JARQ 55 (SI), 559-564 (2021) https://www.jircas.go.jp

REVIEW

Agroforestry System Research: Identification of Land Use Change Drivers and Scaling Up of Trees on Farms for Transforming Livelihoods and Landscapes

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Abstract

Over the past decades, smallholder sectors in developing countries have experienced extensive land use changes, resulting in deforestation and environmental degradation, while drivers of agricultural expansion vary significantly by local/country/regional contexts. Agroforestry has the potential to promote sustainable agricultural intensification and landscape restoration. Due to the significant heterogeneity in the smallholder systems in developing countries in terms of agro-ecological contexts and institutional/political settings, there are no silver-bullet agroforestry interventions in any situation. Understanding what drives deforestation and/or why and how farmers decide to adopt agroforestry technologies can be useful to guide tailoring technology packages to locally specific contexts. The International Centre for Research in Agroforestry (ICRAF), with World Agroforestry as a brand name, has led system research to enhance the contribution of agroforestry in transforming livelihoods and landscapes, and Japanese scientists have played a role. This paper provides an overview of the evolution of ICRAF's research priorities over 40 years with special reference to the contribution of Japanese scientists. It discusses their significance in academic and policy contributions, understanding the causes of deforestation and its effects on people in Southeast Asia, and unpacking farmers' decision-making processes in the adoption of agroforestry technologies in East Africa. The paper concludes with arguments on the way forward for agroforestry research.

Discipline: Farming System
Additional key words: deforestation, land degradation, local contexts, smallholder farmers

Introduction

Over the past decades, smallholder sectors in developing countries have experienced extensive land use changes, resulting in deforestation and environmental degradation (Williams et al. 2020), while drivers of agricultural expansion vary significantly by local/country/regional contexts.

In the decades ahead, developing countries will become even more prominent in driving land use changes as the demand for food, fuel, and income is projected to increase in response to population growth, urbanization, and economic development (Barrett et al. 2020). Consequent pressures on natural resources and biodiversity loss can lead to increased chances of the emergence of zoonotic diseases through increasing cases of wildlife-livestock-human contact at forest/woodland margins (UNEP & ILRI 2020). It is therefore urgent to devise evidence-based interventions to reverse deforestation and land degradation by improving productivity and income opportunities on existing farmlands. Sustainable agricultural pathways require the use of improved and locally adaptable climate smart technologies, practices, and policies that not only increase yield per unit area but also help smallholder farmers adapt to and mitigate climate change (Lipper et al. 2014, Thornton et al. 2018). The scale-up of sustainable agriculture is critical, not only from a poverty eradication perspective but also from a global point of

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Received 24 February 2021; accepted 13 July 2021.

view, as preventing the escalation of the climate crisis and future pandemics requires leaving half of the Earth intact (Willett et al. 2019). Agroforestry has key chrematistics of climate-smart agriculture at different scales of interest. It can enhance soil fertility and soil moisture at the plot level, provide food and income sources at the farm level, while simultaneously contributing to climate change adaptation and mitigation if adopted at the landscape level (Mbow et al. 2014, Hadgu et al. 2019, van Noordwijk 2019).

Agroforestry is a concept that was first defined approximately 40 years ago. Since then, it has evolved tremendously (van Noordwijk 2019). In turn, due to the significant heterogeneity in the smallholder systems in developing countries in terms of agro-ecological contexts and institutional/political settings, there are no agroforestry interventions that are silver bullets in all situations (Iiyama et al. 2018a, Iiyama et al. 2018b). There is a strong demand for local/country/region-specific guidance on how to identify and scale optimal agroforestry systems that are appropriate and fit local contexts to address multi-faceted challenges. Understanding what drives land use change and why and how smallholder farmers decide to adopt agroforestry technologies can be useful to guide the tailoring of technology packages for locally specific contexts.

