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An innovative agroforestry system for food and fuel production

RESEARCH NOTES

ABSTRACT

In the Philippines, as the population passes 100 million, issues of food security, clean energy access and natural resource use have come into sharper focus, as well as the growing threats from climate change. New and innovative agricultural systems are required to satisfy these critical challenges. For the past 20 years, the Sustainable Agriculture and Natural Resource Management Project in Mindanao has been developing solutions to some of these issues. Its conservation agriculture with trees (CAT) system has helped stabilize and build up soils, conserve water, and prevent landslides in the uplands, while increasing food productivity. However, the clean energy component, which is vital for both greenhouse gas mitigation and food security, has been missing. This paper describes the integration of bioenergy into the CAT system. It draws upon cutting edge bioenergy models in the Philippines and internationally to highlight the potential for an integrated food–energy system using agroforestry, livestock, and bioenergy. It outlines the feasibility and merits of such an approach in the upland farms of the Southern Philippines.

Key words: *integrated farming systems, agroforestry, bioenergy, Philippines farming systems, integrated farming systems*

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INTRODUCTION

The Philippines is an archipelago in Southeast Asia between 4°23' and 21°25' north latitude and 116° and 127° east longitude. With an area of 300,000 km^2, the country is composed of 7,107 islands, of which only about 3,144 have names. Luzon, Visayas and Mindanao are the three largest island groups, which are further subdivided into 17 regions, 80 provinces, 143 cities, 1,491 municipalities, and 42,028 barangays. According to the World Bank, about 37.5% of its total land area was devoted to agriculture in 2000 (*Villar 2014*).

Two distinct seasons characterize the tropical climate of this country; the wet and dry seasons. The wet season covers June–November, and the dry season is from December to May. Temperatures ranges from 18.7°C in January to 36.0°C in March (*NSO 2014*).

The Philippines is predominantly an agricultural archipelago with a total population of 93,444,322 in 2010, which is expected to reach 110,404 by 2020, and with an average annual growth rate of 1.7% (*World Bank nd*). Rapid population growth, as well as rising incomes, in an agricultural and developing country such as the Philippines, creates a demand for increased food production. The growing population is largely dependent on land for its food and livelihood. The *UN Food and Agricultural Organization* (*2009b*) predicted that developing countries will need to double their overall food production by 2050. Depending on energy prices and government policies, the production of biofuels could also increase the demand for agricultural commodities. However, the capacity to produce food is being hampered by conversion of agricultural land to other economic uses and by the changing climatic conditions, among others. In 2011, the Agriculture and Fisheries sector's growth of 2.5%, which contributed a gross value added of PhP 676, 209 M, remains below the 4.3–5.3% growth target (*ADBI 2013*). When compared with international situations, the country is an average performer in terms of land productivity (*Habito and Briones nd*). With increasing population, agriculture has expanded into marginal and environmentally sensitive areas, which contributes to forest depletion and land degradation. Furthermore, greenhouse gas emissions are on the rise: national agricultural emissions exceeded 785 MT of CO_2 eq in 2010, which is a 75% increase since 1990 (*FAO 2014a*). Facing these multiple challenges, agriculture in the Philippines

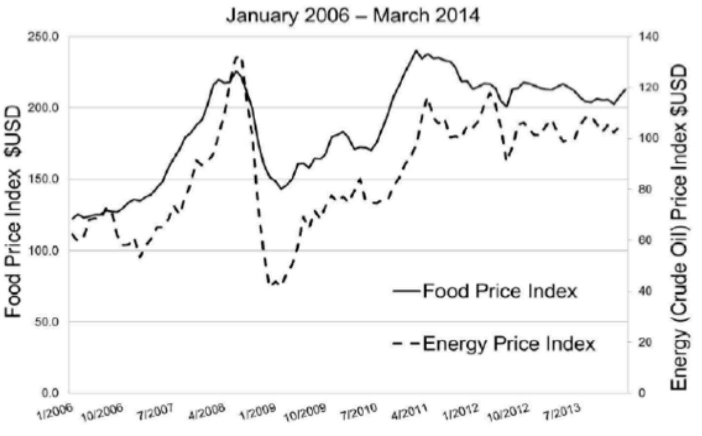

Figure 1. Food and energy prices over time.

