soybean	0.4-0.8	5-6	3-7	18-35	Flower initiation, pod filling
Pigeonpea	0.25-0.9	6-8	1-4	8-30	Flower initiation
Groundnut	0.4-0.9	5-8	2-8	15-50	Peg formation, pod filling
Chickpea	0.4-0.8	6-8	1-4	8-24	Flower initiation, pod formation

(*Source:* Rana *et al*. 2014)

Lumpkin and Sayre (2009) reported that furrow irrigation with raised-bed system saved the irrigation water by ~16-18% for a wide spectrum of legumes compared to traditional farmers' practice (Table 6). Application of anti-transpirants like $MgCO_3$ (5%) and KNO_3 (1%) in soybean enhanced the crop and water productivity in semi-arid climate (Dass and Bhattacharyya 2017). Likewise, application of AM fungi also holds great promises for water stress tolerance besides phosphorus nutrition management in legumes (Harrier and Watson 2003; Suri *et al*. 2013; Kumar *et al*. 2016). Conservation tillage with CRR and organic manures improve the soil macro-aggregates and water storage in soil profile, loosen the soil and decrease soil bulk density (Moreno *et al.* 1997; Paul *et al*. 2014). Conservation tillage also facilitates cropping system intensification (Halvorson *et al*. 2001). Gathala *et al*. (2011) and Paul *et al.* (2014) noticed that no-till with CRR had potential to improve SOC pool; which conserves soil moisture for later crop needs (Bana *et al*. 2016). Soil macro-aggregates in higher proportion ensure more carbon sequestration and more water infiltration in root zone; thus, improving WUE(Kumar *et al.* 2016; Paul *et al*. 2016).Varatharajan *et al.*(2019c) also found that ICM modules comprising zero-tillage with CRR in raised-beds proved superior for higher soil water storage resulting in higher crop and water productivity in pigeonpea (Fig 4). Thus, IWrM is essentially needed for higher crop and water productivity in legumes both in irrigated and rainfed ecosystems.

Table 5 Relative irrigation water use under different crop and land management systems

Legume crop	Irrigation water-use (cm)		% water saving by furrow irrigation
	Raised-bed seeding with furrow irrigation	Conventional seeding with flood irrigation	
Pigeonpea	13	15	16
Soybean	17	20	16
Greengram	17	21	16
Vegetable pea	8	10	18

(*Source:* Lumpkin and Sayre 2009)

