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Agroforestry timber production in Central America: population dynamics and information technologies in Nicacentro and Trifinio

By
Kauê Feitosa Dias de Sousa

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FIRMANTES:

Guillermo Detlefsen, Dr.Sc.
Director de tesis

Elías de Melo Virginio, Ph.D.
Miembro Comité Consejero

Fernando Casanoves, Ph.D.
Miembro Comité Consejero

Diego Tobar, M.Sc.
Miembro Comité Consejero

Francisco Jiménez, Dr. Sc.
Decano Programa de Posgrado

Kauê Feitosa Dias de Sousa
Candidato

DEDICATORY

§ To Central American farmers and their families. That this work can contribute to their quality of life. §

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SUMMARY

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ABBREVIATION AND SYMBOLS

App – Application for smartphones/tablets

DBH – Diameter at breast height

MAI – Mean annual increment

OS – Operational system

PAI – Periodic annual increment

PSP – Permanent sample plot

UI – User interface

US$ - United States Dollar

ABSTRACT

The importance of tropical timber for human activities in developing and developed countries is widely recognized. However, the timber supply from tropical forests has greatly suffered due to the increasing deforestation associated with complex timber harvesting laws. In Central America, as well as in others developing regions, reforestation programs have often been less successful than planned, and agroforestry rises as a strategy to promote the tropical timber supply from smallholders and rural development and provision of environmental services. We evaluated the effects of crop management on timber yields and potential revenues of timber sales in four types of agroforestry systems (silvopastoral, coffee, cocoa and live-fence) in Nicacentral (Nicaragua) and Honduran Trifinio (Honduras). The results suggest that smallholder timber production is a profitable activity, even with lower market prices than timber from forests, due to the absence and lack of knowledge of silvicultural practices. The net present value from timber sales represents 11 to 49% of the total revenue in agroforestry systems. However, this revenue could be 58% higher if farmers manage trees to achieve stem quality. Encouraging the knowledge and adoption of silvicultural practice in agroforestry systems is an important activity to foster and increase timber sales from smallholders in Central America. Therefore, the second part of this research was to validate an interactive tool for smartphones (app) to support data collection and agroforestry planning. The results show savings of approximately 90% in the time spent data processing using smartphone-based inventory. This finding allowed for prompt feedback of silvicultural agroforestry information and planning between farmers and decision-makers. The application is a component of the Agroforestry App Package proposed by the authors and can be used in agroforestry systems worldwide.

Keywords: timber yields, smallholders, agroforestry planning, smartphone app, Central America

RESUMEN

La importancia de la madera tropical para las actividades humanas en países desarrollados y en desarrollo es ampliamente reconocida. Sin embargo, la oferta de madera de los bosques tropicales ha sufrido un gran impacto debido al incremento en los índices de deforestación asociados a las complejas leyes para el aprovechamiento de la madera. En Centroamérica, así como en otras regiones en desarrollo, los programas de reforestación han tenido menos éxito que lo previsto y la agroforestería surge como una estrategia para proveer la oferta de madera tropical a partir de pequeños productores agroforestales, así como el desarrollo rural y la provisión de servicios ecosistémicos. Fueron evaluados los efectos del manejo del cultivo sobre la producción de madera e ingresos potenciales por la venta de madera en cuatro tipos de sistemas agroforestales (silvopastoril, café, cacao y linderos maderables) en Nicacentro (Nicaragua) y en el Trifinio Hondureño (Honduras). Los resultados sugieren que la producción maderable por pequeños productores es una actividad rentable, aún teniendo menores precios de mercado que la madera de bosques, debido a la ausencia y falta de conocimiento de prácticas silviculturales. El valor actual neto por la venta de madera representa un 11% al 49% de los ingresos en sistemas agroforestales, sin embargo estos ingresos podrían 58% superiores si los finqueros manejasen los árboles para lograr calidad en el fuste. Estimular el conocimiento y la adopción de prácticas silviculturales en sistemas agroforestales es una actividad importante para fomentar e incrementar venta de madera de los pequeños productores en Centroamérica. En este sentido la segunda parte de esta investigación buscó validar una herramienta interactiva para teléfonos inteligentes (app) para apoyar la toma de datos y la planificación agroforestal de fincas. Los resultados indican un ahorro promedio de un 90% en el proceso de procesamiento de datos utilizando el app desarrollado en este trabajo, lo que posibilitó una mayor prontitud en la devolución de información a los productores agroforestales para la toma de decisión sobre la planificación de las fincas. La aplicación es un componente del paquete de apps para agroforestería planteado por los autores y puede ser utilizada en todo el mundo.

Palabras-clave: rendimientos de madera, pequeños productores, planificación agroforestal, aplicaciones para teléfonos inteligentes, Centroamérica

General Introduction

1. Background

Tropical forests are a source of many essential resources and products for human needs. Among these products, timber has the greatest interest both commercially and in terms of livelihood and economic returns (Orozco and Somarriba 2005; Chave *et al.* 2009; Detlefsen and Somarriba 2012; Kent and Ammour 2012; SFB 2013; FAO 2014). However, timber harvest in natural forests has become an unfeasible alternative due to issues that have decreased the legal wood supply: deforestation for agricultural activity implementation, the expansion of areas under forest protection and complex laws for timber harvesting (Ibrahim and Camargo 2001; Snelder and Lasco 2008; López and Detlefsen 2012; FAO 2013a).

The establishment of forest plantations is not interesting for smallholders because it is a costly endeavor that requires high initial investments with a long time to obtain an economic return (Snelder and Lasco 2008; Schlönvoigt 2012). To develop profitable, sustainable and resilient production systems that meet the growing global demand of agricultural products is a major challenge, especially for developing countries (FAO 2013b).

Among these challenges, agroforestry emerges as a sustainable alternative to meet the demand for wood and food (ICRAF 2006; Beer *et al.* 2009; FAO 2013c). Agroforestry include various land use systems, such as home gardens, silvopastoral systems, cocoa and coffee-based agroforestry (Nair 1993). Additionally, trees in agroforestry systems allow for increases in crop production, climate change adaptation, and carbon sequestration and are a foremost means to achieve climate-smart agriculture (FAO 2010; Bogdanski 2012; Jamnadass *et al.* 2013; Challinor *et al.* 2014; ICRAF and UK Aid 2014).

Central America has an area of 52.4 million ha, of which 61% is used for agriculture and livestock (FAO 2013c). Approximately 52% of agricultural land has a high tree cover provided with an abundant tree-landscape. Agroforestry has great potential for timber production; however, the timber harvesting in these systems typically is not under a management plan. Usually, the timber is harvested only when there is a crisis in the crop production, especially during droughts, pests incidences and market fluctuations (López and Detlefsen 2012). Without a management plan, timber production tends to decrease until the systems become impoverished (Cruz *et al.* 2010). Natural regeneration is a strategy to maintain timber production and the environmental benefits of trees in agroforestry systems (Current *et al.* 1998; Simón *et al.* 1998; Ibrahim and Camargo 2001; Somarriba *et al.* 2001b; Esquivel and Calle 2002; Esquivel-Mimenza *et al.* 2011; Somarriba *et al.* 2014). To achieve the best timber yields, it is necessary to develop feasible agroforestry-timber management plans.

Information on silvicultural practices need to be shared to support farmers to make better decisions, such as managing farm fields, making changes in tree density and taking advantage of the market (Jain *et al.* 2014). Farmers have detailed knowledge on crop management and yields, but not all of them know about tree growth and management (Somarriba *et al.* 2001a). The use of information technologies, such as smartphone apps in agroforestry projects, is a powerful tool to share the silvicultural knowledge. This thesis aims to evaluate the opportunities for sustainable management of timber species in agroforestry systems and develop a methodology using smartphone apps to support the agroforestry-tree planning in two climate smart territories in Central America: Trifinio and Nicacentro.

2. Objectives

2.1. General objective

To evaluate the opportunities for timber production and sustainable management of timber species on agroforestry systems with coffee, cocoa and livestock in smallholder farms of two Central American climate smart territories: Nicacentro (Nicaragua) and Trifinio (Honduras).

2.2 Specific objectives

a. Evaluate the population dynamic and natural regeneration of timber species on agroforestry systems from smallholders in Nicacentro and Trifinio.
b. Determine the feasibility of timber harvesting on agroforestry systems with a natural regeneration recruitment plan.
c. Evaluate the potential of the timber harvesting financial contribution to agroforestry systems by the implementation of a natural regeneration recruitment plan.
d. Validate a smartphone/tablet app to support the data collection in forestry inventory to reduce the data processing and information feedback time.

3. Research questions

a. Do the agroforestry systems have mechanisms of natural regeneration?
b. Does the natural regeneration in agroforestry systems studied satisfy the population dynamics (inverted "J")?
c. Does the application of silvicultural techniques for managing population dynamics enable sustainable timber harvesting?
d. Does the timber harvesting conducted on farms, according to the criteria of the recruitment plan, contribute to the potential income of the farms?
e. How profitable are timber yields and harvests in agroforestry systems?
f. Can promoting the use of an app for smartphones help reduce the time to data collection, data process and agroforestry planning?

4. The study area

This research was performed in Trifinio (a boundary zone between Honduras, Guatemala and El Salvador) and Nicacentro (a strategic region in Nicaragua proposed by CATIE in 2008 under the Mesoamerican Agro-Environmental Program (MAP). Both regions are in the conceptual mark of the climate smart territories that aim to develop integrated strategies for rural-territorial development. In both territories, agriculture is the main livelihood for the rural population.

Trifinio's region has an area of 7,541 km², 45 towns and 670,000 inhabitants. The average annual precipitation is 1,600 mm with an average annual temperature of 20 °C. The altitudinal ranges are 600 to 1,600 m above sea level (CTPT 2014). The research was conducted in three towns of Honduran Trifinio: Copán Ruinas, Nueva Arcadia and Santa Rita.

Nicacentro has an area of 6,500 km², eight towns and 360,000 inhabitants. The altitudinal range is 350 to 1,750 m.a.s.l. The climate is classified as tropical wet with an average annual temperature of 26 °C and annual precipitation between 1,600 and 2,400 mm (INEC 2006). The research was conducted in El Cuá, a buffer area of the Bosawas Biosphere Reserve (Fig. 1).

Fig. 1. Study areas location.

5. Main results

Forty-six species were identified, and 66% of these species were classified as timber species. *Pinus oocarpa*, *Tabebuia rosea, Swietenia macrophylla*, *Cordia alliodora* and *Cedrela odorata* represent 83% of the accumulated frequency of timber species. High rates in basal area growth and timber volume are related to silvopastoral systems and live-fences, where *P. oocarpa* and *C. odorata*, the most frequent species in these systems, respectively, are also related to higher increments. Nevertheless, lower annual increments of timber volume (1.86 m³ ha^{-1}) and stem quality were found in silvopastoral systems with 40 trees ha^{-1} of *T. rosea*.

We found that trees from agroforestry systems have a lower value than trees from natural forests in the local and exportation market. Buyer's reports indicate that trees from agroforestry systems generally have irregular stem form and low timber quality. However, assuming two scenarios of discount rates to calculate the NPV (6% and 12%) of crop and timber revenues show that agroforestry systems are still profitable to smallholders. Using a discount rate of 6%, the costs and incomes of the agroforestry systems studied, the NPV from timber revenues are more pronounced, mainly in coffee and cocoa systems. We found an expressive incidence of natural regeneration in silvopastoral systems with natural grass that include the silvopastoral systems with *P. oocarpa* and *T. rosea*.

Natural regeneration of *C. alliodora* in cocoa systems is inexpressive, similar to other species in coffee and live-fence systems. According interviewed farmers, the main reason of the absence of natural regeneration in these systems is the agricultural practices in weeding control.

6. Main conclusions

This study demonstrates the effects of system management on the timber yields and farm revenues. The most expressive timber yields, NPV and IRR were observed in silvopastoral systems with *P. oocarpa*, coffee with *C. odorata* and *C. alliodora*, coffee with *S. macrophylla* and live-fence of *C. odorata*. In all systems, the practice of silvicultural management (formative pruning and thinning) by farmers was not observed. The absence of silvicultural management besides the low quality of seeds results in the low sales value of trees. For coffee systems with *S. macrophylla*, for example, the price of trees can be 58% higher than the current price if trees are managed. Even so, the analysis of NPV and IRR in these systems indicates that sales of timber are a profitable activity to smallholders. Timber (for sawmilling) revenues represent 11-49% of the NPV of agroforestry systems depending on the type of system, species and discount rate. Fostering knowledge of silvicultural management and the accessibility of quality seeds are essential to improve the revenues from sales of timber in smallholder's agroforestry systems.

The use of a smartphone-based data collection methodology showed that apps in the agroforestry sector are an important tool to solve logistical and technical problems of participatory agroforestry planning and design. Using appropriated apps on farm analysis, researchers and technicians can spend 90% less time on data processing, invest more effort on farm planning, share knowledge of silvicultural management and take better advantage of opportunities in the timber market.

References

Beer, J.; Ibrahim, M.; Somarriba, E.; Barrance, A.; Leakey, R. 2009. Establecimiento y manejo de árboles en sistemas agroforestales. 198-242 p. (Árboles de Centroamérica) (1).

Bogdanski, A. 2012. Integrated food-energy systems for climate-smart agriculture. Agriculture & Food Security 1(9): doi: 10.1186/2048-7010-1-9

Challinor, A.; Cochrane, K.; Howden, M.; Iqbal, M.M.; Lobell, D.; Travasso, M.I. 2014. Food Security and Food Production Systems. *In* Porter, J.R.; Xie, L. eds. 2014. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Working Group II Contribution to the IPCC 5th Assessment Report - Changes to the Underlying Scientific/Technical Assessment. IPCC (Intergovernmental Panel on Climate Change,, Geneva). p. 82. (Assessment Report).

