Arid Zone Agroforestry: Dimensions and Directions for Sustainable Livelihoods

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Abstract

Drylands, including arid zone lands, cover more than 60% area of the earth's surface and are characterized by severe edapho-climatic conditions. The major distinguishing feature for defining and for planning the arid zone is the low rainfall (below 500mm or Aridity Index <0.20) with more than 50% variability. This makes a great difference in terms of the nature of ecosystem, the socio-economic environment, and the challenges for the sustainability. High wind and solar regimes further increase the effect of rainfall variability and whole complex makes a fragile ecosystem in which small disturbance may cause great loss to the sustainability and sometimes irreversible. In the arid zone, closed forests are seldom available. In India, traditional animal husbandry and agroforestry practices have been used to manage parklands, rangelands, reserved silvipastures near holy places, lay farming, and run-off farming (traditional watershed management). Trees are managed mainly for their non-wood forest products (NWFP) and their environmental services. Animals are an essential part of these production systems. Traditional management of the whole arid zone ecosystem has been developed to minimize the risk of drought in diversified components and to efficiently utilize the scarce available natural resources as well as the products of agroforestry for sustenance of life. With the advancement of science, efforts have also been made to enhance production in the arid zone. Some of the technologies like sand dune stabilization, windbreaks, and agri-horticulture have produced good results because they are developed in synergism with nature and people. But some other technologies imported from less environmentally stressed areas have proven to be unsustainable. For example, the use of tractors in agriculture adversely affected natural regeneration of native trees especially *Prosopis cineraria*, besides increasing wind erosion. Irrigation with waters from the Indira Gandhi canal network has caused problem of water logging and secondary salinization. Several exotic species are either becoming invasive (e.g. *Prosopis juliflora)* or proving economically unproductive (e.g. *F. albida*, Jojaba, etc.). The overall impact of these imported technologies superimposed with high biotic pressure and to fragmented approach to desertification control is observed in terms of loss of biodiversity, increasing desertification, and other problems. It is now imperative to think broadly and plan holistically for the future of arid zone agroforestry, the basis of sustainable livelihoods of arid zone. Policy makers and scientists need to recognize that sustainability of agroforestry in drylands depends on the degree of synergism with the 3Ns, *i.e.*, Nature, Native vegetation, and Native people as well as self-sufficient input supply systems. Some of the future directions for arid zone agroforestry need to focus on the evaluation, improvement and encouragement of sustainable traditional agroforestry systems, exploring the possibilities of natural regeneration/rehabilitation of arid zone ecosystems, NWFPs as the basis of sustainable livelihood, rethinking of research priorities, and policy improvement. In this paper, these topics are discussed with reference to the Indian and African arid zones which will be useful for planning conservation forestry irrespective of geographical boundaries.

INTRODUCTION

Drylands cover more than 60% of the earth's surface. Arid zones are described as a part of the drylands, and have the most severe edapho-climatic conditions. The major distinguishing feature for defining and for planning for the arid zone is the low rainfall (below 500mm or Aridity Index <0.20) with more than 50% inter-annual variability. This makes a great difference in terms of the nature of the ecosystem, the socio-economic environment and the challenges for sustainability. High wind and solar regimes further increase the effect of rainfall variability and the whole complex makes a fragile ecosystem in which small disturbances may cause great loss to the sustainability, which are sometimes irreversible (Houerou, 1996). The hot arid zones of the world are economically and environmentally disadvantaged, with unique problems. The ecosystems of these zones are highly fragile with large risks that cause severe impediments to development programs. Of the total land area in the world, arid zones cover 18.8%. The hyper-arid zones account for 22.3% of the total arid zones (FAO, 1989). These arid zones are diverse in terms of climate, soils, vegetation, animals, and the lifestyles and activities of the people. Little but variability in rainfall and the presence of distinctive periods of drought are the characteristics of the arid tropics. Often, the terms drought and aridity are used incorrectly. A drought is a departure from average or normal conditions in which shortage of water adversely impacts on the functioning of ecosystems, and the resident population of people, whereas aridity refers to the average conditions of limited rainfall and water supplies, not to the departures there from. In general, arid zones are characterized by pastoralism and little farming but there are always exceptions (Malhotra, 1984).

Arid zones are found in almost all the continents of the world (Table 1). In North America, arid zones are found in the southern US and Mexico, and in South America they are located in Brazil, Argentina, Chile, and in some other countries. In Africa, substantial parts of Saharan Africa, Ethiopia, and Namibia, are classed as arid environments.

