Integrating forestry, sustainable cattle-ranching and landscape restoration

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A proposed new image of tropical cattle-ranching involves animals grazing in a shaded and biologically diverse environment, surrounded by high-quality edible biomass. These bulls graze under a rain tree* Albizia saman *at the El Hatico Reserve, El Cerrito, Valle del Cauca, Colombia

This example of natural intensification can simultaneously improve a farming system, generate environmental goods and services and facilitate the release of fragile, marginal and strategic areas for strict conservation.

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The livestock sector occupies about 30 percent of the land surface of our planet through grazing and feed-crop production. It is a leading driver of deforestation, land degradation, pollution, climate change, the sedimentation of coastal areas and invasions by alien species (FAO and LEAD, 2006). The link between livestock production and deforestation is strongest in Latin America, where cattle-ranching activities have expanded, mostly at the expense of forests. A simplified form of cattle-ranching based on grass monocultures has been practised for centuries in Latin America. This type of system has promoted environmental degradation and climate change because it goes against the natural dynamics of tropical forest ecosystems[1] (Wassenaara *et al*., 2007).

A paradox of cattle-ranching in Latin America is that, even though it is currently

[1] In tropical forest ecosystems, most nutrients are locked in living plants, animals and microorganisms. Closed nutrient cycles are promoted by a highly diverse vegetation with dense networks of fine roots and mycorrhizal associations, coupled with efficient decomposer assemblages.

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Cattle can help support complex soil food webs and restore fertility in degraded lands, such as here in the Cesar River valley, Cesar, Colombia

the principal land use, occupying more than 550 million hectares (ha), its average stocking and productivity rates are low (0.59 animals per ha, and 19.9 kg of beef or 89.7 litres of milk per ha per year, respectively; FAO, 2006). With some exceptions, this land use has minimal per-animal and per-ha production indexes and makes a meagre contribution to rural employment in the region.

Despite its inefficiency and its multiple negative effects on the environment, cattle-ranching is not likely to decline any time soon in Latin America. First, this activity is deeply rooted in the Portuguese and Spanish ancestry of the region. Second, a high and growing demand exists for all cattle products. Third, the activity has often been undertaken as a reaction to agricultural failures that result from biophysical constraints (Hernández, 2001; Murgueitio, 2005). Finally, over time, it has become instrumental as a means to consolidate land control (Murgueitio and Ibrahim, 2008).

However, tropical cattle-ranching activities can be improved and need not be destructive. Cattle have the potential to act as "mobile sun-powered catalytic converters", [2] capable of transforming the cellulose in plant biomass into simple carbohydrates that support complex soil food webs and help restore fertility in degraded lands (Patriquin and Moncayo, 1991). Sustainably managed in silvopastoral systems and integrated with connectivity corridors and protected areas, cattle-ranching can even become a tool for landscape-scale restoration. The large-scale transition from input-intensive cattle grazing on degraded pastures to environmentally friendly silvopastures could enhance the resilience of soil to degradation and nutrient loss, sequester large amounts of carbon (1.2 to 6.1 tonnes per ha per year; Ibrahim *et al*., 2010; Udawatta and Jose, 2011), reduce greenhouse gas emissions (Nair *et al*., 2011) and contribute to the protection of water resources by improving soil properties and reducing pollution (Chará, 2010). Jobs could be created, and high-quality food and other products could be produced, in a sustainable way.

This article describes ways to harness the power of the existing tropical cattle-ranching systems into intensive silvopastoral systems (ISPSs), explores sustainable timber production in these systems, including how and why certain species are selected, and discusses incentives for implementing ISPSs.

WHAT ARE ISPSs?

Forest and landscape restoration must go beyond afforestation, reforestation and even ecological restoration to improve both human livelihoods and ecological integrity (Minnemeyer *et al*., 2011; Laestadius *et al*., 2011). Landscapes should be restored and managed for a balanced combination of ecosystem services and goods, not only for increased forest cover.

It has been suggested that a high level of food production can only be achieved in

[2] Catalytic converters convert the toxic components of the exhaust of an internal combustion engine into less toxic substances.