Chave, J.; Coomes, D.A.; Jansen, S.; Lewis, S.L.; Swenson, N.G.; Zanne, A.E. 2009. Towards a worldwide wood economics spectrum. Ecology Letters 12(4): 351-366 doi: 10.1111/j.1461-0248.2009.01285.x

Cruz, A.R.; Detlefsen, G.; Ibrahim, M.; Camino, R.d.; Galloway, G. 2010. Aprovechamiento del recurso maderable en sistemas silvopastoriles de Belice. Recursos Naturales y Ambiente 59(60): 91-98 Available in: http://finnfor.catie.ac.cr/admin/documents/27

CTPT (Comisión Trinacional del Plan Trifinio, El Salvador). 2014. Región del Trifinio en breve. Comisión Trinacional del Plan Trifinio. San Salvador, El Salvador. Available in: http://www.sica.int/trifinio/trifinio/breve_trifinio.aspx?IdEnt=140

Current, D.; Rossi, L.B.; Sabogal, C.; Nalvarte, W. 1998. El potencial de manejo de especies maderables de rápido crecimiento en regeneración natural, sistemas agroforestales y plantaciones puras: Estudios de caso en Brasil, Perú y Costa Rica. *In* I Congreso Forestal Latinoamericano de la IUFRO (Valdivia, Chile) 1998. p. Available in: http://orton.catie.ac.cr/repdoc/A5612E/A5612E.PDF

Detlefsen, G.; Somarriba, E. 2012. Producción de madera en sistemas agroforestales de Centroamérica. 1 ed. Detlefsen, G.; Somarriba, E. eds. Turrialba, Costa Rica, CATIE. 244 p. (Manual técnico no. 109)

Esquivel-Mimenza, H.; Ibrahimb, M.; Harvey, C.A.; Benjamin, T.; Sinclair, F.L. 2011. Dispersed trees in pasturelands of cattle farms in a tropical dry ecosystem. Tropical and Subtropical Agroecosystems 14(2011): 933-941 Available in: http://www.scielo.org.mx/pdf/tsa/v14n3/v14n3a6.pdf

Esquivel, M.J.; Calle, Z. 2002. Arboles aislados en potreros como catalizadores de la sucesión en la Cordillera Occidental Colombiana. Agroforestería en las Américas 9(33): 43-47 Available in: ftp://ftp.fao.org/docrep/nonfao/lead/x6361s/x6361s00.pdf

FAO (Food and Agriculture Organization of The United Nations, Italy). 2010. Climate-Smart Agriculture: Policies, practices and financing for food security, adaptation and mitigation. *In* The Hague Conference on Agriculture, Food Security and Climate Change 2010. Food and Agriculture Organization of The United Nations. p. 47.

_________. 2013a. Advancing Agroforestry on the Policy Agenda: A guide for decision-makers. Place, F.; Gauthier, M. eds. Rome, Italy, Food and Agriculture Organization of The United Nations. 49 p. (Agroforestry Working Paper) (1). Available in: http://www.fao.org/docrep/017/i3182e/i3182e00.pdf

_________. 2013b. Climate Smart Agriculture. Rome, Italy, Food and Agriculture Organization of The United Nations - FAO. 569 p. (1). Available in: http://www.fao.org/docrep/018/i3325e/i3325e.pdf

_________. 2013c. FAO Statistical Yearbook: World food and agriculture. Rome, Italy, Food and Agriculture Organization. (FAO Statistical Yearbook) (1). Available in: http://faostat.fao.org/

_________. 2014. State of the World's Forests: Enhancing the socioeconomic benefits from forests. Rome, Italy, Food and Agriculture Organization of The United Nations. 145 p. (State of the World's Forests) doi: 978-92-5-308270-4 Available in: http://www.fao.org/3/a-i3710e.pdf

Ibrahim, M.; Camargo, J.C. 2001. ¿Cómo aumentar la regeneración de árboles maderables en potreros? Agroforestería en las Américas 8(32): 35-45 Available in: ftp://ftp.fao.org/docrep/nonfao/lead/x6354s/x6354s00.pdf

ICRAF (World Agroforestry Centre, Kenya). 2006. World Agroforestry into the Future. Garrity, D.; Okono, A.; Grayson, M.; Parrott, S. eds. Nairobi, Kenya, World Agroforestry Centre. 213 p. Available in: http://www.worldagroforestrycentre.org/downloads/publications/PDFs/b14409.pdf

ICRAF (World Agroforestry Centre, Kenya); UK-AID (Department for International Development, UK). 2014. Treesilience: An assessment of the resilience provided by trees in the drylands of Eastern Africa. de-Leeuw, J.; Njenga, M.; Wagner, B.; Iiyama, M. eds. Nairobi, Kenya, World Agroforestry Centre. 181 p. (1).

INEC (Instituto Nacional de Estadísticas y Censos, Nicaragua). 2006. Censo de población y de vivienda 2005. Manágua, Nicaragua, INEC. 40 p. (Censos Nacionales) (7).

Jain, L.; Kumar, H.; Singla, R.K. 2014. Assessing Mobile Technology Usage for Knowledge Dissemination among Farmers in Punjab. Information Technology for Development 2014(1): 1-9 doi: 10.1080/02681102.2013.874325

Jamnadass, R.; Place, F.; Torquebiau, E.; Malézieux, E.; Iiyama, M.; Sileshi, G.W.; Kehlenbeck, K.; Masters, E.; McMullin, S.; Weber, J.C.; Dawson, I.K. 2013. Agroforestry, food and nutritional security. Nairobi, Kenya, ICRAF. (ICRAF Working Paper) (170). Available in: http://www.fao.org/forestry/37082-04957fe26afbc90d1e9c0356c48185295.pdf

Kent, J.; Ammour, T. 2012. Análisis financiero y económico de la producción de madera en sistemas agroforestales. *In* Detlefsen, G.; Somarriba, E. eds. 2012. Producción de madera en sistemas agroforestales de Centroamérica. Turrialba, Costa Rica, CATIE. p. 91-111. (Technical Series). Available in: http://finnfor.catie.ac.cr/admin/documents/208

López, A.; Detlefsen, G. 2012. Agroforestería y la producción de madera. *In* Detlefsen, G.; Somarriba, E. eds. 2012. Producción de madera en sistemas agroforestales de

Centroamérica. Turrialba, Costa Rica, CATIE. p. 9-20. (Technical Series). Available in: http://finnfor.catie.ac.cr/admin/documents/208

Nair, P.K.R. 1993. An Introduction to Agroforestry. Netherlands, Kluwer Academic Publishers, ICRAF. 499 p. Available in: http://www.springer.com/life+sciences/forestry/book/978-0-7923-2134-7

Orozco, L.; Somarriba, E. 2005. Árboles maderables en fincas de cacao orgánico del Alto Beni, Bolivia. Agroforestería en las Américas 44(43): 46-53 Available in: http://orton.catie.ac.cr/repdoc/A2331E/A2331E.PDF

Schlönvoigt, A. 2012. Sistemas taungya. *In* Detlefsen, G.; Somarriba, E. eds. 2012. Producción de madera en sistemas agroforestales de Centroamérica. Turrialba, Costa Rica, CATIE. p. 161-180. (Technical Series). Available in: http://finnfor.catie.ac.cr/admin/documents/208

SFB (Serviço Florestal Brasileiro, Brasil). 2013. Florestas do Brasil em resumo. Brasília, Brasil, Serviço Florestal Brasileiro. 187 p. (4). Available in: http://www.florestal.gov.br/publicacoes/tecnico-cientifico

Simón, M.; Ibrahim, M.; Finegan, B.; Pezo, D. 1998. Efectos del pastoreo bovino sobre la regeneración de tres especies arbóreas comerciales del chaco argentino: un método de protección. Available in: ftp://ftp.fao.org/docrep/nonfao/lead/X6322S/X6322S00.pdf

Snelder, D.J.; Lasco, R.D. 2008. Smallholder Tree Growing in South and Southeast Asia. *In* Snelder, D.; Lasco, R. eds. 2008. Smallholder Tree Growing for Rural Development and Environmental Services. Springer Netherlands. p. 3-33. (Advances in Agroforestry). doi: 10.1007/978-1-4020-8261-0_1

Somarriba, E.; Beer, J.; Muschler, R.G. 2001a. Research methods for multistrata agroforestry systems with coffee and cacao: recommendations from two decades of research at CATIE. Agroforestry Systems (53): 195–203 doi: 10.1023/A:1013380605176

Somarriba, E.; Valdivieso, R.; Vásquez, W.; Galloway, G. 2001b. Survival, growth, timber productivity and site index of Cordia alliodora in forestry and agroforestry systems. Agroforestry Systems 51: 111-118 doi: 10.1023/A:1010699019745

Somarriba, E.; Suárez-Islas, A.; Calero-Borge, W.; Villota, A.; Castillo, C.; Vílchez, S.; Deheuvels, O.; Cerda, R. 2014. Cocoa-timber agroforestry systems: Theobroma cacao-Cordia alliodora in Central America. Agroforest Systems 88(1): doi: 10.1007/s10457-014-9692-7

Article 1. Timber yields from smallholder agroforestry systems: a case study from two Central American territories

ABSTRACT

The importance of tropical timber for human activities is increasing, and developed countries are widely recognized for tropical timber production. However, the timber supply from tropical forests has been greatly impacted by increasing deforestation associated with complex and restrictive timber harvest laws. In Central America, as well as in other developing regions, reforestation programs have often been less successful than planned. In these cases, agroforestry presents a useful strategy to promote a tropical timber supply from smallholders, rural development and provisions of environmental services. We evaluated the effects of crop management on timber yields and potential revenues of timber sales in four types of agroforestry systems (silvopastoral, coffee, cocoa and live-fence) in Nicacentral (Nicaragua) and Honduran Trifinio (Honduras). The results suggest that smallholder timber production in agroforestry systems is a profitable activity, despite having lower market prices than timber from forests, due to the absence and lack of knowledge of silvicultural practices. The net present value from timber sales represents 11 to 49% of the total revenue of agroforestry systems. However, this amount could be 58% higher if farmers were to manage trees to achieve better tree quality. Encouraging the knowledge and adoption of silvicultural practice in agroforestry systems is an important endeavor to foster and increase timber sales from smallholder farmers in Central America.
Keywords: timber yields, smallholders, agroforestry, Central America

1. Introduction

Timber is a crucial worldwide forest resource (ITTO 2013) that provides energy and other benefits for developing and developed countries (FAO 2014). Tropical timber (hardwood) has special trade value due to its high mechanical resistance, varied colors, textures and applicability. However, deforestation from agricultural activities, the expansion of areas under forest protection and complex laws concerning timber harvesting have decreased the legal tropical timber supply, especially in Central America (Ibrahim and Camargo 2001; López and Detlefsen 2012; FAO 2013; ITTO 2013).

Large-scale reforestation was expected to be a successful solution for issues with the timber supply and trade; however, recent history reveals that reforestation projects have often been less successful than planned and are responsible for generating several territorial conflicts (Bertomeu 2008; Snelder and Lasco 2008). Timber supply from smallholder agroforestry systems may be an alternative means to promote both timber production and sustainable land use; however this topic has received relatively little attention from policy-makers in developing countries (Scheelje *et al.* 2011; FAO 2013). Diversity amongst agroforestry systems that creates high competition within an ecosystem may generate higher timber yields than homogeneous timber-forests. Many research projects that have focused on timber yields from smallholder agroforestry systems show the potential of tropical timber production (Somarriba *et al.* 2001a; Somarriba *et al.* 2001b; Viera and Pineda 2004; Borge 2009; Cruz *et al.* 2010; Chavarría *et al.* 2011; Somarriba and Beer

2011; Detlefsen and Somarriba 2012; Ibrahim and Zapata 2012; Jiménez 2012; Somarriba *et al.* 2014).

In agroforestry systems, timber is one of the main sources of long-term income. Timber also represents a strategy for crisis prevention in the case of crop system failures, especially during droughts, pest incidences and market strikes (Camargo *et al.* 1999; Ibrahim and Pezo 2012; Somarriba *et al.* 2014). In coffee systems for example, income from timber yield is significant, ranging between 6 and 83% of total farm revenue, depending on the current market prices and quality of the wood (Jiménez 2012). In agroforestry pasturelands, the income generated by the sustainable use of trees can reach between 69 to 480 US\$ ha^{-1} (Plata 2012). These revenues represent between 2.2 and 15% of the total net income of a silvopastoral system with dual purpose cattle production. In cocoa systems in Honduras, at 21 years of production, farmers may have a total income of approximately 65,026 US\$ ha^{-1}, with 85% of this income coming from timber production (Somarriba *et al.* 2012).

Timber from agroforestry systems is a great economic option for farmers, considering it can provide higher revenues than traditional crop systems and can reduce costs of weeding and pest control of associated crops (Bertomeu 2006; Somarriba *et al.* 2012). Nevertheless, Central America lacks a market that values agroforestry products, especially timber, and the complex legal situation regarding timber may decrease farmer interest in participating in these types of production systems (Detlefsen *et al.* 2008; Cruz *et al.* 2010; Leiva 2011; Scheelje *et al.* 2011; Detlefsen and Scheelje 2012; Orozco 2012; Plata 2012; FAO 2013). Furthermore, incorrect species selection for each agroforestry system (Ibrahim and Zapata 2012; Salgado 2012) and lack of knowledge about tree growth and silvicultural management (Somarriba *et al.* 2001a; Santos-Martin *et al.* 2011) decreases the potential for higher timber yields and other market advantages from these systems.

There is no doubt that tropical agroforestry systems may contribute to the global hardwood demand in a sustainable way. To change the paradigm of timber harvesting in the tropics, it is necessary to strengthen knowledge about potential timber yields and agroforestry management. This research aims to evaluate timber yields from agroforestry systems and financial contributions from the timber for smallholder farmers in coffee, cocoa, live-fence and silvopastoral agroforestry systems in Nicacentro (Nicaragua) and Trifinio (Honduras).

2. Methods

2.1. The study area

This research was performed in Trifinio (15° 1′ N, 89° 8′ W), a boundary zone between Honduras, Guatemala and El Salvador; and in Nicacentro (13° 17′ N, 85° 42′ W), a strategic region in Nicaragua proposed by CATIE in 2008 under the Mesoamerican Agro-Environmental Program (MAP). Both regions are included in the conceptual mark of the climate smart territories, where an effort exists to develop integrated strategies for rural-territorial development. In both territories agriculture is the livelihood of the majority of the population.

