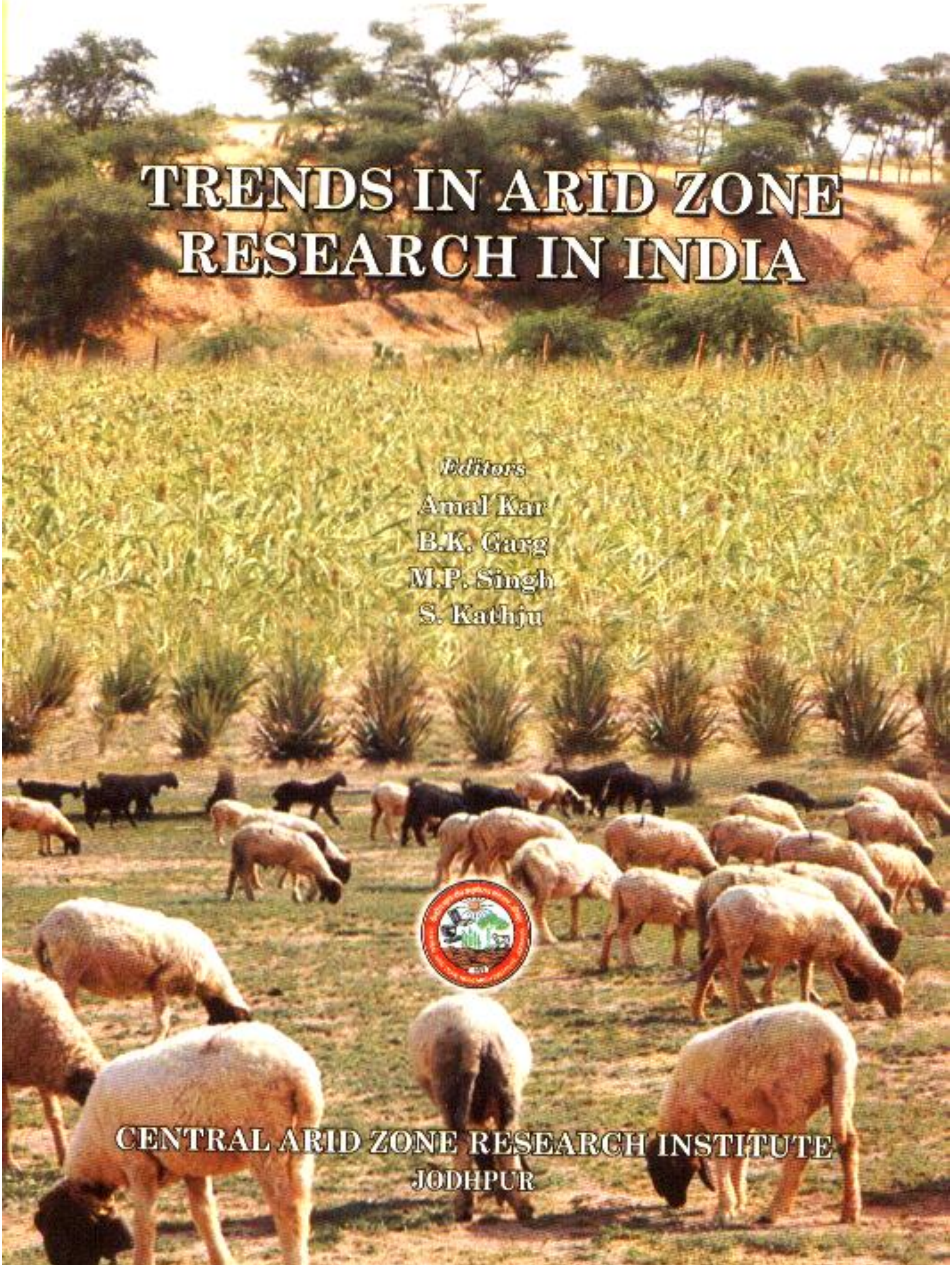

TRENDS IN ARID ZONE RESEARCH IN INDIA

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Alternative Farming Systems for Hot Arid Regions

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Farming system came into existence when man placed first seed in ground and domesticated first animal for his use. Since both these components were complementary to each other, they formed a system together in farming and thus qualified to be called as "farming system". Conceptualization of farming systems, however, is linked with the inception of family institution. Farming is a process of harnessing solar energy in term of economic products (plant and animal) and system is a set of interrelated practices/processes organized into a functional entity. Thus farming system can be defined as a "system, which comprises a set of agricultural activities involving interdependent functional units (farming enterprises) to profitably harvest solar energy, or simply a set of agricultural profession professed on a farm unit". Zandstra (1981) conceptualized farming system as production and consumption activities by farmers to derive benefit from land and other resources/inputs through growing crop or animal rearing or forestry or combination of them with the use of technologies available to him under specific conditions. Thus, it represents an appropriate combination of farm enterprise (crop, livestock, fishery, forestry, etc.) and the means available to the farmers to raise them profitably. A sustainable and efficient farming system aims for enhances productivity, profitability, sustainability, balanced food, clean environment, recycling of resources, adoption of improved technologies, employment opportunities, high input-output ratio, solving feed, fodder, fuel crisis, promoting agricultural oriented industry and ultimately standard of living of farming community.

Arable cropping in arid regions is risky due to their complex and multifarious problems i.e. environmental, biotic, technological and socio-economic. The crop yields are meager and unstable and consequently the income from the existing cropping alone is hardly sufficient to sustain the farmer's family. Therefore to mitigate the risk and uncertainty of income from conventional cropping, it is essential to integrate various agricultural enterprises in production programme that yield regular and evenly distributed income , cater diverse needs of farmers family along with imparting sustainability through conservation and improvement of natural resources in fragile arid ecosystem. These regions are endowed with appreciable agro-ecolgical diversity and hence various components viz. crop, animals, tree, grass, fruit tree, can be integrated in production system. Choice of these components is dictated by interaction of edapho-climatic, technological, infrastructural, institutional, household, policy and socioeconomic factors.

Integrated farming system (IFS) approach has been widely recognized and advocated as one of tool to harmonize use of inputs and their compounded responses to make the production system sustainable. Several studies conducted in different parts of country have revealed that an integrated farming system (IFS) approach besides increasing system productivity also envisages harnessing complementarities and synergies among different agricultural sub-systems/enterprises and augments the total productivity, profitability, sustainability and gainful employment for a household.Gill *et al.* (2009) examined the average yield gap between 27 predominant and 37 diversified farming systems across different agro climatic zones. They revealed that diversification of existing farming systems by integration of enterprises resulted into higher productivity and 30-50% higher profit.