ISPSs combine the high-density cultivation of fodder shrubs with improved tropical grasses and trees. This ISPS in Finca San Marcos, Tamalameque, Cesar, Colombia, incorporates* Brachiaria humidicola *(grass),* Tithonia diversifolia *(fodder shrub) and* Acacia mangium *(timber tree)

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chemically intensive and energy-demanding modern agriculture, which provides a low-quality habitat for wildlife, while alternative agriculture is doomed to low productivity, even if it is more biodiversity-friendly (Perfecto and Vandermeer, 2010). However, agricultural intensification and sparing the land do not necessarily constitute a dichotomy; *natural intensification* exists on the spectrum. This alternative seeks to maximize the efficiency of biological processes such as photosynthesis, nitrogen fixation and nutrient recycling in order to boost biomass production and enhance soil organic matter.

The inputs of naturally intensive systems are biological processes rather than fossil fuels and synthetic compounds, and they apply modern scientific knowledge to combine and manage species with different traits. ISPSs are a good example of natural intensification, in which the productive benefits of the system stem from the same processes that provide ecosystem services.

ISPSs are a form of agroforestry that combines the high-density cultivation of fodder shrubs (more than 8 000 plants per ha) for the direct grazing of livestock with improved tropical grasses and trees. The top vegetation layer may consist of trees or palms with densities ranging from 100 to 600 individuals per ha, in accordance with the biophysical and climatic conditions of each agroecosystem. Tree products – such as timber and fruit – may be directed to local markets, agribusiness or the protection of biodiversity (Murgueitio *et al*., 2010).

ISPSs respond to the increasingly urgent need to transform tropical cattle-ranching into an environmentally friendly activity that can be profitable in the short and medium terms and capable of generating more and better rural jobs while providing safe, high-quality food (meat, milk and fruit), hides and wood. These systems are suitable for beef, milk, dual-purpose or specialized cattle farming as well as buffalo, sheep and goats.

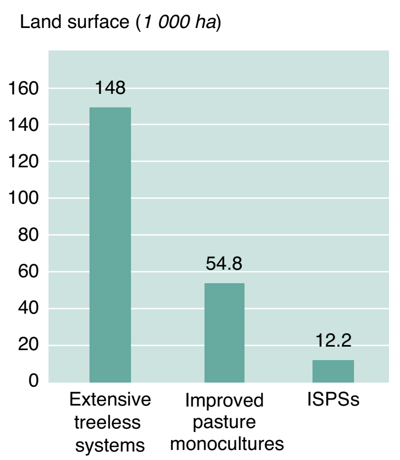
ISPSs should be based on solid scientific and technological knowledge (Dalzell *et al*., 2006; Shelton and Dalzell, 2007; Murgueitio *et al*., 2011; Murgueitio *et al*., 2012; Mahecha *et al*., 2012). They are being increasingly adopted in profitable and modern farms in Colombia and other Latin American countries. Because of their higher stocking density (2–5 head per ha), ISPSs allow farmers to concentrate production in the most suitable areas of their farms and release fragile lands for soil recovery and biodiversity protection (Chará *et al*., 2011). Some key features of ISPSs are high biomass production and the high nutritional quality of the fodder; rotational grazing with high stocking rates and brief grazing periods followed by long periods of plant recovery; and high per-ha productivity (Figure 1).

The proper functioning of ISPSs requires:

- a permanent supply of good-quality water in mobile troughs and mineralized salt;
- live fences planted at the periphery and internal divisions of paddocks;
- electrical fencing or tape, either fixed or mobile, to concentrate grazing on narrow strips;
- non-violent handling of livestock (Ocampo *et al*., 2011).

ISPSs combine elements of traditional livestock management, fodder banks and timber plantations, but are significantly different from these three land-use systems:

- Unlike conventional extensive cattle-ranching, ISPSs require rigorous management, administrative control and permanent adjustments based on careful monitoring. Management protocols are simple but mandatory; for example, once the system is established, fire and herbicides cannot be used. In Mexico,



By replacing extensive pastures with improved pasture monocultures or ISPSs, it is possible to produce the same amount of meat in 36 percent and 8 percent of the land area, respectively (Murgueitio *et al*., 2012).

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Land surface required to achieve an annual production of 10 000 tonnes of meat in the highly seasonal dry Caribbean region of Colombia

the farmers who have achieved the best results owe their success to their previous experience in agriculture and, in some cases, to their training in precision agriculture (Solorio-Sánchez *et al*., 2012).

