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Review/Overview Article

Rainfed integrated farming systems in arid zone of India: Resilience unmatched

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ABSTRACT

Arid zone constitutes about 10% of India's geographical area, where further scope of area expansion under agriculture and productivity enhancement exists. The traditional farming systems are self-contained and show resilience to aberrant weather conditions, but are low yielders. This region is endowed with some of the most drought hardy crops, multi-purpose trees [e.g. *Prosopis cineraria* (L.) Druce (*khejri*) and *Ziziphus mauritiana* Lam. (*ber*)], grasses (e.g. *Cenchrus ciliaris* L., *Lasiurus scindicus* Henrard), and breeds of cattle (e.g. 'Tharparkar', 'Kankrej') and small ruminants (Marwari sheep and goat). The farming system research that began in early eighties derives its tools from rich indigenous knowledge accumulated over the ages for resilience, and amalgamated it with the scientific innovation to achieve higher levels of production, while managing the fragile resource base. Owing to risky crop production, land is put to alternate uses with perennial components like agroforestry, agri-horticulture, agri-pasture, horti-pasture, farm forestry etc. At ICAR-CAZRI, Jodhpur, IFS experiment over 7.0 ha area is being conducted since 2001 in adaptive research mode. Based on the results of this experiment, an IFS model for 5–7 ha farm holding for 250–400 mm rainfall zone has been recommended. This includes arable cropping (20%), agroforestry (30%), agri-horticulture (20%), silvi-pasture (10%) horti-pasture (10%) and boundary plantation (10%). In the livestock component, 'Tharparkar' cattle [0.75 adult cattle unit (ACU)/ha] and 'Marwari' sheep and goat (3 animals/ha) found rational to fully utilize family labour and available fodder. Moisture conservation practices are indispensable component of the model. The expected net returns calculated from this IFS model are ₹70,000/ha with a payback period of 5 years at an (IRR) of 33%. This IFS model is expected to generate employment to the tune of 130 man-days/ha. This diversification is also equally effective to provide ecosystem services, viz. enhanced biodiversity, carbon-sequestration, fuel-wood production and greenery in the desert.

Key words : Alternate land-use systems, Arid zone, Integrated farming system, Resilience

The Indian hot arid zone occupies an area of 32 million ha constituting about 10% of the country's geographical area. It forms a continuous stretch in the north-western states of Rajasthan (61%), Gujarat (20%), Punjab (5%), Haryana (4%) and scattered landmasses in the peninsular states namely Maharashtra, Karnataka and Andhra Pradesh. Inadequacy in quantum and erratic distribution of rainfall (<150 mm to 400 mm, CV 36 to >65%) coupled with high evaporative demand (1600–1900 mm/year) and light textured soils has made agriculture a difficult proposition. This land mass is under cultivation since time immemorial as evidenced by world's oldest remains of cultivated field belonging to pre Harappan era, excavated from Banwali village in Western Rajasthan. In the present time also, it is the most populated desert of the world with 27.5 million human and 11.3 million (ACUs) livestock (Census, 2011; Livestock census, 2012). In order to minimize the adverse effects of environment, the desert dwellers have evolved certain well contained systems that follow a pattern in accordance with the rainfall (Fig. 1). Areas receiving <250 mm rainfall have predominance of grasses and shrubs; hence range/pasture development with livestock rearing becomes the major proposition. In 250–350 mm rainfall zone, besides grasses and shrubs, multipurpose tree species dominate the landscape. Mixed farming encompassing agroforestry system, mixed cropping, livestock and pasture management are main livelihood options. Where rainfall is more than 300 mm, crops and cropping system diversification, agroforestry and livestock rearing are the major systems of sustenance of arid zone farmers (Bhati and Joshi, 2007). These sustainable systems although resilient to weather aberrations, however have low production levels, which are now inadequate to

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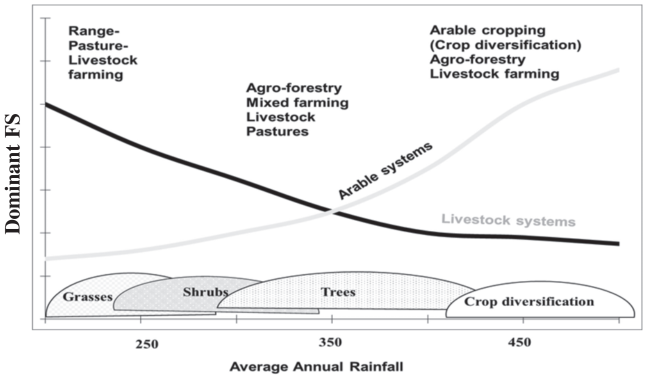

Fig. 1. Dominance of various farming systems according to rainfall pattern in arid zone

Source: Tanwar *et al.* (2017)

fulfill the needs of ever increasing population and their aspirations.

