Agroforestry –An Approach for Mitigating Adverse Climatic Effects in Rainfed Areas

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Abstract
Agroforestry systems have capability to conserve and appreciate natural resources, improve productivity of the land, act as insurance against climatic aberrations and failure of conventional crops in rainfed areas. These provide food, fodder, fruits, vegetables, fuels, wood, timber, medicines, fiber etc.Among various agroforestry systems, agri-horticulture/horti-pasture score merit. However, introduction of such systems in marginal soils requires suitable agro-techniques for better survival and establishment of the species. These also effectively utilize off-season rainfall for their establishment and production enabling the whole system to be stable and sustainable even in degraded soils. Apart from fulfilling the demands of people, more so in problem areas, these systems elevate their socio-economic status.

Introduction
To meet the increasing demand of enough food and fodder of large human and livestock population, we need to produce food grain and green and dry fodder to the tune of 250 and 2085 million tonnes, respectively. In India, 60 per cent of cultivated area (86 million ha) is rainfed, which contributes about 40 per cent of total production of food grains. Due to increasing demand of food grain, fruit, fuel, fodder and timber, cultivation has been extended to marginal and degraded lands. Marginal and small farms compose 75 per cent of land holdings of less than 2.0 ha. The soils are impoverished and less productive. The income generated from such a holding is inadequate to sustain the family. This is so due to frequent droughts and vagaries of monsoon. Under these circumstances, there is no alternative but to integrate tree with agricultural crop, commonly known as agroforestry, which can withstand climatic aberrations and conserve the natural resources efficiently.

Definition of Agroforestry
"Agroforestry is the science of designing and developing integrated self-sustainable land management system, which involves introduction or retention of woody components such as trees, shrubs along with agricultural crops including pasture/animals simultaneously or sequentially, on the same unit of land and at the same time, to meet the ecological as well as socio-economic needs of local people" (Nair, 1985). The author (1989) expressed that a typical agroforestry system will allow economic and ecological interactions between woody and non-woody components and also increase, sustain and diversify the total land output.

AGROFORESTRY INTERVENTIONS FOR DROUGHT MITIGATION

Soil and Water Conservation
Quantification of overall effects of tree-crop interactions in agroforestry systems by several researchers indicated more positive effects than negative interactions. Increased productivity could be due to the efficient utilization of resources (Ong, 1991). Soil fertility improvement is a slow process, occurring due to addition of nutrient rich litter on a long-term basis. The woody component acts as semi-permeable barrier to water movement and mulch from trees, reduces the raindrop impact and

thus, helps in soil conservation. The reduced wind speed and moderating air temperature bring in improvement in the microclimate. The radiation balance and surface wind pattern influence plant water uptake and thus the conversion efficiency increased in the agroforestry system as observed in *Leucaena leucocephala* - pearl millet system at ICRISAT (1986-87). The agroforestry systems relevant for soil and water conservation are: Multistorey tree garden, Perennial crop combination, Contour hedges and Shelter belts/wind breaks.Trees are known to increase water availability in the soil by:

- Reducing runoff and increasing infiltration
- Reducing evapotranspiration through shading by canopy and litter
- Increasing soil available water capacity through maintenance of organic matter

In a study to find out the disposition of rainwater, out of 1106 mm rainfall, runoff was 782, 372 and 66 mm in bare soil, grass land and tree + grass cover, respectively and the remaining infiltrated in to the soil profile (Table 1) indicating the positive interactions of tree + crops in water conservation (Mishra *et al.,* 1979).

Table 1. Rainfall, runoff, water balance and utilization (all in mm) in rainfed conditions

Plot	Runoff	Water infiltrated	Total water in soil	Water left in soil	Water utilized during monsoon
Bare soil	782	324	671	410	261
Grass cover	372	734	1143	741	402
Trees + grasses	66	1040	1276	657	619

Higher survival and biomass generation under agroforestry is possible due to:

Greater efficiency of perennial crops for photosynthesis
Tapping of nutrients and water from deeper layers by perennial crops
Better environmental conditions, and
Efficient utilization of off-seasonal rainfall by the tree component.

Protection and Stabilization of Ecosystem

Deforestation causes adverse ecological manifestations viz., increase of CO_2 concentration in the atmosphere, global warming, enormous soil loss, frequent droughts and floods, serious pollution problems, etc. Trees protect us from adverse effects of different kinds of pollutants such as dust, dirt and other physical air pollutants. It is estimated that one hectare of a close forest filters about 50 t of dust and dirt. Trees also absorb some of the chemical air pollutants.