Table 1. Extent of the arid zone in different continents of the world

Continent	**Area (10^6 hectares)**	Percent **of total**
Africa	1175.5	46.1
Asia	903.0	35.5
Australia	303.0	11.9
Europe	11.0	0.4
North America	84.6	3.3
South America	70.2	2.8
Total	2547.3	100.0

The hot arid regions of India lie between 24° and 29° N latitude, and 70° and 76° E longitude, covering an area of 31.70 million hectares, and involving seven states: Rajasthan, Gujarat, Punjab, Haryana, Andhra Pradesh, Karnataka, and Maharashtra. An area-wise break up of hot arid regions is presented in Table 2. In total, 11.8% of the country is under a hot arid environment. The arid regions of Rajasthan, Gujarat, Punjab, and Haryana together constitute the Great Indian Desert, better known as the Thar Desert, which accounts for 89.6% of the total hot arid regions of India, and constitutes the principal hot arid zone of the country.

Table 2. Distribution of arid regions in different states of India.

State(s)	**Area (10^6 hectares)**	**Percent of total**
Rajasthan	19.61	61.0
Gujarat	06.22	19.6
Punjab and Haryana	02.73	09.0
Andhra Pradesh	02.15	07.0
Karnataka	00.86	03.0
Maharastra	00.13	0.4
Total	**31.70**	**100**

In arid zones, vegetation is typically sparse, and is comprised of perennial and annual grasses, other herbaceous plants, shrubs and small trees. The native plant species have adaptations that enable them to reproduce, grow and survive in the most inhospitable edapho-climatic conditions. Some plants have evolved special root systems, while others have unique leaf characteristics that allow them to withstand prolonged periods of drought.

The number of tree species is very limited in arid zones, and in general, they are very slow growing due to limitations of environmental conditions, but nowhere in the world are they are so intricately associated with the life of human beings. To evade or minimize the adverse affects of frequent droughts, the native peoples in arid zones have often developed production systems in which woody perennials have a very important role, both from a productivity as well as a resource conservation point of view (Tewari, 2000). Their centuries-old experiences, under diverse socioeconomic and cultural conditions, were passed from generation to generation and people have established well-contained systems of production (silivipastoral/agrisilvicultural/agrisilvipastoral/livestock husbandry) that accrue maximum benefits from their woody components. When arid zones have been looked at from the perspective of forestry development, the focus has been on the management of trees and shrubs that are either native to a particular arid zone, or have been introduced, especially for conservation purposes. However, concern for trees and forests has increased in arid zones as it has in many other regions in recent years. This concern has been fuelled mostly by the disappearance of large areas of woodlands and trees from such fragile ecosystems in many countries of world. In the arid zone, closed forests are seldom available. In India, traditional animal husbandry and agroforestry practices have been used to manage parklands, rangelands, reserved silvipastures near holy places, lay farming, and run-off farming (traditional watershed management). Trees are managed mainly for their non-wood forest products (NWFP) and their environmental services. Animals are an essential part of the production system. The whole system has been traditionally developed to spread the risk of drought in diversified components and efficient utilization of scarcely available natural resources.

ARID ZONE AGROFORESTRY

As stated above, the prevalent form of forest management in arid lands is agroforestry, which is concerned with the management of trees and shrubs for conservation and sustainable development. Agroforestry in arid lands differs in many ways from the timber forestry practiced in moist tropical and other temperate ecosystems and in many cases its applications are broader in their scope (Table 3). These applications include production of wood for fuel and poles; horticultural practices for fruit and nut production; range management for fodder and forage production; forestry to modify microclimate for improved agricultural crop production; and protection forestry on land susceptible to wind and water erosion. Many rural people combine these applications of agroforestry with other land uses linked to their needs and social values. The value of forestry in the arid zone is difficult to evaluate in monetary terms. Arid zone agroforestry therefore needs to be understood broadly as management of trees and shrubs to improve the livelihood and quality of life for rural people in the arid environment. It is in this diverse context that policy developemnt must take place if sustainable development of forest resources in the arid zone is to be achieved.

