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Agroforestry on dry and degraded lands: present status and future prospects

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Abstract
This paper examines the role of agroforestry on dry and degraded lands from the perspectives of economic and environmental gains. It has potential in achieving food security, arresting land degradation, combating climate and achieving sustainable evergreen agriculture. There are examples how such an integrated system is more profitable compared to sole cropping on a long term basis. As land degradation problems further accelerates, future land management decisions will require more sustainable and resilient agricultural systems like agroforestry. Despite huge potential of agroforestry in India, the adoption rates are still low. The reasons are many and efforts are needed to overcome the constraints. More adoption of agroforestry on dry and degraded lands in a participatory mode will improve dry land productivity and thus economic status of farmers. Focussing on issues related to role of such systems in mitigating climate change, soil fertility enhancements, improving efficiency of use of soil, water and fertilizers and promoting gender equity will help in better adoption of such systems. The adoption of national agroforestry policy by government of India in 2014 is expected to improve farm productivity and the livelihood of the small and marginal farmers substantially in the future years.

Keywords: Biodiversity, Carbon sequestration, Environmental conservation, Farm income, Land degradation

Introduction

Drylands occupy over 40% of the earth's land area and over 2.5 billion people, nearly a third of the world's population, inhabit such areas. This population is forced to contend with severe environmental degradation and increasing climate variability (EMG, 2011). Land degradation is a global problem. About 78% of total earth's surface is unsuitable for agriculture and out of the remaining 9% suffers from physical, chemical and biological constraints, requiring special management practices for their sustained economic use for agricultural production (Dagar and Singh, 1994). Globally, land degradation affects about one-sixth of the World's population, 70% of all dry lands, amounting to 3.6 billion ha, and one quarter of the total land area of the world (SPWD, 1992). In India, almost 35% of the land is characterised by erratic rainfall with high variability, low soil fertility and depleted natural resources. The farmers in this region have poor economic status (Pathak and Bhatt, 2006). The farmers in dry lands are at high risk of climate change as compared to their counterparts inhabiting other regions (IPCC, 2007; Howes and Wyrwoll, 2012).

Agroforestry is defined as a land use system in which trees and shrubs are grown in association with crops or pastures (with or without) animals in the same land unit. It has the potential to arrest land degradation and rural poverty in the developing country through its service and productive functions. It achieves multiple objectives with minimum inputs in landscape besides the socio-economic benefits. This includes diversity of products and services such as fodder, timber, fruits, firewood, fodder greases, crops and soil fertility improvements. In fact it is an ancient practice with renewed emphasis and technological interventions for improving the livelihoods of the poor *vis* a *vis* enhancing the goals of agricultural development and biodiversity conservation (Puri and Nair, 2004).

There are several studies that indicate that agroforestry empowers women farmers who are usually not in a position to adopt high cost technologies (Rocheleau and Edmunds, 1997; Quisumbing and Pandolfelli, 2010; Kiptot and Franzel, 2011; Kiptot *et al*., 2014; Colfer *et al*., 2015). Also, agroforestry has a very high potential for climate change adaptation and mitigation (Luedeling *et al*., 2014). There is another trend of land grabbing meaning that even the common lands traditionally used for livestock production in semiarid and even arid areas are now being converted into cropland (Van *et al*., 2014). Thus agroforestry interventions assume greater significance.

In this paper present status of agroforestry in the context of dry and degraded lands with respect to their role in increase in primary and secondary agricultural productivity, conservation of natural resources, carbon sequestration, economic benefits to farming community and gender equality is reviewed and future prospects are discussed.

Dry and degraded lands

Dry lands are found on all the continents. However, they are most prevalent in Africa and Asia and are the foundation for both rural and urban communities. Around one billion people rely directly on dry and ecosystem services for their daily survival, whether people rely directly on dry land ecosystem services for their daily survival, whether through rainfed or irrigated farming, or through wide spread pastoralism (EMG, 2011). Unsustainable land and water use and the impacts of climate change are driving the degradation of dry lands. 6 million km^2 of dry lands (about10%) bear a legacy of land degradation. Dry land degradation costs developing countries an estimated 4–8% of their national gross domestic product (GDP) each year (Geogris, 2010).