Soil improvement

Trees ameliorate the problem soils by improving physical, chemical and biological properties. Long-term field studies conducted in northwestern India indicated that leguminous trees like *Prosopis, Acacia* and *Casuarina* ameliorate alkali soils at a much faster rate than non-leguminous trees due to the buildup of organic matter, recycling of nutrients and moisture conservation. The most promising trees identified for agroforestry on such lands are: *Populus deltoids* (Poplar)*, Acacia nilotica* and *Tectona grandis* with intercrops like berseem, guinea grass. *Populus*-based system has proved more remunerative because of its faster growth and high wood value compared to Eucalyptus and Acacia based systems (Singh *et al.,* 1997).

AGROFORESTRY SYSTEMS RELEVANT FOR SEMI ARID REGIONS

Several agroforestry systems have been evolved for different areas and purposes. Nair (1985) classified agroforestry systems considering structure, function, socio-economic and ecological factors. The following systems are common under arid to semi-arid conditions in India.

1. Alley cropping (hedges + crops)
2. Agri-silviculture (trees + crops)
3. Agri-horticulture (fruit trees + crops)/ Agri-silvi-horticulture (trees + fruit trees + crops)
4. Horti-pasture (fruit trees + pasture/animals) / Agri-silvi-pasture (trees + crops + pasture/animals) / Silvi-pasture (trees + pasture/animals)
5. Boundary plantation (trees on boundary) + crops / Shelter belts / wind breaks (trees + crops) / Live fence- shrubs under trees on boundary

Some of the relevant systems are discussed here under:

Alley Cropping System

In this system arable crops are grown between perennial hedgerows spaced at regular intervals. These are cut at 50cm ht. and pruned during cropping season to reduce competition with crops.

In an alley cropping with *leucaena* the yield of sorghum was least affected followed by cowpea and castor in Alfisols at Hyderabad (Singh *et al.,* 1989). The severe reduction in crop yield is likely to be due to competition for soil moisture. Although the crops closely adjacent to the *leucaena* hedgerow experienced intense shading (30 to 85%) for much of the growing period, the presence of a shallow root barrier was sufficient to avoid a reduction in cowpea and sorghum yield unlike with long duration castor. Therefore short duration and shade tolerant intercrops are most suitable to avoid competition for soil moisture.

Agri-silviculture System

In arid to semi-arid regions, where the build-up of organic matter is limited, nitrogen-fixing trees offer immense possibilities of supplying organic matter, conserving soil moisture and supplementing nitrogen needs of crops. At Hyderabad, association of cowpea with *A. lebbeck* reduced its yields drastically unlike with *F. albida*. *A. lebbeck* and *Acacia ferruginea* caused severe shade on cowpea. The low adverse effect or the positive effect of *F. albida* might be due to its reverse phenology,which retained its leaves in the dry season and underwent a defoliation phase during the crop growth period.Two-year data showed yield reduction of about 12, 23 and 38 per cent under *F. albida, A. ferruginea* and *A. lebbeck* respectively, over sole sorghum (Table-2). The B/C ratios were higher and more favourable under NFTs than in sole crops. The net returns increased with nitrogen level up to 40 kg /ha (Suresh and Rao, 1999 and 2000).

Agroforestry with biofuel species

In the light of dwindling energy resources, there is a need to identify suitable alternative species for generating biofuels to meet the needs of the society. Rainfed areas provide an excellent opportunity for this purpose. These can be taken up in areas where arable cropping has not been successful or profitable in view of deterioration of resources. In marginal, undulating and problem soils, biofuel plantations can be taken up even under adverse climatic conditions. Jatropha and Pongamia are ideal sp. in such situations (Rao *et al*., 2006). These can grow even with a low rainfall of 200 mm to 1000mm and 500mm to 2500mm respectively. These can also tolerate high temperatures as well as drought conditions. When these are planted at wider spacing (3x3m for jatropha and 5x5m for pongamia), intercropping is possible for at least 2-3 years. Suitable inter crops in jatropha are greengram, blackgram, cowpea, vegetables, horsegram, castor, pigeonpea, and others. In pongamia, pigeonpea, short duration legumes in kharif and chickpea in rabi are ideal crops (Rao, 2006, 2007).