Various studies undertaken in different parts of country suggests that income of farmers can be increased manifold by way of diversification of farming system for sustainability and economic viability of marginal and small category of farmers (Ganeshan *et al.*, 1990; Shanmugasundaram *et al.*, 1995; Tiwari *et al.*, 1999; Jayanthi *et al.*, 2001; Manjunath and Itnal, 2003; Shelke *et al.*, 2001; Singh, 2004; Gill, 2004; Singh *et al.,* 2007). The agronomic, socio-economic and environmental advantages of IFS are vivid and appealing and these are potentially suitable to all categories of farmers. In view of all these results, there is an urgent need to promote IFS concepts under all agro climatic conditions of country with special thrust on small and marginal farmers of dry lands of arid and semi-arid regions.

Environmental and Socio-Economic Setup

An arid climate is defined as one in which for the greater part of the year precipitation is less than PET and meet less than one third of annual water need (PE).Using an aridity index, the boundaries of the principal hot and cold arid zone of India (Krishnan, 1968) have been delineated, accordingly, 317090 Km^2 area comes under hot arid and 70, 300 km^2 comes under cold arid.

Climate

The climate of hot arid region is characterized by extreme temperature, low and erratic rainfall, high solar radiation, high evapo-transpiration, strong wind regime and low relative humidity. The arid region experienced extreme variation in the diurnal and annual temperature. During the winter season, the north western hot arid region of India experiences very cold temperature ranging from 3-10°C. The temperature begins to rise from March onwards and recorded the highest temperature in May-June, when mean temperature is above 40°C. However on individual day temperature up to 47 to 50°C are also recorded (Ramakrishna and Rao, 1992). The mean annual rainfall of the region varies from <150 mm in north western part to >600 mm in south eastern part. More than 85% of total rainfall is received during the south western monsoon season (July-September). Coefficient of variation (C.V.) of annual rainfall often >50% in most of the parts and is higher than 70% in extreme region of western Rajasthan (Ramakrishna *et al.*, 1992). Crop growing period varies from 7-14 weeks depending upon the location and types of soil (Rao *et al.*, 1994). Occurrence of sowing rains (>25 mm) is another common climatic aberration of the region, which can be delayed as late as first week of August in western part and third week of July in eastern part, instead of normal 1-15 July (Rao and Singh, 1998). In the region sky remains generally clear favoring high insolation by day and rapid back radiation by night (Agnihotri and Singh, 1987). The bright sunshine hours varies from 6.6 hours in July-August to 8.8 hours in winter season and >10 hours in May. Average incoming solar radiation varies from 22.05 MJ m^2 (8.40-27.30 MJ m^2) during month of April-May to 14.7 MJ m^2 (7.98-16.17 MJ m^2) in January (Rao and Singh, 1998).The region experienced very strong wind regime. The average wind speed during hot summer month, monsoon and post monsoon seasons are 14.6-18.5, 9-13, <7 km h^{-1}, respectively. The relative humidity is low in most part of the year. In summer months, especially in the afternoon, the relative humidity (RH) in the region goes down as low as 2-3% .The humidity starts building up from June with the incursion of monsoon air mass over the region during the rainy season and goes up to 60-70% (Ramkrishna, 1997).The annual PET ranges from 160 cm in eastern part to 180 cm in western part of Arid Rajasthan. The evaporation starts increasing from mid of March and reaches 15-16 mm day^{-1} by May. It decreases (6-8 mm day^{-1}) during monsoon period.

Drought is a recurring feature in arid region with variation only in its magnitude from year to year. During last century, 47-62% of the years in arid region of Rajasthan experienced drought of varying intensity and duration (Rao and Singh, 1998).

Soil

Arid region of Rajasthan has been endowed with variety of soils. Soils of arid zone were classified as per US comprehensive System of classification, and accordingly soils of this region grouped into two orders viz. Aridisols and Entisols. The Aridisols and Entisols occupy 41 and 52% area, respectively (Joshi *et al.*, 1998).

Arid zone soils are low in organic matter and N (Jenny and Rayachaudhari, 1960). The region having annual rainfall <300 mm the mean organic carbon varied from 0.05-0.2, 0.2-0.3 and 0.3-0.4%, in light, medium and heavy textured soils, respectively. Average content of P is <20 kg ha^{-1}, out of which 80-85% is in inorganic fraction mainly composed of Ca-bound (Mehta *et al*., 1971; Joshi *et al*., 1973; Choudhari *et al*., 1979). The soils are well supplied with K and total K varied from 0.54-1.57% and is slightly higher in dune and interdunal plains than in sandy soils (Joshi *et al*., 1982). The DTPA soluble Fe , Mn Zn and Cu varied from 2.2-16.7, 1.1-25, 0.27-2.36 and 0.28-1.25 ppm, respectively (Joshi *et al*.,1982; Dhir *et al*., 1983; Sharma *et al*., 1983; Dangarwal *et al*., 1983; Sharma *et al*., 1985) .

About 77.57% of total geographical area of western Rajasthan is affected by wind erosion/deposition hazard (Narain *et al*., 2000). About 22950 km^2 or 10.99% area of the region has been affected by water erosion and 0.11% area is affected by water logging. Thus low fertility, less water retention capacity, high erodibility is major edaphic constraints for crop production in the region.

Vegetation

The vegetation of hot arid region is very sparse and consisted of scattered thorny trees/shrubs and grasses. It is described as Tropical Thorn Forest (Champion and Seth, 1968). Indian Desert has 682 species belonging to 352 genera. According to landforms the vegetation of arid region was divided into five formation types: (i) Mixed xeromorphic thorn forest (ii) Mixed xeromorphic woodland (iii) Dwarf semi-shrub desert (iv) psammophytic scrub and (v) Succulents and halophytic plant community (Satayanaran 1963).

Water resources

Low and erratic rainfall, deep dry sandy soil terrain with dune bodies, absence of and/or disorganized natural drainage in major part, very deep and saline ground water, very high evaporation resulted into scarcity of water in the region. Khan (1996) gave detailed account of surface, canal and ground water resources of the region. Thirteen districts of Rajasthan (Hot arid region) receive an average annual rainfall of 62623 million cubic meters (MCM), which constitutes 89% of the total inflow of water. The total surface water potential is 1361 MCM. The total ground water resources is 4545 MCM in arid Rajasthan, the utilizable ground water resource for irrigation is 3355 MCM and 2957 MCM being gross recharge (Ground Water Department Statistics, 1984). The IGNP is the major canal network that passes through the region. The flow value of the main canal varies from 1.727×10^6 to 2.961×10^6 m^3 in different seasons.

Population

The hot arid region of India is most thickly populated arid region of world. Between 1961 to 2001 the human population in western Rajasthan has increased by 194% and the density increased from 37 km^{-2} to 108 km^{-2}.There is a likelihood that human population will increase from the present 22.5 million to 33.6 million and its density from 108 to 161 by 2025 (Anonymous, 2007).

