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Integrated Farming System: Key to sustainability in arid and semi-arid regions

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ABSTRACT

Ensuring higher productivity and profitability, gainful employment and adequate supply of food, feed, fodder and fiber for a growing human and livestock population, along with maintaining environmental sustainability are major challenges in agricultural production systems of arid and semi-arid regions. Integrated farming systems (IFS) comprising of many agri-innovations have the potential to meet such requirements. An association of individual and interdependent components of farming on a given piece of land, taking cognizance of available natural resources and the differential requirement of a wide range of farming community, remains the guiding principle of IFS. Research conducted across arid and semi-arid regions is reviewed here in order to understand the role of IFS in enhancing production, income and livelihood; minimizing risk associated with farming in arid and drier semi-arid regions; utilizing and conserving the resources; and in enhancing mitigation and adaptation to climate change. It has been conclusively established that IFS involving integration of different enterprises (crop, livestock, horticulture, forestry, poultry and fish) enhanced productivity, profitability, resource use efficiency, generated more employment and minimized resources degradation and risks. IFS, therefore, could be a key form of farming intensification needed for achieving future food security and environmental sustainability in arid and semi-arid regions. Promoting adoption of the location-specific IFS in future is linked directly with coherent policy, institutional commitment, infrastructure development, better coordination among different agricultural and rural development programme and agencies, and a stimulus package of incentives. The relevance of IFS in adaptation to and mitigation of climate change is also discussed.

Key words: Adaptation, Climate change, Crop diversification, Livelihood, Resource use efficiency

Designing a food production system that caters to the diverse need of agricultural products of a growing world population along with maintaining environmental quality, natural resources and ensuring adequate profitability to farm families is emerging as the biggest challenge faced by humanity (Godfray *et al.* 2010, Garnett *et al.* 2013, FAO 2014). Such a challenge is more severe in arid and drier semi-arid regions, which account for approximately 30% of the total world area and are inhabited by approximately 20% of the total world population (Sivakumar *et al.* 2005). In India, arid and semi-arid regions cover approximately 166.2 million ha (Srinivasarao *et al.* 2013) which spread across the length and breadth of the country, and hold an important place with respect to size, human and animal population and agro-ecological diversity. These regions are characterized by hostile environmental conditions that include low and erratic rainfall, high wind velocity, intense solar radiation during most parts of the year and high potential evapotranspiration. Majority of the soils of the regions are coarse in texture, with poor nutrient status and low water holding capacity and therefore, the land productivity is generally low (Shankarnarayan *et al.*1987). Majority of crop production in these regions are rainfed and drought is common features resulting in low and unstable crop yield. Thus, the agriculture in arid and semi-arid regions is facing multiple and complex challenges in terms of decline in factor productivity and the degradation of natural resources. Besides, the size of operational land holding is declining posing a serious threat to the profitability and sustainability of farming (Behera and France 2016). Furthermore, future agricultural production systems would need to be adaptable to unforeseen climate change and market prices challenges.

There is considerable agreement on the urgent need for designing agricultural production system that ensures food and nutritional security, provides social and economic stability, and builds and protects the ecosystem services (Barrett 2010, Godfray *et al.* 2010, Garnett *et al.* 2013, FAO 2014, DeFries *et al.* 2015). Within this context, integrated farming system (IFS) defined as an agricultural production system with multiple crops and enterprises that interact in

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space and/or time on a single farm has been purported to possess these attributes. The studies on IFS conducted in many countries and different parts of India have addressed the issues involving increasing productivity of agricultural production system, harnessing the complementarities and developing synergies among different agricultural sub-systems and/or enterprises and augmenting the total productivity, profitability, gainful employment, efficient resource recycling and resource use efficiencies. This paper presents an overview of the role of IFS in the changed agricultural scenario across arid and semi-arid regions. Key constraints associated with the wide scale adoption of IFS and ways to overcome these constraints are also discussed.

Arid and semi-arid regions of India: extent, agro-ecological conditions

The area receiving annual rainfall between 500-1000 mm and moisture index between -33.3 to -66.7 is classified as a semi-arid region, covering about one third of total geographical area of the country and is largely concentrated in western and southern peninsular parts. The semi-arid region is further divided into dry and moist semi-arid regions. The area with 500-750 mm annual rainfall and a crop growing period of 90-120 days falls under dry semi-arid region and is spread over 41.6 million ha. These regions are endowed with loamy sand, light sandy loam and medium black soils in the northern part, and medium to black soils in the southern parts of the country. The area receiving 750-1000 mm annual rainfall, with a crop growing period of 90-150 days is classified as moist semi-arid region and covers about 72.2 million ha. The soils of this region are sandy loam and loam in the northern part, medium to black soil in the central part and red and medium black in southern parts. With the exception of drier semi-arid regions, crop production in this region is predominantly rainfed and maize, pearl millet, sorghum, cotton, soybean, groundnut and pulses are major crops, livestock rearing being a major subsidiary occupation.

The areas receiving low annual rainfall (<500mm) having moisture index <-66.7% are classified as arid regions. The arid regions are further divided into hot and cold arid region. The hot arid regions cover 31.7 million ha concentrated in the state of Rajasthan (61%), Gujarat (20%), Andhra Pradesh (7%), Punjab (5%), Haryana (4%), and Karnataka (3%). The soils of arid regions are predominantly light textured. Low and erratic rainfall and high atmospheric evaporative demand coupled with a poor water holding capacity of soil limits the crop growing period up to 90 days, and therefore millets and short duration crops (mainly pulses) are largely cultivated in the region. Livestock, particularly small ruminants (sheep and goat) have a significant role in the agrarian economy of the hot arid regions (Rathore *et al.* 2009, 2010). The major characteristics of arid and semi-arid regions of India are summarized in Table 1.