Table 3. Differences between conservation forestry in the arid zone and timber forestry in moist tropics/temperate regions

Objective/type of forestry	Conservation forestry	Timber forestry
Regional	Mainly followed in arid and drylands	Mainly followed in tropical moist or temperate regions
Purpose of management	Medium and long term	Short and medium term
Management responsibility	Local people	Centralized
Land ownership	Mostly private sometimes state lands	Mostly state lands
Area and mode of production	Mostly small to subsistence	Large commercialized
Destination of products	Local	National or international
Diversity in returns	Several economic and ecological returns	Limited economic and ecological returns

Agroforestry is being followed traditionally in the arid zone to minimize the risk of drought and sustain life in climatic adversities. Several need-based systems have developed traditionally and some have been improved or incorporated in recent times.

Trees in Life Support Systems— Traditional Agroforestry

The image of the desert as little but vegetation-less, unbroken, stretches of sand and inaccessible terrain conditions is shattered upon entering the arid zones. There are sparsely distributed trees, beneath which are cultivated arable crops (especially during the *kharif* season, as agriculture is predominantly rain fed) and/or grasses, and other herbaceous flora, in long stretches interspersed among widely scattered village settlements and *dhanis* (a unique settlement pattern of the Thar intended for the life of agriculturists' families during the active cropping period away from the village, but nearby their fields). The Indian arid zone is a vegetated desert having a very rich floral diversity of about 682 species, out of which 131 are known for their economic uses (Bhandari, 1990).

Farmers in the hot Indian arid zone grow arable crops in association with tree species. In fact, such integration of arable crops with trees in the farming systems is a unique, combined, protective-productive system that works on the principles of ecology, productivity, economics, and sustainability (Table 4). These systems are now generally referred to as agroforestry. Because most trees are drought resistant, they are still able to provide fuel, fodder, fruit and other products, when the crops fail, as frequent droughts are a common phenomenon. Thus, trees have a very important place in the life of people in the arid zone of India, as they are directly related to the livelihood of inhabitants, and also provide the important service of climate moderation in an inhospitable environment (Sharma and Gupta, 1996).

Table 4. Main woody components and associated crop/grass species in combined productive-protective systems (extensive agroforestry systems) of the hot Indian arid zone.

Tree /Shrub Species association	Annual rainfall (mm)	Habitats	Associations of crops/grasses
Calligonum-Haloxylon-Leptadenia	100–150	Sand dunes, interdunes	Pearl millet, cluster bean *Lasiurus scindicus*
Ziziphus-Capparis	150–200	Rocky, gravelly pediments	Pearl millet, green gram, moth bean, cluster bean *Cymbopogon jwarancusa, Aristida* sp., *Cenchrus ciliaris*
Calotropis-Calligonum-Clerodendrum	200–250	Sandy undulating plains	Pearl millet, green gram, moth bean, sesame, *Cenchrus ciliaris* with *C. setigerus*
Prosopis-Ziziphus-Capparis	250–300	Alluvial plains, soils, often with kankar pans at 80–150 cm soil depth	Pearl millet, cluster bean, green gram, moth bean, sesame, *Cenchrus ciliaris* with *C. setigerus*
Salvadora-Prosopis-Capparis	250–300	Alluvial plains but soils are moderately saline	Cluster bean, pearl millet and sesame and wheat (irrigated areas) with *Cenchrus setigerus, Sporobolus* sp.
Prosopis-Tecomella	275–325	Sandy undulating plains	Pearl millet, cluster bean, green gram, moth bean -*Cenchrus ciliaris* with *C. setigerus*
Prosopis	300–350	Alluvial plains	Pearl millet, cluster bean, green gram, moth bean-*Cenchrus ciliaris*
Prosopis-Acacia	300–350	Alluvial plains (irrigated)	Sorghum, cumin, pearl millet, mustard, wheat

Source: Saxena, 1997. *Note:* All the crops are grown under rain fed conditions, except where otherwise indicated

Run-off Farming

This is a system of growing crops on harvested and stored water in the farm soils by constructing an earthen dam or a bund across the gentle slope of the farmland in the valley bottom. Shallow, gravelly and rocky uplands normally used for grazing are used as catchments for efficiently harvesting the runoff water. This is locally known as the Khadin system. The major components of the Khadin system are the water collecting area (low rocky catchment), contour bands (channels), moisture storage basins (khadin farm), water impounding mechanisms (bands, spillways and sluice) and a zone of cultivator's settlements.