In India, total land area of is 329 m ha of which 144 m ha is arable land. 65% of arable land (94 m ha) is categorized as dry lands. More than 75% of the farmers engaged in dry farming are small and marginal. Therefore, improvement in dry farming would raise the economic status of farmers thus help in poverty alleviation. It also holds immense significance in the context of fluctuating food grain production and expanding population (EMG, 2011). Land degradation is one of the major problems faced by the world and needs adequate attention so that future land management decisions can lead to more sustainable and resilient agricultural systems (Bhattacharyya *et al.*, 2015). In India, the severity and extent of soil degradation has been assessed by many agencies (Table 1). According to the latest estimates of National Bureau of Soil Survey and Land Use Planning (NBSS & LUP) 146.8 m ha is degraded in India.

Appropriate mitigation strategies for such dry and degraded lands are of utmost importance in present day context. Integrated approaches like agroforestry that combat land degradation and improve livelihood may be given maximum attention.

Agroforestry systems

Agroforestry is an age old practice as a traditional land use system that is able to satisfy a large diversity of socio-economic needs in a sustainable way. In many parts of Africa farmers traditionally practice agroforestry. Trees are planted in agricultural or pastoral systems to provide shade, windbreak, medicines, or to meet household energy needs. Traditional agro-forestry system takes the form of trees scattered on crop fields, woodlots, homestead tree planting and multi-storey home garden (Eyasu, 2002). In India, there are many examples of such traditional systems from all regions and an equivalent number of management practices of multipurpose trees, shrubs and palms (Depommier, 2003). Table 2 depicts major indigenous agroforestry systems and their attributes.

During the last 40 years the scientific discipline of agroforestry is growing and it is receiving attention worldwide. In India, it has received a good deal of attention from researchers, policy makers and others for its perceived ability to contribute significantly to economic growth, poverty alleviation and environmental quality, that is why today agroforestry is an important part of the ‘evergreen revolution’ movement in the country (Puri and Nair, 2004). Several systems of agroforestry have been designed and developed and categorized as agri-silvicultural systems, agri-silvi-pastoral systems, silvipastoral system, agri-hortipasture systems. There have been improvements in terms of species composition and management in the indigenous or traditional systems as well (Singh and Roy, 1991, 1993; Pathak and Roy, 1994; Roy, 2010; Singh and Pandey, 2011).

Economic considerations

In a farm enterprise diversification is preferable in order to increase farm income or minimize income variability by reducing risk, exploiting new market opportunities and existing market niches, diversifying not only production, but also on-farm processing and other farm-based, income-generating activities (Dixon *et al.*, 2001). Agroforestry offers a suitable way to incorporate complementariness at farm level by involving a variety of crops, trees, and livestock along with post-harvest processing. Systems like home gardens besides meeting the subsistence needs of households generate additional cash incomes (Wezel and Bender, 2003).

The crop yields in agroforestry systems may reduce for a variety of reasons. However, there may be trade-offs. The study in traditional agroforestry system showed that effect of residual nitrogen on the yield of rice crop after removal of 15-year old *Acacia nilotica* trees resulted in increase

Table 1. Extent of land degradation in India, as assessed by different organizations

Agency	Year of Assessment	Degraded Area (m ha)
National Commission on Agriculture	1976	148.1
Ministry of Agriculture	1978	175.0
Ministry of Environment & Forests	1980	95.0
National Wasteland Development Board	1985	123.0
Society for Promotion of Wastelands	1984	129.6
National Remote Sensing Agency	1985	53.3
Ministry of Agriculture	1985	173.6
Ministry of Agriculture	1994	107.4
NBSS&LUP	1994	187.7
NBSS&LUP (Revised)	2004	146.8

Source: Bhatacharyya *et al.* (2015)