should further intensify and increase productivity, while minimizing its negative impacts and using clean energy. Previous efforts in agricultural intensification have usually relied on increased inputs of energy, water and agrochemicals. High energy inputs are required for pumping irrigation water, on-farm mechanization, food processing, refrigerated storage, and transport of agricultural products to end consumers. Moreover, a close relationship exists between the rising energy prices and the costs of agricultural production, hence the price volatility of energy services can adversely affect food insecure populations, particularly those located in emerging economies and developing countries. Currently, the integration of a clean energy component is missing in most farming systems in the Philippines (**Figure 1**).

Energy Demand and Supply

The Philippines is still strongly reliant on energy imports, and about 28 million of its population have no access to electricity. The lack of adequate electricity supply, particularly for Mindanao region, endangers various economic activities, thus it is a major challenge that could hinder regional development. Recently, blackouts lasting for about eight hours have been hitting many parts of Mindanao, and residents may suffer longer power interruptions because of the delayed repairs of electric towers that were bombed in North Cotabato and Lanao del Sur. Davao City is also experiencing power outage every day because of the shutdown of a 120 MW generating unit of Therma South coal-fired power plant and the low water levels of Pulangui River in Bukidnon and Lake Lanao, which are the main sources of hydroelectric power in the region. These power outages considerably affect rural areas where farms depend on electricity to run irrigation system. Furthermore, the recent El Niño phenomenon in the Philippines, which hit Mindanao the hardest, damaged about 17,000 ha of rice and cornfields in the said region (*Saunar 2016*). Consequently, more than 20,000 farmers are affected. Water pumps and solar pumps were then distributed to the farmers for irrigation.

Affordable and reliable energy services are vital for reducing poverty, improving health, increasing productivity, enhancing competitiveness, and promoting economic growth (*IEA 2013*). Energy is essential in meeting basic needs, such as cooking, boiling water, heating and lighting. Therefore, clean energy is a prerequisite for both sustainable development and food security.

To date, food production is highly dependent on fossil fuels, giving rise to food insecurity as oil prices fluctuate, as well as negative environmental externalities. On farms, the cheapest and most accessible alternative is often bioenergy from tree branches and animal manure, which are by-products of food production. That energy can in turn help increase food production (e.g., by powering irrigation) and reduce postharvest losses through processing (e.g., drying, refrigeration and cooking). In that way, both the production and use of bioenergy are interwoven with food production. Such integrated food–energy systems (IFES) create synergies between food and bioenergy rather than conflicts as often depicted in 'food versus fuel' debates. Hence, the most accessible bioenergy source in on farms, which are generally regarded as waste, can now be utilized.

Farming Systems in the Philippines

Farming systems vary among locations, depending on the agroecological conditions, biophysical environment, available technology, and the extent and quality of available natural resources (*ADBI 2013*). In Philippine upland areas, agroforestry systems have been introduced to reduce destructive "kaingin" or slash-and-burn farming practices, specifically in degraded areas. Agroforestry is a collective name for land-use systems and technologies with which woody perennials are deliberately combined in the same management unit as herbaceous crops and/or animals, either in some forms of spatial arrangement or temporal sequence (*Lundgren 1982; as cited by Bogdanski et al., 2010*). Two significant roles that agroforestry systems provide are ecosystem services and productive services. The former includes practices that ensure food diversity, seasonal nutritional security and greater resilience to climatic fluctuations, while the latter includes practices that help protect and sustain agricultural production capacity that provides food, fodder, fuelwood, building materials and medicine to the user (*Bogdanski et al. 2010*). A multitude of agroforestry systems and practices exist: intercropping systems (e.g., alley cropping), multistrata systems (e.g. homegardens, shaded-perennial systems), protective systems (e.g. riparian buffer, windbreaks, live fence), silvopasture (e.g. grazing systems, tree-fodder systems), and tree woodlots (e.g. fodder trees, fuel wood trees, degraded land rehabilitation) (*Nair 2012*).