The Trifinio region has an area of 7,541 km², including 45 towns with a total of 670,000 inhabitants. The average annual precipitation is 1,600 mm, with an average annual temperature of 20 °C. The altitudinal range is between 600 and 1,600 m above sea level

(CTPT 2014). This research was conducted in three Honduran towns that form part of Trifinio: Copán Ruinas, Nueva Arcadia and Santa Rita. Nicacentro has an area of 6,500 km², including eight towns with a total of 360,000 inhabitants. The altitudinal range is between 350 and 1,750 m above sea level. The climate is classified as tropical wet with an average annual temperature of 26 °C and an annual precipitation between 1,600 and 2,400 mm (INEC 2006). The research for this study was conducted in El Cuá, a buffer area of the Bosawas Biosphere Reserve.

2.2. Data collection and analysis

The permanent sample plots (PSP) were set up in 2010 in Nicacentro, and 2011 in Trifinio in agroforestry systems with different timber species including silvopastoral systems, coffee farms, cocoa farms and live-fences. Twenty seven PSPs were evaluated, including 10 circular plots with 0.5 ha in silvopastoral systems, rectangular plots with 0.1 ha in coffee (10 plots) and cocoa systems (3 plots), and 4 lineal plots with 100 m in live-fence systems. Tree inventory methodology was conducting the following recommendations from Detlefsen *et al.* (2012), who developed a protocol to measure trees in agroforestry systems. Diameter at breast height (DBH), commercial and total height, stem form, mortality and natural regeneration were evaluated in each PSP in 2010, 2011, 2012 and 2014 in Nicaragua; and in 2011, 2012 and 2014 in Trifinio. A smartphone-based data collection method was adopted in 2014 to assist in PSP measuring in both regions.

To measure the population dynamics, three development stages were considered:

(i) recruits (0.1 m ≥ height < 0.3 m)
(ii) saplings (0.3 m ≥ height < 1.5 m, and DBH < 5.0 cm)
(iii) trees (DBH ≥ 5.0 cm)

Multiple measurements were taken to estimate periodical annual increments (PAI) of basal area and timber volume. Using InfoStat (Di Rienzo *et al.* 2014), correspondence analyses were performed to demonstrate the association of growth in basal area and timber volume between regions, systems and species. According to the ranges observed for PAI, the basal area increment (m^2 ha^{-1} $year^{-1}$) was classified into groups: low (0.1 to 1.0), moderate (1.1 to 2.0) and high (≥ 2.1); and the timber volume yield (m^3 ha^{-1} $year^{-1}$) was classified into groups: low (0.1 to 3.0), moderate (3.1 to 6.0) and high (≥ 6.1).

2.3. Financial analysis

A financial analysis was carried out to determine the cash flow in the farms. Crop yields (coffee, cocoa, milk), labor costs, total revenues per ha, net returns to labor, market timber prices and cost of tree management were derived from interviewing farmers as well as complementary information from Apaza (2011), Leiva (2011) and Toruño (2012). Using the average commercial volume of a harvesting tree (DBH ≥ 45 cm) and the local timber price of a board-foot (0.002360 m³) per species, the price of one tree per species was estimated. This methodology was used to get closer to the local reality, considering that trees are sold individually by their diameter class.

The Net Present Value (NPV, using discount rates of 6% and 12%) and the Internal Rate of Return (IRR) were calculated and the potential revenues of timber harvest in the agroforestry systems were determined. Timber harvesting and transportation costs were not included in the financial calculations because farmers in Nicaragua and Trifinio commonly sell timber as stump in the farms. Costs of land use were also not included.

2.4. Population dynamics model

Usher model transition matrices were used for modeling the population dynamics where natural regeneration was observed. This model was widely used by Somarriba *et al.* (2001b), Súarez and Somarriba (2002), Borge (2009) and Somarriba *et al.* (2014) to calculate tree survival, growth and timber production for *Cordia alliodora* in cocoa-based agroforestry systems.

Rates of recruitment, growth, harvest and mortality from the tree inventory in the PSPs were applied to this model. In this study, trees were sorted into 5-cm intervals of diameter class according to initial diameter, and average intervals by diameter class calculated. The minimum harvest diameter established was 45 cm for sawmilling wood and 35 cm for wood used as firewood.

Growth time was calculated using the following equation:

Equation 1

where T_{ij} is the time it takes for one tree in diameter class i to transition to the next class j; W_i is the interval width of class i (cm); I_i is the mean annual diameter increment in class i (cm·year^{-1}).

The next procedure was to calculate the transition coefficient, using

Equation 2

where $P_{i,j+1}$ is the coefficient of transition from period i to period j, represented in the percentage of individuals moving from one diameter class to the next class; S_i is the tree survival rate in the diameter class.

The coefficient of permanence was calculated with the following equation:

Equation 3

where $Q_{i,}$ is the coefficient of permanence in the period i, represented by the percentage of individuals who remain in the diameter class.

In the latter procedure the following matrix equation was applied:

Equation 4

where n_{t+1} and n represent the diameter distribution (trees ha^{-1}) between successive years t and t + 1.

3. Results and discussion

3.1. Timber species diversity

Forty six species were identified and 66% of those species were classified as timber species. *Pinus oocarpa*, *Tabebuia rosea, Swietenia macrophylla*, *Cordia alliodora* and

Cedrela odorata represent 83% of the accumulated frequency of timber species (Fig. 2). Information about the frequency of these species is described by several authors for coffee, cocoa and pastureland systems in different regions of Latin America (Camargo *et al.* 1999; Ibrahim and Camargo 2001; Camargo *et al.* 2005; Esquivel-Mimenza *et al.* 2011; López and Detlefsen 2012; Salgado 2012; Somarriba *et al.* 2014).

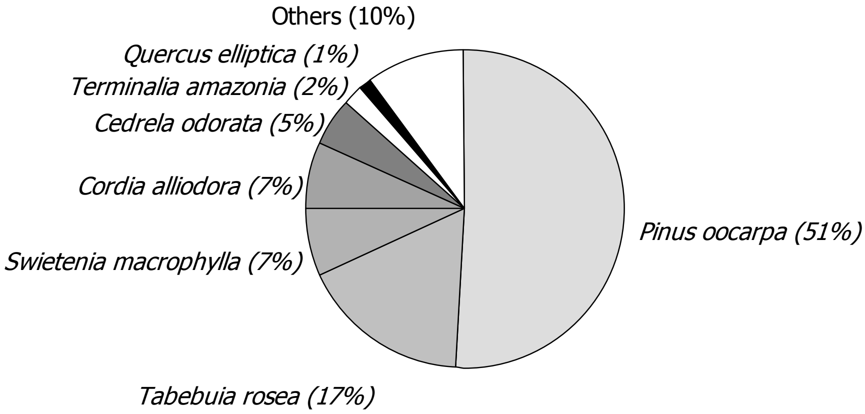

Fig. 2. Accumulated abundance of timber species in cocoa, coffee, silvopastoral and live-fence agroforestry systems identified in Honduran Trifinio and Nicacentral.

Except for *C. odorata* and *S. macrophylla* that were planted by the farmers, the other species found in the study (*P. oocarpa*, *T. rosea* and *C. alliodora*) came from natural regeneration. The management of natural regeneration may provide advantages for farmers, considering that it reduces investments on seedling production, nurseries and planting, as well as reduces the dependency on external seed sources and foreign technologies (Ibrahim and Zapata 2012). In addition, trees from natural regeneration may show higher resistance to microclimatic site conditions (Plath *et al.* 2011), which can contribute to their growth and yields.

3.2. Timber yields

Table 1 presents the results of the PAIs of basal area and timber volume for each species, as well as the frequency, systems and countries where they occur. The results demonstrate an effect of the system on the PAIs of basal area and timber volume from Nicaragua and Honduras (Fig. 3 and Fig. 4). The practice of silvicultural management (pruning and thinning) was not identified in the populations and systems studied; the main reason is the lack of knowledge about trees requirements (Somarriba *et al.* 2001a; Santos-Martin *et al.* 2011).

High rates of basal area growth and timber volume are related to silvopastoral systems and live-fences with *P. oocarpa* and *C. odorata* as the most frequent species, respectively, and are also related to higher increments. In an average population of 88 trees ha^{-1} dispersed in natural pastureland, *P. oocarpa* had a PAI of 12.84 m² ha^{-1} year^{-1} in timber volume. Relevant information for timber yields of *P. taeda*, a species of genus *Pinus* which has similar environmental requirements, was presented by USDA (2000) from silvopastoral systems and by Cubbage *et al.* (2012) from alley crop systems, which found an annual increment of 11.8 m³ ha^{-1} (100 trees ha^{-1}) and 7.6 m³ ha^{-1} in the timber volumes, respectively.

Nevertheless, lower annual increments of timber volume (1.86 m^3 ha^{-1}) and stem quality were found in silvopastoral systems with 40 trees ha^{-1} of *T. rosea*. Trees dispersed in silvopastoral systems generally present low timber quality for sawmilling due to the absence of competition for light and the presence of some traits that restrict the growth in opened areas (Cruz *et al.* 2010; Ibrahim and Zapata 2012).

Table 1. Periodical annual increment (PAI) of basal area and timber volume from different tree populations of agroforestry systems in Honduras and Nicaragua. Basal area growth is classified into: low (0.1 to 1.0), moderate (1.1 to 2.0) and high (≥ 2.1). Timber volume growth rate is classified into: low (0.1 to 3.0), moderate (3.1 to 6.0) and high (≥ 6.1).

Species	Country	System	F (trees ha^{-1})	PAI Basal area (m^2 ha^{-1} $year^{-1}$)	PAI Timber volume (m^3 ha^{-1} $year^{-1}$)
Cordia alliodora	Honduras	Coffee	52	1.61	4.50
	Nicaragua	Cocoa	40	0.63	2.70
	Nicaragua	Coffee	60	0.86	4.20
	Nicaragua	Live-fence	24	0.10	1.00
	Nicaragua	Silvopastoral	14	0.08	0.54
Cedrela odorata	Honduras	Coffee	80	2.16	7.30
	Honduras	Live-fence	44	1.55	11.12
	Nicaragua	Cocoa	50	0.40	2.00
	Nicaragua	Coffee	210	1.09	8.90
	Nicaragua	Silvopastoral	8	0.06	0.48
Pinus oocarpa	Honduras	Silvopastoral	88	2.87	12.84
Swietenia macrophylla	Nicaragua	Cocoa	20	0.35	1.90
	Nicaragua	Coffee	140	1.38	17.40
Tabebuia rosea	Honduras	Live-fence	8	0.06	0.12
	Nicaragua	Silvopastoral	40	0.27	1.86

Timber yields in live-fences with 44 trees ha^{-1} (110 trees km^{-1}) of *C. odorata* and 8 trees ha^{-1} (20 trees km^{-1}) of *T. rosea* showed a correlation with higher rates of PAI for *C. odorata* (11.12 m^3 ha^{-1}) and lower rates for *T. rosea* (0.12 m^3 ha^{-1}). Low increment rates for *T. rosea* in live-fences are due to the dominance of *C. odorata,* which has higher initial growth rates and suppresses growth of *T. rosea*. Even so, planting timber species in live-fences is a great strategy for smallholders. Viera and Pineda (2004), Bertomeu (2006), Borzone *et al.* (2007) and Beer (2012) reported significant results for growing timber species in homogenous live-fences. The authors demonstrate that timber yields in these systems are superior to trees in blocks due to the absence of lateral competition for light.

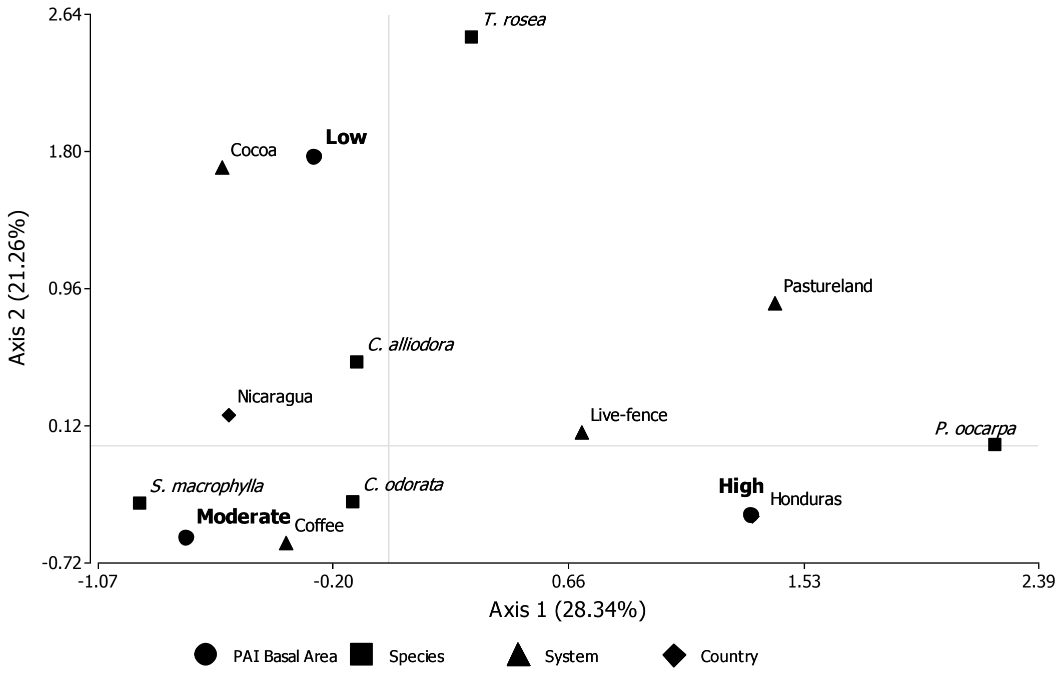

Fig. 3. Basal area growth (m² ha^{-1} $year^{-1}$) from different tree populations of agroforestry systems in Honduras and Nicaragua. Biplot obtained by first two axis from a multiple correspondence analysis. Periodical annual increment (PAI) of basal area growth is classified into: low (0.1 to 1.0), moderate (1.1 to 2.0) and high (≥ 2.1).