Integrated farming system (IFS) approach has been widely advocated for improving productivity, profitability, livelihood and soil health under different agro-ecological settings of India (Gill *et al.*, 2009; Surve *et al.*, 2014; Sahoo *et al*., 2015; Balamati and Shamaraj, 2017). Improving the productivity of annual crops shall remain the focal point for improving the productivity of any farming system. The key elements for improvement of crop productivity envisaged for this region are: efficient rain water management, suitable tillage and sowing operations, selection of improved varieties, appropriate intercropping and crop rotation systems, efficient soil fertility management, proper plant protection measures and contingency crop planning. However, positive impact of these interventions on yield are more perceptible only in normal to mild drought years, causing reluctance of farmers to adopt these improved dryland farming technologies (Bhati, 1997a; Jodha *et al.*, 2012). Long term studies (2001–2018) conducted at ICAR- Central Arid Zone Research Institute (CAZRI) in an established IFS model have revealed that this risk factor of poor or no returns in drought years can substantially be reduced with proper integration of multipurpose tree species (MPTS), pasture grasses, livestock and annual crops. Farmers to a reasonable extent understand the usefulness of perennial component based IFS. But they are further constrained mainly due to poor access to technical knowledge and critical inputs, long gestation period and high transaction cost of small marketable surplus. In this paper, efforts have been made to understand the perspective and current status of IFS research in arid zone and lessons learnt. Although the farming systems of the region have changed to some extent due to the advent of irrigation; it is estimated that, if all the available water is exploited even then 70% of the area shall remain rainfed. Therefore, the scope of this paper is restricted to purely rainfed situations for more focused discussion.

FARMING SYSTEM RESEARCH IN ARID ZONE: CONCEPTUAL DIFFERENCES

The farming system research (FSR) in arid zone and irrigated agro-ecosystems of India have evolved independently. During the green revolution era, single line commodity approach for transfer of technology was highly successful in high input, high yielding irrigated production systems. While in arid regions, the same technologies caused unexpected negative trade-offs. The enhanced complexity of problems were characterized by a variety of environmental and socio- economic stresses. Therefore, it was realized that those technologies should be chosen that address to the whole production system rather than solving individual and isolated ones (Singh, 1996; Singh 1997a; Singh 1997b, Singh, 1998). The limits of science-based recommendations were also acknowledged. This realization in the scientific community in mid-seventies, marked the beginning of FSR in arid zone. The FSR derives its tools from rich indigenous knowledge accumulated over the ages, while managing the fragile resource base (Fig. 2). It has evolved independently as an art of mixing various propositions of alternate land use systems. It comprises dryland farming, agroforestry/forage production, livestock husbandry, management of common property resources (CPRs), rehabilitation of degraded lands and efficient rain water management in totality. Comparatively, the systematic research on IFS in irrigated Indo-gangetic plains is a recent trend that has evolved as a measure to alleviate the problems encountered in post green revolution era and is a successor to crop and cropping system research (Behera and France, 2016). This involves

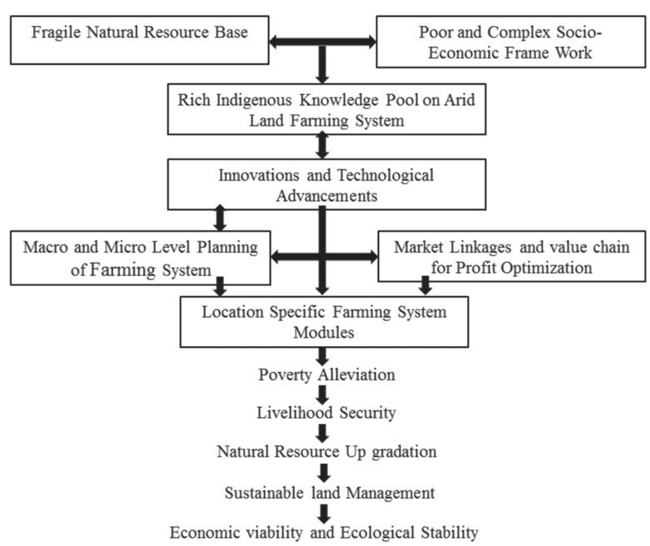

Fig. 2. Farming system perspective of arid zone agriculture

integration of various enterprises and recycling of crop residues and by- products within the farm itself (Behera and Mahapatra, 1999; Rautaray *et al*., 2005). While in arid zone the most important driver of FSR is to achieve resilience at higher levels of production. Recycling of resources is already intricately interwoven in arid zone farming. It harnesses complementarities and synergies among different agricultural sub systems/ enterprises much efficiently than in any other ecological settings.