Land utilization pattern

Low and erratic rainfall, extremes of seasonal temperature, high evaporation loss, meager ground water potential, absence of perennial streams, salinity and duny and rocky/gravelly terrains are the major factors affecting the land use in hot arid region of India (Ram and Lal, 1998). The net sown area has increased from 39.42% in 1960 to 51.56% in 2000 and projected to increase to 55% by 2025. In the same period the fallow land (19.49% to 13.15%) and area not available for cultivation (14.28% to 8.72%,) has decreased substantially (Anonymous, 2007). The intensity of cultivation decreased from east to west. Double cropped area constitutes 7.34% area. Rest of the agricultural land is primarily rain fed. The varying degree of intensity of cultivation viz. 80-100, 60-80, 30-60 and <30% constitutes 18.30, 13.84, 12.20 and 11.17%, respectively of rain fed area of arid Rajasthan. Nearly 28.13% area is occupied by wasteland. The average size of land holding per household decreased from 17.77 ha in 1951 to 6.0 ha at present with over all decrease of 57% during last four decades, and projected to fall <4 ha by 2020.

Source of income

The hot arid region is basically an agrarian economy. An analysis of production and income of year 2004-05 shows that in all four agro climatic zones, returns from agriculture contributes 26-43% of total income and other sectors (including wage/income from service sector, business and allied activities) contributes 56-73% of income. The crop land contribution to total income is 15.03, 21.39, 16.64 and 30.18% in Zone I, II, III and IV, respectively. The income from different sectors of agriculture is also revealing. In all four zones income from cropping provides 59-71% of total agriculture income while livestock rearing provides 28-42% (Anonymous, 2007).

Farming Systems in Vogue

Farming system in arid region of India evolved through centuries of practicing and refining of farming, in consonance with prevailing climatic conditions, available natural resources. The knowledge and experience of people engaged in farming were passed on to successive generation in developing these systems. The arid farming system all through ages were predominantly livestock based. In arid Rajasthan <250 mm rainfall zone grasses and shrubs dominant the scenario and range/pasture development with livestock rearing is the main agricultural preposition. In area receiving rainfall between 250-350 mm besides grasses and shrubs, multi-purpose tree species dominates and mixed farming encompassing agro forestry system, mixed cropping, livestock and pasture management are main livelihood options. In area receiving rainfall >300 mm crops and cropping system diversification, agro forestry and livestock rearing are major system of sustenance of arid zone farmers (Bhati and Joshi, 2007).

There have been several changes in arid landscape in past few decades. There has also been unprecedented increase in human population, resource exploitation and development activities, all exerting immense pressure on resource base of region. This resulted in fragmentation of holding, shift in land use pattern with grassland and tree reserves converted to cultivated field, drastic reduction in fallowing practices, over-exploitation of groundwater resources and erosion of soil fertility and biodiversity.

Over the years, economic considerations have overtaken the sustainability issues. Low and erratic rainfall, frequent drought, the increasing cost of cultivation, lower compensation of labor and inputs has made farming in arid region a challenging enterprise. Employment opportunities in sector other than agriculture have enticed many to cross the floor. The largest segment of farming community however is constrained to make a living from farm related activities. With the opening of market for international trade in farm commodities, the competition have toughened for the resource constrained farmers of arid region of the country. On the other hand, useful technologies have been generated by researchers on many alternative systems, which could be adopted. In this scenario the farmers could benefit greatly by inducing diversification in farming system and by strengthening the traditional systems (Anonymous, 2007).

Opportunities

The mixed crop-livestock, mixed livestock-crop and livestock farming systems form the spectrum of economic activities of farming community in hot arid region of India. The farming systems in arid western Rajasthan represent man-agriculture-tree/shrub- livestock continuum and each component is interdependent. In the region,due to thin population till first quarter of 20th century even through the land productivity was low, these farming system were well balanced and able to meet the requirement of inhabitants because demand then were limited and plenty of rangeland were available for livestock production. However, tremendous population growth of human being as well as that of livestock resulted in destabilization of equilibrium of these systems. Presently, croplands permit no more than subsistence living for the farmers that too, in normal rainfall year.

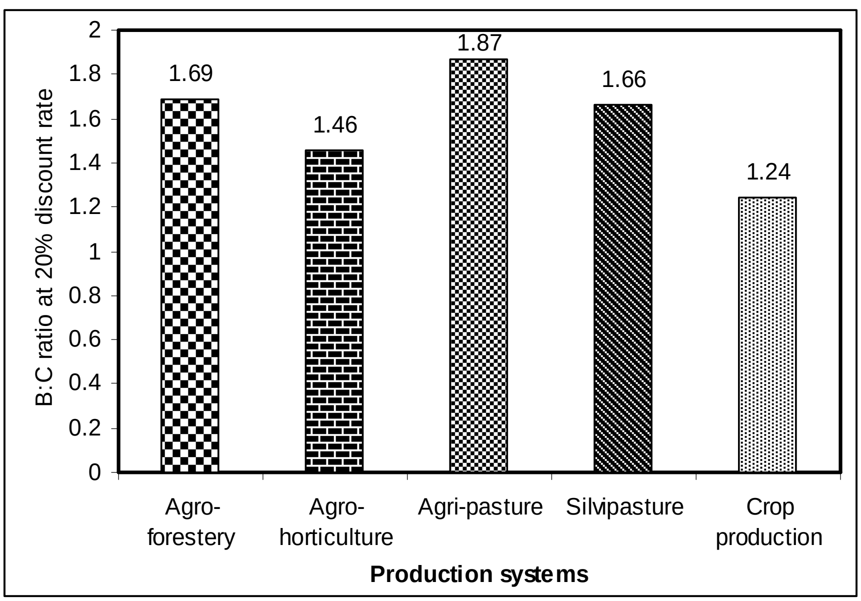

Fig. 2. Benefit:Cost ratio of different land use systems in arid region.

The majority of farming community engaged in dry land farming in arid zone has a subsistence orientation. Dry land farming is main occupation of people as >70% population engaged in it on >90% of cultivable land. About 60-70% farmers in this region reside in village and cultivated their lands only in rainy season. The rest 30-40% farmers made their dwellings on their farms and thus have better control and management of their land and vegetation resources. Absentee landlords are another lot having large holding and leasing out lands for cultivation. Appropriate farming systems could be different for these situations, cropping systems and diversification of crops for first category, integrated farming system with emphasis on perennial component for second category and capital intensive system like agri-tourism may suit last category (Bhati and Joshi, 2007). An economic evaluation of alternate land use system (Fig. 1) over 18 years period clearly demonstrated that integration of perennial vegetation fetched higher benefit cost ratio (1.46-1.87) over arable farming (1.24) (Bhati, 1997).

