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Research Application Summary

Ecological and socio-economic evaluation of dryland agroforestry systems in East Africa

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Abstract

Drylands typically suffer from sustainable land use challenges that have rapidly increased in the recent past. Drylands are face with a number of constraints including, among others, climate variability, natural resources degradation, declining agricultural productivity and high population that are exacerbating retrogressive development pathways. In order to sustainably address these challenges, sustainable dryland land use and management is an important imperative. Agroforestry has been fronted as a critical entry point for dryland sustainability owing to its dynamic and ecologically based natural resources management approach that allows for the integration of trees on farms and diversifies and sustains production in agricultural landscapes. Well designed and implemented dryland agroforestry provides leverage points to alleviating poverty, providing food security and livelihoods, maintaining healthy ecosystems, conserving biodiversity and mitigating greenhouse gas effects through carbon sequestration. This paper discusses advances in agroforestry systems in terms of ecological and socio-economic aspects including classification of agroforestry systems, agroforestry in East Africa, importance of agroforestry in drylands, and socio-economic factors affecting its adoption and agroforestry potential for carbon sequestration.

Key words: Agroforestry systems, carbon sequestration, drylands, ecological, socio-economic, sustainability

Résumé

Les zones arides souffrent généralement de problèmes d'utilisation durable des terres qui ont rapidement augmenté dans le passé récent. Les zones arides font face à un certain nombre de contraintes, y compris, entre autres, la variabilité climatique, la dégradation des ressources naturelles, la diminution de la productivité agricole et de grande population qui exacerbent les voies régressives de développement. Afin de répondre à ces défis de manière durable, l'utilisation des terres des zones arides et la gestion durable sont un impératif important. L'agroforesterie a été affrontée comme un point d'entrée critique pour la durabilité des terres arides en raison de son approche des ressources naturelles et de gestion dynamique et écologique qui permet l'intégration des arbres dans les exploitations agricoles, ses diversifications et son soutient de la production dans les paysages agricoles. Bien conçu et mis en œuvre, l'agroforesterie des terres arides fournit des points de levier pour réduire la pauvreté, assurer la sécurité alimentaire et les moyens d'existence, le maintien des écosystèmes sains, la conservation de la biodiversité et l'atténuation des effets de gaz à effet de serre par la séquestration du carbone. Ce document traite des avancées dans les systèmes agroforestiers en termes d'aspects écologiques et socio-économiques, y compris la classification des systèmes d'agroforesterie, l'agroforesterie en Afrique orientale, l'importance de l'agroforesterie dans les zones arides, et les facteurs socio-économiques qui influent sur son adoption et de l'agroforesterie potentielle de séquestration du carbone.

Mots clés: systèmes agroforestiers, la séquestration du carbone, les zones arides, écologique, socio-économique, la durabilité

Introduction

Globally, areas in which annual evapotranspiration exceeds rainfall and in which agricultural productivity is limited by poor availability of moisture are regarded as dryland ecosystems (Jama and Zeila, 2005). Recent developments have given increasing attention to the dryland environments arising from intermittent crises in these regions particularly in Africa, calling for significant development assistance and frequent humanitarian aid (De Leeuw *et al.*, 2014). These situations are being orchestrated by innumerable challenges such as climate variability, frequent drought, natural resources degradation, declining agricultural productivity and high population increment (Jama and Zeila, 2005). Further, rapid exploitation of dryland woodlands to give way for cultivated crop agriculture, raw materials, human settlement and fuel wood production has accelerated environmental degradation in the dryland ecosystems. The cause-effect relationship of population-environmental degradation in the dryland areas cannot be under estimated. Indeed, it is evident that dryland areas that have experienced rapid population growth have similarly witnessed accelerated rangeland degradation as demand for arable land increases and transitions to cultivated agriculture become more pronounced than reliance on livestock production systems (Jama and Zeila 2005; Egeru *et al.*, 2014). Therefore, the amount of additional dryland converted to agriculture will depend to some extent on how well the productivity of the current agricultural land is maintained and enhanced (Barbier, 1997).