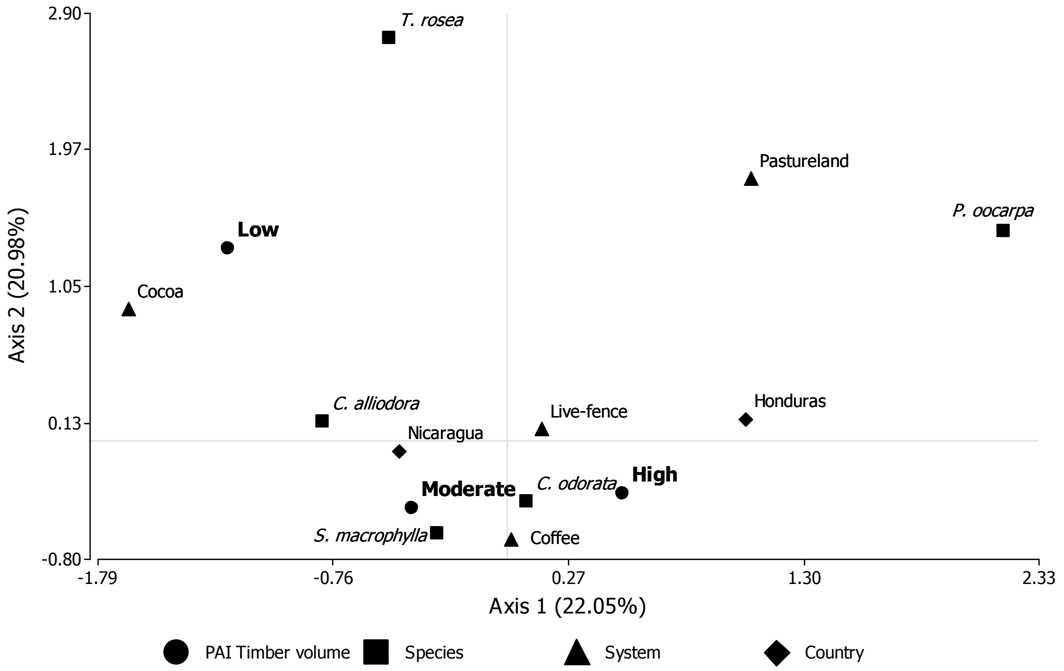

Fig. 4. Timber yields (m³ ha^{-1} $year^{-1}$) from different tree populations of agroforestry systems in Honduras and Nicaragua. Biplot obtained by first two axis from a multiple correspondence analysis. Periodical annual increment (PAI) of timber volume is classified into: low (0.1 to 3.0), moderate (3.1 to 6.0) and high (≥ 6.1).

Coffee systems, as well as *S. macrophylla*, *C. odorata* and *C. alliodora*, the main species in these systems, are correlated with moderate and high increases of the PAIs of basal area and timber volume (Fig. 3 and Fig. 4). These farmers manage a high density of *S. macrophylla* (140 trees ha^{-1}) and *C. odorata* (210 trees ha^{-1}), and this is the reason for the high increments of timber volume (Table 1). High densities in the early years of the systems is a strategy to control vertical tree height growth, as well as avoid the growth of branches. However, to best take advantage of timber yields while not affecting coffee production, it is necessary to reduce tree density by thinning (Haggar *et al.* 2001; Somarriba *et al.* 2001a; Salgado 2012), assuming the optimal level of shade in coffee systems is between 20-50%, depending on the environmental conditions and altitudinal ranges (Haggar *et al.* 2001; Virginio Filho *et al.* 2009).

Results for timber yields of *C. alliodora* in cocoa systems contrasts with the data reported by Somarriba *et al.* (2014) in Central American cocoa systems. The authors reported an increment of 4.43 m³ ha^{-1} in an average population of 48 trees ha^{-1}. Low increments in the cocoa systems may be associated with the age of the trees. In another study undertaken in cocoa systems of Central America, Somarriba *et al.* (2012) reported that trees present a fast growth rate until reaching 30-34 cm of DAP, followed by a period of slow growth. In our study, the average DAP of the trees in cocoa systems was 31 cm.

It was observed that the absence of pruning of *C. odorata* in coffee systems results in irregular growth of trees and stimulates the formation of branches, damaging the quality of the wood. When comparing the growth of *C. odorata* between live-fence and coffee systems, the possibility is noted that even with higher growth of basal area in coffee systems (2.16 m² ha^{-1} in coffee versus 1.55 m² ha^{-1} in live-fences) the timber yields are lower due to malformation of the stem (7.30 m³ ha^{-1} in coffee versus 11.12 m³ ha^{-1} in live-fences).

3.3. Financial attractiveness of agroforestry timber production

We estimate the timber price of a standing tree for sawmilling purchased at the farm, considering the stem quality of trees in the agroforestry systems evaluated in this study (Table 2).

Table 2. Estimated timber price of a standing tree to sawmilling (DBH ≥ 45 cm) from agroforestry systems in Honduras and Nicaragua. The price of *T. rosea* represents the local price of a tree to firewood (DBH ≥ 35 cm).

Species	Board-foot price (US$)	Timber price (US$ m^{-3})	Average harvesting tree volume (m³ $tree^{-1}$)	Tree price (US$ $tree^{-1}$)
Pinus oocarpa	0.70	296.59	0.80	237.27
Cedrela odorata	0.95	402.52	0.90	360.25
Cordia alliodora	0.25	105.93	1.03	109.10
Swietenia macrophylla	1.75	741.48	1.23	912.01
Tabebuia rosea	--	3.85	1.30	5.01

We found that trees from agroforestry systems have lower values than trees from natural forests, both in the local and international market. Buyer's reports illustrate that trees from agroforestry systems generally have irregular stem form and low timber quality. Furthermore, the absence of silvicultural management and the low quality of the seeds offered to farmers can be noted as reasons for the low quality of timber. Hoch *et al.* (2012) noted that the lack of financial support and the insufficient access to good planting material may be reasons for the uncertainty of timber quality of wood from agroforestry systems, as well as from other reforestation programs in the Amazon.

In our case study, farmers could not tell if the quality of seeds supplied for their systems had been tested by laboratory trials. The combination of genetic, physical, physiologic and sanitary attributes determines seed quality and are essential to determine the success of tree growth and higher market value of trees (Popinigis 1983; FAO 1987; Lima Junior *et al.*

2005; Lima Junior 2010; Nyoka *et al.* 2014; Pritchard *et al.* 2014). Agroforestry systems have the advantage of offering short-term economic benefits through agricultural yields, while timber harvest benefits can be expected over medium to long time scales (Kent and Ammour 2012). Nevertheless, without appropriate resources and knowledge for tree management, the timber production in agroforestry systems may present less feasibility than expected by farmers.

Table 3. Average annual costs, crop production and trees harvest in different agroforestry systems of Nicaragua and Honduras.

System	Average annual cost of crop management (US$ ha^{-1})	Average annual crop production (ha)	Unit	Number of trees harvested (ha)	Year
Coffee–Cedrela-Cordia	350.00	16.5	Quintal	19 - *C. alliodora*	20
				18 - *C. odorata*	20
Coffee–Swietenia	350.00	15.5	Quintal	40	24
SSP–Pinus	500.00	10,500	L	20	each 10
SSP–Tabebuia	475.00	9,000	L	5	each 6
Cocoa–Cordia	192.00	7	Quintal	11	20
Live-Fence–Cedrela	--	--	--	31	20

However, assuming two scenarios of discount rates to calculate the NPV (6% and 12%) of crop and timber revenues shows that agroforestry systems are still profitable to smallholders. The NPV from timber revenues in a scenario of 6% of the discount rate are more pronounced, mainly in coffee and cocoa systems (Fig. 5).

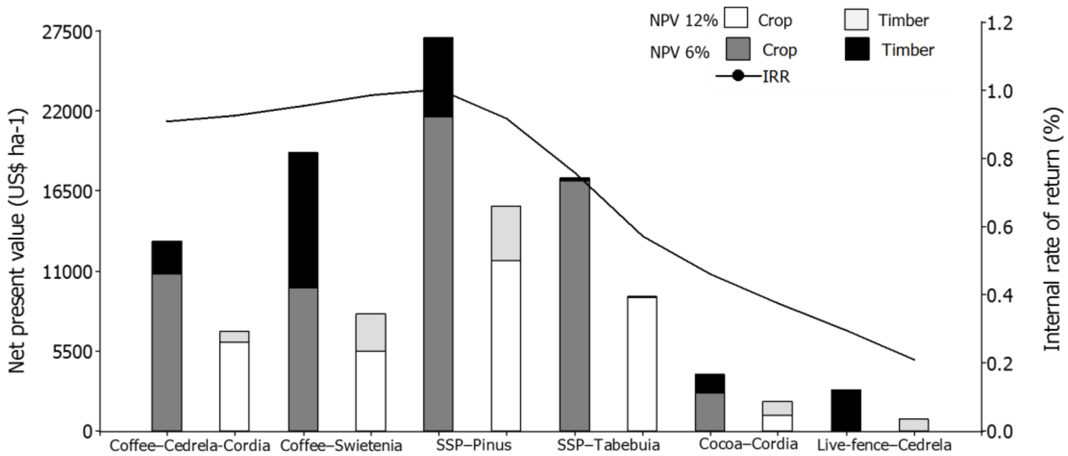

Fig. 5. Net present value by revenues (NPV) from crop production and timber sales, and Internal rate for return (IRR) for different agroforestry systems in Nicaragua and Honduras considering two scenarios of discount rate of NPV (6% and 12%) over twenty-four years.

Silvopastoral systems with *P. oocarpa* need no intensive silvicultural management and have the best IRR and NPV of timber sales in both scenarios. In Nicaragua, trees on silvopastoral systems with *T. rosea* are managed for firewood production and are less profitable from an economic perspective (a tree with an average volume of 1.3 m³ is sold by US$ 5 in the local market). We developed harvesting plans according to the population dynamics of both species; farmers can harvest 20 trees ha^{-1} of *P. oocarpa* every 10 years, and 5 trees ha^{-1} of *T. rosea* every 6 years. Results of population dynamics are explained in the next section. According to our estimation, net revenues from timber sales in silvopastoral systems with *P. oocarpa* under this harvesting plan are 64% superior (an increment of US$ 4,800 ha^{-1}; Fig. 6) in the years of timber harvest (each 10 years). However, financial contributions from timber sales of *T. rosea* in silvopastoral systems are less (only 2% of total net revenues in the years of timber harvest), due to the population dynamics and the strategy of timber sale observed.

It is important to highlight that despite having lower NPV than others systems, live-fences are an alternative to take advantage of important financial returns from underutilized areas of farms (Beer *et al.* 2009), and low NPV does not indicate an unprofitable activity. In our study, live-fences of *C. odorata* yield US$ 483 year^{-1}, with a total income of US$ 9,660 at the 20 year mark, where trees are sold at 31 trees ha^{-1}. Trees in live-fences also provide aesthetic benefits to farms (Beer 2000), ecological connectivity and conservation of biodiversity (Harvey *et al.* 2005; Chacón and Harvey 2006; Pulido-Santacruz and Renjifo 2011; Harvey 2013), wind protection and disease and erosion control (Cleugh 1998; Faustino 2000; Peri and Bloomberg 2002).

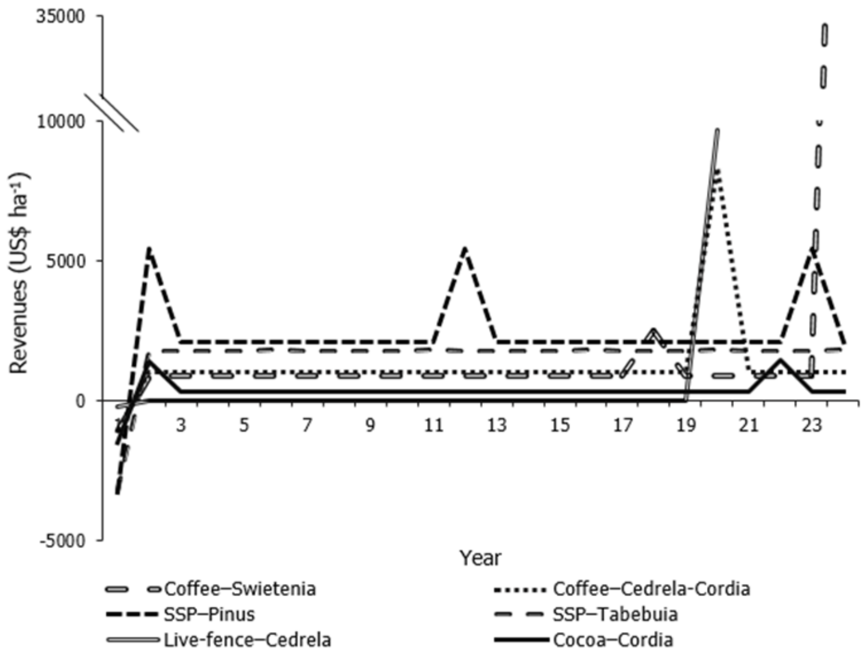

Fig. 6. Cash flow (US$ ha^{-1}) from crop production and timber sales in different agroforestry systems in Nicaragua and Honduras over twenty-four years.

Agroforestry systems with coffee and *S. macrophylla* demonstrate important revenues and, according to our estimation, have the second highest NPV from timber revenues in both scenarios of discount rates (Fig. 5). However, NPV for revenues of timber sales could be 58% higher than current values if the trees on coffee-Swietenia agroforestry system had been managed to acquire higher market prices (assuming that a standing tree of *S. macrophylla* with high stem quality can be sold for US$ 1,300). Even receiving less income from timber sales, due to the low quality of stem, the estimated cash flows of the studied systems show that the timber sales are responsible for important revenue increases for smallholder farmers (Fig. 6).

3.4. Population dynamics

We found an expressive incidence of natural regeneration in silvopastoral systems with natural grass that include silvopastoral systems with *P. oocarpa* and *T. rosea*. The effects of pastureland management on tree cover and natural regeneration occurrence were presented by some researchers in Latin America (Simón *et al.* 1998; Ibrahim and Camargo 2001; Camargo *et al.* 2005; Esquivel *et al.* 2008; Esquivel-Mimenza *et al.* 2011; Harvey *et al.* 2011). In our study, the frequency of seedlings was 74% superior in silvopastoral pastureland with natural grass as opposed to pasturelands with brizantha grass (*Brachiaria brizantha*). The frequency of seedlings and saplings were also 52% and 31% superior, respectively, in pasturelands with natural grass.