COMPONENTS OF FARMING SYSTEM IN ARID ZONE

Diversified cropping

The common crops of the region are: pearl millet [*Pennisetum glaucum* (L.) R.Br.], greengram [*Vigna radiata* (L.) R. Wilczek], dewgram [*Phaseolus aconitifolius* (Jacq.) Marechal], clusterbean [*Cyamopsis tetragonoloba* (L.) Taub.] and sesame (*Sesamum indicum* L.). Mixed seeds of these crops are often broadcast or sown in lines to provide enhanced resilience to the system. This practice is now getting lesser preference due to improved production technology involving mechanization. The crop diversification is now followed either by proportionate area allocation amongst various crops or as intercrops. The most common intercropping systems are greengram/clusterbean + pearl millet (2:2 or 2:1), sesame + greengram/ dewgram/ cowpea (2:1) etc. High value- low volume commodities like medicinal, dye yielding crops etc. could also provide much needed buoyancy in arid farming. This includes *Cassia angustifolia, Aloe vera, Plantago ovata* and *Lawsonia inermis.*

Agroforestry

Arid landscape of Rajasthan is a typical parkland system, where growing of annual crops in association with scattered trees is in vogue. Trees growing in the crop lands as well as in community lands minimize the risk of crop failure during drought and famines by providing fodder and fuel wood (Shankarnarayan *et al*., 1987). Rainfall is the primary governing factor for evolution of different agroforestry systems in the region (Table 1). *Prosopis cineraria* based agroforestry is the most popular and widespread system covering about 60% area of arid zone and dominates the landscape in 300–400 mm rainfall zone. Crops perform better under *Prosopis cineraria* in the order pearl millet> cowpea> greengram> dewgram. Besides achieving good yield of dryland crops, bonus yield of dry leaves (25–30 kg/tree) and fuel wood (40–60 kg/tree) could be obtained from these farm trees through annual lopping (Bhati *et al.*, 2008). However, newer establishment of natural occurring *Prosopis cineraria*, *Tecomella undulata* and other trees has almost ceased mainly due to uprooting of seedlings and offshoots during mechanized field operations, excessive lopping and insect attack. This phenomena is more conspicuous in 200–300 mm rainfall zone. Some tree species have also been introduced in hot arid regions of the country from iso-climatic regions of the world or from other drier parts of the country like *Hardwickia binata*, *Ailanthus excelsa, Acacia tortilis* etc. These were thoroughly evaluated on the basis of information available on climatic homologues, potential inherent plasticity, genetic variability and invasiveness before recommending them for agroforestry programmes (Narain and Tewari, 2005).

*Tree-crop interactions***:** Tree component in agroforestry systems influences crop productivity through soil improvement (Singh and Lal, 1969; Singh *et al.*, 2000), microclimatic modification (Singh *et al*., 2003), soil-water conservation (Gupta and Saxena, 1978) and allelopathy (Joshi and Prakash, 1992; Saxena and Sharma, 1996; Saxena and Tanwar, 2016). However, their magnitude largely depends upon selection of suitable tree species, density, component crops and suitable management practices like pruning, lopping, thinning, root clipping, trenching etc. (Tanwar and Tewari, 2017; Tanwar *et al*., 2017). A number of factors were found responsible for positive effect of *Prosopis cineraria* on arid zone crops. It had improved nutrient availability i.e. organic matter content in the top layer (0–15 cm) 0.6% (under tree) *vs* 0.3% (open field); total nitrogen 250 *vs* 200 kg/ha (Singh and Lal, 1969; Shankar *et al.,* 1976; Harsh *et al.,* 1992) and phosphorus 0.04 *vs* 0.025%, respectively (Singh and Lal, 1969; Gupta and Saxena,

Table 1. Traditional agroforestry systems of arid zone of Rajasthan

Rainfall Zone (mm)	Agroforestry system	Trees/shrubs (Nos./ha)	Density of prominent species (%)
<200	*Ziziphus* spp. – *Prosopis cineraria* – *Salvadora spp.* based	17.2	87.2 (65% *Ziziphus* spp.)
200–300	*Ziziphus* spp. – *Prosopis cineraria*	91.7	100 (92% *Ziziphus* sp.)
300–400	*Prosopis cineraria* based	14.2	80.0%
>400	*Prosopis cineraria* – *Acacia nilotica* based	31.4	80.5%

Source: Naraian and Tewari (2005)