Agroforestry as a dynamic, ecologically based natural resources management system that integrates trees on farms and in agricultural landscapes is an integral component of dryland productivity and sustainability. Its positive outcome diversifies and sustains production for increased social, economic and environmental benefits for land users at all levels that not only support dryland livelihoods, but also helps achieve resilient and sustainable land use and development (Leakey, 1998). The Agenda 21, the blueprint for action into the 21st century adapted by World leaders at the Rio Earth Summit in 1992 identified agroforestry as one way of rehabilitating the degraded drylands of the world (Jama and Zeila, 2005). As such, there is increasing attention to agroforestry by scientists and development community worldwide (Nair, 1993; Alavalapati *et al*., 2003; Edinam *et al.,* 2013) because it can address a wide range of household needs. Agroforestry has definite potential for smallholder farming systems from the perspective of sustainable resource management (Avila, 1989). In agroforestry systems, the trees grown on different farmlands lead to improved wooded environment thereby enhancing environmental protection through increased biodiversity and ecosystem services (Otegbeye, 2002). The interest in agroforestry accelerated in the 1990s after the Rio Earth summit endorsement with policy makers recognizing its potential in solving challenges such as soil erosion, rising salinity, surface and ground water pollution, reducing greenhouse gases concentration and regenerating lost biodiversity (Alavalapati *et al*., 2003). Subsequently, over the last two decades or so the focus has been on exploring biophysical and ecological aspects of agroforestry but unfortunately with limited emphasis on social aspects of agroforestry and especially economics, policy analysis and valuation of associated environmental services (Mercer and Miller, 1998; Edinam *et al*., 2013).

It is evident that in spite of the several advances made so far in agroforestry research, there still remain lacunas in relation to ecological and socio-economic interactions in agroforestry systems. According to Nair (1998) the concern over low adoption rates of agroforestry systems is real. It is therefore critical to consider that the socio-economic elements and the need to integrate it into traditional biophysical agroforestry research are precondition for success. However, due to disaggregated research, the scientific and technical knowledge on trees and agroforestry systems in drylands and information on their contribution to dryland livelihoods is scattered and fragmented (De leeuw *et al*., 2014). Over time this has hampered the collection and analysis of socio-economic benefits of agroforestry in drylands (Paul, 1987). Thus, a more extensive analysis of farmer-led agroforestry is needed for sustainability of dryland ecosystems (Scherr and Frannzel, 2002). Consequently, this paper examines the ecological and socio-economic benefits of dryland agroforestry systems in East Africa.

Classification of agroforestry systems

Different types of agroforestry systems exist in different parts of the world. These have been differentially classified to provide opportunity for unique and yet consistent understanding of agroforestry systems to facilitate management. Agroforestry systems can be classified based on: structural, functional, socio-economic and ecological basis (Nair, 1987). Table 1 presents the various agroforestry systems based on Nair (1993) classification.

Agroforestry systems in the drylands of East Africa

About 80% of Tanzania is classified as drylands as it receives between 400-1200 mm of rainfall annually and the rainfall is highly variable (Mbwambo, 2004). Tanzania started nationwide afforestation efforts in 1960 that led to the Arusha declaration campaign in 1967 whose aim was to plant woodlots in all the climatic zones of the country mainly to address the fuel wood energy crisis (Jama and Zeila, 2005). For the last two decades the World Agroforestry Centre (ICRAF) has been promoting dryland agroforestry in Tanzania, mainly through rotational woodlots, improved fallows, fodder banks and relay cropping especially in Miombo woodlands. Another agroforestry system practiced in Tanzania is called the "Ngitiri"

Table 1. Types of agroforestry sytems based on Nair (1997)