Natural regeneration of *C. alliodora* in cocoa systems is seen, as well as other species in coffee and live-fence systems. According to interviews with farmers, the main reason for the absence of natural regeneration in these systems are the agricultural practices used for weed control by farmers. The same information was reported by some authors in Central America (Camargo *et al.* 1999; Ibrahim and Camargo 2001; Esquivel *et al.* 2008). A strategy to promote the sustainability (timber harvest and trees benefits) of these systems without compromising the crop production and management is to encourage the collection of seeds from the trees and the creation of nurseries in the farms. Nurseries in coffee and cocoa systems have been a common practice over the years, when replacing coffee/cocoa trees is necessary (during the field research we observed farmers managing nurseries of coffee trees). With these nurseries, farmers could produce seedlings from the timber trees associated with coffee seedlings.

Table 4. Growth, survival and transitions coefficients for a population of *Pinus oocarpa* and *Tabebuia rosea* with natural regeneration in pasturelands. R: recruits, S: sapling, P: individuals that move to next diameter class, Q: individuals that stay in the same diameter class.

Species	Diameter upper class limit (cm)	Grow rate (cm year^{-1})	Annual survival	Transition coefficients	
				P	Q
Pinus oocarpa	R	0.50	0.90	0.45	0.45
	S	2.50	0.50	0.25	0.25
	10	0.78	0.90	0.14	0.76
	15	1.38	0.95	0.26	0.69
	20	1.32	0.95	0.25	0.7
	25	1.16	0.95	0.22	0.73
	30	0.86	0.95	0.16	0.79
	35	0.98	0.95	0.19	0.76
	40	0.98	0.95	0.19	0.76
Tabebuia rosea	R	0.50	0.05	0.03	0.03
	S	2.28	0.60	0.27	0.33
	10	1.68	0.60	0.2	0.4
	15	1.58	0.95	0.3	0.65
	20	1.44	0.95	0.27	0.68
	25	1.34	0.98	0.15	0.7

We developed the population dynamic projection associated with timber harvest plans for silvopastoral systems with *P. oocarpa* and *T. rosea* where the natural regeneration was expressive. Timber harvest of these species can be done sustainably by using proper management of the natural regeneration. Table 4 presents the growth rate and transition coefficients of both species.

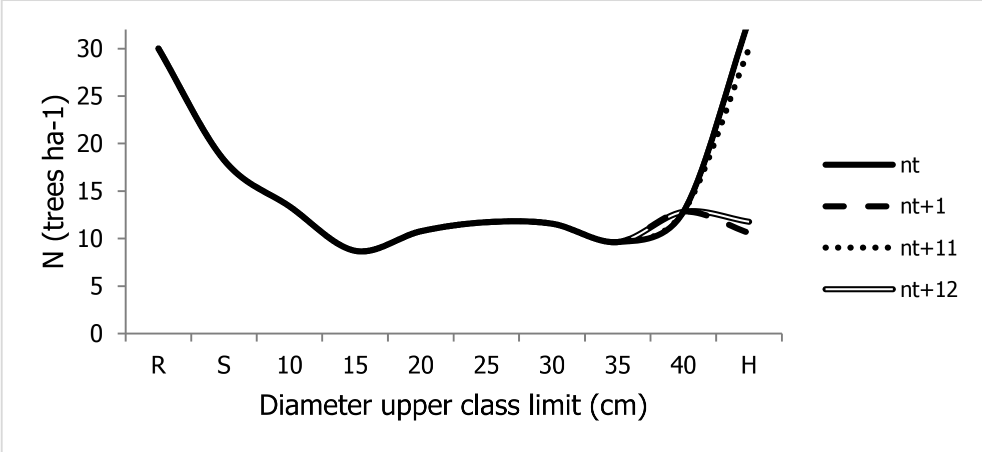

Fig. 7. Simulation of population dynamic of *Pinus oocarpa* with natural regeneration in pasturelands of Honduras with an average tree population of 88 trees ha^{-1} and 30 seedlings ha^{-1} and a timber harvesting cycle of 20 trees ha^{-1} each 10 years. R: recruits, S: sapling, H: harvest.

Assuming the current average population of trees in silvopastoral systems of *P. oocarpa* (88 trees ha^{-1}) and the growth rates that we found within these systems, 20 trees ha^{-1} (DBH ≥ 45 cm) can be harvested every 10 years (Fig. 7). The minimal conditions needed to guarantee the success of the harvest plan are the maintenance of 30 trees ha^{-1} year^{-1} (currently farmers manage that quantity of seedlings), the minimum annual survival rate for each diameter class (Table 4) and seed-production trees. It is important to highlight that silvopastoral systems of *P. oocarpa* are changing the population dynamics by the dominance of seedlings of *Quercus elliptica*, which have a biological interaction with squirrels (*Sciuridae*) that eat the seeds of *P. oocarpa* and disperse the seeds of *Q. elliptica* (the frequency of *Q. elliptica* seedlings was twice than seedlings of *P. oocarpa*). Studying this interaction is key to ensure the sustainability of timber harvest of *P. oocarpa*.

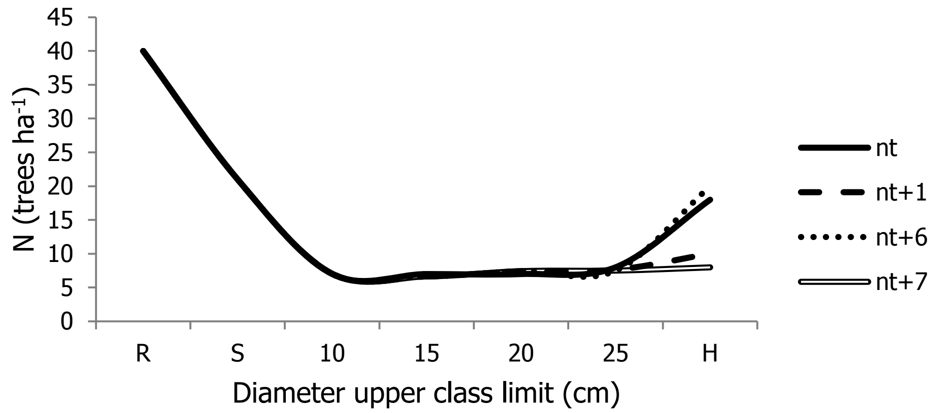

Fig. 8. Simulation of population dynamics and timber harvesting cycle of *Tabebuia rosea* with natural regeneration in pasturelands of Nicaragua with an average tree population of 40 trees ha^{-1} and 40 seedlings ha^{-1} and a timber harvesting cycle of 5 trees ha^{-1} each 6 years. R: recruits, S: sapling, H: harvest.

The population dynamics model for *T. rosea* indicates that to maintain the sustainability of the system, farmers can only harvest 5 trees ha^{-1} every 6 years (Fig. 8). According to our model, the sale of *T. rosea* trees for firewood is an unfeasible activity, increasing only 1% on the NPV of the system's revenues. The main reason is the low growth rate of the species and the low prices found in the local market. Adoption of another market strategy (sale to sawmilling) could improve revenue of timber sales in these systems. We recommend the transplantation of dispersal seedlings of *T. rosea* to high-density homogenous live-fences (considering that this species were suppressed when associated with another species) to promote the apical growth, improve the stem quality for sawmilling and avoid stem furcation (Beer 2000).

4. Conclusions

This study demonstrates the effects of agroforestry system management on timber yields and farm revenues. The most expressive timber yields, NPV and IRR were observed in silvopastoral systems with *P. oocarpa*, coffee systems with *C. odorata* and *C. alliodora*, coffee systems with *S. macrophylla* and live-fences of *C. odorata*. In all systems, the practice of silvicultural management (formative pruning and thinning) by farmers was not observed. Absence of silvicultural management, as well as low seed quality resulted in low sale values of the trees. In coffee systems with *S. macrophylla*, for example, the price of trees could be 58% higher than the current price if trees were managed. Even so, the analysis of NPV and IRR in these systems indicate that sales of timber is a profitable activity for smallholders. Timber (for sawmilling) revenues represent 11-49% of the NPV of agroforestry systems depending on the type of system, species and discount rate.

Furthermore, we observed that the natural regeneration of the studied timber species was expressively presented for *P. oocarpa* and *T. rosea* in silvopastoral systems with natural grass. Coffee, cocoa and live-fence systems showed an inexpressive or absent presence of natural regeneration due to the agricultural practices in crop management and weed control. A strategy to maintain tree benefits and timber revenues without compromising the crop production is the seed collection from trees in the systems and seedling production in nurseries. In coffee systems, the seedling production could be associated with the production of coffee seedlings on farms. We recommend the transplantation of dispersal seedlings of *T. rosea* to live-fences to promote the apical growth and improve the stem quality for sawmilling. Fostering knowledge about silvicultural management and access to quality seeds are essential to improve the revenues from timer sales in smallholder's agroforestry systems.

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References

Apaza, A. 2011. Potencialidades socio-económicas de la producción, procesamiento y mercadeo de productos maderables provenientes de sistemas silvopastoriles en Copán, Honduras. M.Sc. Thesis. Turrialba, Costa Rica, Centro Agronómico Tropical de Investigación y Enseñanza. 155 p.

Beer, J. 2000. Linderos maderables. *In* Méndez, E.; Beer, J.; Faustino, J.; Otarola, A. eds. 2000. Plántación de árboles en línea. Turrialba, Costa Rica, CATIE. p. 69-80. (Materiales de enseñanza).

Beer, J.; Ibrahim, M.; Somarriba, E.; Barrance, A.; Leakey, R. 2009. Establecimiento y manejo de árboles en sistemas agroforestales. 198-242 p. (Árboles de Centroamérica) (1).

Beer, J. 2012. Producción de árboles maderables en linderos. *In* Detlefsen, G.; Somarriba, E. eds. 2012. Producción de madera en sistemas agroforestales de Centroamérica. Turrialba, Costa Rica, CATIE. p. 199-210. (Technical Series). Available in: http://finnfor.catie.ac.cr/admin/documents/208

Bertomeu, M. 2006. Financial evaluation of smallholder timber-based agroforestry systems in Claveria, Northern Mindanao, the Philippines. Small-scale Forestry 5(1): 57-81 doi: 10.1007/s11842-006-0004-6

________. 2008. Can Smallholder Tree Farmers Help Revive the Timber Industry in Deforested Tropical Countries? A Case Study from Southern Philippines. *In* Snelder, D.; Lasco, R. eds. 2008. Smallholder Tree Growing for Rural Development and Environmental Services. Springer Netherlands. p. 177-191. (Advances in Agroforestry). doi: 10.1007/978-1-4020-8261-0_8

Borge, W.A.C. 2009. Producción de madera y carbono en la regeneración de sistemas agroforestales en la reserva indígena de Talamanca, Costa Rica. Ciencia e Interculturalidad 2(2): 108-130 Available in: http://revistas.uraccan.edu.ni/index.php/Interculturalidad/article/view/148

Borzone, H.A.; Bardi, J.F.; Laddaga., J.E. 2007. Crecimiento de Eucalyptus camaldulensis Dehnh cultivado como cortina en un establecimiento agropecuario del Partido de Azul (Pcia. de Bs. As.). Quebracho 1(14): 65-73 Available in: http://www.scielo.org.ar/scielo.php?pid=S1851-30262007000100008&script=sci_arttext

Camargo, J.C.; Ibrahim, M.; Somarriba, E.; Finegan, B.; Current, D. 1999. Factores ecológicos y socioeconómicos que influyen en la regeneración natural del laurel (Cordia alliodora) en sistemas silvopastoriles del trópico húmedo y subhúmedo de Costa Rica. Agroforestería en las Américas 7(26): 46-52 Available in: www.fao.org/wairdocs/lead/x6336s/X6336S00.htm#RESUMEN

Camargo, J.C.; Feijoo, A.; Zúñiga, M.C.; Cardona, H.; Gaviria, J. 2005. Silvopastoral systems with isolated timber trees within pastures in the Coffee region of Colombia. Livestock Research for Rural Development 17(5): Available in: www.lrrd.org/lrrd17/5/cama17051.htm

Chacón, M.; Harvey, C.A. 2006. Live fences and landscape connectivity in a neotropical agricultural landscape. Agroforestry Systems 68(1): 15-26 doi: 10.1007/s10457-005-5831-5

Chavarría, A.; Detlefsen, G.; Ibrahim, M.; Galloway, G.; Camino, R.d. 2011. Análisis de la productividad y la contribución financiera del componente arbóreo en pequeñas y medianas fincas ganaderas de la subcuenca del río Copán, Honduras. Agroforestería en las Américas 48(1): 146-156

Cleugh, H.A. 1998. Effects of windbreaks on airflow, microclimates and crop yields. Agroforestry Systems 41(1): 55-84 doi: 10.1023/A:1006019805109

Cruz, A.R.; Detlefsen, G.; Ibrahim, M.; Camino, R.d.; Galloway, G. 2010. Aprovechamiento del recurso maderable en sistemas silvopastoriles de Belice. Recursos Naturales y Ambiente 59(60): 91-98 Available in: http://finnfor.catie.ac.cr/admin/documents/27

CTPT (Comisión Trinacional del Plan Trifinio, El Salvador). 2014. Región del Trifinio en breve. Comisión Trinacional del Plan Trifinio. San Salvador, El Salvador. Available in: http://www.sica.int/trifinio/trifinio/breve_trifinio.aspx?IdEnt=140

Cubbage, F.; Glenn, V.; Paul Mueller, J.; Robison, D.; Myers, R.; Luginbuhl, J.-M.; Myers, R. 2012. Early tree growth, crop yields and estimated returns for an agroforestry trial in Goldsboro, North Carolina. Agroforestry Systems 86(3): 323-334 doi: 10.1007/s10457-012-9481-0