In this region monsoon rainfall is scanty, erratic and generally the water requirement of most of the crop plants is not fully and properly met. With the result, cropping in the Kharif (rainy season) often becomes a gamble. To offset such a risk and to have some assured crop yield in such environment, one very thoughtfully developed traditional system known as Khadin, has been followed in this region for centuries (Kolavalli and Whitaker, 1996). This system makes the use of shallow gravelly and rocky uplands as the catchments for efficient harvesting of runoff water, which otherwise normally used for grazing. The water is trapped in the low lying valley plains that are converted into farmland where either the kharif or the rabi (winter) crops are raised, depending upon the amount of rainfall and consequent runoff received during the monsoon. The system takes into account not only the vagaries of the climate to raise the crop with such a low rainfall but also prevent any soil deterioration.

Silvi-pasture

In the arid zone there are areas where rainfall is below 200 mm/yr and with this rainfall food production is very difficult. On the other hand there are some grass species, *e.g. Cenchrus cilieria, Lasiurus sindicus* etc., which are very well adapted to such climate and make natural rangelands. The climax tree species like *Prosopis cineraria* and *Zizyphus numularia* naturally come up in these rangelands and make a silvipastural system. Animals like cows, goats and sheep are the part of this farming system. Traditionally the areas near holy places like temples are kept reserved for silvipasture with very well established social fencing. This is a very good example of sustainable management of common property resources that still exist in several places. The silvipasture systems are strictly used according to the land's carrying capacity. Also these systems cover large areas i.e. 100 to 500 km^2. These systems have low productivity but are an example of an excellent synergism between the nature and the natives and that's why they have been sustained for centuries (Shankarnarayan *et.al.* 1987).

Agri-silviculture

This is the most popular system in the areas receiving rainfall between 200-400 mm/yr. People protect the naturally germinated seedlings of useful trees like *P. cineraria, Z. numularia, Tecomela undulata*, etc., which come up in the crop fields. Mixed cropping of pearl millet, moth bean, cluster bean and sesame is carried out under these trees. These trees do not compete with the crops but rather are complimentary in terms of improving the microenvironment. These trees give fodder, fuel, fruit etc. even when crop fails during drought, thus provide sustenance to the farmer during drought. The *P.cineraria* and Pearl millet agroforestry is well known around the world. Some other aspects of this system are discussed with the Non wood forest products.

New Systems Developed

Some of the agroforestry systems have been developed after research and on farm testing are discussed below.

Agri-Horticulture. After two decades of experiments on research farms and farmer's fields, a new agri-horticulture system of jujube (*Ziziphus mauritiana*) inter-cropped with arid legumes *e.g.* clusterbean/mothbean/greengram has been developed for the areas receiving rainfall of more then 250 mm. This agri-horticulture system has been found to give better and earlier production, year-round work and resilience to erratic rainfall. In this system initially the jujube saplings are raised in the farmer's nursery by stored rainwater (farm pond) and then saplings are transplanted at a distance of 5 x 10 meters irrigated twice in first two weeks; thereafter the trees receive only harvested rainwater. Arid legume crops are raised successfully in the interspaces of jujube. It is a short duration (50-75 days) crop, sown at the onset of monsoon and harvested in September/October, *i.e.* before the full growth and blooming of jujube. This offers least competition and both are complimentary as the jujube provides a favorable environment for arid legumes while legumes fix nitrogen, and leaf fall adds organic matter to the soil. Besides fruits and wood from pruning (for fuel or fencing), leaves as fodder are the additional products from jujube. Overall productivity of the system in normal and drought years shows less variation in yield due to variations in rainfall. This system can provide economic returns of Rs 28000- 37000/yr as compared to the sole cropping of arid legumes (Rs. 8000-12000) with low input supply, besides non-tangible environmental improvements which give resilience to drought.

Table 5: Economic production of Jujube – clusterbean system in normal and drought year.

Rainfall (mm)/yr	Economic produce of jujube (kg/ha)			Clusterban yield (kg/ha)	
	Fruit	Dry leaves	Dry wood from pruning	Grain	Dry leaves
416 (Normal)	8460 (42.3)*	1060 (5.3)	1260 (6.3)	597	1871
203 (Drought)	4860 (24.3)	780 (3.9)	940 (4.7)	333	1434
Percent reduction during drought year relative to normal year (Reduction in Rainfall is 51.3%)	42.6	26.5	25.4	44.2	23.4

Figures in parentheses are yields/plant

Lay farming. In this system, on one piece of land a rotation of grasses for 4-6 years, followed by food grain crops like pearl millet or legumes for 2-3 years is followed and then the land is left fallow for 2-3 years. The whole farm is divided into parts in such a way that every year all three practices, *i.e.* grass production, crop production and fallow, are available in one or another part. In this traditional system the rotation was designed considering the poor carrying capacity of arid soils .For that purpose first grasses are grown which improve the soil's physical and biological conditions, then good production is obtained, followed by a fallow period for natural restoration of the soil. During the fallow period several weeds come which improve the soil and the life cycle of various pests is broken. This system is gradually vanishing because of several social changes which are based on the thinking of exploiting nature rather working in synergism with nature.