The production of arable crop is risky and unstable in hot arid regions. In order to minimize the adverse effects of frequent crop failures due to drought, farmers have evolved some combined protective-productive systems by integrating woody perennials and livestock in farming. Historically, the hot arid regions are a land of low-yield and of short-duration crops with high dependence on livestock and traditional agro-forestry (Kar 2014). Detailed account of prevailing farming systems in arid areas, especially of Rajasthan have been described (Bhati and Joshi 2007). In the area receiving annual rainfall up to 250 mm, grasses and shrubs dominate the production scenario and livestock rearing remains the main agricultural proposition. In areas receiving annual rainfall between 250-350 mm, mixed farming encompassing various agroforestry systems and mixed cropping of cereals and legumes dominate, besides a significant role of grasses and shrubs. Livestock, pasture and annual crops management are, therefore, main livelihood options. In areas receiving annual rainfall >350 mm, crops and diverse cropping systems are the major systems of

Table 1 Characteristics of arid and semi-arid ecoregions of India.

Type of climate	Annual rainfall (mm)	Moisture index (%)	Growing period (days)	Physiography	Area (million ha)
Arid					
Cold arid	<500	<-66.7	60-90	Western Himalayas, parts of Jammu & Kashmir	14.3
Hot arid	<500	<-66.7	<90	Western plains and Kutch Peninsula, Deccan plateau	31.7
Semi-arid					
Dry	500-700	-66.7 to -55.8	90-120	Northern plains, Central highlands including Aravallis, Deccan plateau, Tamil Nadu uplands, South Tamil Nadu plains	41.6
Moist	750-1000	-55.7 to -33.3	90-150	Indo-Gangetic plains, Bundelkhand uplands, Malwa plateau, eastern Gujarat plain, Vindhaya hills, Central & Western Maharashtra, North Karnataka, Vidhrabha, North Telangana, Central Karnataka, Tamil Nadu Plains, Punjab & Rohilkhand	72.2

Source: Srinivasarao *et al.* (*2013*) sustenance of farmers with agroforestry and livestock farming taking a secondary role.

Introduction of canal irrigation (from IGNP, Bhakra and Gang canal), rural electrification boosting groundwater irrigation, farm mechanization, new crops and their production technologies, construction of road networks and greater marketing opportunities have brought drastic changes in land use and farming systems of arid regions (Kar 2014). With these changes, interest in traditional mixed farming systems comprising mixed cropping, livestock and extensive agroforestry has declined, and agricultural system have became more and more specialized. New crops like cotton, groundnut, castor, wheat, Indian mustard, cumin etc. requiring more water were added to the spectrum of traditional crops, viz. pearl millet, moth bean, cluster bean, sesame and chickpea. Further, with the replacement of animal-drawn tillage equipment by tractor-drawn tillage implements, the natural vegetation was uprooted, which led to decline in area under traditional agroforestry. A critical analysis of such changes by Kar (2014) speculated that such land use might exaggerate desertification threatening the farmers' livelihood and sustenance of agriculture itself.

Integrated farming system: the guiding principles

Agriculture production system in arid and semi-arid regions needs to be sustainable and resilient encompassing enhanced productivity, higher income, employment generation, risk minimization, resource utilization and conservation, and climate change mitigation and adaptation.

Enhanced productivity: The demand for food, feed, fodder and fiber is increasing with an increase in population, but the availability of land for agriculture is decreasing. The IFS provides an excellent opportunity to increase the yield/ lans time (Manjunath and Itnal 2003a & b, Ravisankar *et al.* 2007, Rathore and Bhatt 2008). The results of various studies conducted in arid and semi-arid regions of India have demonstrated that IFS had higher yields than sole arable cropping (Table 2).

Integration of trees with arable crops improved the productivity compared to sole cropping in arid regions (Harsh and Tewari 1993). Bhati *et al.* (2008) reported that co-cultivation of arable crops with *Prosopis cineraria* in arid region provided a good yield of arable crops along with a bonus yield of dry leaves and twigs (0.65-1.05 t/ ha) and fuelwood (1.8-2.6 t/ha) from the tree. A study conducted in hot arid region at CAZRI demonstrated that production system consisting of arable crops (pearl millet, green gram, moth bean and cluster bean) with *Hardwickia binata, P. cineraria, Z. mauritiana* produced 2.50, 2.95 and 7.55 t/ha yield (pearl millet equivalent yield) compared to 1.77 t/ha under sole cropping. Thus, the IFS had 1.4 to 4.3 times higher yields than sole cropping (Tanwar *et al.* 2018). Higher fodder yield in *P. cineraria*-based production system (*Prosopis* in association with pearl millet – *Brassica tournefortii*) than sole cropping has been reported from arid regions of Haryana (Kaushik and Kumar 2003). Kumar *et al.* (1998) showed that yield of barley enhanced in association with tree in hot arid region of Haryana, and *P. cineraria* enhanced grain yield by 86.0%, *Acacia albida* by 57.9%, *T. undulata* by 48.8%, and *A. indica* by 16.8% over the control. Results of a study to assess the performance of *jujube*-based agri-horticultural system at Jodhpur revealed that a density of 200 *jujube* plants/ha is optimum for co-cultivation of arable crops, and amongst the arable crops cluster bean produced better yields in drought years, mung bean in good rainfall years and cowpea showed yield stability in most of the years. The system gave cowpea grain yield (386 kg/ ha year), fruit (3076 kg/ha year) and fuel wood (1353 kg/ ha year) and provided fodder to sustain 700-1000 animal-days/ha year (Bhati *et al.* 2008). Meghwal and Henry (2008) reported that cultivation of cluster bean and mung bean with ber gave 2.4, 0.5, and 1.0 t/ha of fruit, tree leaf fodder and fuel wood along with 0.28 and 0.18 t ha^{-1} seed yield of cluster bean and mung bean, respectively. Awasthi *et al.* (2009) demonstrated that arable crops (mothbean, cumin and chickpea) cultivated in association with *aonla* had 14-38% higher yields than sole cropping of arable crops in hot arid region at Bikaner. Groundnut – wheat and cluster bean – Indian mustard are important crop rotations in irrigated areas of north western hot arid Rajasthan. Saroj *et al.* (2003) demonstrated that IFS comprising arable crops and ber gave 0.96 t ha^{-1} of fruit with almost equal yields of arable crops obtained in sole cropping system in the hot arid region at Bikaner, Rajasthan.