Diversification is a means of making the arid farming system more remunerative, whereas harsh climatic condition, degraded soils and erratic rains limits choice of vegetation; many alternatives exists, as evidenced by research findings. The indigenous plants with proven potential but neglected or not exploited for their utility need to be introduced in arid farming system. A wealth of medicinal plant suited to arid milieu exists in region, which may be brought under cultivation. Plants and animals from other iso-climatic regions may also be considered. The endemic woody species may also made to yield products such as gum, resins, value additions processes could be undertaken for many other products currently disposed at low costs or not utilized at all.

Sustainability in the existing system may be imparted through judicious and scientific use of available resources. Traditional water conservation structure and practices have become a tale of past. On the other hand, abundantly available solar radiation has not been harnessed exhibiting a poor scenario of resource utilization. The reversal of trend may bring a sea change in productivity of farming system in arid region. The research carried out over the years has generated valuable information. The modules and methods for improvement of productivity of arid farming system need to be adopted by end users to bring prosperity in the region.

An efficient farming system is an integration of appropriate viable technologies within the enterprise and/or integration of one or more additional enterprise at farm according to availability of resources and to sustain and satisfy as many necessities of farm owner as possible along with conservation of natural resources.

Alternative Farming Systems

Alternative crop and cropping systems

The productivity of crops is low under arid region. Diversification of crops and cropping systems with the aim of increasing resource use efficiency and profit seems to be a viable option to impart sustainability in agricultural production system. The intercropping of compatible crops is time tested strategy for improving productivity, resource conservation and reducing risk in arid region. The intercropping of *Ricinus communis* + *Sesamum indicum* (1:3) and *Ricinus communis* + *Arachis hypogea* (1:3) was found more remunerative than sole cultivation of respective crops in Kachchh region of Gujarat (Devi Dayal *et al.*, 2009). Meena *et al.* (2008) reported that intercropping of *Sesamum indicum* + *Cyamopsis tetragnoloba* (1:2) is more sustainable than sole cultivation of these crops in arid region of Gujarat. The intercropping of *Lawsonia inermis* and *Cyamopsis tetragnoloba* (1:1) is also found promising for arid region of Gujarat. The results of an experiment conducted at Bikaner (Rajasthan) revealed that *Vigna aconitifolia* - *Cyamopsis tetragnoloba* cropping systems is better in term of productivity, return and water use efficiency than *Cyamopsis tetragnoloba* - *Pennnisetum typhoides*, *Vigna aconitifolia- Pennnisetum typhoides, Pennnisetum typhoides- Pennnisetum typhoides, Pennnisetum typhoides* + *Cyamopsis tetragnoloba* cropping systems (Rathore *et al*, 2006).

Diversification of traditional *Gossypium-Triticum* cropping system with low water requirement crops e.g. *Vigna radiate, Cyamopsis tetragnoloba, Cajanus cajan, Riccinus communis* + *Vigna aconitifolia* in kharif season and *Hordeum vulgare, Brassica juncea* and *Cicer aeritinium* in Rabi season was found more remunerative (Table 1) (Goswami, 2006).

Diversification of arable cropping through inclusion of more efficient, competitive and high value- low volume commodities like medicinal, dye yielding crops is also an important strategy to overcome many constraints faced by the farmers in arid region. Possibilities of Amaranths cultivation in Kachchh was explored and results indicated that cultivar GA-2 is promising. Grain yield 1206 kg ha^{-1} with net return of Rs. 20000 ha^{-1} are possible with its cultivation (Vyas, 2007; Anonymous, 2009). The cultivation of nutritious minor millet (Proso millet, barnyard millet, foxtail millet and finger millet) is also a viable crop diversification option for the kachchh region and results revealed that grain yield of minor millets varied from 513 to 785 kg ha^{-1}.

Highest yield was registered by foxtail millet followed by proso millet and finger millet (Bhagirath Ram and Vyas, 2005).

Table 1. Economics of Crop Diversification in Canal Command of Irrigated North Western Rajasthan.

Crop	Area (ha)	Total irrigation water (ha- cm)	Irrigation water saving (ha -cm)	Production (q/ha)	Total income (Rs)
Kharif					
G. americanum	10	500 (5)	--	12	216000
G. americanum (50%)	5	250 (5)	250	12	108000
Vigna radiata (80%)	8	96 (2)	--	10	144000
C. tetragnoloba (40%)	4	72 (2)	--	12	48000
C.cajan (10%)	1	30 (3)	--	12	21600
R. communis + V. aconitifolia (20%)	2	52 (4)	--	12 +2	38400+ 12000
Rabi					
T. aestivum	10	500 (4)		30	210000
T. aestivum (50%)	5	250 (4)	250	30	105000
B. juncea (35%)	3.5	105 (2)	--	16	89600
H. vulgare (20%)	2	70 (3)	--	26	31200
C. aertinium (30%)	3	75 (1)	--	10	45000

*In *Kharif* crops on an average 300 mm effective rainfall have been considered for cotton and pigeon pea and 270 mm for other *Kharif* crops. Values in parentheses indicate the number of post sowing irrigations.

During last decades, rising population, inadequate supply of the drugs in certain parts of the world, high cost of synthetic medicine and their side effects have increased the interest in herbal drugs. This lead to the spurt in the use of herbal medicine and consequently the international trade in medicinal plants has recorded a sharp rise. Some of plants with proven medicinal properties have potential for cultivation in hot arid region. *Cassia angustifolia, Aloe vera, Plantago ovata* are promising medicinal plants for commercial scale cultivation in region. Under average rainfall condition in arid region of Gujarat, *C. angustifolia* provides 522.6 kg ha^{-1} total dry matter productivity with net return of Rs. 3020 ha^{-1}. Application of 100 kg N and 40 kg P ha^{-1} with planting at 40 x 40 cm spacing was found optimum for getting higher productivity in the hot arid region of Gujarat.

The effectiveness of cultivation of Aloe in strip plantation to arrest soil erosion was explored at Bikaner. The result showed that strip plantation of Aloe resulted in net soil deposition of 179.2 t ha^{-1} against soil loss of 248.3 t ha^{-1} from bare soil, at Bikaner. Thus preliminary results showed that introduction of Aloe along with arable crops in strips provide opportunity for conservation of soil resources (Rathore *et al.*, 2008).