Detlefsen, G.; Pomareda, C.; Ibrahim, M.; Pezo, D. 2008. La legislación forestal debe ser revisada para fomentar y aprovechar el recurso maderable en fincas ganaderas de

Centroamérica. Turrialba, Costa Rica, CATIE. 34 p. (Síntesis para Decisores) Available in: http://orton.catie.ac.cr/repdoc/A2445E/A2445E.PDF

Detlefsen, G.; Marmillod, D.; Scheelje, M.; Ibrahim, M. 2012. Protocolo para la instalación de parcelas permanentes de medición de la producción maderable en sistemas agroforestales de Centroamérica. Turrialba, Costa Rica, CATIE. 19 p. (Manual técnico no. 107) doi: 978-9977-57-574-2 Available in: http://finnfor.catie.ac.cr/admin/documents/184

Detlefsen, G.; Scheelje, M. 2012. Las normativas legales y el aprovechamiento de la madera en fincas. *In* Detlefsen, G.; Somarriba, E. eds. 2012. Producción de madera en sistemas agroforestales de Centroamérica. Turrialba, Costa Rica, CATIE. p. 211-244. (Technical Series). Available in: http://finnfor.catie.ac.cr/admin/documents/208

Detlefsen, G.; Somarriba, E. 2012. Producción de madera en sistemas agroforestales de Centroamérica. 1 ed. Detlefsen, G.; Somarriba, E. eds. Turrialba, Costa Rica, CATIE. 244 p. (Manual técnico no. 109)

Di Rienzo, J.A.; Casanoves, F.; Balzarini, M.G.; Gonzalez, L.; Tablada, M.; Robledo, C.W. 2014. InfoStat. versión 24-03-2011 ed. Córdoba, Argentina, Universidad Nacional de Córdoba. Available in: http://www.infostat.com.ar/

Esquivel-Mimenza, H.; Ibrahimb, M.; Harvey, C.A.; Benjamin, T.; Sinclair, F.L. 2011. Dispersed trees in pasturelands of cattle farms in a tropical dry ecosystem. Tropical and Subtropical Agroecosystems 14(2011): 933-941 Available in: http://www.scielo.org.mx/pdf/tsa/v14n3/v14n3a6.pdf

Esquivel, M.J.; Harvey, C.A.; Finegan, B.; Casanoves, F.; Skarpe, C. 2008. Effects of pasture management on the natural regeneration of neotropical trees. Journal of Applied Ecology 45(1): 371-380 doi: 10.1111/j.1365-2664.2007.01411.x

FAO (Food and Agriculture Organization of The United Nations, Italy). 1987. A guide to forest seed handling with special reference to the tropics. Willan, R.L. ed. Rome, Italy, FAO. (FAO Forestry Paper) (2). Available in: http://www.fao.org/docrep/006/ad232e/ad232e00.htm

________. 2013. Advancing Agroforestry on the Policy Agenda: A guide for decision-makers. Place, F.; Gauthier, M. eds. Rome, Italy, Food and Agriculture Organization of The United Nations. 49 p. (Agroforestry Working Paper) (1). Available in: http://www.fao.org/docrep/017/i3182e/i3182e00.pdf

________. 2014. State of the World's Forests: Enhancing the socioeconomic benefits from forests. Rome, Italy, Food and Agriculture Organization of The United Nations. 145 p. (State of the World's Forests) doi: 978-92-5-308270-4 Available in: http://www.fao.org/3/a-i3710e.pdf

Faustino, J. 2000. Cortinas rompevientos. *In* Méndez, E.; Beer, J.; Faustino, J.; Otarola, A. eds. 2000. Plántación de árboles en línea. Turrialba, Costa Rica, CATIE. p. 23-41. (Materiales de enseñanza).

Haggar, J.P.; Schibli, C.; Staver, C. 2001. ¿Cómo manejar árboles de sombra en cafetales? Agroforestería en las Américas 8(29): 37-41

Harvey, C.A.; Villanueva, C.; Villacís, J.; Chacón, M.; Muñoz, D.; López, M.; Ibrahim, M.; Gómez, R.; Taylor, R.; Martinez, J.; Navas, A.; Saenz, J.; Sánchez, D.; Medina, A.; Vilchez, S.; Hernández, B.; Perez, A.; Ruiz, F.; López, F.; Lang, I.; Sinclair, F.L. 2005. Contribution of live fences to the ecological integrity of agricultural landscapes. Agriculture, Ecosystems & Environment 111(1–4): 200-230 doi: 10.1016/j.agee.2005.06.011

Harvey, C.A.; Villanueva, C.; Esquivel, H.; Gómez, R.; Ibrahim, M.; Lopez, M.; Martinez, J.; Muñoz, D.; Restrepo, C.; Saénz, J.C.; Villacís, J.; Sinclair, F.L. 2011. Conservation value of dispersed tree cover threatened by pasture management. Forest Ecology and Management 261(10): 1664-1674 doi: 10.1016/j.foreco.2010.11.004

Harvey, C.A.T., N. I. J.; Estrada, A. 2013. Live fences, isolated trees, and windbreaks: tools for conserving biodiversity in fragmented tropical landscapes. *In* Götz Schroth, G.A.B.d.F., Celia A. Harvey, Claude Gascon, Heraldo L. Vasconcelos, Anne-Marie N. Izac.

ed. 2013. Agroforestry and biodiversity conservation in tropical landscapes. Washington, D.C., USA, Island Press. p. 261-289.
Hoch, L.; Pokorny, B.; de Jong, W. 2012. Financial attractiveness of smallholder tree plantations in the Amazon: bridging external expectations and local realities. Agroforestry Systems 84(3): 361-375 doi: 10.1007/s10457-012-9480-1
Ibrahim, M.; Camargo, J.C. 2001. ¿Cómo aumentar la regeneración de árboles maderables en potreros? Agroforestería en las Américas 8(32): 35-45 Available in: ftp://ftp.fao.org/docrep/nonfao/lead/x6354s/x6354s00.pdf
Ibrahim, M.; Pezo, D. 2012. Interacciones en sistemas silvopastoriles. *In* Detlefsen, G.; Somarriba, E. eds. 2012. Producción de madera en sistemas agroforestales de Centroamérica. Turrialba, Costa Rica, CATIE. p. 69-90. (Technical Series). Available in: http://finnfor.catie.ac.cr/admin/documents/208
Ibrahim, M.; Zapata, P. 2012. Producción de madera en sistemas silvopastoriles. *In* Detlefsen, G.; Somarriba, E. eds. 2012. Producción de madera en sistemas agroforestales de Centroamérica. Turrialba, Costa Rica, CATIE. p. 112-132. (Technical Series). Available in: http://finnfor.catie.ac.cr/admin/documents/208
INEC (Instituto Nacional de Estadísticas y Censos, Nicaragua). 2006. Censo de población y de vivienda 2005. Manágua, Nicaragua, INEC. 40 p. (Censos Nacionales) (7).
ITTO (International Tropical Timber Organization, Japan). 2013. Annual review and assessment of the world timber situation, 2012. Yokohama, Japan, International Tropical Timber Organization (ITTO). 182 p. (Annual report) Available in: http://www.itto.int/annual_review/
Jiménez, N.G. 2012. Producción de madera y almacenamiento de carbono en cafetales con cedro (Cedrela odorata) y caoba (Swietenia macrophylla) en Honduras. M.Sc. Thesis. Turrialba, Costa Rica, CATIE. 121 p.
Kent, J.; Ammour, T. 2012. Análisis financiero y económico de la producción de madera en sistemas agroforestales. *In* Detlefsen, G.; Somarriba, E. eds. 2012. Producción de madera en sistemas agroforestales de Centroamérica. Turrialba, Costa Rica, CATIE. p. 91-111. (Technical Series). Available in: http://finnfor.catie.ac.cr/admin/documents/208
Leiva, E.R. 2011. Efectos del marco político y legislativo en el aprovechamiento de la madera de sistemas agroforestales del Municipio de El Cuá, Nicaragua. M.Sc. Thesis. Turrialba, Costa Rica, Centro Agronómico Tropical de Investigación y Enseñanza. 177 p.
Lima Junior, M.J.V.; Ellis, R.H.; Hong, T.D.; Ferraz, I.D.K. 2005. Drying method influences the development of germinability, dessication tolerance and subsequent longevity of immature seeds of sumaúma. Seed Science and Technology 33(1): 147-156
Lima Junior, M.J.V. 2010. Manual de procedimentos para análise de sementes florestais. Lima Junior, M.J.V. ed. Londrina, Brazil, Associação Brasileira de Tecnologia de Sementes - ABRATES. 83 p.
López, A.; Detlefsen, G. 2012. Agroforestería y la producción de madera. *In* Detlefsen, G.; Somarriba, E. eds. 2012. Producción de madera en sistemas agroforestales de Centroamérica. Turrialba, Costa Rica, CATIE. p. 9-20. (Technical Series). Available in: http://finnfor.catie.ac.cr/admin/documents/208
Nyoka, B.; Roshetko, J.; Jamnadass, R.; Muriuki, J.; Kalinganire, A.; Lillesø, J.-P.; Beedy, T.; Cornelius, J. 2014. Tree Seed and Seedling Supply Systems: A Review of the Asia, Africa and Latin America Models. Small-scale Forestry: 1-21 doi: 10.1007/s11842-014-9280-8
Orozco, L. 2012. Instrumentos y política forestal de Nicaragua: Implicaciones para el fomento de los sistemas silvopastoriles. Turrialba, Costa Rica, CATIE. 2 p. (Policy Brief) Available in: http://finnfor.catie.ac.cr/admin/documents/197
Peri, P.L.; Bloomberg, M. 2002. Windbreaks in southern Patagonia,Argentina: A review of research on growth models, windspeed reduction, and effects oncrops. Agroforestry Systems 56(2): 129-144 doi: 10.1023/A:1021314927209
Plata, O.F. 2012. Análisis ex ante del aprovechamiento maderable de árboles en potrero, con implementación de prácticas silviculturales, en sistemas silvopastoriles en Esparza,

Costa Rica. M.Sc. Thesis. Turrilba, Costa Rica, Centro Agronómico Tropical de Investigación y Enseñanza. 123 p.

Plath, M.; Mody, K.; Potvin, C.; Dorn, S. 2011. Do multipurpose companion trees affect high value timber trees in a silvopastoral plantation system? Agroforestry Systems 81(1): 79-92 doi: 10.1007/s10457-010-9308-9

Popinigis, F. 1983. A germinação das sementes. 2 ed. Brasilia, Brazil, Pax - Gráfica e Fotolito Ltda. 289 p.

Pritchard, H.W.; Moat, J.F.; Ferraz, J.B.S.; Marks, T.R.; Camargo, J.L.C.; Nadarajan, J.; Ferraz, I.D.K. 2014. Innovative approaches to the preservation of forest trees. Forest Ecology and Management 1: 1-11 doi: 10.1016/j.foreco.2014.08.012

Pulido-Santacruz, P.; Renjifo, L. 2011. Live fences as tools for biodiversity conservation: a study case with birds and plants. Agroforestry Systems 81(1): 15-30 doi: 10.1007/s10457-010-9331-x

Salgado, J. 2012. Producción de madera en sistemas agroforestales con café. *In* Detlefsen, G.; Somarriba, E. eds. 2012. Producción de madera en sistemas agroforestales de Centroamérica. Turrialba, Costa Rica, CATIE. p. 145-160. (Technical Series). Available in: http://finnfor.catie.ac.cr/admin/documents/208

Santos-Martin, F.; Bertomeu, M.; van Noordwijk, M.; Navarro, R. 2011. Why smallholders plant native timber trees: lessons from the Philippines. Bogor, Indonesia, ASB Partnership and ICRAF. 4 p. (Policy Brief) Available in: http://outputs.worldagroforestry.org/record/6570/files/ICRAF-2014-414.pdf

Scheelje, M.; Detlefsen, G.; Ibrahim, M.; Chavarría, A. 2011. Honduras: la simplificación de trámites para el manejo y comercialización de árboles maderables en fincas ganaderas puede estimular la incorporación y manejo de árboles en forma sustentable por parte de pequeños productores. Turrialba, Costa Rica, CATIE. 2 p. (Policy Brief) Available in: http://finnfor.catie.ac.cr/admin/documents/45

Simón, M.; Ibrahim, M.; Finegan, B.; Pezo, D. 1998. Efectos del pastoreo bovino sobre la regeneración de tres especies arbóreas comerciales del chaco argentino: un método de protección. Available in: ftp://ftp.fao.org/docrep/nonfao/lead/X6322S/X6322S00.pdf

Snelder, D.J.; Lasco, R.D. 2008. Smallholder Tree Growing in South and Southeast Asia. *In* Snelder, D.; Lasco, R. eds. 2008. Smallholder Tree Growing for Rural Development and Environmental Services. Springer Netherlands. p. 3-33. (Advances in Agroforestry). doi: 10.1007/978-1-4020-8261-0_1

Somarriba, E.; Beer, J.; Muschler, R.G. 2001a. Research methods for multistrata agroforestry systems with coffee and cacao: recommendations from two decades of research at CATIE. Agroforestry Systems (53): 195–203 doi: 10.1023/A:1013380605176

Somarriba, E.; Valdivieso, R.; Vásquez, W.; Galloway, G. 2001b. Survival, growth, timber productivity and site index of Cordia alliodora in forestry and agroforestry systems. Agroforestry Systems 51: 111-118 doi: 10.1023/A:1010699019745

Somarriba, E.; Beer, J. 2011. Productivity of Theobroma cacao agroforestry systems with timber or legume service shade trees. Agroforestry Systems 81(2): 109-121 doi: 10.1007/s10457-010-9364-1

Somarriba, E.; Orozco, L.; López, A. 2012. Producción de madera en sistemas agroforestales con cacao. *In* Detlefsen, G.; Somarriba, E. eds. 2012. Producción de madera en sistemas agroforestales de Centroamérica. Turrialba, Costa Rica, CATIE. p. 133-144. (Technical Series). Available in: http://finnfor.catie.ac.cr/admin/documents/208

Somarriba, E.; Suárez-Islas, A.; Calero-Borge, W.; Villota, A.; Castillo, C.; Vílchez, S.; Deheuvels, O.; Cerda, R. 2014. Cocoa-timber agroforestry systems: Theobroma cacao-Cordia alliodora in Central America. Agroforest Systems 88(1): doi: 10.1007/s10457-014-9692-7

Súarez, A.; Somarriba, E. 2002. Aprovechamiento sostenible de madera de Cordia alliodora de regeneración natural en cacaotales y bananales de indígenas de Talamanca, Costa Rica. Agroforestería en las Américas 9(35-36): 50-54

Toruño, I. 2012. Análisis financiero-económico de fincas con varias actividades productivas y el rol de la familia en la producción y toma de decisiones en el Centro Norte de Nicaragua. M.Sc. Thesis. Turrialba, Costa Rica, Centro Agronómico Tropical de Investigación y Enseñanza. 157 p.