Wind breaks/shelterbelts. Wind erosion, a high thermal regime and hot desiccating winds are some of the serious problems, which affect the establishment, growth and yield of crops in arid areas. A mixture of trees and shrubs planted across the wind direction help in reducing the wind speed. Evaporative demand studies conducted at CAZRI with three row shelterbelts of *Acacia tortilis, Cassia siamea* and *Prosopis juliflora* as side rows and *Albizzia lebbeck* as the central row were found effective in reducing wind speed and wind erosion. Micro-shelterbelts of tall growing plants have also been found quite effective in providing protection with about a 20 to 40 per cent increase in yield of vegetable crops grown with irrigation.

CHALLENGES FOR SUSTAINABLE ARID ZONE AGROFORESTRY

Agroforestry has been followed since time immemorial for sustainable livelihood in the arid zone, but in the recent past some changes have occurred, due to which the need is being felt to develop agroforestry systems, which may be able to meet the requirements of sustainable livelihood in the future. Some of these changes are discussed here.

Heavy biotic pressure

Chalcolithic and Iron Age maps of the Indian subcontinent suggest that human occupation of the current Thar Desert region was thin during these earlier ages, and that populations depended upon hunting and limited pastoralism. From the analysis of available census records, the population of the Thar Desert region registered an increase of 490% from 1901 to 1991. The present population of the Thar is about 40 million. Decennial variation in population from 1901 to 1991 in the Thar showed a growth rate of 186% (between 1901 and 1971) as compared with 132% for the whole country. The population growth rate for the decades 1971–1981 and 1981–1991 were 36.7% and 30.7%, respectively. The population density is quite high compared with the global average of 6–8 persons/km^2 for arid zones. The major factor responsible for such phenomenal growth of population in the Thar is a wide gap between birth and death rates. Moreover, social values favor large families and positive sanctions for fertility outnumber negative ones.

Cropping on marginal lands

Of the total area of the Thar, only 1.3% is now under forest cover. The net cultivated area increased by 54.1% from 1915 to the early 1980s. This trend in cultivated area increase has further accelerated during the past decade (the 1990s), having increased by 11.7% compared with the amount in the early 1980s. As a consequence of this, barren, cultivable and uncultivable wastelands, permanent pastures, and fallow land have declined substantially (Dhir, 1997). There was a significant decline in grazing land area as marginal lands were brought under cultivation in recent years (the late 1990s). Because of low and erratic precipitation, restricted to a very short period, only one crop, the kharif (monsoon) season crop, is sown each year in most of the Thar. The common crops are pearl millet, cluster bean, green gram, moth bean and sesame. In the arid zone of peninsular India, in addition to these crops, sorghum, maize pigeon pea and other coarse millets are also grown. It has been observed that the agricultural holdings during late medieval times were only one fifth of those found today. By 1951, much of the potential agricultural land was brought under plow, and the trend since then in already established agricultural tracts has been intensification of farming, and the expansion of agriculture into new lands that may be considered environmentally marginal. Mechanized field operations (use of tractors) not only increase soil erosion but also reduces the naturally regenerated population of various useful species (Jodha, 1997).