Lawsonia inermis is a promising dye yielding shrub and widely used as herbal hair dye and staining body's skin. Its cultivation has been proved to be profitable enterprises for farmers in drought prone area of Western Rajasthan. Its cultivation provides an average net return of ~ Rs. 12500 ha^{-1} under rainfed situation (Chand *et al.*, 2005). Suitable agro-techniques for optimizing the productivity and quality of *Lawsonia* have developed. The crop can be grown along with the multipurpose trees and in the orchard of fruit plants like *Mangefera indica, Emblica* etc. (Vyas and Swamy, 2003). The maximum dry leaf yield and return was obtained at the plant population of 50,000 plants ha^{-1}. Even during bad rainfall years (52.9 mm) it could provide a net return of Rs.6331 ha^{-1} at Bhuj (Vyas, 2005).

Growing environmental hazard, non-sustainability of food production and less safe food quality in modern chemical input intensive crop production are some of the important concerns that are being projected in favor of organic agriculture. In hot arid region due to high risk associated with crop production, the use of agro chemicals is very less. Thus farmers are practicing organic agriculture since age by default. The system despite its low productivity compared to conventional system has established itself highly efficient in terms of resource recycling and providing better food and economic sustainability in the arid region Some promising crops for production under organic system are cumin (spice), psyllium (medicine), sesame (oilseed), cluster bean (gum), moth bean (traditional confectionery items e.g. *papad*, *bhujia*), etc. Enhanced quality of these corps's products in the existing production system with better utilization of local resources could make a considerable contribution in strengthening the economic sustainability of this region. The improvement in this production system is possible by intervention in nutrient management and plant protection aspects. For nutrient management practice of ley farming, inclusion of legume in crop rotations and efficient recycling of biomass are important for the region. Even under prolonged dry spell it provided some produce to meet the farmer needs. For effective non-chemical plant protection some measures e.g. crop rotation (Lodha, 2008), use of compost as soil application along with foliar spray of compost extract (Lodha and Burman, 2000), application of oil cakes or residues of mustard with one summer irrigation (Lodha, 2008) and application of neem based pesticides (Satyavir and Yadav, 2005) have found promising. Thus organic cultivation of selective crops having higher export potential provides an opportunity to strengthen the economy of the region.

Agri-silviculture

Growing of trees with agricultural crops is an age old practice in arid and semi-arid region of India. Trees by virtue of their perennial nature impart stability in production along with improvement in microclimate and soil fertility. *Prosopis cineraria*, *Holoptelia integrifolia* and *Hardwickia binata* are some of the tree species suitable for agrisilviculture system in dry land area of this region (Muthana and Arora, 1977; Shankarnarayan *et al.*, 1987). Harsh (1995) outlined suitable tree and shrub for different rainfall region of arid zone (Table 2).

Table 2. Tree species for different rainfall regions

Rainfall (mm)	Species
>250	*Zizyphus nummularia, Acacia tortilis, A. senegal, Prosopis cineraria, Calligonum polygonoides, P. juliflora, Tecomella undulata*
250-400	*P. cineraria, Hardwickia binata, Colophospermum mopane, Dichrostachyus nutans, Ailanthus excelsa, Acacia catacheu, Grewia tenax, Acacia nilotica, Zizyphus mauritiana*
400-600	*Albizzia amara, A. lebbek, Cassia siamea, Emblica officinialis, Hardwickia binata, Alianthus excelsa, Moringa olefera*

Harsh and Tewari (1993) found that growing of trees with crops increase the total productivity per unit of land as compared to sole arable cropping in arid region.Agri-silvi system consisting *Tecomella undulat* as woody component with various dryland crops was found promising due to improved soil fertility, microclimate and moisture availability. A tree density of 100-200 plants ha^{-1} was found optimum for minimum interference with yield of dry land crop like *Cyamopsis tetragonoloba* under *P. cineraria* canopy shade. *Vigna sinensis* and *Pennisetum typhoides* showed better performance with tree species than *Vigna radiata* and *Vigna aconitifolia*. Besides good yield of dry land crops, bonus yield of dry leaves and twigs (650-1050 kg ha^{-1}) and fuel wood (1.8-2.6 t ha^{-1}) could be obtained from *Prosopis* tree (Table 3) through annual lopping (Bhati *et al.*, 2008).

A study conducted in arid region of Haryana on *Prosopis cineraria* based agro forestry system revealed that the tree influenced grain and fodder yield of associated crops. Fodder yield and net return was more in association with tree as compared to sole cropping. Maximum net returns (Rs. 15197 ha^{-1}) was obtained with pearlmillet - *Brassica tournefoila* cropping system in association of Prosopis (Kaushik and Kumar, 2003)

Table 3. Yield of various dry land crops and *Prosopis cineraria* as influenced by tree-crop combination

Crop	Radial distance from tree bole (m)				Produce from *P. cineraria* (kg ha^{-1})	
	2	3	4	5	Dry leaves and twigs	Fuel wood
V. radiata	75	112	125	125	800	2000
V. aconitifolia	16	42	84	113	1050	2500
V. sinensis	106	175	156	173	850	2200
P. typhoides	780	1037	1354	1388	650	1800

In arid region of Gujarat, *Azadirachta indica and Ailanthus excelsa* based agri-silvi culture system involving cowpea, green gram, clusterbean and sesame, on an average fetched 59.3% and 25.7% more income, respectively than sole cropping. Besides higher economic return the system also improve soil organic carbon along with catering diverse need of farmer viz.fodder, fuel wood and timber. These agri-silvi systems are promising for north and north western Gujarat (Patel *et al.,* 2008).

Preliminary results of an experiment conducted Bikaner to assess performance of *Calligonum polygonoides* and *Acacia jacquemontii* in agri-silvi-pasture system indicated that integration of perennial vegetation imparts stability in production.As out of four years of experimentation (2003-2007) the arable crops failed to attained harvest maturity due to paucity of rainfall. Under these situation, the perennial woody components viz. *Calligonum polygonoides* and *Acacia jacquemontii* provided fodder and fuel wood. Further the growth of *Calligonum* is influenced by associated component and it attained maximum growth in association with legume (*C. tetragnoloba* and *V. aconitifolia*) and least with association of grasses (*L. sindicus and C. ciliaris*). Studies conducted at Pali revealed that strip cropping of *Lawsonia inermis* consisting 4 rows of henna alternated with 4 rows of *C. tetragnoloba* at 60 cm spacing provided higher return than their sole planting (Singh *et al.*, 2005).

Proper management of tree and crops is vital for optimizing productivity of agri-silviculture production system. Harsh (1995), reported that in an agri-silvi system comprising *Holoptelia integrifolia* (12 years old plantations) and arid legume. The yield of *V. radiata* was 25% higher under lopped tree as compared to un-lopped trees.

Besides improving productivity, the agri-silviculture system improves the soil properties. Tarfdar (2008) made an attempt to study the effect of different farming system on improvement in beneficial biological activities under arid ecosystem and reported substantial improvement in soil biological activities under agri silvi system as compared to sole crop (Table 4).