Agroforestry practice (system)	Brief description
1. Improve fallow	Woody species planted and left to grow during the fallow phase
2. Alley cropping (hedgerow intercropping)	Woody species in hedges, agricultural species in alleys in between hedges
3. Multilayer tree gardens	Multispecies, multilayer dense plant associations with no organized planting arrangement
4. Multipurpose trees on cropland	Trees scattered haphazardly or according to some systematic patterns or bunds, terraces or plot/field boundaries.
5. Taungya	Combined stand of woody and agricultural species during early stages of establishment
6. Plantation crop combination	Integrated multistory mixtures of plantation crops
7. Home gardens	Intimate multistory combination of various trees and crops around homesteads
8. Trees in soil conservation and reclamation	Trees on bunds, terraces, raisers etc with or without grass strips, trees for soil reclamation
9. Shelter belts and windbreaks, live hedges	Trees around farmlands/plots
10. Multipurpose woodlots	For various purposes (wood, fodder, soil protection)
11. Trees on rangeland or pastures	Trees scattered irregularly or arranged according to some systematic pattern
12. Apiculture with trees	Trees for honey production.
13. Protein banks	Production of protein-rich tree fodder on farm/rangeland for cut-and-carry production

system; a system of "bush fallow" management used by the Sukuma people of Shinyanga region in northern Tanzania. This system is primarily for fodder production and ensures fodder security during drought episodes. Further, trees in the system enrich the soil, reduce soil erosion and provide fuel wood to the communities. This farmer-led and farmer-managed system evolved out of the traditional grazing management practices of the Sukuma people and has thus provided a basis for sustainable silvopastoral agroforestry in dryland settings of East Africa (Magasha *et al*., 1996).

Uganda's drylands are unique due to their sub-humid (450-800 mm annually) characteristics. In Uganda, drylands occupy what is referred to as the "cattle corridor" about 40% of the total land area (Jama and Zeila, 2005). Agroforestry in Uganda was started by the Forestry Department and CARE in the early 1980s. Since then, ICRAF and the Forest Resources Research Institute (FORRI) and other non-governmental organisations (NGOs) and community based organisations (CBOs) including Vi Agroforestry have promoted different agroforestry technologies and systems. A notable example has been the promotion of on-farm wood and energy production using dryland tree species, fodder production, improved fallows and improved fruit trees (Willy *et al*., 2004). The Vi agroforestry project has promoted alley farming and hedgerows in Masaka district as a system that allows farmers to overcome reduction in arable land yet ensure food security and better livelihood options. (Vincent *et al.,* 2012). The Government of Uganda under the Forest Policy 2001 has institutionalized agroforestry. The Plan for the Modernization of Agriculture, 2000 and the National Forest Plan, 2002 support the promotion and adoption of agroforestry as a strategy for poverty alleviation (Jama and Zeila, 2005). However, experiences by ICRAF and FORRI indicate the need to harmonize respective agroforestry initiatives promoted in different areas of the country (FORRI, 2003).

At 83% dryland coverage of the total land area, Kenya has the largest dryland coverage in East Africa. Agroforestry systems play a central role particularly in coping with intermittent drought in the drylands of Kenya particularly by supporting the provision of forage resources to various livestock species and non-timber products such as edible plants. The Vi Skogen, a Swedish development cooperation organization, has been promoting agroforestry in Kenya for over 33 years. With initial agroforestry projects in 1983 in the drylands of Kenya (West Pokot), the goal of Vi Agroforestry was halting desertification and soil erosion through tree planting. It has spread to other regions and mainly in the Lake Victoria basin. Other NGOs and CBOs advocate for tree planting, for instance, the Greenbelt Movement which begun in 1977 has to date resulted in planting of over 50 million trees in Kenya. Further, the Drylands Natural Resources Centre (DNRC) has been promoting dryland agroforestry in Makueni County since 2008, specializing in multiple woodlots systems. In central part of Kenya, farmers plant fruit trees in home garden agroforestry systems to supplement the family diet and generate income. They also promote live hedges to mark property boundaries to provide timber and act as windbreaks (ICRAF, 1994; Wafuke, 2012).

Importance of agroforestry in drylands. Agroforestry in dryland areas of East Africa is an inevitable option providing a foundation for sustainable land use management. This is because it is rooted in and evolved out of concerns for ecological and economic sustainability–

resilience of the environment and diversity landscapes and benefits it confers (Jama *et al*., 2005). According to Paul (1987) agroforestry is arguably the single most important discipline for the future of sustainable development in Africa. The benefits of agroforestry are wide ranging and are indicated in Table 2.