Unsustainable development policies

With the advancement of science and technology, efforts have also been made to enhance production in the arid zone. Some of the technologies like sand dune stabilization, wind-breaks and agri-horticulture have produced good results because they are developed in synergism with nature (ecosystem) and natives (people and vegetation). But some other technologies imported from less environmentally stressed areas have proven to be unsustainable. For example use of tractors adversely affected the natural regeneration of native trees like *Prosopis cineraria*, and increases wind erosion. Irrigation with waters from the Indira Gandhi canal network has caused problems of water logging and, secondary salinization (Dhir, 1983). Several exotic species either become invasive, like *Prosopis juliflora*, or didn't prove economically productive, like *Faidherbia albida*, jojaba etc. The overall impact of these imported technologies, along with high biotic pressure and a fragmented approach to desertification control, can now be observed in terms of loss of biodiversity, increasing desertification, and other adverse impacts. It is now imperative to think broadly and plan holistically for the future of arid zone agroforestry, the basis of sustainable livelihood in the arid zone. Throughout the arid zones, there is no dearth of problems, but rapidly increasing desertification (some call it land degradation) is a worldwide problem. Land degradation appears to be more of a descriptive term than desertification, as it better describes the process of wind and water erosion, soil salinization, and loss of vegetation cover. It helps in clarifying relationships among climate, topography, soil structure, land use, hydrology, and vegetation. Throughout the arid zones of the world, the major factor responsible for land degradation is soil degradation. At the world scale, the GLASSOD database indicates that in arid zones, more than 60% of soil degradation is caused by wind erosion, with human-induced water erosion accounting for 8% of the phenomenon. At the global level, 349.6 million hectares of land in arid zones are characterized by a light to moderate degree of soil degradation, and 42.9 million hectares have strong to extreme soil degradation (see Table 6). Besides wind and water erosion, over-grazing, high magnitude agricultural degradation activities, over exploitation of vegetation for domestic use, *e.g.* for fuel, and faulty land use are other factors responsible for ever increasing land degradation in arid zones.

Table 6. Degree of soil degradation in the arid zones of the world (million hectares)

Continent	Light and Moderate	Strong to Extreme	Total
Africa	150.2	22.3	172.5
Asia	131.9	18.8	150.7
Australia	48.9	0.0	48.9
Europe	4.8	0.0	4.8
North America	6.3	1.6	7.9
South America	7.5	0.0	7.5
Total	349.6	42.7	392.3

The links between land or soil degradation and vegetation in arid zones are complex. Vegetation and soils display differing resilience to disturbance. Although in arid zones vegetation communities can be readily disturbed and degraded, recovery rates are very slow in comparison with those of other ecoclimatic conditions. Vegetation in arid zones is highty sensitive to natural climatic variability. Decreased production and an ability to lie dormant are two strategies displayed by arid zone plants for survival at times of moisture deficiency. Although an adequate database is not available, two useful relationships between soil degradation and vegetation can be determined. First, vegetation cover may help to indicate the vulnerability of a particular habitat to soil degradation, and second, vegetation cover or community type or plant species may indicate that soil degradation.

POLICY, RESEARCH AND DEVELOPMENT RECOMMENDATIONS

Every ecosystem has some buffering capacity that enables it to remain unchanged for some time if it is overexploited. While this applies to the arid zone, its fragile nature limits its buffering capacity. Thus, for a few decades the shortcomings of policy were not observed but as the buffering capacity is gradually being eroded, the indicators of unsustainability as a whole, *e.g.* decreasing natural resources, deforestation and desertification, become visible. For fragile ecosystems, like those that occur in arid zones, one thing needs to be recognized by policy makers and scientists, that is; sustainability of agroforestry in the arid zone depends on the degree of synergism with '3Ns' i.e. Nature, Native vegetation and Native people.

Some of the future directions for arid zone agroforestry need to focus on the evaluation, improvement and encouragement of sustainable traditional agroforestry systems, exploring the possibilities of natural regeneration/rehabilitation of arid zone ecosystems, NWFPs as the basis of sustainable livelihood, rethinking of research priorities, and policy improvement. These will be discussed in turn.

Evaluation, improvement and encouragement of sustainable traditional agroforestry systems that have been developed for centuries in harmony with nature. As mentioned earlier, agroforestry systems have been developed and used in this region since time immemorial. This may be because the inhabitants of this region found that no other option was sustainable aside from conserving and harvesting whatever nature is giving. The present forms of traditional agroforestry developed over the centuries through the experiments of earlier generations in all types of climatic variations. The validation of their sustainability is very difficult to establish by conducting short-term experiments lasting only 5-6 years. Thus, there is immense possibility for evaluation, improvement and encouragement of these traditional agroforestry systems.