Table 2. List of indigenous agroforestry systems

Parklands	It is random scattering of trees in fields with crops. The management of trees in this system requires pruning of branches and the tops to reduce shading. The trees provide valuable products such as fuelwood, charcoal, construction materials and fodder for livestock.
Homegardens	It consists of an assemblage of multi-purpose trees and shrubs with annual and perennial crops and livestock within compounds of individual houses managed by family labour. The home gardens are characterized by high species diversity and usually 3-4 vertical canopy strata.
Woodlots	It is a small patch of land planted with trees to provide fuelwood, pole or timber products to rural communities as well as for purposes of environmental regeneration.
Hedges	It is a horizontal strip of multipurpose trees or shrubs that is used for soil erosion control on sloping lands. The hedges at the same time provide high quality fodder (e.g. *Leucaena* hedges), firewood, stakes for climbing beans and mulch material. Contour hedges control erosion by providing a physical barrier as well as through increased infiltration as a result of leaf litter layer creating good soil structure.
Improved Fallows	This is a process of *land resting from cultivation,* enriched with planting leguminous trees to speed up soil fertility replenishment process. Leguminous trees and shrubs such as *Sesbania sesban, Tephrosia vogelii*, *Gliricidia sepium, Crotalaria grahamiana,* and *Cajanus cajan* rapidly replenish soil fertility in one or at mosttwo growing seasons. It takes a maximum of 3 years to replenish fertility of extremely degraded soils through improved or planted fallows.
Trees on Soil Conservation Structures	Planting trees/shrubs on earth structures such as soil and stone bunds, terraces, raisers, etc. combines soil conservation with production of various products such as fodder, fruit or fuel wood. This makes productive use of the land. The challenge is to guard against is some of the species like *Prosopis juliflora* introduced for soil conservation are becoming weeds.
Tree based systems	Dry lands cover considerable areas in peninsular India, in its north-western, central and southern parts, where trees may be observed in many different farming systems and spatial arrangements in the agrarian landscapes: associated with irrigated or rainfed cropping systems, in agri-silvicultural or silvipastoral systems.

Source: Depommier (2003); Mulugheta (2013)

in the crop yield (12.5 t ha^{-1}) that was almost equal to thereduction in the crop yield suffered during 15 years of the tree growth in the agroforestry system (Pandey and Sharma, 2003). There may be yield reductions on account of microclimate modification but compensated in the long term (Kohli and Saini, 2003).

In Central Indian upland rice fields trees of *Acacia nilotica* (20 trees/ha) on a 10 year rotation yield a variety of products viz., firewood (30 kg/tree), brushwood for fencing (4 kg/tree), small timber for farm implements and furniture (0.2 m^{-3}), and non-timber forest products such as gum and seeds. Thus, trees account for nearly 10%

of the annual farm income distributed uniformly throughout the year than in rice monoculture of smallholder farmers with less than 2 ha farm holding. So with the combination of *Acacia* and rice traditional agroforestry system has a benefit/cost (B/C) ratio of 1.47 and an internal rate of return (IRR) of 33% at 12% annual discount rate (10 year) (Viswanath *et al.*, 2000).

In dry areas of Andhra Pradesh (India), on farm experiments revealed that although in the second year intercrop yields were 45% of the sole crop in eucalyptus system and 36% in leucaena system; yet agroforestry was profitable compared to arable cropping under rainfed conditions (Prasad *et al.*, 2011). In other regions as well, agroforestry systems were 4.46 times more profitable compared to sole cropping (Pandey, 2011). Studies to maximize the trade-off in yield of crops and wood have shown that in situation of rainfall around 1000 mm and fairly good soils in Andhra Pradesh; introduction of eucalyptus (density 1666 trees/ha, uniformly spaced wide rows of 6 m or inter-pair spacing of 7-11 m) improving intercrop performance without sacrificing wood production (Prasad *et al.*, 2010).

In Rajasthan, optimum tree density in relation to their age has been standardized with respect to important crops in the arid regions (Singh *et al.*, 2004, Singh *et al.*, 2005). Neem (*Azadirachta indica*) is an important tree in this region and studies have shown that although crop (black gram) decreases under canopy, higher economic returns are realized on account of increase in wood volume and fruit yields (Pandey *et al.*, 2010).

Environmental considerations

As tree species have potential to conserve moisture and improve fertility status of the soil in agroforestry systems, incorporation of legumes is most effective for promoting soil fertility. In addition, deep rooted species reduce competition for nutrients and moisture with crops by pumping from deeper layers of soil (Das and Chaturvedi, 2008). On account of deeper roots, trees improve ground water quality by taking up the excess nutrients that have been leached below the rooting zone of crops. These nutrients are then recycled back into the system through root turnover and litter fall, increasing the nutrient use efficiency of the agro-ecosystems (Jose, 2009).