Conservation Agriculture with Trees

To increase agricultural productivity, restoring the soil health is often the first entry point because soil nutrient depletion is extreme in most areas where farmers have small holdings (*Garrity and Nair 2012*). Crops such as maize can deplete the soil; to help address this, ICRAF established the conservation agriculture with trees (CAT) farming system in its demonstration farm in Claveria, Misamis Oriental. CAT helps restore the eroded and impoverished soils in the uplands, and consequently increase yields and incomes. It involves minimum tillage, crop rotation and diversification, covering the soil with organic matter or groundcover plants, and integrating trees that anchor the soil and help prevent landslides. The integration of trees also increases soil carbon levels, thus the system plays a role in reducing global warming (*Mutua et al. 2014*). The system has helped in stabilizing and building up soils, conserving water, and preventing landslides in the uplands, while increasing food productivity and farmers' incomes.

EverGreen Agriculture

EverGreen Agriculture is an agroforestry system that has been developed and practiced in Africa. It emphasizes the application of sound, tree-based management practices and the knowledge to adapt these to local conditions to optimize fertilizer and organic resource-use efficiency for greater crop productivity. This system is similar to the principles of conservation agriculture, except that it incorporates trees – typically nitrogen-fixing trees. (I*CRAF 2012*). The African indigenous acacia, Faidherbia albida, is widely used, drawing nitrogen from the air and transfering it to the soil through the leaf and litter. Hence, this tree increases food security by enhancing millet, sorghum, and livestock fodder production in countries such as Mali, or

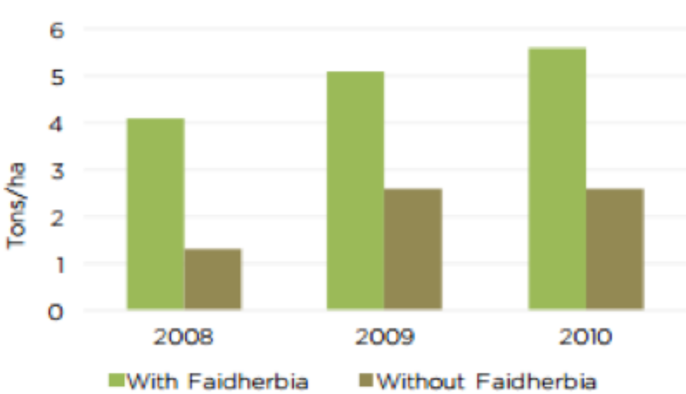

Figure 2. Faidherbia trial results in Zambia showing maize yields with zero fertilizers (average of 40 locations; differences highly significant).

Zambia where it increases maize yield (**Figure 2**), or in Malawi. Hence, national governments across Africa are deepening their support for the expansion of the EverGreen Agriculture systems (*ICRAF 2012*).

Agroforestry has gained increasing worldwide attention for its role in addressing food security and environmental resilience (*Garrity and Nair 2012*). The integration of beneficial trees, such as fertilizer and fuel wood trees, into food crop agriculture can increase food and energy production for small-scale farmers, which is one example of IFES.

Integrated Food Energy Systems

There are broadly two types of IFES: Type 1 combines the production of food and bioenergy on the same land by combining crops for food and others for bioenergy. An example would be agroforestry, in which the trees or perennials can be harvested for bioenergy but they also enhance the food crop (which could also be livestock or aquaculture) by providing shelter, soil carbon, nitrogen fixation etc. Type 2 IFES typically use a food or feed crop that also has a bioenergy component. Sugar cane could be an example of this, where the sugar is used for food, the molasses for animal feed and the bagasse or other residues burnt for fuel. Type 2 IFES also includes 'cascading' use of biomass. For example, livestock manure is a by-product of food production that still contains energy that the gut of the animal was not able to extract. Technologies such as anaerobic digestion make it possible to extract and use that energy. IFES function at various scales and configurations, from small-scale systems that operate at the village or household level mainly for the purpose of self-sufficiency, to large scale industrial operations (*Bogdanski et al. 2010*).