The results of a study conducted in Punjab indicated that crops + dairy and crops + dairy + poultry production systems produced 25.0 and 25.5 t/ha crop equivalent yield compared to 12.5 t ha^{-1} from sole cropping (Gill *et al.* 2009). Thus, productivity under IFS was double in comparison to sole cropping. There are several reports that indicated that integration of tree with pasture enhanced fodder yields. Results of a study conducted in hot arid region at Jodhpur demonstrated that integrated production system comprising *Cenchrus ciliaris* and *Hardwickia binata* gave 17% higher fodder yields than sole pasture (Patidar and Mathur 2017). Kumar *et al.* (2009) assessed fodder production of sole *Dichanthium* and *Dichanthium* + aonla in semi-arid environment at Jhansi, and reported that *Dichanthium* + aonla production system produced 0.56 t ha^{-1} higher fodder than sole *Dichanthium* along with 12.1 t/ha of fruit yield.

Higher income: Declining profitability of farming is a major concern especially in the arid and semi-arid regions. The IFS has great promise for improving the profitability by reducing the cost of production and/ or enhancement of productivity (Table 3). The IFS has the ability to reduce cost of production through recycling wastes as by-products of one enterprise becomes input to other enterprises (Manjunath and Itnal 2003b, Ravisankar *et al.* 2010), and minimizing the need for external inputs (Ryschawy *et al.* 2012, Wilkins 2008).

Integration of *A. senegal* with pearl millet had 61% higher net return than sole pearl millet in hot arid region of Rajasthan (Harsh and Tewari 2007). A study conducted in hot arid environment at CAZRI, Jodhpur demonstrated

Table 2 Productivity of integrated and conventional farming/ production systems in different regions of India

Location/System	Productivity (t/ha)	Remarks	Reference
Rajasthan, Jodhpur			
*CFS : Sole cluster bean	0.50 t/ha G	The IFS gave 2.4 t ha^{-1}ber fruit, 0.5 t ha^{-1} TLF and about 1 t ha^{-1} FW	Meghwal and Henry (2008)
Sole Mung bean	0.22 t/ha G		
IFS : Cluster bean + ber	0.28 t/ha G + 2.4 t/ha F + 0.5 t/ha TLF + 1 t/ha FW		
Mung bean + ber	0.18 t/ha G + 2.4 t/ha F + 0.5 t/ha TLF+ 0.9 t/ha FW		
CFS : Crops (pearl millet, green gram, moth bean and cluster bean in 3:1:1:1 ratio)	PMEY: 1.77 t/ha	IFS had 1.4 to 4.3 times higher yield than CFS	Tanwar *et al.* (2018)
IFS : Crops + *Prosopis cineraria*	PMEY: 2.95 t/ha		
Crops + *Ziziphus mauritiana*	PMEY: 7.55 t/ha		
Crops + *Hardwickia binoata*	PMEY: 2.50 t/ha		
CFS : Sole pearl millet	4.4 t/ha G+ 22.0 t/ha S	IFS had additional yield of gum & fodder	Harsh and Tewari (2007)
IFS : Pearl millet + *Acacia senegal*	160 kg gum + 2.7 t/ha G + 13.3 t/ha Fo		
CFS: Sole *Hardwickia binoata*	2.34 t/ha TLF + 3.31 t/ha FW	IFS gave a higher fodder yield than sole tree or pasture cultivation	Harsh and Tewari (2007)
Sole *Cenchrus ciliaris*	Fo 3.06 t/ha		
IFS: *H. binnata + C. ciliaris*	Fo&TLF 3.89 t/ha+ FW 2.25 t/ha (yields are average of 5 years)		
CFS: Sole pasture **(***Cenchrus ciliaris***)**	Fo 22.59 t/ha	The IFS gave 17-20% higher fodder yield than sole pasture	Patidar and Mathur (2017)
IFS: *Hardwickia binoata* **+** *Cenchrus ciliaris*	Fo& TLF 26.4 t/ha		
Cholospermum mopane + C. ciliaris	Fo& TLF 27.0 t/ha		
Rajasthan, Bikaner			
CFS : Groundnut – wheat (GN-W)	0.35 t/ha pod (GN) + 0.93 t/ha G (wheat)	Ber + Aloe or ber + clusterbean -Indian mustard had better yields	Saroj *et al.* (2003)
Clusterbean – Indian mustard (CB-IM)	5.18t/ha GP (CB) + 1.11 t/ha G (Indian mustard)		
IFS : Ber + groundnut –wheat	0.96 t/ha F (ber) + 0.34 t/ha pod (GN) + 1.0 t/ha G (wheat)		
Ber + Cluster bean – Indian mustard	0.98 t/ha F (ber) + 5.09 t/ha GP (CB) + 1.15 t/ha G (Indian mustard)		
Ber + Aloe	1.35 t/ha F + 20.8 Aloe pad		
CFS : Mothbean – cumin (MB –C)	0.41 t/ha G (MB) + 0.44 t/ha G (C)	Crops in association with aonla had 14-38% higher yields than sole cropping	Awasthi *et al.* (2009)
Mothbean – chickpea (MB –CP)	0.42 t/ha G(MB) + 1.08 t/ha G (CP)		
IFS : Aonla + Mothbean – cumin (MB –C)	0.45 t/ha G (MB) + 0.60 t/ha G (C)		
Aonla + Mothbean – Chickpea (MB –CP)	0.49 t/ha G (MB) + 1.49 t/ha G (CP)		
Uttar Pradesh, Jhansi			
CFS: Sole Dicanthium	Fo : 3.29 t/ha	The IFS gave 17% higher fodder yield along with extra fruit yield than CFS	Kumar *et al.* (2009)
IFS : Aonla + Dicanthium	Fo : 3.85 + F (Aonla) 12.1 t/ha		
Punjab			
CFS: Crop (1.0 ha)	CEY: 12.5 t/ha	IFS had double yields than CFS	Gill *et al.* (2009)
IFS_1: Crop (0.6 ha)+ dairy (0.4)	CEY: 25.0 t/ha		
IFS_2: Crop (0.6 ha)+ dairy (0.4)+Poultry(100)	CEY: 25.5 t/ha		
Karnataka, Northern dry zone, rainfed			
CFS : Sole Bengal gram	0.76 t/ha G		Yaragattikar and Itnal, (2003)
Sole safflower	0.87 t/ha G		
IFS : Ber + Bengal gram	0.48 t/ha G + 2.80 t/ha F		
Ber + safflower	0.51 t/ha G + 2.61 t/ha F		