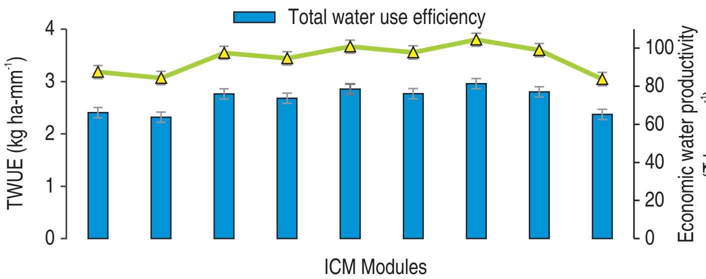

Fig 4 Effect of different ICM modules on total water use efficiency (TWUE)and economic water productivity (₹ ha-mm^{-1}) in pigeonpea. Where; ICM_1: CT+FB + 100% RDF + pendimethalin 1 kg a.i./ha (PE) fb imazethapyr 75 g a.i./ha (POE) at 25 DAS + 1 HWM + 3 Irr; ICM_2: CT+FB + 75% RDF+AMF+ NPK-bf + pendimethalin-PE fb imazethapyr-POE + 1 HWM + 3 irr; ICM_3: CT+RB + 100% RDF + pendimethalin-PE fb imazethapyr-POE + 1 HWM + 2 Irr; ICM_4: CT+RB + 75% RDF+AMF+ NPK-bf + pendimethalin-PE fb imazethapyr-POE + 1 HWM + 2 Irr; ICM_5: ZT+ FB + CRR @ 3 t/ha + 100% RDF + glyphosate (PP) 1.0 kg a.i./ha fb pendimethalin-PE fb imazethapyr-POE + 1HWM + 2 Irr; ICM_6: ZT+FB + CRR @ 3 t/ha + 75% RDF+AMF+NPK-bf + glyphosate-PP fb pendimethalin-PE fb imazethapyr-POE + 1HWM + 2 Irr; ICM_7: ZT+PRB + CRR @ 3 t/ha + 100% RDF + glyphosate-PP fb pendimethalin-PE fb imazethapyr-POE + 1HWM + 2 Irr; ICM_8: ZT+PRB + CRR @ 3 t/ha + 75% RDF+AMF+NPK-bf + glyphosate-PP fb pendimethalin-PE fb imazethapyr-POE + 1HWM + 2 Irr; ICM_9: CT+FB + CRR @ 3 t/ha + FYM @ 5 t/ha + AMF + NPK-bf + 2 HWM (20, 40 DAS) + 2 Irr. [AbbreviationsAMF: AM Fungi; NPK-bf : NPK biofertilizer; PE: Pre-emergence; POE: Post-emergence; PRB: Permanent raised-bed; HWM: hand-weeding and its mulching; Irr: Irrigations].

Integrated disease management in legumes

Plant diseases are considered as an important biotic constraint in legumes which lead to significant crop losses worldwide to the tune of ~46-96% depending on the crop and varieties (Pooniya *et al*. 2015). Plant diseases are caused by a variety of causal agents, *viz*. fungi, bacteria, viruses, phytoplasmas and nematodes, etc. The concept of integrate disease management (IDM) integrates a range of disease management methods like biological, cultural, physical and chemical control strategies in a holistic way proving more effective and sustainable rather than using a single component strategy. Under ICM, the IDM calls for minimal use of chemicals, and only if deemed necessary, giving preference to other control methods such as host-plant resistance, cultural practices and biological control. Seed treatment plays an important role in protecting the seeds and seedlings from seed and soil borne diseases and insect pests affecting crop emergence and its growth. Prasad *et al*. (2012) revealed that IDM module with combination of seed treatment with carbendazim + soil applied *Trichoderma viride* @ 2.5 kg ha^{-1} multiplied in FYM (50 kg ha^{-1}) had highest pigeonpea yield and lowest wilt incidence. Pawar *et al*. (2013) also revealed that IDM package consisting of seed treatment with thiram and carbendazim + *T. viride* + *Rhizobium* in addition to soil application of *T.viride* was significantly superior in controlling pigeonpea wilt disease. Singh *et al*. (2017) revealed that IDM strategy in lentil comprising *T. harzianum* seed treatment (4 g/kg seed) with carbendazim (1 g/kg seed) + intercropping with linseed (2: 1 ratio) had 30.1% lower wilt incidence with higher yield in lentil (1.29 t ha^{-1}) over control.Varatharajan *et al.* (2019a, c) also found that ICM modules comprising ZT+RB+ CRR coupled with fungicide seed treatment and need based spray of fungicides in later growth period proved superior w.r.t. to disease infestation in pigeonpea over CT+FB without CRR coupled with fungicide seed treatment and need based IDM. IDM also includes deep summer ploughing, field sanitation, growing resistant varieties, crop rotations, soil solarization *etc*. to reduce soil-borne diseases (Pooniya *et al.* 2015). Thus, IDM is a holistic way for better disease management in legumes for higher crop productivity with minimal fungicide use.

Integrated pest management in legumes

About 250 insects have been recorded feeding on legume crops, however, pod borers, stem borers, leaf miners, foliage caterpillars, cutworms, jassids, aphids and whiteflies are the most important (Pooniya *et al.* 2015).Thus, integrated pest management (IPM) is a worldwide accepted strategy under ICM for efficient pest management. In order to address the deleterious impacts of chemical pesticides, integrated pest management (IPM) has been evolved as an eco-friendly way of pest management. In IPM, the ETL of pest forms the basis for pest management decisions with judicious use of pesticides and other possible eco-friendly pest management options. Ahmad (1999) have also suggested appropriate IPM module for effective control of gram pod borer using NPV @ 250 LE followed by cypermethrin 0.02% at 10 days interval compared to NPV @ 250 LE alone. Jakhar *et al*. (2016) reported that among different IPM modules in pigeonpea the package containing resistant variety + intercropping with sorghum (10 : 1) + bird perches + neem soap spray @ 10 g/l + need-based indoxacarb spray (10 ml/l) emerged as best module with least damage from pod borer and pod fly (5.8%) with maximum yield of 1.68 t ha^{-1}. Thus, IPM should include selection of resistant or tolerant varieties, sowing time, crop rotations, intercropping, trap crops/non-host crops, pheromone traps and other eco-friendly approaches with need-based pesticides for minimizing the pest damage.