Table 4: Improvement in microbial population and biomass under different agri-silvi system as compared to sole crop.

Silvi component	% increase over sole crop			
	Fungi	Bacteria	Actinomycetes	Microbial biomass
P. cineraria	13-24	21-37	9-18	18-23
T. undulata	18-27	27-39	10-16	19-25
Z. mauritiana	19-39	23-53	23-53	20-77

Agri-pasture

Studies conducted at Jodhpur and Bikaner on agri-pastoral systems i.e. cropping between grass strips laid out against prevalent wind direction revealed that average yield of *C. tetragonoloba* at Jodhpur was 418 kg ha^{-1} under unprotected plot, which increased up to 503 kg ha^{-1} in protected plot. Thus with strip cropping at least some biomass is produced in low rainfall years besides reducing soil erosion. In good rainfall year, production of arable crops increased along with increased forage yield of grasses. At Bikaner, average yield of cluster bean during normal and low rainfall were 589 and 181 kg ha^{-1}, respectively. Dry forage yield of *Lasirus sindicus* with strip cropping system obtained during normal and low rainfall year were 6400 and 2650 kg ha^{-1}, respectively. This practice of strip cropping of legumes and grasses holds promises for Bikaner region (Singh, 1989 and 1995). Ley farming also increased grain yield of crop significantly over control (Singh and Gupta, 1997). Dauley (1994) reported that intercropping of arid legumes with *Cenchrus ciliris* gave higher yield, return and moisture use efficiency than sole pasture.

Agri-horticulture

Due to harsh edapho-climatic conditions arable crop production is risky in hot arid region and threatening the agriculture, Under such situation, horticulture based production system is considered effective strategy for improving productivity, employment opportunities, economic condition and nutritional security (Chundawat, 1993; Pareek, 1999; Chadha, 2002). Several drought hardy fruit crops like *Cappirs decidua*, *Salvadora oleoides*, *Cordia dichotoma*, *Cordia gharaf*, *Zizyphus nummularia* var. *rotundifolia*, *Z. mauritiana* are suitable for the area receiving rainfall <300 mm. Besides providing fruit these plant produce moisture laded nutritious leaves for animal. Several other fruit such as *Emblica officinialis*, *Punica granatum*, *Aegle marmelos*, *Phoenix dactylifera*, and *Tamarindus indica* can be grown in the area having irrigation facilities. Among the vegetable crops *Solanum melongena*, *Lagnaeria siceraria*, *Luffa acutangula*, *Luffa cylindrica*, *Citrullus lanatus*, *C. lanatus* var. *fistulosus*, *Cucumis melo* var. *utillismus*, *C.* melo var *momardica*, *C. callosus*, *Moringa oleifera*, *Cymopsis tetragnoloba* and *Vigna ungiculata* are suitable for horticultural based framing systems (Pareek and Awasthi, 2008).

The management practices of horticultural crops have been standardized for optimizing the productivity. Suitable rootstocks for improved cultivar of ber have identified. Bio-fertilizer inoculation of ber seedlings recorded improved growth and nutrient uptake (Meghwal *et al.*, 2006). Seed treatment of *Cordia myxa*'s seed with GA (250 and 500 ppm) improved the germination (Meghwal, 2007). Seed treatment of karonda with treatment of GA_3 (Anonymous, 2001) and of *Emblica* with 1% KNO3 improved the germination. In some of indigenous fruit plants the vegetative propagation techniques have standardized. In Kair (*Capparis decidua*), hardwood cutting rooted better (30-40%) in July-August (Meghwal and Vashishtha,1998). In *Cordia myxa*, I-budding during July-September gave highest success (Meghwal, 2007). Pruning management of fruit is very important to attain sustainable yield. As regards to pruning severity in ber is concerned, pruning at 17-23 nodes on the main axis produce vigorous shoot with maximum fruit production. The main axis of the branches should be pruned keeping 15-25 nodes depending on climatic conditions i.e., 20-25 nodes in arid areas and 15 nodes in semi-arid area along with complete removal of secondaries (Pareek and Vishalnath, 1996; Pareek, 2001). In case of Phalsa, pruning in last week of December at 120 cm from ground level was found optimum (Meghwal, 2006).

Water harvesting techniques has developed to augment water availability to fruit plants. Higher run-off yield was obtained from catchments having 5% slopes (Sharma *et al.*, 1982). Circular catchments around each tree (1.5 m radius) with 5% slope towards tree trunk and covering the catchment with black polyethylene sheet has found effective to conserve moisture. The application of irrigation water at 1.0 IW: CPE ratio at 10 cm depth with 11 to 12 irrigation from June to February was found to be the best for pomegranate for higher fruit yield (Anonymous, 1990-91). Drip irrigation resulted in early commercial fruit production in *Ziziphus, Punica granatum* and *Emblica* and application of water equal to 60% of pan evaporation (PE) registered significantly higher fruit yield compared to 40% PE.(Anon., 2007).Beniwal *et al.*(2006) attempted to schedule irrigation in Kagzi lime under drip irrigation. They found irrigation at 0.7 Etc was better over 1.0 and 0.40 Etc in terms of plant growth and saving of water.

Results of different agri-horticultural system evaluated at Pali showed that highest yield of mungbean (2.70 q ha^{-1}) was in lemon plants and of clusterbean (3.8 q ha^{-1}) in Karonda plants. Maximum increment in height was found in pomegranate and collar diameter was found in *ber*. Intercropping of bottle guard and during *kharif* season and pea (arkel) and kasuri methi with ber plantation did not cause adverse effect on three year old ber and produced 40900 kg ha^{-1}, 5200 kg ha^{-1} and 8100 kg ha^{-1} green leaves and 880 kg seeds ha^{-1} of bottle guard, peas and methi respectively. (Singh and Kumar, 1993)