*CFS: conventional farming system; IFS: integrated farming system. **G: grain, S: straw, F: fruit, Fo : fodder TLF : tree leaf fodder, FW : fuel wood, CEY :crop equivalent yield, GP: green pod, PMEY: pearl millet equivalent yield

Table 3 Relative profitability of integrated and conventional farming/ production systems

Location/System	Profitability	% increase over conventional farming	Reference
Rajasthan, Jodhpur			
CPS: Sole pearl millet	NR : ₹ 3600/ha	+61	Harsh and Tewari (2007)
IFS: Pearl millet + *Acacia senegal* (140 plant ha^{-1})	NR : ₹ 5782/ha		
CPS: Sole *Hardwickia binata*	NR : ₹ 4000/ha	+25 over sole tree	Harsh and Tewari (2007)
Sole *Cenchrus ciliaris*	NR : ₹ 3061/ha	+65 over sole grass	
IFS: *H. binnata* + *C. ciliaris*	NR : ₹ 5019/ha		
CFS : Arable crops	NR : ₹83000 for 7/ha		Tanwar *et al.* (2016)
IFS : IFS comprising arable crops+ tree + fruit crop (ber)+ grass + 7 ACU (4 cow, 8 bucks and 4 rams)	NR : ₹243000 for 7/ha	+ 193	
CFS : Sole mung bean	NR : ₹ 2200/ha		Meghwal and Henry (2008)
Sole clusterbean	NR : ₹ 5140/ha		
IFS : Mung bean + ber	NR : ₹ 11700/ha	+432	
Clusterbean + ber	NR : ₹ 13487/ha	+162	
Rajasthan, Bikaner			
CFS : Mothbean – cumin	NR : ₹ 18035/ha		Awasthi *et al.* (2009)
Mothbean – chickpea	NR : ₹ 16283/ha		
IFS : Aonla + Mothbean – cumin	NR : ₹ 28260/ha	+57	
Aonla + Mothbean – Chickpea	NR : ₹ 25024/ha	+54	
Haryana, Hisar			
CFS: Cropping alone	NR : ₹ 4615/ha		Singh *et al.* (1993)
IFS1: Cropping + crossbreed cattle	NR : ₹ 20581/ha	+346	
IFS2: Cropping + buffalo	NR : ₹ 6218/ha	+35	
Haryana, Bawal			
CFS: Clusterbean - barley	NR : ₹ 15935/ha		Kaushik *et al.* (2017)
IFS : Khejri + Guava + Clusterbean - barley	NR : ₹ 76650/ha	+381	
Khejri + Aonla + Clusterbean - barley	NR : ₹ 68000/ha	+327	
Uttar Pradesh			
CFS: Cropping alone	NR : ₹ 41017/ha	+16	Gill *et al.* (2009)
IFS: Crops + dairy	NR : ₹ 47737/ha		
CFS: Cropping	NR : ₹ 66371/ha		
IFS_1: Crops + dairy	NR : ₹ 103615/ha	+56	
IFS_2: Crop + dairy + horticulture	NR : ₹ 107467/ha	+62	
IFS_3: Crop + dairy + apiary	NR : ₹ 134382/ha	+102	
IFS_4: Crop + dairy + vermicomposting	NR : ₹ 139472/ha	+110	
Punjab			
CFS: Crop (1.0 ha)	NR: ₹ 47.97×10^3/ha		Gill *et al.* (2009)
IFS_1: Crop (0.6 ha)+ dairy (0.4)	NR : ₹ 58.73×10^3/ha	+22	
IFS_2: Crop (0.6 ha)+ dairy (0.4)+ Poultry(100)	NR : ₹ 59.91×10^3/ha	+25	
Karnataka, Northern dry zone, rainfed			
CFS : Sole Bengal gram	NR : ₹ 5630/ha		Yaragattikar and Itnal (2003)
Sole safflower	NR : ₹ 5485/ha		
IFS : Ber + Bengal gram	NR : ₹ 16330/ha	+190	
Ber + safflower	NR : ₹ 14840/ha	+171	