Table 2.Yield (kg/ha) of cowpea and sorghum as influenced by NFTs and nitrogen application at Hyderabad

Treatments NFT species	**Cowpea**				**Sorghum**			
	Grain yield	**Dry fodder yield**	**Net returns (Rs./ha/yr)**	**B/C ratio**	**Grain yield**	**Dry fodder yield**	**Net returns (Rs./ha/yr)**	**B/C ratio**
Faidherbia albida	544	1361	7631	3.96	1012	2589	6327	2.96
Acacia ferruginea	485	1096	5483	2.95	889	2162	4325	2.34
Albizia lebbeck	440	995	6090	3.15	720	1794	4587	2.44
Sole crops	601	1523	3927	2.67	1154	2973	2724	1.98
N level (kg/ha) Cowpea Sorghum								
0 0	376	829	4379	2.66	493	1400	2754	1.94
10 20	482	1179	5782	3.04	926	2303	4421	2.45
20 40	587	1453	6503	3.36	1144	2761	5300	2.67
30 60	615	1583	6716	3.34	1205	3016	5488	2.66

Agri-Silvi-Pasture System

In an agri-silvi-pasture system at Dharwad, sorghum yield was significantly reduced nearer to the teak alley compared to 5m from teak (Muthanal *et al*., 2001). The reduction in grain yield was 40, 32, 21 and 8 per cent in 1,2,3 and 4 m from teak, respectively compared to 5 m alley, while, sorghum yield increased by 6.6 per cent on western side of teak than on eastern side. This might be due to higher soil moisture retention (10.8-12.1 per cent) on western side than on eastern side (10-11.7 per cent) highlighting importance of row direction in drought mitigation.

Agri-Horticultural System

Rainfed horticulture along with arable crops/ fodders is ideal for controlling land degradation. In rainfed areas, the competition between trees and crops for water is a major problem. Hence, it is necessary to identify trees with low water requirement. A large variety of fruits cover nearly 7 % of cropped area in India. In agri-horti. system, short duration arable crops raised in the interspaces of fruit trees provide seasonal revenue. The system works best in medium to deep soil with good water holding capacity or with well-distributed rainfall pattern or with supplemental irrigation at active crop growth period coinciding with flowering and fruiting. When these are grown in marginal soils, micro site improvement, micro-catchment and other related agro-techniques are essential. Suitable fruit crops for rainfed areas are given in Table 3.

Ber based

Tree-crop interactions studied under semi-arid conditions revealed useful interaction of annual crops with fruit species: Ber. The promising intercrops with Ber at different locations were:At Solapur- pearl millet + pigeonpea, at Rewa- blackgram and pigeonpea, at Dantiwada- castor, at Agra and Hisar- all pulse crops and at Hyderabad - clusterbean.

Custard apple, pomegranate and *Aonla* based

At Hyderabad, it was observed that the yields of rainfed intercrops of sorghum, groundnut and mungbean in association with fruit crops (pomegranate and custard apple) were reduced by 23-26% compared to the sole crops (CRIDA, 1999). The yield reduction was higher with custard apple compared to pomegranate. Among the different systems, groundnut grown with pomegranate or custard apple gave highest gross income (Rs.19, 540–19,770/ha). Custard apple + mungbean recorded highest yield advantage (54%) over respective sole crops.

Table 3. Suitable fruit crops and varieties for dryland regions

Crop	**Botanical Name**	**Cultivars**
Ber	*Zizyphus mauritiana*	Gola, Umran, Banarasi, Karaka, Kaithli
Custard apple	*Annona squamosa*	Bala Nagar selection, Arka Sahan
Guava	*Psidium guajava*	Allahabad Safeda, , Arka Mridula. Lucknow-49, Sardar
Aonla	*Phyllanthus emblica (Emblica officinalis)*	Kanchan, Krishna, Narendra –7
Jamun	*Syzygium cuminii*	-
Bael	*Aegle marmelos*	Narendra Bael-5, Narendra Bael-9
Tamarind	*Tamarindus indica*	PKM-1, Pratisthan, Yogeshwari
Karonda	*Carissa carandes*	American red and green
Phalsa	*Grewia sub-inequalis*	-
Sapota	Achras zapota	Cricket Ball, Kalipatti.
Mango	*Mangifera indica*	Banganpalli, Alampur Benishan, Neelum, Mallika, Bombay Green, Amrapali, Kesar.
Pomegranate	*Punica granatum*	Ganesh, Jyothi, P-26, Jalore seedless
Fig	*Ficus carica*	Poona, Black Ischia.
Passion fruit	*Passiflora edulis*	Kaveri
Sweet orange	*Citrus sinensis*	Mosambi, Kodur Sathgudi, Valencia, Blood Red, Malta
Lime	Citrus limettoides	Tenali, Promalini, Vikram
Papaya	*Carica papaya*	Coorg Honey Dew, Pusa Delicious, Pusa Majesty, Pusa Dwarf,Taiwan
Drumstick	*Moringa oleifera*	PKM-1
Wood apple	*Ferronia elephantum*	-
Chironji	*Buchanenia latifolia*	-
Soapnut	*Sapindus mukorosii*	-

Guava based

Guava needs about 4-5 years to develop full canopy under medium rainfall and marginal fertility conditions and thus allows intercrops in the initial years. Cowpea, clusterbean and greengram are suitable intercrops during *kharif* and cucurbits in summer (CRIDA, 1999).