The International Centre for Research in Agroforestry (ICRAF), with World Agroforestry as a brand name, has led system research to enhance the contribution of agroforestry in transforming livelihoods and landscapes by reversing deforestation and soil degradation in the tropics, with Japanese scientists playing a role. This paper provides an overview of the evolution of ICRAF's research priorities over 40 years with special reference to the contribution of Japanese scientists. The paper discusses their significance in academic and policy contributions, understanding the causes of deforestation and its effects on people in Southeast Asia, and unpacking farmers' decision-making processes in the adoption of agroforestry technologies in East Africa. The paper concludes with arguments on the way forward for agroforestry research.

The evolution of ICRAF research priorities over the last 40 years

Agroforestry is a collective name for land-use systems and technologies where woody perennials (e.g., trees, shrubs, palms, and bamboos) are deliberately used on the same land management unit as agricultural crops and/or animals, in some form of spatial arrangement or temporal sequence (van Noordwijk 2019). Agroforestry as a word first appeared in the 1970s, while it is as old as agriculture as a practice. Behind the emergence of the concept in the late 1970s, there was an increasing critique of intensified monocultural forms of agriculture associated with the 'Green Revolution', and the expectation that existing combinations of trees, crops, and livestock on farms could benefit from a more systems-oriented understanding under a new umbrella term (van Noordwijk 2019).

Since then, the definitions of agroforestry have evolved from plot to landscape and policy-level concepts. In the early years starting at the late 1970s, agroforestry research was built on agronomy research traditions and focused on efficiency and trade-offs in the productive use of land, labor, and capital at a plot level, through investigating interactions and competitions of light, water, and soil nutrients between crops and trees.

However, it became increasingly clear that agroforestry productivity estimates could not be measured in subjectively selected areas within an agronomy trial plot, but should be established ecologically in the whole plot, including the border areas. Experimental designs were not able to replicate uncontrolled crop, tree, and management heterogeneity on different farms. Then, agroforestry research adopted more system approaches, with a shift from components and cause-effect relations to one of feedbacks, buffering, and filtering at a landscape and livelihoods level. Subsequently, in the early 1990s, the landscape and livelihood scale gradually emerged as a relevant scale for understanding agroforestry.

More recently, since the late 2000s, the policy-level debates have necessitated the integration of agroforestry and forestry research, with increased perception of agriculture as a threat to forests and of forestry rules as a threat to on-farm production of 'forest' resources. For the latter, for example, as often only generic non-agriculture conditions are considered as forests, species-rich agroforests, excluded from forest categories, have often become a target for conversion to monoculture plantations, necessitating to revisit a fuzzy concept of 'forest' (van Noordwijk et al. 2017). Furthermore, analyses of global tree cover on farms indicated more than 40% of agricultural land had at least 10% tree cover (Zomer et al. 2016), which is considered the lower limit of the definition of 'forest' according to some international agreements (van Noordwijk 2019). There has been also increasing recognition among scientists and policy makers to regard agroforestry as a sustainable practice which helps to achieve not only adaptation objectives at household level but also mitigation goals at policy scale (Mbow et al. 2014). With the obvious overlaps, more explicit integration of agriculture and forestry agendas into system research approaches can take advantage of global initiatives on climate change adaptation and mitigation.

The research priorities of ICRAF have evolved over the years along with agroforestry concepts and practices. The ICRAF was established in 1978 in response to a call for promoting agroforestry research in developing countries. During the early years, the ICRAF operated as an information council focused on studying and documenting agroforestry in Africa. In 1991, it joined CGIAR and changed its name from the Council to the Center to conduct strategic research on agroforestry throughout the tropics, including Asia and Latin America. Since then, ICRAF has been explicitly linking its work to the goals of CGIAR, reducing poverty, increasing food security, and improving the environment, through two means: overcoming land depletion in smallholder farms in sub-humid and semi-arid Africa, and searching for alternatives to slash-and-burn agriculture at the margins of humid tropical forests. In 2002, the Center acquired the brand name "World Agroforestry Centre (Centre was later dropped as merging with the Center for International Forestry Research/CIFOR)" while ICRAF retained its legal name. Over the years, ICRAF and CIFOR have strengthened their cooperation on research projects, including the CGIAR Research Program on Forests, Trees, and Agroforestry (FTA), the world's largest research-for-development initiative aimed at enhancing the role of forests, trees, and agroforestry in sustainable development. The collaboration of the two centers culminated in an effective merger on January 1, 2019. CIFOR-ICRAF has an annual budget of over USD 100 million and employs approximately 700 people throughout the Global South (World Agroforestry 2020a).