Agroforestry has also the potential to bring favourable changes in physical, chemical and biological conditions of soil (Nair, 2011). Such systems in form of contour hedgerows and improved fallows provide permanent vegetation covers that improve soil organic matter, infiltration, soil structure and fertility besides soil biological activity

The threat of degradation and desertification is becoming alarming in recent years. Climate exerts a strong influence on soil processes that contribute to degradation. Higher temperatures and drier conditions lead to lower organic matter accumulation in the soil resulting in poor soil structure, reduction in infiltration of rain water and increase in runoff and erosion (Rao *et al.*, 1998). Similarly, expected increase in the occurrence of extreme rainfall events will adversely impact on the severity, frequency, and extent of erosion (WMO, 2005). An assessment by IIASA predicted that the arid and semi-arid areas in Africa will increase by 5-8% by 2080 (Fischer *et al.*, 2005).

The improved fallows using fast growing species like *Crotalaria grahamiana* and *Tephrosia spp* have controlled soil erosion significantly in western Kenya (Young, 1997; Jose, 2009). However, the studies on quantified soil faunal activity are relatively less. Observation made in Kenya indicated that one year old Sesbania fallows have the ability to restore the soil biological activity to the same level as in natural forest. It was higher by seven times in the cropped fields or grass fallows (Mulugeta, 2013). Significant improvement in soil biological activity has been reported under different tree based agroforestry systems in Rajasthan (India). Soil microbial biomass C, N and P under agroforestry varied between 262–320, 32.1– 42.4 and 11.6–15.6 ì g g^{-1} soil, respectively with corresponding microbial biomass C, N and P of 186, 23.2 and 8.4 ì g g^{-1} soil under a no tree control (Yadav *et al.*, 2008). In Rajasthan, fluxes of C, N and P through microbial biomass were significantly higher in *P. cineraria* and other tree based systems in comparison to no tree control (Singh, 2009). Also, a diverse combination of trees is useful not only for diverse products but also in rendering stable nutrient cycling (Semval *et al.*, 2003).

All over the world biodiversity is under threat and rate of loss is not slowing down (Butchart *et al.*, 2010). This leads to decreased ecosystem functioning and services. Agroforestry has major roles in conserving biodiversity through providing suitable habitat, alternate goods and services, erosion control and water recharge, corridors between habitat remnants, germplasm preservation etc. (Pandey, 2007; Jose, 2009). There are reports of agroforestry systems supporting higher biodiversity (50-

80%) than the comparable natural systems (Noble and Dirzo, 1997). Such systems also act as buffers to parks and protected areas as natural vegetation alongside agroforestry allows noncrop-crop spillover of a diversity of functionally important organisms (Anand *et al.*, 2010).

In peri-urban setup, agroforestry can be useful for utilization of sewage-contaminated waste water from urban systems (Bradford *et al.*, 2003; Singh *et al.*, 2010). It may also be utilized in bio-drainage for preventing water logging in canal-irrigated areas (Ram *et al.*, 2011; Roy *et al.*, 2016).

Carbon sequestration

One of the very important roles of agroforestry in context of climate change is in mitigation of emissions of CO_2. The tree component of the agroforestry systems can act as sink for carbon in agricultural lands. The three major paths through which tree can be of use in reducing atmospheric carbon include conservation of existing carbon pools through practices such as avoided deforestation and alternatives to slash and burn; sequestration through improved fallows and integration with trees, and substitution through biofuel and bioenergy plantations to replace fossil fuel use (Montagnini and Nair, 2004). Schroeder (1994) estimated carbon sequestration through agroforestry practices to be 9, 21, 50, and 63 Mg C ha^{-1} in semiarid, sub-humid, humid, and temperate regions, respectively. It is based on the aasum-ption that average carbon content of above ground biomass of 50%. Many studies have confirmed a good potential for such systems in acting as effective carbon sinks (IPCC, 2000; Albrecht and Kandji, 2003; Montagnini and Nair, 2004; Palm *et al.*, 2005; Bhatt *et al.*, 2008; 2010). The C sequestration potential of tropical agroforestry systems in recent studies is estimated between 12 and 228 Mg ha^{-1} with a median value of 95 Mg ha^{-1} Table 3. The studies suggest that based on the global status of the area suitable for the agroforestry (585-1215 x 106 ha), 1.1-2.2 Pg C could be stored in the terrestrial ecosystems over the next 50 years (Albrecht and Kandji, 2003). Another estimate of C stored in agroforestry systems, derived from a recent review of studies with global coverage, range from 0.29 to 15.21 Mg ha^{-1} yr^{-1} aboveground, and 30 to 300 Mg C ha^{-1} (up to 1 m depth) in the soil (Nair *et al.*, 2010).