1978; Harsh *et al*., 1992; Gupta *et al*., 1998). Reduction in *p*H and electrical conductivity was also observed (Shankar *et al.* 1976; Mann and Saxena, 1980). Quantified improvement in biological activities was also reported (Tarafdar, 2008). Burman *et al.* (2002) investigated effect of 14 tree species prevalent in arid zone and found higher buildup of amino acids, amino sugars, hydrolysable NH_4 –N and total hydrolysable N under *Prosopis cineraria* and *Hardwickia binata*. The peak nutrient release period from the decomposing leaf litter of *Prosopis cineraria* coincide with peak nutrient demand period of arid zone crops (Yadav *et al.*, 2008).Trees on farm also bring about favourable changes in micro-climatic conditions by influencing radiation flux, air temperature, wind speed, saturation deficit of under storey crops etc. (Monteith *et al*., 1991). The moisture regime in the soil profile (120 cm) remained higher under *Prosopis cineraria* and *Tecomella undulata* as compared with other species (*Prosopis juliflora, Albizia lebbeck, Acacia senegal*) and the open field (Singh, 2009; Singh and Rathore 2016). Root architecture also plays an important role in deciding tree–crop competitions. Being a phreatophyte, *Prosopis cineraria* draws water from aquifers usually 10–25 meters deep and thus offer no competition to crops (Shankarnarayan *et al*., 1987; Gupta *et al*., 1998).

Agri–horticulture system

Arid zone of India is endowed with some of the most water economizing horticultural crops having multiple uses. These can be grown in association with annual crops with less or no competition and in some cases synergistic relationship was also observed (Pareek, 1999; Pareek and Awasthi, 2008; Bhandari *et al*., 2014; Singh *et al*., 2017). Since per unit returns from horticultural crops are always higher, their inclusion in the system improves net return of farmers, provide buoyancy and utilize surplus family labour. Common fruit trees/shrub for the region receiving rainfall <300 mm are: *Ziziphus mauritiana*, *Ziziphus rotundifolia, Ziziphus nummularia, Cordia myxa, Capparis decidua, Salvadora oleoides* etc. Several other fruits such as *Emblica officinalis, Punica granatum, Phoenix dactylifera, and Tamarindus indica* can be grown under limited irrigation. *Ber* is the most promising tree that fits best in rainfed farming systems of arid zone. Growing of leguminous crops between trees of *ber* is a prevalent traditional practice. If adequately spaced, alleys of *ber* are most suited for growing greengram without any negative effect on yield of both the crops (Bhati *et al*., 2008; Singh *et al.*, 2018). This agri-horticulture system has shown resilience to adverse weather conditions also. On the basis of 8 year study, it was inferred that two hundred *ber* plants per hectare (5 m × 10 m) is the optimum population of *ber* for agri-horti system in Jodhpur. In this system, amongst the arable crops clusterbean recorded better yields in drought years, greengram in good rainfall years and cowpea showed yield stability in most of the years. The system produced grains (0.39 t cowpea grain equivalent/ha/ year), fruits (3.08/ha/year), fuel wood (1.353 t/ha/year) and fodder (Bhati *et al*., 2008). Under subnormal rainfall conditions (51% less rainfall), the yield reduction of greengram was higher in sole cropping as compared to that in *ber* based integrated production system (Faroda, 1998). These systems also improve soil conditions. The nutrient status of dune soils remarkably increased after ten years of plantation of *ber.* Nutrient returns through litter fall of *ber* followed the order N > K > Ca > P (Awasthi and Singh, 2010). Cover cropping with cowpea (*Dolichos biflorus*) in *ber* orchard was found to increase water holding capacity of light soils due to increased organic carbon content in soil (Pareek and Vishal Nath, 1996). During establishment phase, the inputs applied for the ground storey crops enhance the vegetative vigour of *ber* plants than sole plantation. However, growing of wheat was not found remunerative in *ber* orchards (Saroj *et al.*, 2003)

Silvi-pastoral system

The grass species found in arid zone of India are very drought hardy, palatable and nutritious (Table 2). The community pastures are the integral part of farming systems of arid zone as they provide fodder to the livestock for a considerable part of year (4–6 months). But they are now highly overgrazed i.e. having a stocking rates of 1 to 4 ACU/ha (adult cattle unit) against the carrying capacity of 0.2–0.5 ACU/ ha leading to degradation of more than two third area under pastures (Dhruvanarayana, 1993). A substantial part of these degraded pastures can be reclaimed through integrating trees with grass cover commonly known as silvi- pastoral systems. These systems are found to be best suited for areas receiving <200 mm rainfall, or in degraded rocky-gravelly areas (Soni *et al.*, 2016; Table 3). It was found that during the establishment phase, grasses adversely affected the growth of trees to varying degrees but trees did not have any consistent impact on understory grasses. However, at later stage, grasses face higher competition from trees (Harsh *et al*., 1992; Sharma *et al*., 1993). Silvipasture systems responds positively to fertilizer application during rainy season and 40 kg N/ha was reported optimum for enhanced biomass production and water-use efficiency in *Hardwickia binata* + *Cenchrus ciliaris* system (Patidar and Mathur, 2017). In an established silvi-pasture (eleven years), leaf fodder of *Colophospermum mopane* and *Hardwickia binata* trees contributed 15 and 9%, respectively to the total system productivity, but the animals preferred *Hardwickia binata* leaves over *Colophospermum mopane* (Patidar and Mathur, 2017; Patil *et al.*, 2011). Carrying capacity of silvi-pasture system was observed almost double over that of pure pasture (Tewari and Harsh, 1998). *Ziziphus nummularia* + grass (strips in 1:2 ratio) gave higher economic returns from grazing goats due to weight gain of the animals and higher wool production (Bhati, 1997a). Silvi pasture system with *Z. rotundifolia* and *Cenchrus. ciliaris* sustained 554 cattle days/ha (Tharparkar breed) with 60% pasture utilization (Bhati, 1997b).