Exploiting the possibilities of natural regeneration/rehabilitation of arid zone/arid zone agroforestry as an alternative to failed plantation/rehabilitation strategies. It is a mechanism of restoration or maintenance of ecosystems by nature that trees produce numerous seeds. A small part of this seed population is sufficient to replace the loss of plant population due to various factors. Human beings propagate the plants artificially to compensate for what they harvested form the natural vegetation or to get a higher quantity of the natural products. Those needed in large quantities have already been domesticated, *e.g.* food crops, fruit trees *etc.* Still a large number of natural species are wild or depend on natural regeneration. Trees in agroforestry may fall under this category. Natural regeneration as well as artificial tree establishing technologies works comparatively better in humid and irrigated areas. In the arid zone, due to climatological, physiological and sociological reasons artificial establishment has not achieved the required success.

The need for domestication and technology development for sustainable harvesting and value addition for non-wood forest products (NWFPs). Unlike the humid or sub-humid regions where trees are typically grown for timber, the trees are grown in this arid region mainly for non-wood forest products (NWFPs). In the arid zone closed forests are seldom available and agroforestry has been followed since time immemorial in which people conserve and manage whatever seeds of native tree species like *Prosopis cineraria* and *Zizyphus numularia* germinate in the crop field or on the common land. After the establishment of trees only annual lopping of branches is done which provides precious fodder during scarcity/drought. Taking the example of *P. cineraria*, this tree is found in this region at densities ranging from 40 to 120 trees/ha. This we can say is the natural forest in common or private lands otherwise no dense forest is found as in the high rainfall areas. People lop the branches of this tree in the month of December and it becomes lush green in the month of May-June when no other fodder is available. Simultaneously, pods develop which are used as vegetables. Similarly other tree species provide fodder, pods, fruits etc. The interesting thing is that, during drought when annual crops fail, the yield of NWFPs does not decrease drastically, thus trees provide food security during drought. Besides some trees produce other products like gum, resins, edible/non-edible oils *etc.* which increase the income of the marginal farmers who are in the majority in this region (Sharma, 2000).

The services provided by the trees in hot arid regions are equally important for moderating the climate. Cultivated in the form of shelterbelts, they reduce wind erosion and conserve soil and water. In agroforestry systems, trees reduce the solar heat load on crops and also decrease wind speed and soil temperature, conserve soil moisture, increase biological activities in the soil and thereby improve the microenvironment for crops. The yield of crops grown under *P. cineraria* is generally higher than sole crops, knowing this fact agroforestry has been followed in this region for centuries. The edapho-climatic conditions in this region are so harsh that every tree improves the environment, it may be at micro level, yet its impact is visible (Sharma, 1998).

The other important NWFPs in these arid areas are plants with medicinal values. Due to climatic specialty there are medicinal plants which are either endemic to this region or their quality deteriorate if they are grow/found in higher rainfall areas.

Research priorities. Considering the social and ecological demands, policy on agroforestry research also needs to be prioritized. Some of the possible priorities are-

In-situ rainwater conservation for tree establishment and for agroforestry more generally. Water is the most limiting factor for productivity and sustainability in the arid zone. As described earlier, the effect of bringing additional water through canals or ground water has been the cause of unsustainability in the ecosystem. Thus the only possibility remains the conservation of rainwater (Gupta and Sharma, 1998). Trees are the keystone of arid zone conservation and once trees are established the other conservation processes start automatically e.g. rainwater conservation, development of vegetation cover etc. (Sharma, 2000).

Further research is required on:
(i) Development of *in-situ* rainwater conservation techniques that require less labor and maintenance;
(ii) Development of plant-based water absorbing/retaining materials;
(iii) Initiatives for widespread adoption of rainwater conservation techniques;
(iv) Improvement in traditional water harvesting systems;
(v) Development of simplified windbreak establishment techniques.

Improvement of policy. There are some important aspects on which improvement of policy is needed for creating a more congenial environment for development. These include:

Increased international funding for arid-zone research and development. The arid regions of the world in general suffer from a vicious cycle of low productivity, a low level of investment and as result, poverty. Greater priority is given at the international level for funding of projects and programs related to timber forestry and rainforest management, perhaps because these activities contribute more to international trade. Very limited funds aimed at combating desertification are available to the arid lands. Forestry and agroforestry activities in arid regions no doubt contribute less to international trade but they provide substantially support to the livelihood of people in these climatically less favored regions. There is a need to rationalize these priorities and for the international community to give due importance to the non-tradable benefits of forestry/agroforestry, which are otherwise the basis of sustainability and livelihood.