Integrated energy management in legumes

Shortage of energy is well-recognized worldwide, but, little attention has been given to energy efficiency in agriculture. Energy measuring and monitoring is essential to have high efficiency and its saving in crop production. Food legumes are an important food source due to high protein and nutrients such as vitamins and minerals though grown under energy starved conditions (Choudhary *et al.* 2015; Kumar *et al*. 2019). Thus, special attention is needed for energy management in these crops. To achieve this, we require detailed analysis of energy use on the farm inputs, field operations as well as farm machinery use through a detailed energy budgeting (Rohullah 2016). The net energy of a cropping system can be quantified for sound planning of sustainable systems (Chaudhary *et al*. 2006). Yield of different crops can be increased up to 30% by using optimal level of energy input (Sidhu *et al*. 2004; Chaudhary *et al*. 2006). In general, higher production costs are incurred on tillage management. In this context, conservation agriculture (CA) reduces the use of non-renewable energy significantly (Singh *et al*. 2008; Choudhary *et al.* 2017). The CA is cost-effective, energy-efficient and beneficial to environment as compared to CT (Varatharajan *et al.* 2019c) (Table 6). Energy-use efficiency (EUE) can also be increased by reducing inputs such as tillage operations and consumption of herbicides, pesticides and fertilizers following ICM practices (Varatharajan *et al.* 2019a, b, c).

Ratke *et al*. (2007) described that crop rotations imbedded with legumes and reduced tillage, improved the energy-efficiency of crop production systems. Rohullah (2016) found that reduction in energy consumption with ZT both under flat-bed and raised-bed based ICM modules may be due to energy saving in ploughing and seed bed preparation. But at the same time, the residue management involved more energy consumption due to the retention of enormous quantity of crop residues in the soybean production. On the other hand, the energy output and specific energy increased under CA based ICM modules both under FB or RB system over their CT based ICM counterparts (Varatharajan *et al.* 2019c) (Table 6). Overall, ZT pigeonpea eventually reduced the input energy on farm operations and lead to enhanced output energy and energy-efficiency with reduced production costs.Thus, agronomic interventions like CA will eventually reduce the input energy and will lead to enhanced output energy and EUE with reduced production

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

Treatment	Energy input (MJ ha^{-1})	Energy output (MJ ha^{-1})	Net energy (MJ ha^{-1})	Energy profitability
ICM_1	11399	203396	191998	16.84
ICM_2	10892	197037	186145	17.09
ICM_3	11943	211196	199253	16.68
ICM_4	11436	207172	195736	17.12
ICM_5	35691	218741	183050	5.13
ICM_6	35185	211614	176429	5.01
ICM_7	36848	223664	186816	5.07
ICM_8	36796	213851	177055	4.81
CD (P=0.05)	-	20071	20071	1.22