In India, average sequestration potential in agroforestry has been estimated to be 25 Mg ha^{-1} but there is substantial variation in different regions depending upon the biomass production. However, compared to any degraded areas agroforestry may hold more carbon (Sathaye and Ravindranath, 1998).

The idea of possible trade-offs between carbon storage and profitability of agroforestry systems is very relevant and needs to be looked into when the issue of promotion of such systems in a given location is considered

Table 3. Potential of carbon storage for agroforestry systems in different eco-regions of the world

Continent	Eco-region	System	C Storage Mg C (ha^{-1})
Africa	Humid tropic high	Agro-silvicultural	29-53
South America	Humid tropic low	Agro-silvicultural	39-102[a]
	Dry low land		39-195
Southeast Asia	Humid tropical low	Agro-silvicultural	12-228
	Dry lowland		68-81
Australia	Humid tropics low	Silvipastoral	28-51
North America	Humid tropics		133-154
	Humid tropics low		104-198
	Dry low lands		90-175
Northern Asia	Humid tropics low		15-18

[a]Carbon storage values were standardised to 50-year rotation; **Source:** Albrecht and Kandjii (2003)

Table 4. Identified driving factors for adoption of agroforestry in some major dry regions of India

Region	Main driving factor	Reference
Northern	Additional income and an emergency source of cash	Kareemulla *et al.* (2005)
Bundelkand	Developmental works like water harvesting and cash income	Palsaniya *et al.* (2010)
Central	Ease in management, multiple products and services, marketing arrangements, institutional mechanism to compensate poors	Pethiya (1999)
Eastern	Risk aversion, land availability, farmers' attitude	Glendinning *et al.* (2001) Mahapatra *et al.* (2001)
Southern	Risk aversion, institutional arrangements, quality planting material	Pandey *et al.* (2007)

(Gockowski *et al.*, 2001). The estimates suggest that an increase of 1 tonne of soil carbon of degraded cropland soils leads to increase in crop yield by 20 to 40 kg ha^{-1} for wheat, 10 to 20 kg ha^{-1} for maize, and 0.5 to 1 kg ha^{-1} for cowpeas.

Technological advances and constrains

Agroforestry could contribute to livelihoods improvement in India and elsewhere where people have a very long history and accumulated local knowledge. India is particularly notable for ethno-forestry practices and indigenous knowledge systems on tree growing. Domestication of non-timber forest trees and forest fruit trees offer significant opportunity for livelihood improvement through providing host for globally valued products and generating cash surplus through commercialization of valued products. This has added advantage of reducing pressures on natural forests (Belcher *et al.*, 2005; Chandrashekara, 2009). The results of community plantations of non-timber forest products in tribal areas such as Jharkhand indicate that they serve dual purpose of conserving the useful species as well as livelihoods improvement of local people (Dwivedi, 2001; Quli, 2001; Jaisalwal *et al.*, 2012).A study of 8 year old agroforestry intervention in Palamau district of Jharkhand found that community dependent solely on rainfed farming and animal husbandry definitely gains positively by agroforestry interventions (Minj and Quli, 2000).Promotion of species used in woodcarving industry strengthens livelihood support through exports and domestic consumption by using traditional knowledge and skills (Pandey *et al.*, 2010).

Despite huge potential of agroforestry in India, the adoption is low. One of the main reasons is location specificity. However, it is argued that agricultural systems are site specific, yet modern agricultural technologies have gained widespread adoption in India and many answers have been postulated (Puri and Nair, 2004). Based on the available studies, main points for adoption of agroforestry in some major dry regions of India are summarised in Table 4.