Mango based

Since mango takes several years to grow to its full size, intercropping to utilize the interspaces is desirable. Legumes like sunhemp, cowpea and vegetables are suggested. However, wheat, oat, sorghum and pearl millet proved harmful to mango due to their common time of grain formation with flower bud initiation and the competition for moisture and nutrients.

Among different intercrops (groundnut, greengram and cowpea) tried in four-year-old mango orchard at Hyderabad, groundnut was a successful intercrop (CRIDA, 1995). There was considerable reduction (53 to 56 %) in pod yield of groundnut (506-539 kg/ha) in agri-horticultural system over sole groundnut (1148 kg/ha). The leguminous intercrops can be taken in mango orchard up to at least 8 years after planting with minimum reduction in yields of crops. In young mango plantations in Karnataka, ragi and groundnut intercropping is very common.

Horti-Pasture system

Horti-pasture system, a combination of fruit trees and pasture, is identified as one of the potential alternative land use options in undulating shallow rainfed soils. In guava-based system at CRIDA, yield reduction of stylo was found to be less under widely spaced trees (8m x 5m) compared to closer spacing (5m x 5m), indicating the necessity of wider spacing for fruit trees when grown with stylo (Osman and Rao, 1999) (Table-4). *Cenchrus ciliaris* out yielded stylo and took less time for establishment compared to stylo.

Table 4. Fresh yield of forage and fruit in Guava based horti-pasture system at Hyderabad.

Spacing (m)	**Fodder yield (t/ha)**		**Fruit yield (kg/ plant)**
	Stylo legume	**Cenchrus**	
5x5	5.22 (40.4)	2.45 (3.9)	95.4
8x5	6.56 (25.1)	2.14 (16.1)	99.7
Control	8.76	2.55	---
Mean	6.84	2.38	97.5
CD (0.05)	0.88	NS	N.S

Economic evaluation of agri-horticultural system

Survey carried out in 100 randomly selected guava and mango orchards of average 1.5 ha size in semi-arid conditions in Andhra Pradesh with rainfed groundnut, sorghum, vegetables in Shadnagar and sugarcane and turmeric in Zaheerabad indicated that agri-horticulture was more viable and profitable than horticulture alone(Reddy and Sudha,1988). Agri.Horti. Systems were observed to perform better than cultivation of arable crops as given below (Table 5). However, establishment of such systems demands heavy initial investments and proper marketing and it may not be possible to adopt them in small holdings.

Table 5. Economics of alternate land use systems

Alternative land use systems	B/C ratio
Agri-horticulture with ber	5.00
Agri-silviculture	2.00
Arable crops	1.20-1.75
Dryland horticulture:	
Mango	3.21
Acid lime	3.04
Guava	2.18
Sweet lime	2.89

Rehabilitation of degraded lands, village common property lands

In rainfed areas the problems of desertification are continuously increasing due to over exploitation of natural resources resulting in degradation of soils. Most of these problems are location specific needing appropriate solutions. Such areas need to be thoroughly surveyed utilizing remote sensing techniques for arriving at suitable options. Horti-pastoral systems are the best options in such areas. Transplanting 6-12 month old sapplings of mango, guava, ber, custard apple and seeding of stylo, cenchrus, *Dichrostachys nutan* etc. are to be explored. Technologies evolved at research stations must be available to the farmers. A close interaction and dedicated effort on the part of researchers - developmental agencies - NGOs - farmers is essential to develop a sustainable technology and give a clean environment to the people.

RESEARCH THRUST NEEDED IN DROUGHT MANAGEMENT

Water conservation in agroforestry systems for drought mitigation. Possible allelopathic effect of different tree species or leaf litter. Below ground interactions, which are poorly understood in agroforestry systems. Microbial association of tree species with VAM for higher growth and yield. Role of agroforestry systems in stabilizing greenhouse gases. Identification of alternative tree/plant species for drought tolerance.

CONCLUSIONS

The apparent advantages of agroforestry systems are their applicability to control soil erosion, soil and water conservation, creating congenial and conducive microclimate for trees and understorey crops. Agroforestry also increases the land use intensity and generates employment opportunities even during drought period and in off-season. These systems can be sources or sinks of greenhouse gases, depending on the component of the system. These could be managed to stabilize greenhouse gases in three ways, viz., sequestering carbon dioxide in plants and storing carbon and nitrogen in perennial vegetation and soils for a longer period to encourage afforestation and sustained production of biofuels (fuels, wood and crop stems, roots, fibre etc) and to cut down the combustion of fossil fuels. Thus, extension of such systems as suitable to a region will help in monitoring the weather aberrations and mitigating drought in long run, compared to sole crop systems.

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