- Unlike mixed fodder banks or other cut-and-carry systems, ISPSs are designed to tolerate direct browsing by cattle. Electric fencing must be handled properly in order to guarantee the heavy but instantaneous grazing of narrow strips of shrubs and grasses in each paddock. These short rotations minimize the negative impact of cattle on the soil and facilitate the recovery of shrubs and grasses. Once the cattle have moved forward to a fresh fodder strip, dung beetles and earthworms quickly bury or degrade the dung, thus interrupting the life cycles of various parasites (Giraldo *et al*., 2011; Murgueitio and Giraldo, 2009).
- ISPSs differ from tree plantations in their lower planting densities, the spatial arrangement of trees in rows alternating with strips of pasture or shrubs, the west–east (instead of north–south) orientation of tree rows and the timing and intensity of tree thinning and pruning, both chosen to minimize pasture shading.

Silvopastoral systems can enhance biodiversity in agricultural landscapes, as revealed by an analysis of the changes in the richness of bird species following the implementation of the Regional Integrated Silvopastoral Approaches to Ecosystem Management (RISAEM) project in Quindío, Colombia. After five years, total bird richness in the project area increased from 146 to 193 species, forest-dependent birds increased from 74 to 104 species, migratory birds increased from 10 to 19 species and one endangered species recolonized the area (Chará *et al*., 2011). The diversity of ant species in silvopastoral systems was equivalent to that recorded in remnant forest. Silvopastoral systems with complex vegetation can support significant levels of biodiversity (Harvey *et al*., 2005, 2006; Sáenz *et al*., 2007) and provide ecosystem services such as natural pest management, carbon sequestration, water and soil conservation, nutrient cycling, hydrological protection and crop pollination.

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For an ISPS to function properly, certain controls must be in place. On El Chaco farm, Pedras, Tolima, Colombia, electrical tape allows grazing to be concentrated on narrow strips. Note the browsed* Leucaena leucocephala *shrubs at the front

INTRODUCING TREES AND TIMBER PRODUCTION INTO ISPSs

ISPSs can combine the short-term profit from milk and/or meat production with a long-term investment in timber.

Tree species, silvicultural treatments and agroecological factors determine timber production in ISPSs. Timber trees are planted in double or triple lines separated by 15–30 m wide grazing strips. The initial density of trees in these systems is thus half or less the density in homogeneous tree plantations. With light interception by timber trees varying between 10 and 40 percent, ISPSs permit grazing until the final harvest of the trees. Controlled grazing is allowed four to eight months after the grasses and fodder shrubs have been planted; however, entrance of the cattle to the timber lines is restricted for up to 18 months by electric fencing. After that period, animals have access to the whole ISPS area.

Depending on the species and region, timber thinning or harvest may begin at year 7, with successive harvests up to

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ISPSs can enhance biodiversity in agricultural landscapes, such as this 2-year-old ISPS established in degraded soils of the Amazon foothills. Buenos Aires farm, El Doncello, Caquetá, Colombia

year 20–25. The total volume of wood is estimated to be 30 percent lower than in conventional plantations, but this reduction is offset by the increased price of timber at final harvest. In these systems, thinning and pruning are designed to maximize diameters above 30 cm (for pine and eucalyptus, in 15–16 years), increasing the volume of high-priced timber by 50 percent (Esquivel *et al*., 2010).

Selection of species

The livestock component of ISPSs biases the selection of trees toward nitrogen-fixing species, fruit trees that can supplement cattle nutrition and timber sources for farm use, local markets and industry.

Crown architecture is another important aspect of tree selection. In general, species with straight trunks and small crowns and that are self-pruning, such as *Cordia gerascanthus*, are preferred to highly branched trees with twisted stems. However, large nitrogen-fixing trees with edible seeds such as *Albizia saman*, *Albizia guachapele* and *Enterolobium cyclocarpum* (all in the Fabaceae family) are usually kept within ISPSs at a low density.

Species with open crowns that allow enough sunlight to reach the ground are used instead of trees with dense canopies that block sunlight. Mango trees are an exception because the benefits provided by their large crops of nutritious fruit and the increased nutrient recycling compensate for the reduced fodder production beneath their crowns. Species with small and rapidly decomposing leaflets are preferred to those with large, thick leaves that form persistent litter. *Tectona grandis* is an exception because the cattle eat some fallen leaves, while the combination of trampling and urine accelerates the decomposition of remaining leaves.