Benefits of IFES

Multiple benefits can be obtained from this integrated farming system. *Bogdanski et al.* (*2010*) stated that IFES can improve the farmer's livelihood when the farmer or local community becomes self-sufficient in terms of food and energy production, or when the food and/or energy generated provides income to the farmer of community. According to the type of system used, this holistic approach intends to stabilize or increase yields for food, feed, and other useful plants, increase the efficiency of livestock production and use of renewable energy, thereby increasing the resource use efficiency (*Gradual transformation 2011*) Resource efficiency is key in a world concerned about environmental impacts, climate change, material prices, and security of supply (*OECD 2008*). Agriculture, forestry and other land use are major producers of GHG emissions, accounting for a quarter of total global GHGs in 2010. A global potential mitigation of 770 Mt CO_2 eq yr^{-1} by 2030 was estimated from improved energy efficiency in agriculture (*IPCC 2007*). Improved technology, farming and management practices for IFES could enable emission reductions while strengthening the adaptation to climate change through the integration of cropping, livestock, forestry, fisheries, conservation of biodiversity and ecosystem services (*Bogdanski et al. 2010*).

IFES in Sri Lanka

Much of Sri Lanka's population is completely off-grid and without any electrical power. The country's dependence on imported fossil fuels poses environmental and economic problems. Only around 15%–20% of the off-grid population in the country have been provided with energy needs by solar and mini-hydro power. The government set a target of 100% country-wide electrification by 2015, hence the Ministry of Power and Energy formulated the National Energy Policy and Strategies for Sri Lanka in 2008 (*Gunasekare 2014*). During the past 25 years, partners have worked on developing a dendro power industry that is largely based on Gliricidia as feedstock.

In 2005, *Gliricidia sepium* was ranked as the fourth plantation crop by the Sri Lankan government (after tea, rubber, and coconut), considering its multi-purpose use as fodder, fuel, and fertilizer. *Gliricidia* is recognized as a promising crop for dendro-thermal applications due to its growth characteristics, such as high wood yield, tolerance to frequent harvesting, low mortality, easy establishment even on marginal lands, easy handling due to appropriate size of branching and versatility. The nitrogen-fixing (NF) *Gliricidia* trees can be used as fuel wood because they are fast growing and well-suited for tropical countries such as Sri Lanka. *Gliricidia* can be planted under coconut plantations as intercrop; or as a shade tree in tea, cocoa, and coffee plantations; as a crop for reforestation; or as a vine support in pepper and vanilla plantations. It has multiple other benefits, such as soil moisture conservation and nitrogen enrichment. It can withstand adverse weather conditions and climate change impacts. Its foliage is an ideal base for organic fertilizer and constitutes an attractive fodder for cattle. Dendro power using *Gliricidia* already accounts for a significant chunk of the power requirements in diverse industries of tea, rubber, and pepper industries, as well as food processing and textile industries in Sri Lanka. A 35 kW generator that is exclusively operating on *Gliricidia* wood has been installed by Lanka Transformers Limited (LTL) as a demonstration unit. Upon success, LTL launched community-scale 4 kW and 9 KW systems using *Gliricidia* feedstock from smallholders for electricity generation, together with Ankur gasifier systems (*ICRAF 2005*). More than 10 Sri Lankan villages have been electrified throughdendro power (*Laguihon and Pagbilao nd*).

Economic analyses of IFES

The cost-benefit analysis result of an agroforestry system may be affected by geographic locations, unstable market, fluctuating price of agroforestry products, and other factors. *Thang et al.* (*2015*) conducted an analysis on four agroforestry systems in Vietnam, which have been widely established in northern mountainous provinces. Star anise and tea yielded the highest economic benefits (US$ 6,527 ha y^{-2}), followed by cassava and bead tree system (US$ 2,905 ha y^{-2}), acacia hybrid and cassava (US$ 1,043 ha y^{-2}), and *Acacia mangium* and maize (US$ 870 ha y^{-2}), respectively. Challenges, such as unstable market, have been encountered in such analysis, thus challenges and opportunities of such systems should still be discussed and dealt with for sustainable development. In Puerto Rico, the AMISCONDE project showed that coffee/tree systems have significantly higher returns than coffee without trees, reduce the risk from coffee price fluctuations and reduce the need for chemical fertilizers (*Mehta and Leuschner 1997*).