that IFS [arable crops + tree + fruit crop + grass + livestock (4 cow, 8 bucks, 4 rams)] on 7 ha land holding size fetched higher net return (₹ 243000 for 7 ha) than sole arable crop production systems (₹ 83000 for 7 ha). Thus, the IFS had 193% higher net return than arable cropping (Tanwar *et al.* 2016). Kaushik *et al.* (2017) assessed profitability of arable cropping (cluster bean – barley) and IFS (*Prosopis cineraria* +*Psidium guajava* + cluster bean – barley;

Prosopis cineraria + *Emblica officinalis* + cluster bean – barley) in semi-arid environment at Bawal, Haryana and demonstrated that IFS fetched 4.3 to 4.8 -folds higher net returns than sole arable cropping.

The ber-based agri-horticultural production system enhanced profit in arid and semi-arid regions (Gupta *et al.* 2000). The integration of legume crops (cluster bean and mung bean) with ber was found more profitable (B: C ratio 2.03 to 2.15) than sole ber (B:C ratio 2.1), and legume crop (B:C ratio 1.42 to 1.93) production in arid regions (Meghwal and Henry 2008). The economic performance of integration of legume crops (cowpea, cluster bean and moth bean) with aonla, ber and pomegranate was evaluated in arid regions of Gujarat. The ber + cluster bean had highest profitability (B:C ratio of 1.83) followed by ber + moth bean (B:C ratio 1.65) (Dayal *et al.* 2015). Patel *et al.* (2008) demonstrated that *Ailanthus excelsa* and *Azadirachta indica* based agri-silvicultural system gave 26% and 59% higher income than sole cropping in arid regions of Gujarat. A study conducted at Pali indicated that strip cropping of *Lawsonia inermis* and cluster bean provided higher returns than their sole cultivation (Singh *et al.* 2005). Results of a study conducted in semi-arid environment at Haryana demonstrated that integration of milch buffalo and crossbreed cattle with cropping had 35 and 34.6% higher returns than sole cropping (Singh *et al.* 1993). Gill *et al.* (2009) demonstrated that IFS comprising crop + dairy, crop + dairy + horticulture and crop + dairy + vermicomposting recorded 56, 62 and 110% higher net return, respectively than sole cropping in Uttar Pradesh.

Besides higher income, the IFS provides a continuous flow of money to the farmers throughout the year through sale of a variety of farm produce (milk, egg, mushroom, vegetables, fruits, food grains) (Behera and Mahapatra 1999, Kumar *et al.* 2013) which helps to meet the fiscal requirement of farmers throughout the years. In contrast, the income from conventional arable cropping is season-specific which bounds the farmers to borrow the money from formal and informal credit sources on interest which might lead to the distress sale of farm produce to money lenders.

Employment generation: Crop-based agriculture is highly season-specific, with peaks of labor requirement at certain time of year and farmers don't have adequate employment during the rest time of the year. The IFS has ability to generate additional employment and more equitable distribution of employment throughout the year, and thus ensures a steady sink for local labor force. IFS is a labor intensive system, which creates on-farm employment and most of the labor required in the production process is contributed by the farmer and his family members (Dasgupta *et al.* 2015).

A study conducted in hot arid environment at CAZRI, Jodhpur demonstrated that IFS [arable crops + tree + fruit crop + grass + livestock (4 cows, 8 bucks, 4 rams)] on 7 ha land holding size generated 866 man-days employment/ year compared to 447 man-days annual employment from arable cropping, Thus, the IFS had 1.9-times higher employment generation than arable cropping (Tanwar *et al.* 2016). Kumar *et al.* (2009) assessed employment generation of sole pasture and pasture + aonla production systems in semi-arid environment at Jhansi, and reported that pasture and pasture + aonla production systems generated 25 and 60.3 man-days/ha year, respectively. Thus, pasture + aonla production systems generated 2.4 times higher employment than sole pasture. The study conducted in Punjab indicated that integration of dairy, dairy + fishery and dairy + fishery + piggery with arable cropping generated 138.2, 136.6 and 171.9 additional man days compared to the sole arable cropping system (Gill *et al.* 2009).

Risk minimization: A single commodity-based agriculture is more vulnerable to climatic, biotic (pests and diseases) and economic (relative prices of input and output) changes compared to IFS. Adoption of IFS would help farmers escape such situations and reduce the risk involved in the crop failure (Shukla *et al.* 2002) and it has been reported that IFS are often less risky than single enterprises based production system (Lightfoot 1990, Pullin 1998, Prein *et al.* 1998).

Scarcity of rainfall is an important constraint in crop production in hot arid regions of India. It has been demonstrated by various studies that in the case of crop failures due to rainfall scarcity, the perennials provide fodder, fruit and fuel wood. Faroda (1998) demonstrated that under subnormal rainfall conditions (51% less rainfall than the long term average of 360 mm), the yield reduction of mung bean was higher in sole cropping compared to that in *Ziziphus*-based integrated production system and this integrated production system provides a year round supply of fodder for five sheep/goat and fuel wood for a family having 4 members. Another study demonstrated that under delayed monsoon onset conditions (monsoon onset in first week of August), the IFS comprising agri-horticulture, agri-pasture, silvi-pasture provided higher returns than those from sole arable cropping, and the IFS produced fodder sufficient for 8 adult cattle unit (4 cow, 8 buck and 4 ram), with a production of 7712 litres milk, 292 kg meat and 6500 kg farmyard manure (Tanwar *et al.* 2014). Furthermore, IFS provides opportunities to cultivator to tactically adjust the allocation of input (land, water, forage) across and between enterprises in response to fluctuations in prices and climatic conditions. The integrated crop-livestock production system provides an opportunity to producer to convert a grain crop to a forage crop mid-season during low rainfall years when grain yield prospects are low or when livestock prices are higher relative to grain prices.