In arid region, agri-horti system involving *Z. rotundifolia + V. radiata/V. aconitifolia/C. tetragonoloba* and *Z. mauritiana + V. radiata/C. tetragonoloba* have been found environmental friendly and economically viable even during drought years. In agri-horti system involving *Ziziphus* and *V. radiata* during subnormal year when rainfall was 51% less than long term average of 360 mm, the yield of mungbean was reduced by 44% whereas under sole crop mungbean yield was reduced by 51%. The inventory of system showed that this agri-horti system can provide round the year supply of fodder for 5 goat/sheep ha^{-1} and fuel wood for family off 4 members, besides efficient nutrient cycling and increase in economic stability (Faroda, 1998). Gupta *et al.* (2000) reported that 3-years old plantation of *Z. maruitiana* @ 400 plants ha^{-1} in association with green gram performed well with seasonal rainfall of 210 mm and fruit yield from intercropped increased net profit to Rs. 288.6 ha^{-1}, this shows that agri-horti system minimize risk in arid regions and thus helps in imparting economic stability. This system is recommended for the region having rainfall <250-300 mm. Saroj *et al.* (2003) recommended *C. tetragonoloba – B. juncea* and Indian aloe as ground storey component in ber to optimize productivity and profitability under arid ecosystem. Experiment conducted at Pali (Rajasthan) revealed that integration of *C. tetragonoloba*, *V. radiata* and *Sesamum* with *Z. mauritiana* (Cv. Seb), the yield of fruit increased three fold (14.8 kg tree^{-1}) as compared to pure orchard (5.2 kg tree^{-1}) (Singh, 1997). Intercropping in newly planted ber orchard had no adverse effect on plant growth up to 5 years. The intercrop also exhibited higher yield when planted with ber compared to monoculture under rain fed conditions. Agri-horti system comprising *Zizyphus* + mungbean provided fruit, fuel wood and round year employment even in below average rainfall year (Sharma and Gupta, 2001). Intercropping of mungbean in ber orchard was recommended by Gupta (1992). According to Singh *et al.* (2003) intercropping of legumes with ber orchard produced higher grain yield of intercrops by 5-20% over their sole cropping and intercropping is promising particularly during juvenile period of fruit plantation.

An experiment conducted at Pugal (Bikaner) revealed that intercropping of annual crops with fruit trees provides the extra income to farmers when fruit trees are in their juvenile phase . Highest total income and net profit was realized with bael + groundnut intercropping followed by ber +groundnut and kinnow + groundnut (Yadava *et al*., 2006). The highest B:C ratio was recorded with bael + clusterbean followed by bael + Mothbean (Table 5).

Table 5. Economics of different agri-horti system at Pugal in District Bikaner

Agri-horti system	Net profit (Rs ha^{-1})	B:C Ratio
Ber + Mothbean	10854.0	2.06
Ber + Clusterbean	12970	2.33
Ber + Groundnut	20379	2.45
bael + Mothbean	14310	2.86
Bael + Clusterbean	16054	3.02
Bael + Groundnut	21799	2.75
Kinnow + Mothbean	11015	2.20
Kinnow + Clusterbean	11122	2.10
Kinnow + Groundnut	19830	2.50

A study on kinnow based agri-hortisystem under irrigated arid condition at Sriganganagar showed that intercrop did not show any significant negative effect on fruit yield .The yield was highest under mung bean and lowest under cotton intercropping, the fruit yield was at par with intercropping of mungbean, cotton-barley and cotton- chickpea (Bhatnagar *et al*., 2007). Lal (2005) reported that integration of arable crops (clusterbean, horse gram, mungbean and henna) with pomegranate improve the profitability over sole pomegranate on medium soil of Pali (Table 6). Pomegranate has been found compatible with pearl millet, mung bean, Isabgol, sorghum and cumin in jalore district of Rajasthan (Gupta, 2000).

Table 6. Fruit yield and return from pomegranate based agri-horti system

System	400 plants ha^{-1}		500 plants ha^{-1}		667 plants ha^{-1}	
	Yield (kg ha^{-1})	Gross return (Rs. ha^{-1})	Yield (kg ha^{-1})	Gross return (Rs. ha^{-1})	Yield (kg ha^{-1})	Gross return (Rs. ha^{-1})
Fallow	816.0	12507	1475	22345	1734	26197
Clusterbean	908.0	15351	1625	26410	2247	35009
Horsegram	640.0	13383	1230	24260	2487	42885
Mungbean	544.0	10967	1055	21008	1647	34076
Henna	452.0	16292	1835	49931	1087	25785

Aonla based multi storey production system initiated at Central Institute of Arid Horticulture (CIAH), Bikaner, comprising aonla-ber-brinjal-mothbean-fenugreek and aonla-bael-karonda-moth bean-gram showed that ground storey crops did not affect growth of over storey crop and vice versa and these systems have been promising under arid conditions of Rajasthan (Awasthi *et al.*, 2005; 2008).The net return obtained from above cropping through ground storey crop during first year was to the tune of Rs. 23614 and 25662 ha^{-1}, respectively, which increased up 20 and 15%, respectively, in 2nd and 3rd years. This indicates that during juvenile phase of fruit tree, there are ample opportunities for raising annual, biennial and perennial crops which can meet diversified need of farmers. Samadia *et al.* (2004) proposed suitable horticultural crops for agricultural production system of arid region (Table 7)

Table 7. Vegetable crop components for cropping system in the hot arid region

Rainfall	High storey crop	Medium storey crop	Ground storey			Microwind break, biofence
			Vegetable	Agronomic crop	grasses	
Rain fed (rainfall < 150-300 mm)	Khejari, Ber	Ber, kair	Materra, kachari, snape melon, tumba	Guar, moth, bajra, til	Cenchrus, Lasirus	Ker, Phog, Khimp, Jharber
Rain fed (rainfall < 300-500 mm)	Br, lasora, khejari	Sehjana, Lasora	Materra, kachari, snape melon, tinda, brinjal, Indian bean, Clusterbean, cowpea	Guar, moth, bajra, til	Cenchrus, Dicanthium, Pannicum	Ker, Khimp, Jharber
Irrigated	Datepalm, ber ,aonla	Lime, guvava, pomegranate	Cucurbits, chilli, tomato, brijal, cole crops, peas, beans, onion, okra and leafy vegetables	Cumin, Isabgol, groundnut, mustard		Lasora, Shenjna, Karonda