Working throughout the Global South with footprints in Africa, Asia, and Latin America, ICRAF's thematic research priorities have revolved around natural resource management, especially soil, land health, water, and domestication initiatives through the Genebank and African Orphan Crop Consortium. In turn, unlike other CGIAR Research Centers, it has not been very involved in breeding programs. The implementation of agroforestry research for sustainable development has been undertaken at regional/country offices, whose projects have been designed to address specific challenges faced by smallholder farmers in specific contexts. For example, studies in Southeast Asia have emphasized enhanced agroforestry systems for improved livelihoods, stable income, and landscape restoration. In East Africa, the focus has been on enhancing the role of trees in ensuring food security and restoring degraded landscapes.

From 1993 until recently, at ICRAF, there were four Japanese scientists, mostly from social science backgrounds. They included Dr. Shigeru Iida (economist, seconded from Japan International Cooperation Agency/JICA for the period of 1993 – 1996), Dr. Motoe Miyamoto (socio-economist, seconded from Japan International Research Center for Agricultural Sciences/JIRCAS for the period of 1997 – 2000), Dr. Zenroku Oginosako (ecologist, 1998 – 2007), and Dr. Miyuki Iiyama (economist, 2008 – 2016 as ICRAF staff, 2016 – 2019 as joint JIRCAS-ICRAF staff). The research outputs of Miyamoto in the Southeast Asia region and Iiyama in the East Africa region are reviewed in the following sections. Their works are contextualized in the debates over agriculture as drivers of deforestation, while Iiyama also looked at enabling factors of the adoption of agroforestry practices.

Understanding the causes of deforestation and its effects on people in Southeast Asia

Miyamoto was seconded from JIRCAS to the ICRAF Southeast Asia regional office in Bogor, Indonesia in 1997. She was engaged in the research project "study on the role of local communities in deforestation and forest restoration" funded by JIRCAS until December 2000. Previous studies found that the expansion of agricultural land was the main factor contributing to tropical deforestation; in particular, export commodities such as rubber, palm oil, beef, and soybeans had a greater impact on deforestation than shifting cultivation (Chomitz & Griffiths 1996, Fearnside 2001, Motel et al. 2009). In this project at ICRAF, Miyamoto examined the causes of deforestation and its effects on people, based on a household survey in rural rubber villages in Sumatra, Indonesia. The study method included structured questionnaire interviews with 160 households and statistical data analysis (e.g., ordinary least squares regression and Lorenz curves). The research highlighted that rubber (export crops with higher prices than crops for subsistence or domestic sales) and roads (reducing the cost of transporting agricultural products from the villages to markets) raised agricultural profitability in rural areas and accelerated deforestation (Miyamoto 2006a, Miyamoto 2007). This study also highlighted the vicious cycle of poverty and deforestation (Miyamoto 2006b). Rubber smallholders often sold their plantations for living expenses (e.g., housing construction and medical expenses), and some of them became landless again and went to clear forests to get new agricultural land.