Suggested areas for increased investment in the arid zone are as follows:
(i) *Organic farming in virgin arid lands.* The philosophy of the traditional systems was to work in synergism with nature and use locally available natural resources. High input agriculture (HIA) on the other hand is only sustainable with assured input supply, *e.g.* irrigation, fertilizers *etc*, which is not always possible in drylands. Thus the chances of failure are much greater than in traditional systems during drought. Also due to less use of synthetic chemicals in the past, these lands are comparatively free from the residues of such chemicals. Hence organic farming, based on traditional systems and conservation of local natural resources can be one area for investment without much effort. Organic farming of NWFPs can be the first choice for investment (Sharma, 2001).
(ii) *Eco-tourism.* Investment in eco-tourism can prove to be a large income generator in the arid lands. Increasing numbers of people are spending increasing amounts of time and money enjoying the unique resources of these arid land environments, *e.g.* spectacular scenic beauty, diverse wildlife population, relatively clean air and other amenities such as large open spaces. Investment in the forestry sector can be in amenity plantations, desert parks, buffer strips, roadside plantations and green belts can be economically as well as environmentally beneficial for the arid zone.

Exploring the potential of arid zone agroforestry as a tool for solving environmental problems.

Conservation of biodiversity. Biodiversity is the essential safety mechanism of any ecosystem and as the arid zone is considered to be fragile in nature the importance of conservation of biodiversity is further increased. Because of biotic interference and developmental activities, not only is the population of various species reduced but also their natural habitats have been destroyed. Thus the easiest way to save these species is *ex-situ* conservation with protection. This is possible through arid zone agroforestry, in which all types of plants *e.g.* trees, shrubs, climbers *etc* can be accommodated, combining conservation with domestication for increased production.

Desertification control. Desertification is the result of exploitation of arid zone ecosystems beyond their carrying capacity. The carrying capacity of the arid lands is inherently low thus they are highly prone to desertification. Through soil and water conservation and sustainable management of vegetation, the carrying capacity of natural resources can be enhanced. Various arid zone agroforestry models, e.g. wind breaks, sand dune stabilization, silvipasture, agri-horticulture etc. can be appropriate for soil and water conservation in arid lands (Gupta and Sharma, 1997), and the productivity of lands suffering form desertification can be enhanced and in this way desertification can be controlled. Arid lands can be considered simulated desertified drylands for planning of desertification control. This can be important for preventive strategies for drylands rather than to control desertification after the process starts. Any technology or strategy that is found suitable to increase the productivity of arid lands, would give better results if applied to the desertification-prone drylands because they have a better environment than the arid lands.

Assessing the potential of arid zones as carbon sinks. In addition to their other benefits, trees on farms or in pastures also store carbon. Arid lands cover almost one forth of the earth's surface and any effort to increase tree populations substantially contributes to their value as carbon sinks. Due to their perennial nature and high root turnover, grasses can also prove to be a good carbon sink. Silvipasture systems are prevalent in most of the arid zone and when both the tree and grass components are properly managed, an increase in net carbon storage can be achieved. The arid lands are prone to desertification and trees and shrubs can be grown on these lands to prevent further soil degradation and to produce biofuel. These trees also enhance soil organic carbon content and thereby increase soil carbon storage. About 104 million ha land area in the world is affected by strong and extreme soil erosion. Assuming a low rate of increase of soil organic carbon content at 40-60 kg C ha^{-1} $year^{-1}$ the potential of C sequestration in soil is estimated at 0.004-0.006 Pg C $year^{-1.}$ There are an additional 930 million ha of salt affected soils in the arid and semi arid regions of the world. Adoption of reclamation measures on these soils could potentially increase above and below ground biomass production and increase soil organic carbon (SOC). Assuming that the rate of SOC increase through adoption of reclamation measures is 200-400 kg C ha^{-1} $year^{-1}$, the potential for C sequestration is 0.186-0.372 Pg C $year^{-1}$ (Izaurralde et.al.2000). Thus rehabilitation of arid lands can contribute to a great extent to solving the green house problem of the world.

CONCLUSION

Arid zones are known to be fragile ecosystems and interference without knowing the ecological linkages within these systems can result in their degradation, which is often irreversible. Agroforestry as traditionally followed in these regions is a complete, ecologically sustainable livelihood system. To meet both present and future demands, policies need to be supportive of the development of these traditional agroforestry systems based on synergism with nature. There is also a potential to utilize arid zone agroforestry to solve global problems like desertification, global warming (through increased carbon sequestration), and biodiversity conservation, which will require that greater international policy support for arid zone agroforestry.

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