In Brazil, an economic feasibility of candeia cultivation, in risk situations, under conditions of monoculture and intercropped with other agricultural crops, was conducted. The agroforestry systems being tested are economically feasible, noting that the system in which candeia is cultivated at spacing intervals of 10 × 2 m, intercropped with corn in between rows, is more profitable and less risky than the others (*Silva et al. 2012*).

Sri Lanka has been practicing IFES by using dendro power. *Chaturika and Gunawardena* (*2005*) analyzed the economics of two dendro power plants in Sri Lanka and used two study sites: a power plant with a capacity of 5 kW operated under the management of a community-based organization in an off grid area in Moneragala district (case 1) and a power plant with a capacity of 3.5 kW operated under a private ownership in a high yielding coconut estate. Both power plants produce electricity via gasification and internal combustion engine technologies using in-situ grown *Gliricidia sepium* sticks. The major costs of both projects are initial costs of power plant installation, operational and maintenance costs. The major benefits of case 1 are crop protection from wild animals and electricity benefit, and that of case 2 are fertilizer substitution benefit from *Gliricidia* leaves and electricity benefit. They found that both cases are viable from the economic point of view even with a 10% increase of total cost and a 10% reduction in total benefits. Their study recommends that the dendropower plants are viable ventures from economic point of view where enough lands are available to grow sustainably grown fuel wood.

A sustainable food and charcoal production in the Democratic Republic of Congo was also analyzed. Kinshasa, the capital of this country, consumes about 6 MT of bioenergy equivalent per year. The bioenergy used by the urban households consists mainly of fuelwood, such as charcoal and firewood. Charcoal needs and most of the staple starchy food are provided by slash-and-burn shifting by carbonization of the patches of forest and tree savannahs, which continue to deteriorate. Consequently, the production becomes scarce and expensive. Soil fertility is declining, and crop yields are decreasing after fallow. Thus, their plantations were developed, and farmers were required to manage their tree plantation by combining food crops with acacia. The total charcoal production from the plantation currently varies between 8000–12000 t yr^{-1}. The farmers also produce 10000 t yr^{-1} of cassava, 1200 t yr^{-1} of maize, and 6 tons/year of honey. Such production means an income of US$ 9000 yr^{-1} (US$750 mo^{-1}) for individual farmer who uses 1.5 ha of his parcel. In comparison, a taxi driver in Kinshasa earns US$ 100–200 mo^{-1} (*Bogdanski et al. 2010*).

Another example of the economic analysis of IFES is that of Tosoly Farm in Colombia presented by *Bogdanski et al.* (*2010*). This 7-ha farm has sugar cane (feed for pigs, food, and energy) and coffee and cocoa (food and energy), with multipurpose trees. Most of the energy on the farm is produced through gasification of the sugar cane bagasse and the stems from the mulberry and Tithonia forages. The 800 W installed capacity of photovoltaic panels are estimated to yield 8 KWh daily. The eight biodigesters produce 6 m^3 daily of biogas, two thirds of which are converted to electricity (6 KWh day^{-1}) using it as fuel in the same IC motor generator attached to the gasifier. The remainder is employed for cooking. Low-grade heat energy, produced by the solar water heater and wood stove, are not included in the energy balance. After deducting the electricity used to drive the farm machinery and to supply the house, the potentially exportable surplus is 104 KWh daily, which at the current price of electricity (US$ 0.20/KWh), would yield an annual return of US$ 7,600. The gasifier produces 4.4 t of biochar yearly, which is returned to the soil. Assuming that the 65% of carbon in the biochar is not oxidized in the soil (*Lehmann 2007*), then the effective sequestration of carbon dioxide is in the order of 11 t annually. The combined house and machinery use 11 KWh d^{-1} of electricity. The farm produces 10-fold this amount, mostly through the gasifier but 8.0 KWh d^{-1} comes from the solar panels and 6.0 KWh d^{-1} from the biodigester. Therefore, 104 KWh d^{-1} is sold to the grid for around US$20, or US$7 558 yr^{-1}.