USDA (United States Department of Agriculture, USA). 2000. From pine forest to a silvopasture system. United States of America, USDA. 4 p. (Agroforestry Notes) (18).

Viera, C.J.; Pineda, A. 2004. Productividad de lindero maderable de Cedrela odorata. Agronomía mesoamericana 15(1): 85-92 Available in: http://teca.fao.org/es/read/3712

Virginio Filho, E.M.; Barrios, M.; Morales, I.T. 2009. ¿Cómo podemos mejorar la finca cafetalera en la cuenca? Managua, Nicaragua, CATIE. 71 p. (Capacitación agricola - guías) (1).

Article 2. Supporting agroforestry planning for timber production with a smartphone app

ABSTRACT

Agriculture is an important sector of the global economy that is continuously impacted by changes in world climate dynamics. Proper investments and planning at the farm level to develop sustainable and resilient agroforestry systems can increase the potential of farms to provide food and timber. Many farmers have enough knowledge about crop management; however, they are usually unaware of silvicultural practices that can increase timber production. Information on silvicultural practices needs be shared to support farmers so they can make better decisions about farm planning and take advantage of opportunities in the market. The use of information technologies is key to achieving this challenge. We developed an app for Android™ OS to support timber production and its natural regeneration management in agroforestry systems. The application was used to develop a plan for 20 farms in Costa Rica, Nicaragua and Honduras. The results show savings of approximately 90% in time spent on data processing using the smartphone-based inventory. This allowed for prompt feedback of silvicultural agroforestry information and planning to farmers and decision-makers. The application is a component of the Agroforestry App Package proposed by the authors and can be used in agroforestry systems worldwide.
Keywords: smartphone-based data collection; agroforestry planning; timber yields; smartphone app

1. Introduction

Agriculture is an important sector of the global economy, responsible for providing food and wood products in both developed and developing countries. This sector has a growing demand; by 2050 the worldwide demand for agricultural products will be 60% higher than present (FAO 2013a). Changes in global climate dynamics make the challenge of ensuring worldwide food security even more difficult. Agroforestry is an alternative to guarantee production, sustainability and resilience of agricultural systems (ICRAF 2006; Detlefsen and Somarriba 2012; Dawson *et al.* 2013; FAO 2013b). To achieve a successful agroforestry system, it is necessary to invest efforts on farm planning (Dewi *et al.* 2011; Gold *et al.* 2013), mainly regarding proper selection and management of tree species, considering trees are the main component responsible for the important benefits and products, such as timber (Snelder and Lasco 2008; Kent and Ammour 2012; Pye-Smith 2013; Somarriba *et al.* 2014).

Farmers need access to specialized information regarding cultivation techniques for their crops. In the agroforestry systems studied, farmers were able to provide detailed information on crop management and yields, but not all knew about tree growth and tree management (Somarriba *et al.* 2001; Santos-Martin *et al.* 2011). Information on silvicultural practices needs to be precise and accurate to support farmers in making better decisions, such as managing farm fields, making changes in tree density and taking advantage of the timber market (Jain *et al.* 2014). However, the lengthy feedback time of information to the farmers does not allow for quick and efficient farm decision-making, and may decrease the impact of participatory projects.

Since 2007, smartphones have been changing the way that information is collected and organized, creating new interfaces for data processing and sharing. However, the current perception is that smartphones are gadgets exclusively used for social media; in fact the smartphone was created mainly for this purpose. Nevertheless, in opposition to this paradigm, the use of smartphones for professionals shows that this technology has a huge potential and several useful applications (Burdette *et al.* 2008; Fuentes *et al.* 2012; Godlevsky *et al.* 2013; Gopinath *et al.* 2014; Wallace and Bargeron 2014; Wu *et al.* 2014). The agricultural sector has important apps in many different areas, such as natural forest dynamic, tree height measurement, REDD+ monitoring, crop nitrogen index, forest fuel loading, soil-color evaluation, leaf area measurement and mobile GIS technology in silviculture (Inman-Narahari *et al.* 2010; Itoh *et al.* 2010; Pratihast *et al.* 2012; Delgado *et al.* 2013; Ferster *et al.* 2013; Gómez-Robledo *et al.* 2013; Gong *et al.* 2013; Ferster and Coops 2014; Kennedy *et al.* 2014). However, there have not been studies on the use of the smartphone in agroforestry, or on how the technology could be used to promptly provide information on timber stock and tree population dynamic management. We developed a smartphone/tablet application that acts as a tool for assisting in tree inventory to support agroforestry system evaluation and planning, using smartphone-based data collection methodology.

2. Methods

2.1. Agroforestree structuration

We developed the app Agroforestree for use with Android™ OS 4.0 or above. Using Android SDK in Java Development Kit (JDK), we wrote the user interface (UI). This OS was selected because it is an open source platform, has low cost devices and the largest number of users, composed of 65% of global smartphone owners (GWI 2014).

In efforts to reach the highest number of users possible, the app was built to support English, Spanish and Portuguese languages, with English as the default language. Agroforestree has four activities that aid in the collection of information about tree diversity, timber stock and natural regeneration. Tree inventory methodology follows Detlefsen *et al.* (2012), which developed a protocol to measure trees in agroforestry systems.

Tree attributes supported by the app include species name, measurement at breast height (diameter or circumference), total and commercial height (with clinometer or a direct measure method), crown diameter, crown density, stem form, tree health and mortality (for continuous studies). The attribute for natural regeneration evaluation is species name and quantity of individuals for each development stage (seedling, sapling and young trees). In addition, the user can register baseline data for the farm and/or plots where the measurements were taken. Each attribute in the app must be entered following pre-specified format conditions (e.g., the commercial height cannot be greater than the total height). The data are saved in the device's memory as a comma separated value (*.csv) file classified by the data type (farm, plot, trees or seedlings) and can be accessed on a computer via USB connection, or sent to a cloud-drive or e-mail account when internet access is available.

2.2. Agroforestree validation

We validated the app in 2014 using two mobile devices powered by Android 4.4, an LG Nexus 4 (4.7-inch touchscreen smartphone) and an Asus Nexus 7 2013 (7-inch touchscreen tablet). These devices were selected because they both have Android "Pure version" and are low cost (between US$ 199.00 and US$ 350.00). We verified the app feasibility in Costa Rica, Nicaragua and Honduras on 20 farms (47 plots) under agroforestry management.

In Costa Rica, the efficiency of the app's ability to take tree inventory for agroforestry planning was assessed via a working group of graduate students at CATIE. The working group compared the time needed to collect data manually and the time needed to enter the data into the forest inventory app. In 2013, using paper-based inventory, we evaluated a silvopastoral system (6 lineal-plots of 100 m) in Turrialba, Costa Rica, and in 2014 we used smartphone-based inventory to evaluate another silvopastoral system (11 lineal-plots of 50 m) in Hojancha, Costa Rica.

In Honduras and Nicaragua, timber stock and natural regeneration were evaluated using smartphone-based data collection in permanent sample plots (PSP) in smallholder's agroforestry systems. These PSPs were established in 2010 in El Cuá, Nicaragua, and in 2011 in Trifinio, Honduras, and have been taking measurements annually. Plots were established on silvopastoral (10 circular-plots of 0.5 ha), coffee (11 rectangular-plots of 0.1 ha), cocoa (3 rectangular-plots of 0.1 ha) and live-fence (6 lineal-plots of 100 m) systems. Data from 2014 was compared with the last evaluation data taken manually to ensure the precision of the smartphone-based inventory. In all three countries, data were processed for the study area using a database structured on Microsoft® Access 2013, containing volumetric and diametric equations to calculate tree commercial volume, classify species as timber or non-timber and classify trees in diametric classes. Results and recommendations were shared with each farmer and decision-maker in a workshop.

3. Results and discussion

3.1. Device usability and UI

We compared the app usability in both devices selected. The app runs fluently in both devices; however, the tablet demonstrated better performance in the data collection process. Features like a better battery and larger display (7" instead of 4.7") made the use of the tablet preferable over the smaller phone by the working group. The tablet display makes it possible to show, on the left hand side of the screen, the tree list (or farms/plots list) and demonstrates improved navigation between different data entries (Fig. 9).

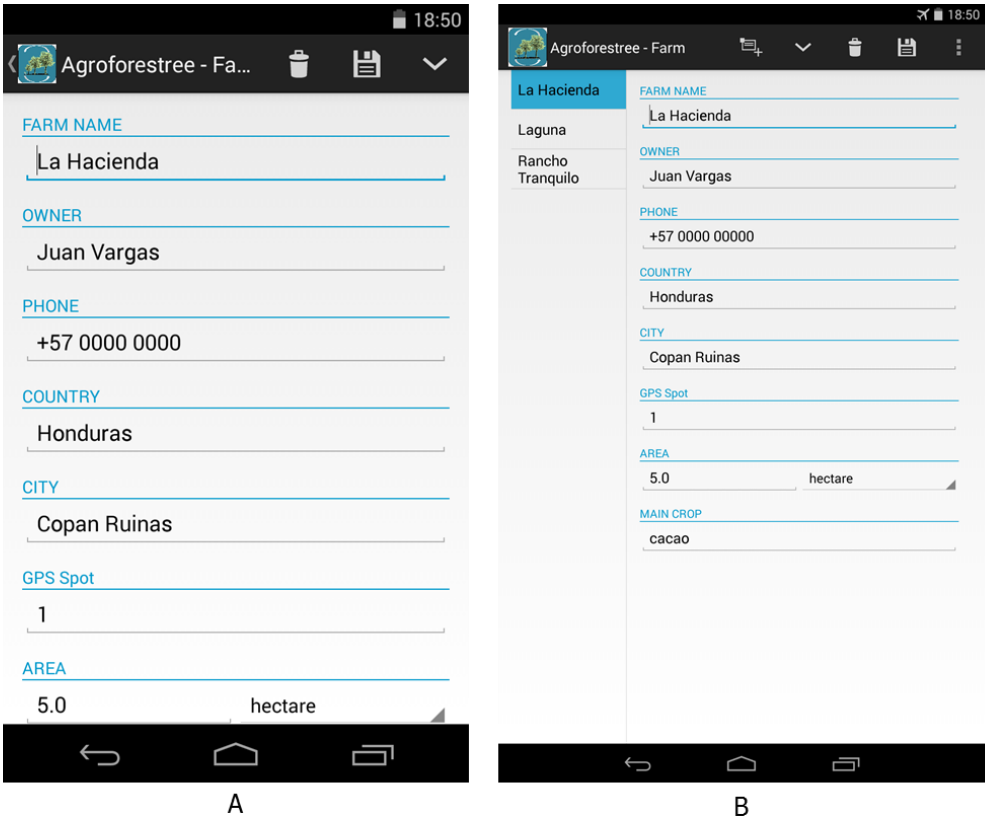

Fig. 9. Comparison between Agroforestree app UI in a smartphone (A) and tablet (B).

In rainy conditions, neither device showed problems with performance. This was because to control the situation, we used transparent zip-lock plastic bags to protect the devices so that the date collection could continue in the rain.

3.2. Data collection and processing inputs

In the PSP, we inventoried 1,170 trees in four types of agroforestry systems (silvopastoral, coffee, cocoa and live-fence) in the three countries. We identified no difference in the time spent collecting data between paper-based and smartphone-based inventory collection methods. The average time to collect data was 2 min tree^{-1} using both methodologies. Relevant information was presented by Inman-Narahari *et al.* (2010) and Kennedy *et al.* (2014), which noted that possible causes of delayed time in data collection were the time taken to validate the data, required by the app or the time taken for the user to adapt to using the interface of the app (Fig. 10). However, in the data processing, which consists of data entry and error check, the average time spent in paper-based inventory was 1:23 min tree^{-1} and in smartphone-based inventory it was 5 min file^{-1}. In our study case, this represented a time saving of 90% for data processing.

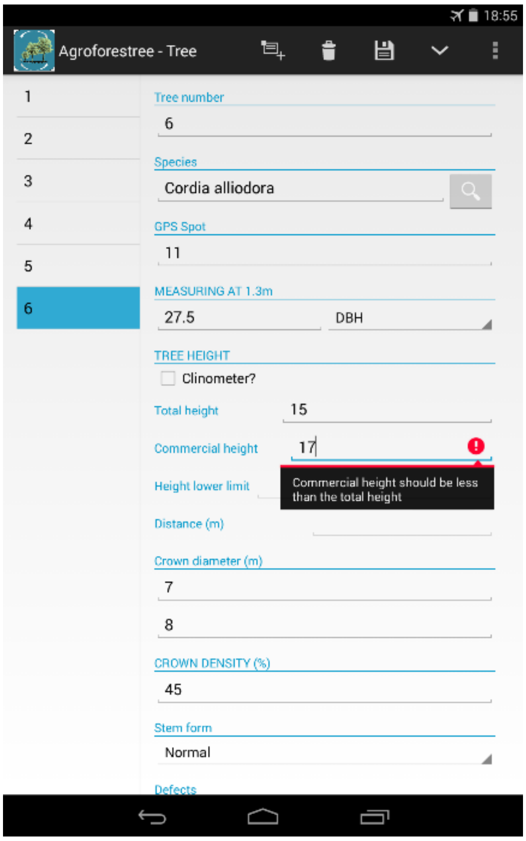

Fig. 10. Data validation error message for tree height in the activity to tree data collection.