Horti-pastoral systems

In arid regions where livestock is a major component of farming system, horti-pastoral system forms an efficient drought coping mechanism. *Ziziphus nummularia* (Jharberi) is an important top feed species of arid region and almost every part of it has a use. The leaves make excellent fodder having high crude protein (13–17%) and fibre (15%). It generally dominates the common village grazing lands of Bikaner, Barmer and Jaisalmer districts with a relative dominance of 75–90%. In these districts, high density of this shrub (200–400 shrubs/ha) is also seen in cultivated fields having well-defined *kanker* pan at 100–150 cm depth. Exposed gravelly plains supports a shrub density of 120–150 shrubs/ha. In comparatively higher rainfall zone (300–500 mm) another *ber* species *Ziziphus rotundifolia* predominates and provides very good quantity of leaf fodder, fuelwood and fruits.

Growing of grasses or grass-legume mixtures in the interspaces of *ber* orchard (*Ziziphus mauritiana*) was found suitable in Class IV and V type of land (Tewari *et al*., 2001; Sharma, 2004). The grass should be sown after two years of establishment of *ber* because in these initial years, *ber* may not compete with the vigorous root system of grass (Sharma and Vashistha, 1985). No adverse effect of grasses was observed on growth and yield of *ber* in later years (Vashistha and Prasad, 1997). Additional 1.55 tonnes/ha/year grass fodder was obtained, when *Cenchrus ciliaris* grass was introduced between tree rows of a sixteen years old *ber (Ziziphus mauritiana*) orchard (spacing 6 m × 6 m; Tewari *et al.,* 1999). Higher returns are expected from third year of establishment of horti-pasture system (Sharma and Diwakar, 1989; Gajja *et al*., 1999). It significantly improved the organic carbon status of the soil as compared to other tree combinations (Sharma *et al*., 1993).

Table 2. Suitable grasses of arid zone according to rainfall gradient

Grass	Rainfall zone (mm)	Remarks
Lasiurus scindicus (Sewan)	100–250	Most drought resistant grass of the desert found in sandy plains, hummocky plains avoiding sand dune, inter dunal plains, exposed rocky surfaces particularly flood plains.
Cenchrus ciliaris (Dhaman or Anjan)	150	Highly palatable grass adapted to be grown even under tree shade. Shekhawati region appears to be its natural habitat. It can be cultivated on sandy to gravelly soils in arid regions and on sandy to sandy loam soils in semi-arid regions also.
Cenchrus setigerus (Moda Dhaman)	150	Highly palatable. It grows luxuriously on sandy soils, as well on heavy textured and gravelly soils.
Dicanthium annulatum (Kharad)	>350 mm or in low lying areas of arid zone	Comparatively a shallow rooted grass occurs mainly in moderately high rainfall areas. In sub-humid regions, it is a grass of uplands and adapted well to heavy soils.

Table 3. Important trees, shrubs and grass combinations for silvi-pasture development in western Rajasthan

Rainfall (mm)	Trees/ Shrubs	Grasses / Pasture legumes
150–250	*Acacia tortilis, Ziziphus nummularia, Prosopis cineraria.*	*Lasiurus scindicus, Cenchrus ciliaris, Panicum antidotale*
250–350	*Acacia. tortilis, Ziziphus nummularia, Prosopis cineraria, Acacia senegal, Calligonum polygonoides, Ziziphus rotundifolia, Hardwickia binata.*	*Cenchrus ciliaris, Cenchrus setigerus, Lasiurus scindicus*
350–500	*Acacia nilotica, Ailanthus excelsa, Holoptelea integrifolia, Albizia lebbeck, Azadirachta indica, Hardwickia. binata, Ziziphus rotundifolia*	*Cenchrus ciliaris, Dicanthium. annulatum, Lablab purpureus, Clitoria ternatea*

Source: Modified from Soni *et al.* (2016)