Discussion of IFES in the Philippines

The Philippines has the second highest electricity price in Asia (*Morales 2012*), yet demand continues to rise, and the country is strongly reliant on imported fossil fuels. Currently experiencing power shortages, the Philippines is planning an additional 5,198.40 MW of power projects from 2014 to 2020, as reported by the Department of Energy in 2014 (*"GE technology uses" 2014*). Hence, IFES are especially needed to produce sustainable fuels without displacing food production.

Numerous IFES have already been established in the Philippines. The Mindanao Baptist Rural Life Center (MBRLC) has long-established configurations that use pig manure for biogas production (cascading use of biomass) but has not generally used the nitrogen fixing shrubs and trees for energy.

This review presented the idea of combining Conservation Agriculture with Trees (CAT), the EverGreen Agriculture principles and the Sri Lankan *Gliricidia* model. The CAT approach enables abundant biomass to be produced and removed for animal feed and bioenergy without depleting the soil, unlike in most conservation agriculture systems. This is because the roots of the trees and the groundcover perennials ensure high carbon stocks and stability in the soil. The principle of EverGreen Agriculture combines well with the *Gliricidia* model because an additional layer of photosynthesis exists all-year-round in both models because of the tree canopy. This would be cut back regularly before shading of surrounding crops becomes a problem.

The trees in the system, ideally, should be nitrogen-fixing and able to be coppiced or pollarded for the wood, which can be fed into a gasifier to produce electricity. Generally, the leaves, which are high in protein, would be fed to livestock along with the groundcover plants (e.g., *Arachis pintoi*). The slurry from the livestock would be used for biogas production – a very clean cooking fuel that can bring major health benefits by improving indoor air quality, as well as reducing the burden on women of collecting firewood. Candidate trees species include those being used in the SALT system. Some potential nitrogen-fixing trees and shrubs for SALT hedgerows at MBRLC, can be utilized for the integrated farming system of food and fuel (**Table 1**).

A criterion for good hedgerow species is the ability to produce seed under local conditions, which is important for the reproducibility of the system. Based on local experiences, *Calliandra* sp. needs at least 500 m to 600 m of altitude for good seed production (*Palmer 1999*). *Leucaena diversifolia* shows promise, but has not performed as well as

Table 1. Most utilized and promising species of nitrogen-fixing trees and shrubs for SALT hedgerows at MBRLC, 1988 to 1995 (*Palmer 1999*).

NFT/S Species	Fresh, T ha^{-1}	Dry, T ha^{-1}
*Calliandra tetragona**	51.9	16.1
Calliandra calothyrsus	49.8	15.9
Leucaena diversifolia	42.3	11.8
Gliricidia sepium	36.5	8.4
Erythrina poeppigiana	34.3	5.8
Flemingia macrphylla	34.1	9.5
Desmodium rensonii	31.0	6.5
*Indigofera anil***	28.5	9.1

*First harvest-December 1990
**First harvest-November 1980
All other species were planted and first harvested in 1988

others in actual farm trials. This variety is a good seeder and is tolerant to jumping plant lice, which plagues larger leafed *Leucaenas* in the area. *Gliricidia sepium* is one of the most widely-used NFT/S in Asia. Well-known for use as fencing material- largely via cuttings- and animal feed, *Gliricidia* is possibly one of the best species choice for hedgerows as well. Its benefits are evident, as shown in the *Gliricidia*-based dendro power industry in Sri Lanka. However, effort should be made to find local seed sources. *Gliricidia* seems only to set seed well in areas with dry zones having at least a 4 to 6 months dry period.

Erythrinas are good nitrogen fixers and grow well from seeds or cuttings, but are limited as hedgerows because of their thorns. Meanwhile, *Flemingia macrophylla* may be the most widely adaptable NF contour hedgerow species since it also originates in Asia and may also be the best NF hedge in terms of providing a long lasting ground cover after trimming. *Desmodium rensonii* is still fairly unknown around the world, but is possibly the best animal feed in the tropics. With a crude protein content of 23%, rivalling alfalfa in temperate climates, *D. rensonii* has been successfully tested as an animal feed for goats, sheep, cattle, rabbits, guinea pigs, swine, and fish. *Indigofera tyesmani* (anil) shows promise in hedgerow systems, as an animal feed, and as a fuelwood crop. In simple tests at the MBRLC, Nubian goats fed a diet of 100% *Indigofera* for over a year, grew well and even kidded.