This study contributes to uncovering deforestation mechanisms, combined with her subsequent studies. First, this study provides empirical evidence that the increase in agricultural rent (i.e., agricultural land profitability) is the leading proximate cause of deforestation (Miyamoto 2006a). Furthermore, the study revealed the effects of export crops and roads on agricultural rent and forest conversion. Second, this research helped identify the underlying causes of deforestation, which had previously been controversial and unclear. Miyamoto (2020) showed that poverty has a strong impact on forest area change in countries and identifies poverty as the primary underlying cause of deforestation. It is based mainly on the results of this project (Miyamoto 2006a, Miyamoto 2006b), a Malaysian socio-economic study (Miyamoto et al. 2014), and a multinational study (Michinaka & Miyamoto 2013). Third, this study helped understand the seemingly complicated relationship between poverty and deforestation. Rubber and roads increased agricultural profitability in the Indonesian sites, but the rubber plantations were still extensive agriculture (called "jungle rubber") and had lower profitability than rubber monoculture. The study results identified that forest conversion to agriculture continued because the agricultural profitability was high enough to motivate local people to convert forests, but not high enough to lift them out of poverty, so the demand for new agricultural land did not decrease (Miyamoto 2006b). In contrast, Malaysian study results showed that deforestation slowed down because highly profitable agriculture, especially oil palm plantations, greatly reduced poverty (Miyamoto et al. 2014). These findings revealed that the relationship between poverty and deforestation depends on whether agricultural profitability is high enough to overcome poverty (Miyamoto, 2020). The research work at ICRAF, integrated with the subsequent studies, contributed to deriving comprehensive explanations for deforestation mechanisms and developing effective strategies to halt deforestation. Miyamoto (2020) suggests that policy options for reducing poverty can be sustainably effective in reducing deforestation.

Unpacking farmers' motivation to adopt agroforestry innovations in East Africa

The East Africa region is characterized by diverse agro-ecologies from sparsely populated arid lowlands to extremely densely populated humid highlands due to topographical variations attributed to the Great Rift Valley. Correspondingly, the smallholder agriculture systems in the region are heterogeneous, from pastoral, agro-pastoral to mixed crop-livestock, while heavily relying on biodiversity and natural resources as the basis for food production and socio-economic development. Despite rich natural resources and diverse ecosystems, the region faces various challenges, including low agricultural productivity and environmental degradation under increasing population pressures and climate variability. Therefore, agroforestry research and development must address sustainable agricultural intensification and landscape restoration by tailoring interventions into various contexts such as agroecological and market conditions, while incorporating local knowledge and prioritized local needs (World Agroforestry 2020b).

Iiyama joined ICRAF's Eastern Africa region (later consolidated as Eastern and Southern Africa region) in 2008 and was assigned to a research project entitled, "The provision of sustainable bioenergy within agroforestry systems in East Africa" funded by the Government of Japan and partially by other donors until March 2019. The outcomes of the project included a feasibility study of bioenergy crops, providing an objective assessment of the productivity of *Jatropha curcas* under smallholder conditions. The studies (GTZ 2009, Iiyama et al. 2013) were among the first critical pieces of evidence for the species during its hype period, attributing farmers' failure to achieve anticipated high yields to the use of unimproved germplasm and the application of sub-optimal management practices with poorly defined biophysical boundaries of high yield.

In turn, in the region, a more pressing issue concerning bioenergy than the feasibility of untested oil crops has been unsustainable woodfuel (Iiyama et al. 2014). Woodfuel has been blamed as one of the leading causes of deforestation and forest degradation. In reality, clearing land for agriculture to compensate stagnant crop productivity for the growing population has been a more fundamental driver of land use change, where woodfuel has been a byproduct. Thus, a woodfuel issue is not solved by solely promoting tree planting but requiring a system approach to understand incentives affecting farmers' land management (Iiyama et al. 2014, Iiyama et al. 2017a). The work on biophysical and socioeconomic assessments of (un)sustainable woodfuel, that is, charcoal production, produced a series of policy and institutional reform recommendations, calling for harmonizing regulations to create enabling environment to promote multi-purpose agroforestry systems compatible with farmers' needs under local farming systems and socio-economic contexts (Iiyama et al. 2014, Ndegwa et al. 2016a, Ndegwa et al. 2016b, Iiyama et al. 2017a, Ndegwa et al. 2017, Ndegwa et al. 2018). The work was later developed into the CIFOR-ICRAF joint woodfuel systematic reviews under the CGIAR Research Program FTA (Cerutti et al. 2015, Sola et al. 2016, Sola et al. 2017).