Transition from open pastures to ISPSs is often accompanied by a greater appreciation of biodiversity within the farming system. For example, some dairy farms in the central and eastern Andes of Colombia have replaced their *Pennisetum clandestinum* (kikuyu grass) monocultures with ISPSs that combine caespitose and stoloniferous grasses, creeping legumes, a middle layer of *Sambucus* species and *Tithonia diversifolia* fodder shrubs, and the nitrogen-fixing Andean alder *Alnus acuminata* in the upper canopy. Once herbicides are suppressed, some weedy herbs colonize the system. However, farmers have learned to value "weeds" such as *Sida acuta* and *Sida rhombifolia*, both of which are readily eaten by cattle.

Barriers to introducing trees

Tropical cattle ranchers will often admit that they have a bias against trees in pasture-lands. Grass monocultures are favoured in Latin America, at least partly for aesthetic reasons. Herbicide manufacturers have helped to strengthen this taste for open pastures, and some research institutions focus on improving "miracle grasses" and promoting the large-scale cultivation of a few species of *Brachiaria*, rather than on developing more complex and natural systems.

A few exotic fast-growing timber trees have proved useful in weakening such barriers. Some early adopters of ISPSs chose to plant familiar species such as *Eucalyptus* species, *Pinus* species, *Acacia mangium*, *Gmelina arborea* and *T. grandis*. However, some native timber trees are gradually emerging as protagonists of ISPSs in different regions.

Successful selection of native species

Introducing new species in ISPSs, as in reforestation, involves risks. Projects may fail because of inappropriate species choice, a consequence of insufficient knowledge about the performance of native trees in different site conditions. Nevertheless, an important pool of knowledge has developed on native trees. More than 130 neotropical species have been screened by various national projects and several have shown good early growth and survival in degraded areas (van Bruegel *et al*., 2011;

F. URIBE

Crown architecture is an important aspect of tree selection. **Cordia gerascanthus** ***is a native species of global conservation concern with the ideal architecture for ISPSs***

Hall *et al*., 2011; Montagnini and Finney, 2011, and references therein).

A pioneer farmer in the Andean foothills of Meta department in Colombia chose to test the endemic and rare *Mimosa trianae* on his farm, together with *A. mangium*, *G. arborea* and other species. This virtually unknown native tree species outperformed its exotic competitors and has shown impressive growth. Collected by botanists only eight times since 1856, this nitrogen-fixing species will probably become one of the key elements of ISPSs in the Andean foothills, where, paradoxically, cattle-ranching could contribute to saving it from extinction.

Another example is the silvopastoral system based on the managed succession of *Piptocoma discolor* in the Amazon foothills of Caquetá, Colombia. Once herbicides are eliminated as a tool for maintaining pastures in this moist region, this species regenerates vigorously and is browsed by the cattle. It is not only an excellent fodder shrub, it is also a fast-growing timber tree that forms straight poles that are useful for construction. Thus, *P. discolor* provides fodder and timber and has the ideal tree architecture for live fences and silvopastoral systems (Hurtado *et al*., 2011).

Some ISPSs combine two or more native timber tree species. An area of Colombia's dry Caribbean region has some seasonal limitations because of insufficient drainage. One ISPS for dual-purpose cattle combines improved pastures, a middle layer formed by the native tree *Guazuma ulmifolia* planted at high density for direct browsing and managed as a fodder shrub, and a canopy layer that combines strips of the native timber species *Cordia gerascanthus* and *Tabebuia rosea* and the endangered *Pachira quinata* (Galindo *et al*., 2010; Galindo, Galindo and Blanco, 2010; Calle *et al*., 2012).

INCENTIVES FOR THE ADOPTION OF ISPSs

Those who have an interest in implementing ISPSs face two main classes of barrier:

1. *Financial*. The high initial costs of establishing most ISPSs challenge the traditional view of tropical cattle-ranching as a low-investment activity. Even though the investment can be recovered in a relatively short period (3–4 years), most farmers, technicians and banks have not assimilated this relatively new thinking about cattle-ranching.
2. *Knowledge*. The complexity of ISPSs demands specialized knowledge and technical assistance (Calle, 2008; Chará *et al*., 2011).