Following the model of the *Gliricidia*-based dendro power industry in Sri Lanka, a similar system of IFES can be adapted for the Philippines. Several potential trees for integration have been mentioned. *Flemengia macrophylla*, the native species, which can be easily available and suitable for the climate, as well as the widely-used *Gliricidia* can be utilized. *Flemengia*, which remains green throughout the year, can be used as fodder as in Ghana. Producing 6.8 t of dry woody stems ha^{-1} from a 2-year old stand with a spacing of 0.5 × 4, this species is a source of fuel. A good windbreak, nitrogen-fixer, shade and intercrop, *Flemengia* can be used in IFES. In addition, *Gliricidia* is relatively free of serious diseases, despite the fact that it is widely grown. The toxicity of its leaves mixed with cooked maize can even be used as rodenticide in Central America, which can be due to the conversion by bacteria of coumarin to dicoumerol, a haemorrhagic compound, during fermentation (*Cook et al. 2005*). However, when correctly managed, *Gliricidia* can provide fresh feedstuff to cattle, sheep, and goats because it is generally used as a high protein supplement to low quality basal feeds such as grass; its supplementation levels vary, but are usually in the range of 20 to 40%. A number of reports have already revealed the increase in weight gain and milk production in both large and small ruminants when *Gliricidia* forage is used as a supplement. The differences in the palatability of this forage may vary because of different causes, such as differences in management climatic or edaphic effects on leaf chemical composition, and differences in behavior or in rumen flora between animals in different places, or genetic variation in *Gliricidia* itself (*FAO 2009a*). Often used for firewood and charcoal production, *Gliricidia* can now be utilized as feedstock for electricity generation, as in Sri Lanka, via gasification. As it can also be used for its services for erosion control, improving soil, and as barrier/boundary among others, *Gliricidia* is a beneficial tree in the Philippines.

Private sector stakeholders applying IFES

In Pampanga, napier grass is currently being developed for use in a power plant. GE Distributed Power sealed a deal with Advance Energy Technologies (AET) to supply an integrated gasification biomass solution to sustainably run Pampanga's Best operations by using napier grass for gasification and electricity production. Byproducts of bio-char and ash go back to the farmers as fertilizers ("*GE technology uses*" *2014*). Being a C4 crop, the napier grass is more efficient at photosynthesis and can thus produce additional biomass for electricity without forfeiting the feed output compared with the baseline of pasture grass.

Bronzeoak Philippines is another leader in the development and implementation of renewable energy projects based in the Philippines. It was established in 2003 and has been working with a range of local and international partners and investors in its projects. In 2006, Bronzeoak inaugurated the first integrated sugarcane, ethanol and power cogeneration plant in Asia, located on Negros Island, Philippines. To date, San Carlos Bioenergy has been capable of an annual production of 40 M l of fuel ethanol, 40 M kg of sugar syrup and 60 M KWh of renewable electricity.

Swaminathan (*2012*) concluded that building a successful evergreen revolution requires four components: technology, services, favorable public policies, and farmer enthusiasm; technological advances and novel solutions should be linked with ecological thinking to drive a sustainable agricultural revolution. With the presence of technologies and power plants and possible private partners, a public-private collaboration can be made among stakeholders to further improve and develop the bioenergy or fuel production from the beneficial trees that could be integrated in the current agroforestry systems to meet the country's energy demand while addressing the need for food security.

Byproducts of bioenergy that can increase food production

Biochar has been shown to increase soil fertility in some situations, especially where the soil is degraded. It is produced by thermal decomposition of organic material under limited supply of oxygen and at relatively low temperatures (<700 °C) (*Lehman and Joseph 2009*). This product also allows waste management as its production reduces the volume and weight of waste material in the farm. Moreover, as the process recovers energy from the waste, it indirectly mitigates climate change. The capture of energy during bio-char production and, conversely, using the bio-char generated during pyrolysis bioenergy production as a soil amendment is mutually beneficial in securing the production base for generating the biomass (*Lehmann 2007, as cited by Lehman and Joseph 2009*), as well as for reducing overall emissions. Adding bio-char to soil instead of using it as a fuel does, indeed, reduce the energy efficiency of pyrolysis bioenergy production; however, the emission reductions associated with bio-char additions to soil appear to be greater than the fossil fuel offset in its use as fuel (*Gaunt and Lehmann 2008*). Pyrolysis can in turn provide opportunities for more efficient energy use than traditional wood burning.