Iiyama also contributed to the compilation of books. One of them, "Treesilience", the writing of which was sponsored by the UK Department for International Development (DFID) highlighted the critical roles of trees in enhancing the resilience of drylands in East Africa (De Leeuw et al. 2014). Another title, "Climate Smart Agriculture" which was co-edited by ICRAF, Oregon State University, Mekelle University, WeForest, and JIRCAS, collected evidence of good agricultural practices, including agroforestry technologies, and guided how to tailor them to local contexts (Hadgu et al. 2019).

Iiyama also engaged in research for development projects aiming at tailoring and scaling up agroforestry technologies in different agroecologies of the East Africa region. In an attempt to characterize and understand complex and heterogeneous systems, Iiyama developed a set of composite variables to represent distinctive tree-on-farm patterns across different agro-ecological conditions and assess smallholders' motivations to adopt them. The method was applied to Ethiopia (Iiyama et al. 2017b) and Rwanda (Iiyama et al. 2018a), revealing farmers' preferences for tree species with multiple utilities derived from ecosystem services (ex. provision of goods such as fuel, fodder, stakes, and services, such as soil erosion control). Furthermore, she developed a cost- and time-effective, easy-to-implement approach to identify farmers' priorities and critical agroforestry intervention areas (Iiyama et al. 2018b). These studies identified essential conditions for sustainable adoption of agroforestry technologies, including the availability of quality materials/inputs, compatibility with existing crop and livestock farming systems, resilience to climate risks/resistance to pests and diseases, low management complexity, and guaranteed access to markets, aside from selecting an optimal portfolio of suitable tree species to local agroecologies.

Conclusion

Deforestation and biodiversity loss have contributed to increasing changes in wildlife-livestock-human contact and subsequently zoonotic diseases. Once zoonotic diseases become pandemic, the global economy plunges into a deep crisis, as we are witnessing as of 2020/2021. To avoid future climate change and pandemics, half of the land on Earth must be conserved. According to Williams et al. (2020), however, a significant portion of ecosystems which should be left undisturbed/protected has already been modified by human activities. Most affected ecosystems were found in tropical and subtropical grasslands, savannah, shrubland ecosystems, and Southeast Asian forests. To reverse deforestation and land degradation, understanding and identifying their drivers is essential. The Japanese scientists who worked at the ICRAF revealed context-specific drivers of land-use changes, aside from poverty as a common cause. In Southeast Asia, smallholder farmers cleared forests for cash crop farming as urged to earn a higher income to escape poverty. In sub-Saharan Africa, in turn, stagnant productivity against the growing population led to the expansion of subsistence farming. These diagnoses are critical in tailoring strategies to reverse land use change, addressing poverty in Southeast Asia, and productivity in Africa.

Similarly, restoring ecosystems through agroforestry requires an understanding of locally specific contexts, while smallholder farmers in developing countries have been increasingly affected by the impacts of changing climate, especially by extreme events. Agroforestry is expected to be a potentially triple-win technology, by improving the productivity and resilience of farmers, while mitigating climate change through carbon sequestration and avoiding deforestation. However, there are no silver-bullet agroforestry interventions in any situation. To ensure the scaling up of agroforestry technologies by understanding local/country/region-specific land use drivers, and heterogeneity in enabling conditions by agro-ecological contexts and institutional/political settings, cost- and time-effective, easy-to-implement approaches, as reviewed in this paper, will be useful. Further research is needed in a systematic manner to analyze agroforestry at the interface of agriculture and forests.

Acknowledgment

The authors greatly appreciate all those who supported their work at ICRAF over years, including colleagues and partner institutions including JIRCAS, as well as financial contributions by donor agencies, including the Government of Japan. We thank anonymous reviewers for their valuable comments to improve the manuscript.

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