National agroforestry policy

Although, there are increasing thrusts on agroforestry all over the world; India proclaimed its National Agroforestry Policy (NAP) in 2014. The policy defines agroforestry as a ‘land use system which integrate trees and shrubs on farmlands and rural landscapes to enhance productivity, profitability, diversity and ecosystem sustainability’. It is considered as a forward-looking action plan and aims to enhance the livelihood opportunities of small farmers, the landless and women (GoI, 2014). The policy identifies some of the hindering factors in promoting agroforestry. This include restrictive legal provisions, lack of quality planting materials, inadequate marketing infrastructure and price discovery mechanisms, lack of post-harvest processing technologies, lack of institutional support mechanisms etc. A significant aspect is that policy ropes in existing decentralized institutions of local governance for appropriate roles in regulatory mechanism of agroforestry policy.

The NAP of India mentions that one of the most challenging tasks in introducing an agroforestry system is to ensure water availability and supply in the tree establishment phase. Since the motivation of farmers, particularly smallholders are guided by tree survival and their utility; the policy aims to address smallholders’ needs rather than to provide them with one fixed type of cropping system (FSI, 2013; Bose, 2015). It has proposed to set up a National Agroforestry Mission or an Agroforestry Board for effective implementation of the policy.

Future potential and thrust areas

The areas where agroforestry may be practiced are extensive and it has a wide applicability in existing agricultural systems as well. It is now being recognized that expanding market opportunities for smallholders particularly in niche markets and high value products is critical to the success of agroforestry innovations. The major constraints to the growth of the small holder tree product sector are in policies and physical and social barriers to smallholder participation in markets. However, there are promising developments including contract fuel wood schemes, small-scale nursery enterprises, charcoal policy reform etc. (Russell and Franzel, 2004). The possibilities for integrating farms with traditional and non-traditional trees that provide fruits, nuts and other food products, medicinal plants (Rao *et al.*, 2004), short rotation woody crops (Rockwood *et al.*, 2004), and biomass energy plantations (Hall and House,1993) are plenty, if suitable market structures are put in place.

If time-averaged above ground carbon is considered, agroforestry systems store substantial quantities of carbon compared to degraded land, croplands or pastures (Albrecht and Kandji, 2003). However, it is unclear how smallholders can benefit from carbon sequestration projects and CDM (Montagnini and Nair, 2004). Thus, better quantification of carbon sequestered is required to establish how much carbon is sequestered and how much is added to the soil carbon pool before any of this can figure in carbon audits and provide incentives to smallholder farmers. In areas where success of green revolution is yet to be realized due to lack of soil fertility, agroforestry holds promise. Systems like agro-horticultural, agro-pastoral, and agro-silvipasture may be promoted for soil organic matter restoration.

Often new policies fail to address the fundamental rights of marginal groups such as indigenous peoples, women and youths. One of the objectives of India's NAP is to enhance the livelihood opportunities of small farmers, the landless and women (GoI, 2014). However, the question remains, how will India's bold step to introduce the agroforestry policy help gender equity and the social relations of marginalised rural men and women (Bose, 2015).

The following thrust areas are suggested-

➡ Appropriate linking of indigenous knowledge and technological advances in the field of agroforestry with action

Setting of user driven goals in management of agroforestry systems

Implementation of agroforestry projects in a participatory mode with active involvement of all stakeholders

Identification of knowledge gaps and planning of experimental projects to fill the gaps

Appropriate flexibility in implementation of agroforestry recommendations to accommodate site specific biophysical and socio-economic considerations.

Understanding on the extent to which agroforestry contribute to rural livelihood improvements when compared to other land uses and undertake research to remove uncertainty, if any.

Selection of such species into agroforestry programmes that will be useful for local and national food security.

High emphasis on complementarity of root interactions in agroforestry systems as it has strategic importance.

Conclusion

The traditional knowledge coupled with experimental results in the discipline of agroforestry need be utilized for designing and developing appropriate agroforestry site specific models for a variety of situations in dry and degraded lands to arrest degradation on one hand and provide diverse products for home use and surplus cash generation for the farming community. Such innovations will provide options for reducing poverty, improving food and income security and also in sustaining environmental quality. Growing inequality, changing gender norms, lack of education, access to land and trees and participation of concerned local institutions will actually govern the extent of equitable benefit sharing in the dry lands for success of agroforestry initiatives.

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