Silvipastoral system

Silvipasture refers to combination of pasture grasses/legumes with trees for optimizing land productivity, conserving plants, soil and nutrient to produce forage, fuel wood, timber etc on sustainable basis. About 75% area of hot arid region of country is degraded (Dhurvanarayan, 1993). Therefore it is essential to renovate the degraded land through perennial vegetation to check further degradation and to meet requirement of livestock and human. Silvipasture system has been found as an ideal alternative for development of such degraded land in our country (Rai, 2008). Keeping 10-15% of total land holding as fallow for 2-3 years is normal practice among farmers of arid areas. Such areas may be developed as silvi-pasture and then as agroforestry and agri-horti system. For silvi-pasture development, *A. lebbeck, T. undulata, C. mopane, A. Senegal, Z. numularia* and *Z. rotundifolia* are some woody species that are compatible with grass component. Among pasture legumes *C. ternata* and *L. purpureus* showed good compatibility with *L. sindicus* and *C. ciliaris* (Bhati *et al.*, 1986).Shankar (1980) opined that compared with other land use in marginal and submarginal land, the silvi-pasture provide forage/grazing availability and quality for a longer period of year and 5-7 times more forage yield compared to natural grazing land can be obtained. The silvii-pasture systems are more remunerative as compared to rainfed farming in arid and semi-arid region. He emphasized that for getting optimum production from this system, knowledge of species for different zones, planting techniques, fertilizer application and harvesting schedule are of prime importance (Shankar, 1995). Gupta and Mohan (1982) attempted an analysis of arid and semiarid areas and concluded that silvipasture system provided more net annual return than arable crop, and recommended that multiple use of silvipasture system to be economically attractive in addition to many ecological benefits. Shankarnarayan *et al.* (1987) worked out the productivity and economics of *Acacia tortilis* based silvi-pastoral system in arid Rajasthan and inferred that this system fetched more return than sole tree or grass planting, they reported higher revenue generation (Rs. 3895 ha^{-1}) from silvipasture system compared to sole *Acacia tortilis* (Rs. 3000 ha^{-1}) and sole grass (Rs. 1150 ha^{-1}) (Table 8). Gajja *et al.* (1999) reported that silvipasture was more profitable than arable farming. Economics of different silvipasture system at CSWRI, Avikanagar revealed that three tier system was more remunerative (Rs. 2056.3 ha^{-1}) followed by two tier system (Rs. 1913.47 ha^{-1}), single tier system (Rs. 1616.29 ha^{-1}) and natural pasture (Rs.922.42 ha^{-1}). (Anonymous, 1998). Gajja and Harsh (2002) rated silvipasture with cattle grazing as an economically viable preposition in arid region.

Integration of *Z. nummularia* with *Cenchrus ciliaris* strips in 1:2 ratio gave higher live weight (33 kg ha^{-1} yr^{-1}) and wood production (5.65 kg ha^{-1} yr^{-1}) over sole pasture there by high return Rs. 1326 ha^{-1} $year^{-1}$ from grazing of mixed flock of sheep and goat (Bhati *et al.*, 1987). Further silvipasture of *Z. rotundifolia* and *Cenchrus ciliiris* could sustain 554 tharparkar cattle days ha^{-1} with 60% pasture utilization (Partap Naraian and Bhati, 2004).

Table 8. Productivity and economics of *A. tortilis* based silvipastoral system

System	Fuel wood (t ha^{-1})	Grass yield (t ha^{-1})	Total revenue (Rs ha^{-1})
Acacia tortilis (5 x 10m) + Natural grass	6.0	-	3000
Acacia tortilis (10 x 10m) + Natural grass	3.2	-	1600
Acacia tortilis (5 x 10m) + *Cenchrus ciliris*	5.0	5.6	3895
Acacia tortilis (10 x 10m) + *Cenchrus ciliris*	2.8	5.3	2795
Grass alone	-	4.6	1150

Silvipastoral studies conducted at Bhuj with combination of trees like neem, Acacia and subabul and grasses namely *C. ciliaris* and *C. setegerus* showed that Neem + grasses combination is the most productive silvi-pastoral system for the Kachchh region in term of both grass yield and tree growth. Among the grasses, Cenchrus ciliaris was found to be superior to *C. setigerus* in terms of fodder production. Total number of tiller per grass plant and dry fodder yield of grass did not differ significantly due to association of trees with grasses in a silvipasture system (Devi Dayal *et al*., 2008). Silvipastoral systems improve the soil organic carbon and K content of degraded (Shamsudheen *et al*., 2009).

Horti-pastoral system

This involves growing of fruit crops and grasses together as per suitability of species. . To meet the growing demand of fruits and fodder, horti-pasture system was therefore identified as on of the potential alternate land use option in shallow to medium deep soils (Singh and Osman, 1995). In view of the assured income from fruit trees and greater demand of fodder, several attempts were made to integrate fruit trees and pasture so as to make the system more productive and lucrative to the farming community.

Horti-pastoral studies on sandy rangelands of Rajasthan revealed that *C. ciliris-Z. mauritiana* system produced 1.2 t ha^{-1} forage yields and did not affect fruit yield (Sharma and Diwakar, 1989). Study conducted at Avikanagar by Singh and Jain (1990) showed that higher yield of grass can be obtained with ber. Long term study conducted at Samadari (in District Pali of Rajasthan) on sandy rangeland with plantation of *Z. rotundifolia* @ 280, 140 and 170 ha^{-1} with *C. ciliris* produced 624 to 824 kg ha^{-1} forage yield and density of 280 plants ha^{-1} can be safely kept(Sharma and Vashishta, 1985). Under semi arid condition of Jhansi, introduction of pasture did not show adverse effect on growth parameters of orchard during establishment phase up to 5 years and produce 3-7 t dry matter ha^{-1} forage in initial 3 years (Sunil Kumar *et al.,* 2002). Gajja *et al.* (1999,2004) viewed that hortipasture system are more profitable than arable cropping under arid condition and they revealed that horti-pasture comprising ber and C. ciliaris are highly economic viable on the basis of B:C ratio, net present worth and annuity value at 10% rate of interest under arid ecosystem.

Consrtraints

There are several constraints which impede the implementation of the alternative farming system in arid region (Bhati, 1995). Beside climatic constraints, the uncontrolled and free grazing after harvest of Kharif crop is major handicap for the adoption and development of these production systems. Further long gestation period i.e. considerable time lag between investment and return also a reason of apathy among farmers towards adoption of these systems. Lack of co-ordination of different agricultural and rural development agencies coupled with lack of orientation of research and development professionals about farming system perspective is another important bottleneck for fostering these programmes. There are also lack of suitable policy to implement these systems at larger scale and harmonizing with other agricultural and rural development policies and programmes.

Conclusion

In the light of research evidences outlined in this paper, it is clear that alternative farming system comprising perennial component and livestock imparts stability and sustainability in production under arid ecosystem. The increasing human and livestock pressure, degrading and squeezing resources, daunting energy crisis, climate change and competition imposed by trade liberalization pose serious threats to farming profession in the fragile arid ecosystem and the alternative farming system seems to viable option to overcome these threats and secure livelihood of resource poor peasants. However, there is an urgent need to foster these production systems in holistic manner with sound policy and in effective people-public - private perspective.

Future Thrust

1. Identification and characterization of micro-farming situations covering bio-physical and socio-economic parameters.
2. Developing sustainable farming system models in farmer participatory mode in accordance with resource endowment and need of farmers.
3. Developing multidisciplinary team comprising biological, physical and social scientist to undertake research on farming system perspective with proper incentives.
4. Preparation of a contingent planning to counteract the weather vagaries/climate threats under different farming situations.
5. Policy framework for logistic support to the farmers for quick and large scale adoption of farming systems models developed by the research and development institutions.

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