Resource utilization and conservation: The IFS leads to efficient utilization, recycling and conservation of natural resources. Behera and Mahapatra (1999) demonstrated that the integration of crop, poultry, fishery, duckery and mushroom production ensured efficient recycling of resources amongst enterprises. The integration of woody perennials with crops provides opportunity for efficient nutrient cycling via the tree's ability to absorb the nutrients from deeper layers of soil and supplying the absorbed nutrients to crops through litter fall. A study conducted at Modipuram (UP) indicated that in IFS, the recycling of organic resources is able to provide 79 and 58% of N, and P_2O_5 requirement of field and plantation crops (Gill *et al.* 2009). This indicates self-sustainability of IFS and reduction of dependency on external nutrient sources.

Maintaining soil organic matter (SOM) is essential for sustaining crop productivity. IFS involving livestock and woody perennials are an effective mean for maintaining and enhancing SOM. Trees have greater root biomass and deeper rooting depth compared to majority of annual crops, both of which contribute to organic matter accumulation over time. Wind and water erosion are major soil degradation processes in arid and semi-arid regions. The integration of perennial trees and grasses provide vegetative cover to the soil and minimize the soil erosion. Thus, the integration of tree with arable crops have the potential to reduce soil erosion, and to maintain SOM, improve soil physical properties and augment nitrogen fixation and promote efficient nutrient cycling. Singh *et al.* (2014) assessed biomass productivity and soil properties of different production systems consisting combination of silvicultural species (*P. cineraria*, *A. excelsa* and *C. mopane*), horticultural species (*Z. mauritiana*, *Cordia myxa* and *E. officinalis*) intercropped with wheat in hot arid region. The authors demonstrated a significant enhancement in SOC (7%) and NH_4–N (8%) in agroforestry plot compared to sole tree plots. Yadav *et al.* (2011) assessed the effect of trees (*P. cineraria, Dalbergia sissoo, Acacia leucophloea, Acacia nilotica*) on soil biological characteristics in semi-arid regions and reported that agroforestry system enhanced soil biological activity (soil microbial biomass C, N and P), and amongst the trees, *P. cineraria* based system brought maximum enhancement of soil biological properties.

The IFS ensures recycling of the leftover by-product of one enterprise as an input for other enterprises (Shekinah *et al.* 2005, Gill *et al.* 2009), which leads to better utilization of resources. Many studies demonstrated that resource (water and nutrient) use efficiencies enhanced, when the livestock, poultry, fishery, etc. was associated with crops (Shekinah *et al.* 2005, Samra *et al.* 2003). Water is the scarcest resource in arid and semi-arid regions, and multiple use of water is an important strategy for its efficient utilization. IFS ensures multiple use of water by putting the same water into several uses like producing crop, fish, dairy, mushroom, poultry, etc. simultaneously within a farm (Singh and Gautam 2002) to obtain higher water productivity (Sharda and Juyal 2007, Gill *et al.* 2005). Gill *et al.* (2005) reported that integration of fish and fish + piggery with arable cropping had 56 and 86% higher water productivity than sole arable cropping in Punjab. A study conducted at Rahuri, Maharashtra showed that IFS involving crop, horticulture, dairy, poultry and fishery had 164% higher water productivity (₹ 991/ha-cm in IFS, and ₹ 374/ha-cm in sole cropping) than arable cropping (Surve *et al.* 2014). The efficient multiple uses of groundwater before irrigation via adopting multiple enterprises (agriculture–fishery–horticulture–agroforestry–livestock) have been demonstrated by farmers in Punjab. Similarly the use of canals for aquaculture has potential to generate extra income for farmers (Behera *et al.* 2012).

Climate change mitigation and adaptation: Since the industrial revolution, the concentration of greenhouse gases (GHGs) in the atmosphere has increased which are mainly responsible for global warming and associated climate change. CO_2 is a major GHG, and its concentration during 2000 to 2011 has increased from 369 to 391.5 ppm (Conway and Tans 2012). Finding low-cost methods to sequester carbon (C) is a major international policy goal in the context of increasing concern about global climate change. The IFS has tremendous potential of storing C in the ecosystem (Dasgupta *et al.* 2015). The IFS has an important role in reducing atmospheric CO_2 concentration because (a) integration of woody perennials (trees and shrub) enhances C storage, (b) integration of livestock provides manure, and application of manure enhances C storage in the soil, and (c) integration of woody perennials and livestock with arable crops provides nutrients to crops via effective recycling of resources which reduces need of fertilizers and hence, indirectly saves fossil fuels.