Nevertheless, Latin American cattle-ranchers must quickly adapt to a changing climate and to the challenges of recent free-trade agreements that will demand producing high-quality beef and dairy

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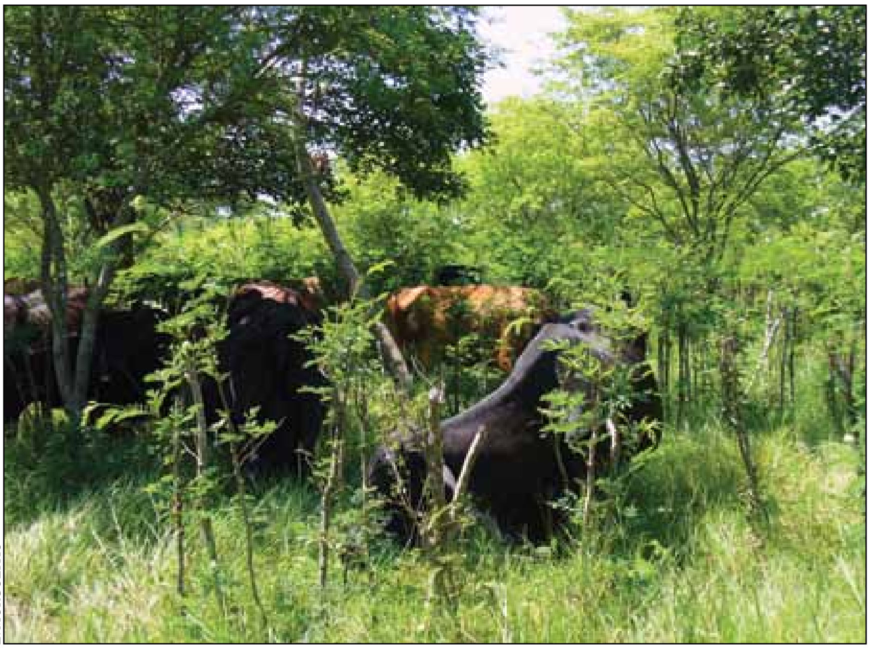
An important pool of knowledge has been developed on the success rate of native trees in ISPSs. **Mimosa trianae Benth *(Fabaceae)* *is an endemic and virtually "unknown" tree that has outperformed its exotic competitors in silvopastoral systems in the Andean foothills. Andorra farm, Cubarral, Meta, Colombia***

TABLE 1. Types of incentives used to promote the transition of conventional unsustainable practices to silvopastoral systems and other sustainable land uses

Incentive	Socio-economic context and scale of application	Constraints
Donation of trees, supplies and equipment	Small and local groups of farmers	Only multipurpose trees that offer a direct economic benefit without competing with cash crops are attractive to farmers **Risks:** Paternalism, limited adoption and lack of tree care when projects end
Processing of land property documents	All scales (small to large landowners), post-conflict areas and settlements in the agricultural frontier	This incentive should be the final step in closing an agricultural frontier once zero deforestation has been achieved. Certification of a property must be based on clear environmental standards to protect conservation areas **Risks:** Corruption, perverse incentives for deforestation, land concentration and land acquisition by international buyers
Land tax exemption	Fertile lands and high-priced lands near cities and infrastructure such as water-supply systems, dams and roads Local scale (municipality), but often related to a national policy	Up-to-date information on land property must be available. The incentive should be consistent with the opportunity cost of the land; it is insufficiently attractive in areas with profitable and unsustainable activities such as mining and commercial monocultures
Financing of technical assistance (TA) and silvopastoral extension	Necessary at all scales	Requires specialized training for extension workers and technicians The cost of TA must be appropriate for every scale of production. TA should be neither fully subsidized nor very expensive. It demands the permanent availability of financial resources
Credit for establishing ISPSs	Necessary at all scales, but must be adjusted to each group of stakeholders	The main limitations are the lack of access of small farmers to credit, and bureaucratic obstacles. The financial system poses barriers (raising interest rates or requesting more guarantees) A risk of failure exists if the technology is not appropriate for a given ecosystem Credit schemes must be designed so that the flow of payments is synchronized with the biological aspects of the system
Special incentives linked to silvopastoral credit (such as the Rural Capitalization Incentive in Colombia)	National policy with application at all scales	Technological development is needed to ensure the adequate investment of incentives. The technology must be adapted to special conditions such as tropical mountain ecosystems, areas subject to flooding, acid soils and low-fertility areas Limited by available funding. Faces the same limitations as access to credit. Group loans must be developed. National funds to achieve landscape-scale changes are not yet available
Application of forestry incentives to livestock systems (such as the Forestry Incentive Certificate in Colombia)	Should be applicable at all scales but, in practice, incentives are concentrated in high-timber-production areas. Can reach national or regional scales. With further technological development, benefits available for livestock systems could become equivalent to those of forest plantations	More knowledge on native species is required. Technology for the introduction of forest species in ranchlands is nonexistent Development of silvicultural practices, markets and wood-processing techniques for timber produced in silvopastoral systems are insufficient
Payments for ecosystem services	Water may provide opportunities for small landowners in focal watersheds; biodiversity applies at different scales; carbon is attractive mostly to large landowners or large-scale projects Local scale for water, regional scale for carbon and biodiversity. National-scale incentives exist only in specific countries	Requires baseline knowledge and monitoring of the ecosystem service being offered Funding is very limited (i.e. under the United Nations Framework Convention on Climate Change). Most countries have no specific funds and depend on international cooperation Differentiation of short- and long-term payments is very important. Native trees require an additional stimulus
Specialized market incentives (included in the prices paid for products of ISPSs)	Necessary at all scales. Small farmers need access to markets and subsidies throughout the certification process. Larger and entrepreneurial producers need incentives and promotion to enter marketing chains	Requirements include: traceability and certification of milk, meat and wood; certification protocols; impartial certifiers; someone paying for the cost of certification, and a demand for the certified products in specialized markets (biodiversity friendly, carbon neutral, low water footprint or fair trade products) Strong and prolonged campaigns for consumers play an important role in increasing the demand for ISPS products