Another process that can be optimized in IFES is anaerobic digestion (AD), which naturally occurs when bacteria break down organic matter, such as green crop residues, in the absence of oxygen. Addressing both soil and energy needs, AD produces biogas consisted of methane and carbon dioxide; methane can be burnt to generate heat or electricity, while the digestate can serve as fertilizer.

Synergies have been discovered between liquid digestate from AD and biochar. When combined, the high cation exchange capacity of the biochar helps to reduce nutrient losses from the digestate, and soil fertility is promoted. Biochar is reported to remove nutrients, such as phosphorus and ammonia from wastewater. In an experiment to test the synergistic effects of the combination of effluent-treated biochar with biodigester effluent on soil improvement, soaking the biochar in the effluent for 72 hr gave a threefold increase in above ground growth of maize and of the maize roots when effluent was also applied as fertilizer. In the absence of effluent as fertilizer there was no response to prior soaking of the biochar in effluent. These responses support the concept of the biochar acting as a habitat where microbial biofilm facilitates the action of consortia of microorganisms in releasing minerals located in close proximity to their substrates (*Preston, et al. in the process of publication*). The first experiment in this series was carried out on a farm in Colombia where a downdraft gasifier had been installed and where effluents from tubular plastic plug-flow biodigesters were the principal sources of fertilizer. The sub-soil, application of biochar had no effect until it was combined with biodigester effluent, when the combination of the two amendments supported the same growth of maize as that achieved on the fertile soil (*Rodriguez et al. 2009*).

Agroforestry-based IFES

Generally, agroforestry is based on the overall assumption that the integration of trees on farms and in agricultural landscapes diversifies and sustains production for increased social, economic and environmental benefits for land users at all levels (*Roshetko et al. 2007*). However, adoption rates are low in many agroforestry projects. According to *Bogdanski et al.* (*2010*) constraints to adoption could be at the farm level or beyond. Farm level constraints include the knowledge, technology, financial, workload, and residue competition, whereas beyond farm level constraints involve access to markets, technical support, access to financing mechanisms, access to information and training, politics, and policies. A study in Leyte (*Santos-Martin et al. 2011*) showed another constraint factor is land tenure. As reported by *Sharma* (*2013*), among the agroforestry challenges is the selection of appropriate species and the quality of planting material. Hence, studies and surveys should be made on the appropriate tree species and farming system suited for a certain area in the application of IFES. Multiple and locally adapted species should be utilized.

In the Philippines, the government and policy-makers should give further attention to this farming system to help address two of the major issues that the country is facing: food and energy security. With the current high electricity cost, IFES will be significant in reducing household expenses while further generating additional income for the farmers.

CONCLUSIONS AND RECOMMENDATIONS

Energy and food production are two needs that developing countries with growing populations must address. Various agroforestry system models exist around the world, where some have used indigenous trees as a bioenergy component. In the Philippines, some farming systems have already been in practice, but the integration of an energy component is not a focus. Trees and other plant species should be deliberately included in farming system, not only to have a climate-smart production, but to obtain clean energy that can be considerably useful for smallholder farmers. Such system will not only rise against climate change but can also be income-generating. This kind of diversification will therefore increase the efficiency of tproduction, satisfying both food and energy needs in household level.

Coordinated action is needed from key people in government, research, and private sector to establish IFES. As with any agricultural market, private sector engagement and investment are vital for long-term success. Government support through secure land rights, feed in tariffs, and other incentives can help stimulate that private sector involvement, while public spending on research and development can aid in further developing the economics of the systems and minimising investor risks through IFES demonstrations.

Considering farmers' preferences is also important. Proper awareness and capacity-building steps must be taken to clearly communicate to farmers how innovative agroforestry-based IFES work and can benefit them through increased production and income levels, helping them adapt to climate change scenarios on a household level while meeting their food and energy needs.

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