Wind strip cropping and ley farming

Wind strip cropping is a method of farming, where perennial grasses or other plants are established in the field at right angle to the prevailing wind direction and crops are grown in between these strips. Grasses like *Lasiurus scindicus* and *Cenchrus ciliaris* are suitable for strip cropping. However, *Saccharum munja*, *Panicum antidotale* and *Panicum turgidum* can also serve the purpose effectively. A strip cropping of grasses and *kharif* legumes in 1:2 ratio (5m wide strip) has been recommended for wind erosion prone regions like Bikaner, Rajasthan (Singh, 1989 and 1995). Where farmers are reluctant to adopt grasses, strips of *Ziziphus nummularia* (pala) would be readily acceptable. Ley farming i.e. grass–crop rotation significantly increased grain yield of crop over control (Dauley, 1994; Bhati *et al*., 1997a). It acts as a self-fertility regenerating system especially with respect to nitrogen (Singh and Gupta, 1997).

Shelterbelts and windbreaks

Soil erosion by wind is one of the foremost problem in Indian arid zone. Shelterbelts minimize the harmful effects of strong winds and increase farm productivity through moderation of micro-environment at field level (Mertia, 1986). The term shelterbelts and windbreaks are often used inter changeably, but a distinction can be made. A shelterbelt is a long belt of shrubs and trees for protecting fields, whereas wind break is a protective planting around farm, orchard or a building. The shelterbelt technology involves raising of porous vegetative barriers comprising strips of trees, shrubs and bushes planted across the prevailing wind direction. An increase of 305.6% in net returns has been observed by shifting from non-shelter belt to shelterbelt in farms of Jaisalmer district (Gajja *et al.,* 2008).Volumes of data on shelterbelts have been generated addressing designs, composition, suitable tree species, planting technique, etc. (Mertia, 1992; Mertia *et al*., 2006).

Water harvesting and in-situ moisture conservation

Crops in the arid zone suffers varying degrees of moisture stress in their life cycle. Technologies to enhance soil moisture may be grouped as, generating runoff from catchment area and storage (e.g. inter-plot water harvesting), reducing runoff from the cultivated field and reducing evaporation. In areas, where rainfall is < 200 mm and farms have less productive land, micro-catchments can be prepared in one or both sides of cropped area. In this system, two-third area of the field is to be used for cropping, leaving one-third as catchment (Singh, 1988). Contour bunding is recommended on slopes ranging from 1 to 6%. Singh (1984) recommended contour bunding of 75 cm height and 80 cm vertical spacing combined with contour furrowing of 10–15 cm depth and 100–125 cm vertical spacing. Contour vegetative barriers (CVB) may also be designed using locally available fast growing perennial grasses with extensive root system such as *Cymbopogon jwarancusa, Cenchrus ciliaris* and *Cenchrus setigerus* transplanted 0.3 m apart on contours at 0.6 m – 1.0 m vertical interval forming a dense hedge (Sharma *et al.,* 1997 and 1999).

In-situ moisture conservation decides the survival of crops in arid zone. Studies on preparatory tillage suggested that one sub-surface cultivation (disking) once in three years followed by harrowing and planking is required for good crop stand and higher yields of crops (Gupta and Gupta, 1986). Sandy soils with poor organic matter status generally get compacted and thus affect further percolation of rain water. Soil amendments like pond sediments, vermiculite, FYM, etc. were found very promising in improving moisture retention capacity of the soil (Gupta *et al.*, 1979). Use of mulches has been reported to favorably modify the hydrothermal regimes of soil and suppress weeds in arid regions (Parihar *et al.,* 1977; Gupta, 1978, 1980; Gupta and Gupta, 1983). But the effect of mulches was perceptible only in drought years (Dauley *et al.*, 1979).

Run off farming: Khadin cultivation

Runoff farming locally known as *Khadin* is a unique practice of water harvesting and moisture conservation in arid Western Rajasthan (<200 mm rainfall) followed since times immemorial (Balak *et al*., 1995, Faroda *et al.*, 2007). In this system, runoff from rocky uplands and rocky surfaces is collected in the adjoining lower valley formations that are converted into bunded farm land structure (*khadin*). Soils in the *khadins* are extremely fertile because of the frequent deposition of fine sediments, while the water that seeps away removes salts (Kolarkar *et al.*, 1983). Either *kharif* or *rabi* crops are raised, depending upon the amount of rainfall and consequent runoff received during the monsoon. Crops like wheat, mustard, taramira (*Eruca sativa*) and chickpea are successfully grown during post-rainy season on receding moisture. The productivity of *khadins* can be improved by provision of spillway, recycling of excess stored water for either growing of crops in down reaches or for life saving irrigation in upper reaches and adjoining land, standardization of fertilizer requirement of different crops and adoption of multi-production systems such as agroforestry, fisheries, etc. (Prasad *et al.,* 2004).