Agroforestry adoption in a socio-economic context. Agroforestry technologies and practices offer an alternative solution to resource-constrained smallholder farmers. Over the last two decades, interest has grown on agroforestry. However, further research is needed on developing a better understanding of adoption uncertainty and insights into how and why farmers adopt and modify adopted systems (Mercer, 2004). According to Mcneely and Schroth (2006), the common reason that led to adoption failure was inadequate attention given to socio-economic factors in the design and development of agroforestry systems' projects. This led to a significant failure of many early agroforestry projects because they were not anchored on producing financial benefits for the farmers (Current and Shrerr, 1995).

Achieving the full promise that agroforestry could deliver requires recognizing and addressing important factors that determine involvement of farmers in agroforestry activities, how and why farmers make long term land-use decisions and applying such knowledge to the design, development and marketing of agroforestry innovations (Mercer, 2004). Farmers are rational beings and make decisions to adopt to certain agroforestry systems based on the household and field characteristics such as gender, tree tenure security, seed supply, contact with extension and research agencies, soil erosion index, size of land holding, fuel wood scarcity and main source of family income (Banana *et al.,* 2008). Other farmer characteristics such as: age, gender educational level of household head, wealth, family size, group membership and farm resources including farm size, land tenure, availability of credit and other inputs influence adoption of agroforestry systems (Masangano, 1996).

Security of land tenure is considered among the most important determinants of agroforestry innovation and adoption because land ownership gives farmers control and rights over land and tree resources regardless of gender (Garrity and Arnold, 1997). Different farmer capital levels influence farmer entry into "new" land use options like agroforestry. They include: human capital (knowledge), social capital (supportive village level institutions), natural capital (availability of suitable land and in-situ tree germplasm), and financial capital (opportunities to invest time and money) (Noordwijk *et al*., 2001), farmers' wealth status, and management knowledge and experience (Mahapatra and Mitchell, 2001; Edinam *et al*., 2013). The most common knowledge gap in socio-economic research is understanding factors influencing adoption behaviour and the impacts of agroforestry on farm household (Mercer and Miller, 1998). Recognizing and tackling these socio-economic components can provide opportunity to attract more farmers in the dryland areas into agroforestry.

Economics of dryland agroforestry systems. Agroforestry research so far undertaken has largely focused on developing a better empirical understanding of the biophysical and socio-economic processes and principles involved (ICRAF, 1990). Economic questions about agroforestry were barely explored before 1980 (Sullivan *et al*., 1992) but since then, some

Table 2. Documented benefits of agroforestry systems

Benefit	Description	Source
Improved soil fertility	Enhancing and maintaining soil fertility is vital for food security, reducing poverty, preserving environment and for sustainability. Efficient ways of restoring organic matter. Control runoff and soil erosion thereby reducing losses of water, soil materials, organic matter and nutrients.	Jama and Zeila, (2005); Pandey 2007
Increased income	The diverse components of agroforestry provide increased and diverse income from the multiple harvests at different times of the year. This could be in terms of increased food production, improved supply of forage and fuel wood, etc.· Agroforestry systems reduce the risk of crop failure and ensure alternative income to the farmers.	Pandey (2007)
Increased productivity	Studies show that forest-influenced soils give higher yields than ordinary soil. Taungya cultivators observed higher yields than farmers engaged in mono agriculture	Prasad (2003)
Reduced vulnerability	Agroforestry increases the resilience of farming systems by buffering against various risks, both biophysically such as soil fertility and financially such as diversification of income	Verchot *et al.* (2007)
Increased carbon stock	Agroforestry has huge potential as mitigating strategy to the changing climate because of its potential to sequester carbon in its multiple plant species and soil.	Albrecht *et al*. (2005)
Aesthetic value	Agroforestry adds tree biodiversity, which adds variety in the landscape and hence improving aesthetics.	Albrecht *et al*. (2005)
Intensive and longer cropping period	Agroforestry allows longer cropping period and intensive cropping.	Kanga and Wilson, 1987; Mosango, 1999
Less chemical fertilizes	Agroforestry reduces requirements of external inputs of fertilizers.	Kanga and Wilson, 1987; Mosango, 1999

progress has been made. For instance, Hoekstra (1990) discussed the multi-period budgeting and cost–benefit analysis for agroforestry, Scoones and Pretty (1989) explored rapid appraisals techniques for agroforestry economics, and Swinkels and Scherr (1991) undertook a bibliographic study on economics of agroforestry.