The empirical evidences on C-sequestration, climate change mitigation and adaptation potential of the IFS are scanty. However, the effects of different land use systems, particularly the agroforestry on C-sequestration are extensively available for different agro-ecologies. Trees in agricultural landscapes plays a critical role in reducing vulnerability to uncertain and shifting climate (Van Noordwijk *et al.* 2011). Besides providing variety of products (wood, fuel, food, fodder, etc.), trees can buffer microclimate, improve water use, modifiy nutrient flows, store C, and improve biodiversity. The agroforestry provide a unique opportunity to combine the twin objective of climate change adaptation and mitigation. The estimates of C stored in AFS range from 0.29 to 15.21 t/ha/ year above ground, and 30 to 300 t C/ha up to 1 m depth in the soil (Nair *et al.* 2010). The average C sequestered by these practices has been estimated to be 9, 21, 50, and 63 t C ha^{-1} in semi-arid, sub-humid, humid, and temperate regions. Dhyani *et al.* (2016) gave a detailed account of the carbon sequestration potential (CSP) of AFS in India. The authors demonstrated that CSP of tree and crops in AFS varied from 0.25 to 19.14 and from 0.01 to 0.60 t C/ ha year, respectively; and the contribution of AFS in soil carbon sequestration varied between 0.003 to 3.98 t C/ ha year. Ajit *et al.* (2017) estimated the CSP of existing AFS for a period of 30 years in twenty six districts from ten selected states of India. The average estimated CSP of AFS, representing varying edapho-climatic conditions, on farmer's field at country ranged from 0.05 to 1.03 t C/ha year with an average value of 0.21 t C/ha/year which is equivalent to 0.77 Mg/ha/yr CO_2 mitigation.

The CSP of some AFSs in arid and semi-arid regions of India is presented in Table 4. A study conducted by CAZRI in Gujarat demonstrated that the silvi-pastoral system (tree: *Acacia tortilis* and *Azadirachta indica*; grass: *Cenchrus ciliaris* and *Cenchrus setegerus*) sequestered 36.3 to 60.0%

Table 4 Carbon sequestration potential (CSP) of various agroforestry systems in India

Location	Agroforestry system	Tree species	Number of trees/ha	Age (year)	CSP (Mg C/ha/ year)	Reference
Ludhiana, Punjab	Agri-silviculture	*Populus deltoides*	493	6	6.22	Chauhan *et al.* (2011)
Jhansi, UP	Agrisilviculture	*Albizia procera*	312	7	3.70	Ramnewaj and Dhyani (2008)
Kurukhestra, Haryana	Silvipasture	*Acacia nilotica*	1250	7	2.81	Kaur *et al.* (2002)
		Delbergia sissoo	1250	7	5.37	
		Prosopis juliflora	1250	7	6.50	

Source: Ajit *et al.* (2017)

more total soil organic carbon (SOC) stock compared to sole tree and 27.1 to 70.8% more SOC stock than sole pasture systems (Mangalassery *et al.* 2014). Besides climate change mitigation via C sequestration, the AFS helps in adapting to climate change via moderating climate extremes, in particularly high temperatures, as well as intra-annual climatic fluctuations (Mbow*et al.* 2014).

Selected IFS models for arid and semi-arid regions

Various suitable IFS for arid and semi-arid regions were developed in farmers' field and at research station by integrating various compatible enterprises such as crops (field crops, horticultural crops), agroforestry (agri-silvi culture, agri-horticulture, agri-pastoral, silvi-pastoral, horti-pastoral), livestock (dairy, pigs, poultry, small ruminants), fishery, mushroom, biogas production and tree plantation (Bhati 1997, Bhati *et al.* 2008, Singh *et al.* 1999, Jayanthi *et al.* 2001, Singh *et al.* 2007, Gill *et al.* 2009, Surve *et al.* 2014). Some of the suitable IFS models identified for arid and semi-arid regions of India are presented in Table 5.

The agroforestry based integrated production system is suitable for improving productivity, employment opportunities, economic condition and nutritional security in arid regions (Chundawat 1993, Pareek 1999, Chadha 2002, Harsh and Tewari 2007). The *P. cineraria, H. binata, A. senegal, Alianthus excelesa* are suitable tree species for hot arid regions. *Emblica officinalis, Punica granatum, Aegle marmelos, Phoenix dactylifera* are suitable fruit trees for areas having irrigation facilities, whereas *Capparis decidua, Salvadora oleoides, Cordia dichotoma, C. gharaf, Ziziphus nummularia* var. *rotundifolia, Z. mauritiana* are suitable for areas receiving annual rainfall <300 mm. *Solanum melongena, Lagenaria siceraria, Luffa acutagula, Luffa cylindrica, Citrullus lanatus, Citrullus lanatus* var. *fistulosus, Cucmis melo* var. *utilissimus, C. melo* var. *momardica, C. callosus, Cyamposis tetragonoloba* are suitable vegetable for horticultural based farming system in arid region (Pareek and Awasthi 2008). IFS comprising *Z. mauritiana*/Z. *rotundifolia* + arid legume crops (mung bean, mothbean, cluster bean) is suitable system for hot arid regions (Bhati *et al.* 2008). Under limited irrigation facilities, the Clusterbean – Indian mustard and Indian Aloe are suitable ground storey component for *Ziziphus* based production system (Saroj *et al.* 2003). Kinnow based agri-horti system (kinnow + mung bean, cotton, cotton – barley and cotton-chickpea) were found suitable for irrigated lands of Sriganganagar (Bhatnagar *et al.* 2007). The pomegranate + cluster bean/horsegram/mung bean/henna (Lal 2008), and pomegranate + pearl millet/