EXPERIENCES OF AN INTEGRATED FARMING SYSTEM MODEL FOR ARID ZONE

Considering the average land holding (1991 census) of Western Rajasthan being large, a purely rainfed (300–400 mm rainfall) integrated farming system experiment was established over 7.0 ha land at ICAR-CAZRI in adaptive mode. This has now completed 17 years. The objective was to develop a rainfed integrated farming system having both higher returns and resilience. It should fully utilize family labour, provide year round fodder for animals and do maximum recycling of resources. It is based on twin strategy of system and crop diversification. It comprised of 8 land use systems, viz. arable (crops alone, 1 ha), agroforestry (*Prosopis cineraria* + crops, 0.75 ha), agri-horticulture system (*Ziziphus mauritiana* + crops, 0.75 ha), agri-silviculture (*Hardwickia binata* + crops, 0.75 ha), silvi-pasture (*Colophospermum mopane* + grass, 0.75 ha), agri-pasture (rotation of *grass* and crops for 5 years, 0.75 ha), horti-pasture (*Ziziphus mauritiana* + grass, 2 ha) and farm forestry (*Acacia tortilis* alone, 0.75 ha). The *kharif* crops grown were pearl millet, clusterbean, greengram, and dewgram in 2:1:1:1 ratio following cereal–legume rotation. The grass in different systems was *Cenchrus ciliaris.* Six adult cattle units (4 cows, 8 bucks and 4 rams) were managed under mixed feeding system (i.e. stall feeding + grazing). Daily record of all the inputs and outputs was maintained.

Component wise economic analysis of the model from 12 to 15 year showed that amongst different land use systems, the net returns from agri-horticulture system were 6 times higher over arable cropping (Table 4). The net returns from *Prosopis cineraria* based-agroforestry system (₹24.4 × 10^3) were almost double than arable cropping and 28% higher over *Hardwickia binata* based agri-silviculture system. This might be due to synergistic effect of *Prosopis cineraria* on annual crops and additional availability of top feed and fuelwood from tree component. As evident from B: C ratio, tree based systems showed more stability in income compared to crops alone.

Whole farm analysis revealed that this model not only improved the gross returns by many times over arable cropping, but also imparted stability over the years under aberrant weather conditions (Tanwar *et al.*, 2014; Tanwar, 2016). The year 2012 was abnormal with delayed monsoon (4 August), 2013 had normal monsoon, while terminal drought occurred during 2014. In spite of such diverse weather situations, it had generated net returns from 0.20–0.28 million (Table 5). Also, it had generated yearlong employment for the family of 6 members with 3 adult workers (823–931 mandays). Thus, the total income for

Table 4. Economics of alternate land use systems of integrated farming system

System	Component	Cost of cultivation (₹ 10^3 /ha)	Net returns (₹ 10^3 /ha)	Benefit: cost ratio		
				2012–13	2013–14	2014–15
Arable farming	Crops alone	14.6	11.9	1.46	1.86	2.05
Agroforestry	*P. cineraria* + crops	19.4	24.5	2.02	2.34	2.41
Agri-silviculture	*Hardwickia binata* + crops	19.5	19.0	1.52	1.82	2.31
Agri-horti	*Ziziphus mauritiana* + crops	47.4	66.1	2.42	2.39	2.36
Horti- pasture	*Ziziphus mauritiana* + grass	29.2	29.8	1.56	2.54	2.12
Silvi- pasture	*Colophospermum mopane* + grass	16.4	39.6	2.94	3.75	3.48
Agri-pasture	Grass alone	16.3	32.2	2.9	3.29	2.65

Source: Tanwar *et al.* (2016)

Table 5. Whole farm economics of integrated farming system *vis-a-vis* arable farming (7.0 ha)

	Integrated farming system			Arable farming system		
	2012–13	2013–14	2014–15	2012–13	2013–14	2014–15
Gross returns (×₹ 10^3)	459.8	573.7	516.8	120.9	231.3	204.3
Total cost (×₹ 10^3)	260.7	292.5	268.6	83.1	124.4	99.6
Net returns (×₹ 10^3)	199.1	281.2	248.2	37.8	106.8	104.7
Benefit: cost ratio	1.76	1.96	1.92	1.46	1.86	2.05
Employment generation (Man-days)	845	931	823	442	460	438
Wages (×₹ 10^3)	151.6	167.6	148.1	79.5	82.8	78.8
Total earning (Net returns + family wages) (× 10^3)	350.7	448.8	396.3	117.4	189.6	183.5

Source: Tanwar *et al.* (2016)

the household ranged between 0.35–0.45 million compared to 0.12–0.19 million under arable system. The model produced grains (2.01 tonnes), fruits (2.26 tonnes), grass seed (0.56 tonnes), fuelwood (9.71 tonnes), milk 6540 litres) and meat (0.24 tonnes) averaged over 3 years.