(*Source:* Varatharajan *et al.* 2019c). Where; ICM_1: CT+FB + 100% RDF + pendimethalin 1 kg a.i./ha (PE) fb imazethapyr 75 g a.i./ha (POE) at 25 DAS + 1 HWM + 3 Irr; ICM_2: CT+FB + 75% RDF+AMF+ NPK-*bf* + pendimethalin-PE fb imazethapyr-POE + 1 HWM + 3 irr; ICM_3: CT+RB + 100% RDF + pendimethalin-PE fb imazethapyr-POE + 1 HWM + 2 Irr; ICM_4: CT+RB + 75% RDF+AMF+ NPK-*bf* + pendimethalin-PE fb imazethapyr-POE + 1 HWM + 2 Irr; ICM_5: ZT+ FB + CRR @ 3 t/ha + 100% RDF + glyphosate (PP) 1.0 kg a.i./ha fb pendimethalin-PE fb imazethapyr-POE + 1HWM + 2 Irr; ICM_6: ZT+FB + CRR @ 3 t/ha + 75% RDF+AMF+NPK-*bf* + glyphosate-PP fb pendimethalin-PE fb imazethapyr-POE + 1HWM + 2 Irr; ICM_7: ZT+PRB + CRR @ 3 t/ha + 100% RDF + glyphosate-PP fb pendimethalin-PE fb imazethapyr-POE + 1HWM + 2 Irr; ICM_8: ZT+PRB + CRR @ 3 t/ha + 75% RDF+AMF+NPK-*bf* + glyphosate-PP fb pendimethalin-PE fb imazethapyr-POE + 1HWM + 2 Irr; ICM_9: CT+FB + CRR @ 3 t/ha + FYM @ 5 t/ha + AMF + NPK-*bf* + 2 HWM (20, 40 DAS) + 2 Irr. [*Abbreviations* AMF: AM Fungi; NPK-*bf* : NPK biofertilizer; PE: Pre-emergence; POE: Post-emergence; PRB: Permanent raised-bed; HWM: hand-weeding and its mulching; Irr: Irrigations].

costs. The pressure on non-renewable sources of energy input is considerably reduced under CA systems over CT (Hamzei and Seyyedi 2016). Since, integrated energy management is an integral part of ICM approach, thus, while adopting ICM modules there should be an integrated input and resource strategy with reduced dependence on off-farm inputs so that energy input is considerably reduced with higher energy outputs. Overall, ICM is such a technology which combines good farming practices with modern technology to avoid resource and energy wastage in agriculture.

Integrated crop management in legumes: future strategy

A brief insight of the available literature on ICM reveals that most of the research work is done on one, two or at the most three ICM components in legumes or other field crops. Moreover, as per FAO, the ICM has been adopted recently in agriculture and is of much significance and relevance than the individual approach of soil, water, nutrients, crops, pests and energy management. Many research workers have tried to enhance the crop productivity with efficient integrated crop and resource management besides improved soil health (Das *et al*. 2013). Saharawat *et al.* (2009) reported that ICM practices, *viz*. crop establishment methods, tillage, crop residue management, fertilizer management, weed management as well as efficient use of farm machinery led to enhanced crop productivity, profitability and resource-use efficiency in rice-wheat system in IGPR. Patel *et al*. (2008) have also advocated the superiority of ICM practices in rice over SRI and conventional rice production systems. In current scenario, the deteriorated soil-water-plant continuum is direly indicating the urgent need to follow ICM principles in the agrarian sector especially in vulnerable areas. However, little attention has been given to develop ICM practices in field crops while poor attention has been given to legume production systems in particular. Thus, ICM practices in legumes need to be developed on holistic manner as a complete package on cropping system basis. Moreover, the influence of various ICM modules imbedded with tillage, nutrient, weed, water and integrated pest management etc. on crop productivity, profitability, input use efficiency, soil health as well as water, labour, and energy saving are not worked out systematically. Thus, the future strategy should be to develop site-specific/resource-base specific ICM modules for different cropping systems/ different agro-ecologies with socially acceptable, practically feasible and environment resilient ICM recommendations in this frontier area of research.

Conclusion

Overall, ICM being a recent concept, a meager work has been done on developing holistic ICM practices in field crops while poor attention has been given to legume or pulse production systems. Overall, the most of the previous studies have taken at the most two or three ICM factors into account while preparing the ICM modules in these crops which needs to be developed on holistic manner as a complete package. The influence of various ICM modules imbedded with tillage, nutrient, weed, water and integrated pest management etc. on crop productivity, profitability, input use efficiency, soil health as well as water, labour, and energy saving is not worked out systematically. Thus, it is high time to develop ICM modules for different crops and cropping systems specifically in those agro-ecologies which are suffering from acute production- and resource vulnerabilities with threats of climate change as well.

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