The time saved on data processing allowed the working group to focus their efforts on their recommendations pertaining to silvicultural management and accurate farm planning for agroforestry systems. The average feedback time using a smartphone-based inventory was 2:30 h farm^{-1}. This feedback included presenting a report in a workshop that illustrated the population dynamics, timber yields, timber stock and silvicultural recommendations to the farmers.

We compared the two inventory methodologies and built a feedback process that is shown in Fig. 11. Using smartphone-based inventory collection in participatory agroforestry planning, we can eliminate two unnecessary steps in the feedback process, accelerating accurate decision-making for the tree component of agroforestry systems. In developing regions where collection and transfer of knowledge is not simple, such as in the Amazon, Central America or Sub-Saharan Africa, the use of this tool is a way to foster participatory policy agenda, rural development, and the sharing of agricultural and silvicultural knowledge (FAO 2013b; Ferster *et al.* 2013; UNESCO 2014; WEC 2014).

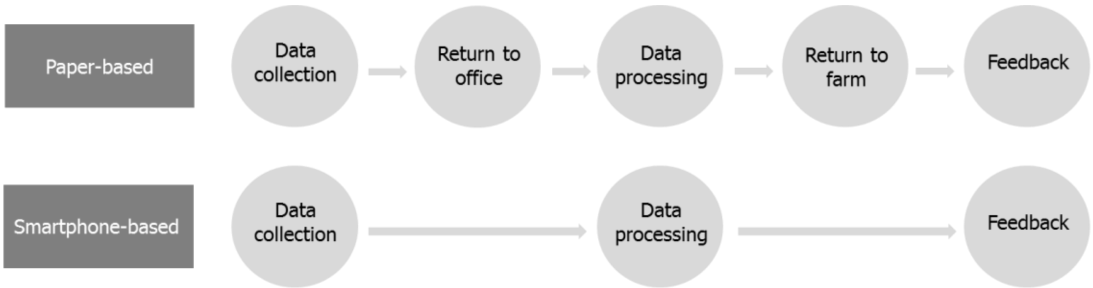

Fig. 11. Feedback process in paper-based and smartphone-based inventory in tree agroforestry planning.

4. Conclusions

This study showed that apps on agroforestry sector are important tools to solve logistical and technical problems of participatory agroforestry planning and design. The Agroforestree app was successfully developed and is a component of the Agroforestry Apps Package developed by the authors of this article. Using appropriated apps on farm analysis, researchers and technicians spent 90% less time on data processing, investing more effort on farm planning and could promptly share knowledge of silvicultural management, assuming that farmers lack this knowledge. Considering that the app validation was performed in different countries and agricultural systems, we can recommend the use of this app in worldwide tropical agroforestry systems, including forestry systems. The app could be used in different environmental situations, including rainy conditions. In developing regions where the collection and transfer of data is not easy, the use of this tool helps foster participatory policy agenda, rural development and sharing of agricultural and silvicultural knowledge.

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References

Burdette, S.D.; Herchline, T.E.; Oehler, R. 2008. Practicing medicine in a technological age: using smartphones in clinical practice. Clinical Infectious Diseases 47(1): 117-122 doi: 10.1086/588788

Dawson, I.K.; Guariguata, M.R.; Loo, J.; Weber, J.C.; Lengkeek, A.; Bush, D.; Cornelius, J.; Guarino, L.; Kindt, R.; Orwa, C.; Russell, J.; Jamnadass, R. 2013. What is the relevance of smallholders' agroforestry systems for conserving tropical tree species and genetic diversity in circa situm, in situ and ex situ settings? - A review. Biodiversity Conservation (22): 301–324 doi: 10.1007/s10531-012-0429-5

Delgado, J.A.; Kowalski, K.; Tebbe, C. 2013. The first Nitrogen Index app for mobile devices: Using portable technology for smart agricultural management. Computers and Electronics in Agriculture 91: 121–123 doi: 10.1016/j.compag.2012.12.008

Detlefsen, G.; Marmillod, D.; Scheelje, M.; Ibrahim, M. 2012. Protocolo para la instalación de parcelas permanentes de medición de la producción maderable en sistemas agroforestales de Centroamérica. Turrialba, Costa Rica, CATIE. 19 p. (Manual técnico no. 107) doi: 978-9977-57-574-2 Available in: http://finnfor.catie.ac.cr/admin/documents/184

Detlefsen, G.; Somarriba, E. 2012. Producción de madera en sistemas agroforestales de Centroamérica. 1 ed. Detlefsen, G.; Somarriba, E. eds. Turrialba, Costa Rica, CATIE. 244 p. (Manual técnico no. 109)

Dewi, S.; Ekadinata, A.; Galudra, G.; Agung, P.; Johana, F. 2011. LUWES: Land use planning for Low Emission Development Strategy. Bogor, Indonesia, World Agroforestry Centre - ICRAF, SEA Regional Office. 47 p.

FAO (Food and Agriculture Organization of The United Nations, Italy). 2013a. Climate Smart Agriculture. Rome, Italy, Food and Agriculture Organization of The United Nations - FAO. 569 p. (1). Available in: http://www.fao.org/docrep/018/i3325e/i3325e.pdf

________. 2013b. Advancing Agroforestry on the Policy Agenda: A guide for decision-makers. Place, F.; Gauthier, M. eds. Rome, Italy, Food and Agriculture Organization of The United Nations. 49 p. (Agroforestry Working Paper) (1). Available in: http://www.fao.org/docrep/017/i3182e/i3182e00.pdf

Ferster, C.J.; Coops, N.C.; Harshaw, H.W.; Kozak, R.A.; Meitner, M.J. 2013. An Exploratory Assessment of a Smartphone Application for Public Participation in Forest Fuels Measurement in the Wildland-Urban Interface. Forests 4: 1199-1219 doi: 10.3390/f4041199

Ferster, C.J.; Coops, N.C. 2014. Assessing the quality of forest fuel loading data collected using public participation methods and smartphones. International Journal of Wildland Fire 23(4): 585-590 doi: 10.1071/WF13173

Fuentes, S.; Bei, R.d.; Pozo, C.; Tyerman, S. 2012. Development of a smartphone application to characterise temporal and spatial canopy architecture and leaf area index for grapevines. Wine and Viticulture Journal 27(6): 56-60

Godlevsky, L.; Bidnyuk, E.; Bayazitov, N.; Kresyun, N.; Kovalenko, A.; Lyashenko, A.; Balykov, V. 2013. Application of mobile photography with smartphone cameras for monitoring of early caries appearance in the course of orthodontic correction with dental brackets. Applied Medical Informatics 33(4): 21-26

Gold, M.; Cernusca, M.; Hall, M. 2013. Handbook for agroforestry planning and design. Gold, M.; Cernusca, M.; Hall, M. eds. Missouri, USA, The Center for Agroforestry - University of Missouri. 81 p. (1). Available in: http://centerforagroforestry.org/pubs/training/index.php

Gómez-Robledo, L.; López-Ruiz, N.; Melgosa, M.; Palma, A.J.; Capitán-Vallvey, L.F.; Sánchez-Marañón, M. 2013. Using the mobile phone as Munsell soil-colour sensor: an experiment under controlled illumination conditions. Computers and Electronics in Agriculture 99: 200-208 doi: 10.1016/j.compag.2013.10.002

Gong, A.; Wub, X.; Qiu, Z.; He, Y. 2013. A handheld device for leaf area measurement. Computers and Electronics in Agriculture 98(2013): 74-80 doi: 10.1016/j.compag.2013.07.013

Gopinath, S.C.B.; Tang, T.-H.; Chen, Y.; Citartan, M.; Lakshmipriya, T. 2014. Bacterial detection: From microscope to smartphone. Biosensors and Bioelectronics 60(0): 332-342 doi: 10.1016/j.bios.2014.04.014

GWI (Global Web Index, United Kingdom). 2014. GWI Device Report 2014. London, United Kingdom, Global Web Index. 31 p. (Reports)

ICRAF (World Agroforestry Centre, Kenya). 2006. World Agroforestry into the Future. Garrity, D.; Okono, A.; Grayson, M.; Parrott, S. eds. Nairobi, Kenya, World Agroforestry Centre. 213 p. Available in: http://www.worldagroforestrycentre.org/downloads/publications/PDFs/b14409.pdf

Inman-Narahari, F.; Giardina, C.; Ostertag, R.; Cordell, S.; Sack, L. 2010. Digital data collection in forest dynamics plots. Methods in Ecology and Evolution 1(3): 274-279 doi: 10.1111/j.2041-210X.2010.00034.x

Itoh, T.; Eizawa, J.; Yano, N.; Matsue, K.; Naito, K. 2010. Development of Software to Measure Tree Heights on the Smartphone. Journal of the Japanese Forest Society 92(4): 221-225 doi: 10.4005/jjfs.92.221

Jain, L.; Kumar, H.; Singla, R.K. 2014. Assessing Mobile Technology Usage for Knowledge Dissemination among Farmers in Punjab. Information Technology for Development 2014(1): 1-9 doi: 10.1080/02681102.2013.874325

Kennedy, R.; McLeman, R.; Sawada, M.; Smigielski, J. 2014. Use of Smartphone Technology for Small-Scale Silviculture: A Test of Low-Cost Technology in Eastern Ontario. Small-scale Forestry 13(1): 101-115 doi: 10.1007/s11842-013-9243-5

Kent, J.; Ammour, T. 2012. Análisis financiero y económico de la producción de madera en sistemas agroforestales. *In* Detlefsen, G.; Somarriba, E. eds. 2012. Producción de madera en sistemas agroforestales de Centroamérica. Turrialba, Costa Rica, CATIE. p. 91-111. (Technical Series). Available in: http://finnfor.catie.ac.cr/admin/documents/208

Pratihast, A.K.; Souza-Junior, C.M.; Herold, M.; Ribbe, L. 2012. Application of mobile devices for community based forest monitoring. *In* Sensing a Changing World II (II, Wageningen, Netherlands) 2012. Wageningen, Netherlands, Wageningen UR. p. 3.

Pye-Smith, C. 2013. Trees for Life: Creating a more prosperous future through agroforestry. Nairobi, Kenya, World Agroforestry Centre. 167 p. Available in: http://www.sifi.se/wp-content/uploads/2014/09/ICRAF_lo_res_bookV14.pdf

Santos-Martin, F.; Bertomeu, M.; van Noordwijk, M.; Navarro, R. 2011. Why smallholders plant native timber trees: lessons from the Philippines. Bogor, Indonesia, ASB Partnership and ICRAF. 4 p. (Policy Brief) Available in: http://outputs.worldagroforestry.org/record/6570/files/ICRAF-2014-414.pdf

Snelder, D.J.; Lasco, R.D. 2008. Smallholder Tree Growing in South and Southeast Asia. *In* Snelder, D.; Lasco, R. eds. 2008. Smallholder Tree Growing for Rural Development and Environmental Services. Springer Netherlands. p. 3-33. (Advances in Agroforestry). doi: 10.1007/978-1-4020-8261-0_1

Somarriba, E.; Beer, J.; Muschler, R.G. 2001. Research methods for multistrata agroforestry systems with coffee and cacao: recommendations from two decades of research at CATIE. Agroforestry Systems (53): 195–203 doi: 10.1023/A:1013380605176

Somarriba, E.; Suárez-Islas, A.; Calero-Borge, W.; Villota, A.; Castillo, C.; Vílchez, S.; Deheuvels, O.; Cerda, R. 2014. Cocoa-timber agroforestry systems: Theobroma cacao-Cordia alliodora in Central America. Agroforest Systems 88(1): doi: 10.1007/s10457-014-9692-7

UNESCO (United Nations Educational Scientific and Cultural Organization, France). 2014. Reading in the mobile era: A study of mobile reading in developing countries. Paris, France, United Nations Educational Scientific and Cultural Organization. 85 p. (1).

Wallace, R.D.; Bargeron, C.T. 2014. Identifying invasive species in real time: early detection and distribution mapping system (EDDMapS) and other mapping tools. *In* Dukes, J.S.; Ziska, L.H. eds. 2014. Invasive species and global climate change. Wallingford, CABI. p. 219-231. doi: 10.1079/9781780641645.0219

WEC (World Economic Forum, Switzerland). 2014. The Global Information Technology Report 2014. Bilbao-Osorio, B.; Dutta, S.; Lanvin, B. eds. Geneva, Switzerland, World Economic Forum. 368 p. (Reports)

Wu, H.; Chang, C.; Lin, C.; Tsai, M.; Chang, C.; Tseng, M. 2014. Developing screening services for colorectal cancer on Android smartphones. Telemedicine and e-health 20(8): 687-695

Appendix

Appendix A. Data categories and attributes supported by Agroforestree app.

Data category	Attributes	Unit	Categories Options
Farm	Farm name	text	--
	Owner	text	--
	Phone	number	--

Data category	Attributes	Unit	Categories Options
	Country	categorical	List of world countries
	City	text	--
	Community	text	--
	GPS Spot	number	--
	Area	categorical	hectare; square meter; acre; square yard; manzana
	Main Crop	text	--
Plots	Plot number	number	--
	GPS Spot	number	--
	Implementation/Evaluation Date	date	--
	Area	number/categorical	hectare; square meter; acre; square yard; manzana; linear meter
	Slope	%	--
	Plot form	categorical	Rectangle; Circle; Line; Irregular
	System type	categorical	Pastureland; Coffee; Cocoa; Migratory agriculture; Taungya; Boundary; Agroforestry; Quezungual; Home garden; Forest
Tree	Tree number	number	--
	Species	text	--
	GPS Spot	number	--
	Measure at 1.3 m	number/categorical	DBH; CBH
	Total height	number/categorical	Clinometer; Visual estimation
	Commercial height	number/categorical	Clinometer; Visual estimation
	Crown diameter	number	--
	Occlusion	%	--
	Stem form	categorical	Normal; Forked; Broken; Sinuous; Inclined; Asymmetric
	Health	categorical	Healthy; Sick
	Mortality	categorical	Harvest; Thinning; Fire; Natural causes; Wind; Diseases; Clandestine cut
	Evaluation date	date	--
	Observations	text	--
Seedling	Species	text	--
	Seedling quantity	number	--
	Sapling quantity	number	--
	Young tree quantity	number	--
	Evaluation date	date	--
	Observations	text	--