E. MURGUEITIO

Providing incentives to invest in ISPSs can lead to enhancing productivity of farming systems and the generation of ecosystem goods and services while helping to conserve and restore degraded lands. El Chaco farm, Piedras, Tolima, Colombia

products, at a lower cost and adhering to rigorous environmental standards. Therefore, incentives and financial instruments are needed to promote the large-scale adoption of ISPSs. In the past, private, public and international cooperation programmes have used incentives to promote the adoption of silvopastoral systems and other agroecological practices. The main tools for scaling-up ISPSs are financial incentives, payments for ecosystem services, specialized technical assistance, innovation awards for farmers and market preferences. Table 1 presents incentives that have been used, the scale of their application and their constraints.

The average cost per ha of implementing ISPSs in the dry Caribbean region of Colombia is US$2 500, one-fourth of which (US$625) corresponds to labour (Solarte *et al*., 2011). For the RISAEM project, the average income per ha from cattle-ranching increased from US$237 to US$888 in Colombia, Costa Rica and Nicaragua as a result of the adoption of silvopastoral practices (not exclusively ISPSs) (The World Bank, 2008). On average, conventional pastures provide one rural job per 100 ha, while consolidated ISPSs provide five jobs in the same land area. During the establishment phase, ISPSs can provide as much as one job per 3 ha (Centro para la investigación en sistemas sostenibles de producción agropecuaria [CIPAV], unpublished data). This statistic applies to small-, medium- and large-scale cattle farms, as ISPSs are suitable for all scales, provided that the financial and knowledge barriers can be overcome.

ISPSs can improve the carrying capacity from as few as 0.5 animals per ha to 3 per ha. One ha of ISPS can increase farm income by at least US$440 per ha per year. Therefore, these systems have a substantial potential to contribute to the reduction of rural poverty (CIPAV, unpublished data).

In 2006, dual-purpose farms of the dry Tepalpatepec and Apatzingán valleys in Michoacán, Mexico, began replacing their treeless cattle-ranching systems, which used abundant feed and chemical inputs, with intensive silvopastoral systems. So far, more than 4 000 ha of ISPSs have been established. A recent evaluation of the social and economic impacts of this project revealed that the internal rate of return of such systems increased from 5–11 percent to 33.5 percent when the profitability of milk, meat and leucaena seed was considered. The five-fold increase in farmer income and the doubling of farm expenses have boosted the local economy. Additionally, ISPSs have increased local land value by 33 percent (González-Pérez and Solorio-Sánchez, 2012).

CONCLUSION

In some parts of Latin America, ecological restoration is untenable unless it manifestly bolsters the ecological base for human survival (Society for Ecological Restoration International Science and Policy Working Group, 2004). Restoration must complement and enhance food production (Minnemeyer *et al*., 2011). ISPSs are a good example of a land use that can increase the productivity and profitability of a farming system, enhance the generation of ecosystem goods and services, and facilitate the release of fragile, marginal and strategic areas for strict conservation, all at the same time. However, it will only be possible to scale up these systems in Latin America with national and international support through government policy, market preferences and payments for ecosystem services.

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