According to Nair (1990), agroforestry economic studies are complex owing to multi-dimensionality of components involved with different developmental cycles, variable management over time and producing both tangible and intangible outputs and strong interactions of social and political environments. Further, (i) limited empirical data on scale and distribution of productivity, on management, and on use; (ii) the complexity and variability of many agroforestry systems on spatial-temporal scale; (iii) methodological challenges associated with valuation of environmental benefits; and (iv) disciplinary specializations leading to limitations on the part of agricultural economists to analyse economics of agroforestry systems add to the complexity. Therefore, economic analysis of agroforestry remains a high priority in the development context for sustainability of development projects in the drylands of East Africa.

Drylands, agroforestry and carbon sequestration. Ecologically, drylands are important sink in the fight against climate change. Globally, the total soil organic carbon of dryland soils is estimated at 241 Pg (1 Pg = petagram = 1015 g = 1 billion metric ton) about 15.5% of the world's total of 1550 Pg to the 1-meter depth. Dryland soils offer a real viable avenue for carbon sequestration. For example, if at least two-thirds of the historic carbon loss is re-sequestered, a SOC of 12 to 20 Pg C over a 50-year period can be realised (Lal, 2004a). This will make SOC sequester and offset about 5 to 15% of the global fossil-fuel emissions (Lal, 2004b). Further, land use and management practices that are critical in carbon sequestration include afforestation with appropriate species, soil management on cropland, pasture management on grazing land, and restoration of degraded soils and ecosystems through afforestation and conversion to other restorative land uses (Lal, 2004a). Although agroforestry systems are not primarily designed for carbon sequestration, there are many recent studies that substantiate the evidence that agroforestry system can play a major role in storing carbon in above-ground biomass, and in soil and in belowground biomass (Nair *et al*., 2009). Within Africa, East Africa is a preferred destination for carbon investors with most of the projects being non-Kyoto compliant, and representing voluntary emissions reductions efforts. Overall, these projects are expected to contribute to the sequestration of 26.85 million tCO2 (Jindal *et al*., 2008).

It is important to note that several other agroforestry initiatives occurring in the region at a smaller farmer level scale contribute to sequestration efforts but have barely been evaluated for their net contribution. As such, agricultural ecosystems represent a very important component of carbon (C) sequestration (Henry *et al*., 2011). Trees in agroforestry systems store C through fixation of atmosphere CO_2 into biomass, some of which is indirectly sequestered as soil organic carbon during putrefaction (Nair *et al*., 2009). Trees can store C both ex-situ (products) as well as in-situ (biomass and soil) and are considered effective C sinks (Montognini and Nair, 2004). Agroforestry practices in humid tropics have been reported to reduce soil emission of N_2O and CO_2 and increase CH_4 sink strength when compared to other agricultural systems (Mutuo *et al.,* 2005). Intercropping of Populus into agroforestry systems reduced N_2O emissions while trees intercropped in agroforestry systems reduced N_2O emissions due to reduced fertilizer use and efficient N recycling (Liang and Thevathansan, 2003; Thevathasan and Gordon, 2004).

Conclusion

This review paper has shown the considerable potential that dryland agroforestry has on various fronts including the socio-economic and biophysical dimension. It offers opportunity for sustainable land use management of drylands as fragile ecosystems. Understanding the socio-cultural and economic dimensions that drive agroforestry adoption as well as the design and development agroforestry projects remains a critical facet for agroforestry success in the drylands of East Africa.

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