Table 5 Suitable IFS models for arid and semi-arid regions of India

Region	IFS model	Reference
Semi-arid vertic Inceptisols of Tamil Nadu	Crop + poultry (20) + goat (4) + sheep (6) + dairy (1)	Solaiappan *et al.* (2007)
Tungbhadra project area of Karnataka	Crop (0.74 ha)+ horticulture (0.18 ha) + fodder crop (0.02 ha) + livestock (2 cow, 1 buffalo,14 goat)+ vermicompost units (4) + compost unit (1) + *Azolla* unit (1)	Basavanneppa and Gaddi (2017)
Dryland western zone of Tamil Nadu	Sorghum + cowpea (grain purpose), sorghum + cowpea (fodder) and *C. glaucus* each in 0.33 ha intercropped with *Emblica officinalis* + goat (5+1)	Radhamani (2001)
Semi-arid Gujarat	Crops:pearl millet – wheat (0.44 ha), mustard – pearl millet (0.22 ha), cotton – fodder sorghum (1 ha) + horticulture: papaya (0.04 ha) + dairy buffalo (6)	Patel *et al.* (2007)
Semi-arid irrigated Punjab	For 2 ha land: Crop (1.14ha) + dairy (0.22) + fishery (0.56) + piggery (0.24)	Gill *et al.* (2009)
Semi-arid Haryana	Cropping + buffalo or cropping + crossbreed cattle	Singh *et al.* (1993)
Arid Rajasthan	IFS for 7 ha land: Agroforestry (*Prosopis cineraria* + crop), agroforestry (*Hardwickia binata* + crop), agri-horti (*Zizyphus mauritiana* + crops), hortipasture (*Zizyphus mauritiana* + grass), silvipasture(*Colophospermum mopane* + grass) with six adult cattle unit (4 cow, 8 bucks and 4 rams)	Tanwar *et al.* (2016)

Table 6 Vegetable crop components for cropping systems in hot arid\regions

Rainfall	High storey crops	Medium storey crops	Ground crops			Micro-wind break, biodefense or field divider
			Vegetable	Agronomic	Grasses	
Rainfed areas (150-300 mm rainfall)	Khejri, ber,	Ber, kair	Mattera, kachri, snapmelon	Guar, moth, bajra, til	*Cenchrus*, *Lasiurus*	Ker, phog, khimp, jharber
Rainfed areas (300-500 mm rainfall)	Ber, lasora, khejri	Sehjana, lasora	Mattera, kachari, snapmelon, tinda, brinjal, Indian bean, cluster bean, cowpea	Guar, moth, bajra, til	*Cenchrus*, *Dichanthium, Panicum*	Ker, phog, khimp, jharber
Irrigated areas	Date palm, ber, aonla	Lime, guava, pomegranate	Cucurbits, chilli, tomato, brinjal, cole crops, pea, beans, onion, okra and leafy vegetable	Cumin, isabgol, groundnut, mustard		Lasora, sehjana, karonda

Source: Samadia *et al.*(2004).

mung bean/isabgol/sorghum/cumin (Gupta *et al.* 2000) are suitable production systems for Pali and Jalore regions of Rajasthan, respectively. Samadia *et al.* (2004) proposed crop components for horticulture based production systems in the hot arid regions of Rajasthan (Table 6)

Up scaling of IFS

The research experiences accumulated over the years have shown that IFS increases diversification, intensification, improves natural resource use efficiency, productivity and sustainability. Despite many economic and ecological advantages provided by IFS compared to single commodities based agricultural production system, the IFS approach has not implemented up to the desired extent. There are numerous constraints for adoption of IFS. Adequate transport, processing and marketing facilities is pre-requisite for full realization of the economic potential of IFS involving horticulture and livestock components. The inadequacy of transport, processing and marketing facilities, particularly in rural areas in arid and semi-arid regions is another important constraint for wide scale adoption of IFS in these regions. It is well established that with changing of single commodity production system to integrated production system, the requirement of management skill increases. For harnessing full benefits of IFS, the producers have to understand the management of various enterprises and their interactions, and plan to determine the best combination of enterprises which requires good management skills. Majority of the farmers have inadequate managerial skills to operate IFS, which impede wide scale adoption of IFS in these regions. Most of the programs and policies implemented for agricultural development are commodity specific, i.e., targeting food grain, pulses, oilseed, milk, etc. There is a lack of programs for promoting diversified and integrated farming systems. Additionally, the coordination amongst different agricultural and rural development agencies and programs is inadequate. Therefore, adequate institutional and enabling police support for promoting IFS are important considerations. The farmers' participation in designing, evaluating and refinement of farming systems research is essential for the adoption of IFS (Shukla *et al.* 2002). The cropping activities in the majority of rainfed hot arid regions are confined to rainy season (July – November), and during the rest of the period of the year, the livestock freely graze in cultivated areas. The damage of woody perennial components (silvi and horticultural tree and shrub) by grazing livestock, particularly during the establishment stage (up to 2-3 years after planting) is another important constraint for adoption of IFS involving horticultural and silvi-cultural components in rainfed hot arid regions.

The way forward

IFS seem to be an important option to ensure nutritional security, profitability, gainful employment and environmental security in arid and semi-arid regions. In order to widen the implementation of IFS and harness the full potential of IFS, the research, policy and practice will have to progress towards: (i) creating adequate storage, transportation and marketing facilities for agricultural produces (particularly animal and horticultural produces) in rural areas; (ii) strengthening extension activities for effective dissemination of IFS and periodical trainings of farmers and extension personnel for imparting knowledge and skill for implementation of IFS; (iii) maintenance of the traditional IFS and strategic creation of new target domain specific IFS along with integration of modern soil and moisture conservation, crop husbandry practices; (iv) continuous assessment (in terms of yield, profitability, employment, resource use efficiencies, climate change mitigation and adaptation potential) and refinement of developed IFS models in farmer participatory approach; (v) strengthening coordination among different stakeholders involving agricultural and rural development agencies, along with ensuring enabling policy framework for adoption of IFS is required for implementation of IFS to the desired extent.

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