This system has shown great potential for eco-system services. A rich biodiversity was maintained in this model. It enhanced carbon stock (in soil and perennial components) by 29% over the prevailing system of annual cropping at natural tree density. When extrapolated on regional scale, it stored as much carbon as that would require 20% area under afforestation. Fuelwood production and top feed in the farm would further reduce degradation of CPRs. Thus IFS approach in arid regions not only provide adaptation measures to climate change, but also can be an important tool for mitigation.

The system was refined based on subsidiary experimentation. The roots of *Colophospermum mopane* were found more confined to top 80 cm soil layer as also reported by other workers (Singh and Singh, 2015, Singh and Rathore, 2012). Animals showed less preference to the leaves of this plant causing reduction in animal productivity (Patidar and Mathur, 2017). Also it had shown very high evasiveness. In the subsidiary experiment *Hardwickia binata* and *Ailanthus excelsa*-based silvipasture systems showed higher productivity and palatability than mopane based system (CAZRI, 2013, 2014 and 2015). On the other hand, when fully grown up, *Hardwickia binata* showed competition to understorey crops during severly drought years. Hence appropriate location for *Hardwickia binata* seems to be in combination with grass rather than crops. The original IFS model was surplus in top feed and fuelwood. Hence more number of small ruminants (additional 6–7) may be introduced in the system. The fuelwood providing *Acacia tortilis* may be replaced with more remunerative trees producing other products like *Acacia senegal* (for gum production), *Dalbergia sissoo* (timber purpose), *Hardwickia binata* (fodder tree) etc. In the diversified cropping system, it was observed that the productivity of dewgram is consistent but low and hence the dew gram may be grown only when monsoon arrival delay by 30 July. This may be replaced by pearl millet, as the system was marginally deficit in pearl millet forage during abnormal year. Farmers also do not prefer to uproot grass in 5 years and hence agri-pasture system may be abandoned. Based on the above considerations, following IFS model is recommended for 5–7 ha land holding with a family of 6 members (Table 6). The expected net returns calculated for this system are ₹ 70×10^3 (including wages for family labour) with a payback period of 5 years at an IRR of 35%. This is expected to generate 130 mandays/ha. The system is in place with these modifications (in totality) for two crop seasons and adopted by the Rajasthan state agriculture department in their package of practices.

LESSONS LEARNT AND WAY FORWARD

The present research efforts in IFS have rightly amalgamated the rich indigenous knowledge to capture the resilience of traditional farming now at higher production levels. Further improvement in income requires incorporation of newer enterprises and value addition. There is a need to create a database on farming systems of this region and further documentation of coping strategies practiced by the local inhabitants. IFS involving agroforestry and livestock rearing, needs to be revived through government policy support. Livestock is the backbone of farming system and a considerable fodder requirement is met through CPRs, therefore community mobilization to improve the sustainable use of permanent pastures and rangelands should be carried out. Plant biodiversity of the arid region form the core of most drought coping strategies, it has to be maintained and harnessed scientifically. Plants like *Commiphora wightii* (guggal) are now on the verge of extinction due to over-exploitation, while others like *Aloe vera*, *Citrullus colocynths* (tumba), *Salvadora oleoides*, *Acacia senegal* etc., have received belated attention for

Table 6. Synthesized rainfed IFS model for 5–7 ha farm size in arid zone (rainfall 300–400 mm)

System	Component	% area allocation
Arable cropping	Diversified cropping of pearl millet, greengram, clusterbean in 4:1:1 ratio. Replace 30% pearl millet with dewgram under delayed monsoon (30 July onwards)	20
Agroforestry	*Prosopis cineraria* (spacing 10 m × 15 m) + crops	30
Agri-horticulture	Ber (Var. Seb, Gola; spacing 5 m × 10 m) + crops)	20
Silvi-pasture	*Hardwickia binata*/ *Ailanthus excelsa* + grass (*Cenchrus ciliaris*)	10
Horti-pasture	*Ziziphus rotundifolia*/ *Ziziphus mauritiana* + grass (*Cenchrus ciliaris*)	10
Boundary plantation	*Acacia senegal*, *Hardwickia binata*, *Dalbergia sissoo* + trenching after 3 years of plantation.	10
Cattle	Tharparkar breed	0.75 ACU/ha
Goat and sheep	Marwari breed	3 animals/ha

medicinal, industrial and food values. Technologies for deriving benefits from these and other local plant materials should be strengthened. Vast data available on productivity of crops, interactions among the components may be utilized for simulation modeling. This could ultimately led to development of a Decision Support System (DSS) through which tailor made integrated farming system models could be suggested for individual farm situation. This could also reduce the extensive farm trials. Experiences of arid zone may be used for developing climate smart technologies in other regions also as these regions already experiences the vagaries like high temperature, erratic rainfall etc.

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