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Agroforestry in Bolivia: opportunities and challenges in the context of food security and food sovereignty

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SUMMARY

Agroforestry systems have long been implemented in Bolivia, but little is known about their overall current status. Interviews with farmers, policymakers and members of civil society organizations about the challenges and opportunities that agroforestry faces, as well as field visits to agroforestry projects revealed a wide range of agroforestry initiatives in Bolivia that provide ecosystem services, food and income to local families. All interviewees attributed a high potential to agroforestry, for example, to promote biodiversity, water conservation, food sovereignty and adaptation to climate change impacts. However, agroforestry initiatives lacked support because government incentives were channelled to cattle rearing and large-scale monocultures rather than diversified farming systems, and agroforestry initiatives tended to be small and isolated. A nationwide policy is needed which is coordinated with civil society organizations and individual farmers and strategically and efficiently supports agroforestry initiatives – especially in the most vulnerable first years of establishment – through extension services and access to materials, markets, knowledge and financial resources.

Keywords: agroforestry, Bolivia, diversified farming systems, food security, food sovereignty

INTRODUCTION

Agroforestry has been called the 'future of global land use' (Nair & Garrity 2012). In Bolivia, which faces soil degradation and biodiversity loss as well as vulnerability to food insecurity and malnutrition, and where highly diverse ecosystems have provided a setting for agroforestry projects of different organizations for decades, little is known about the state of agroforestry implementation and the potential that different stakeholders attribute to it. While about 50% of the country is covered with a wide diversity of forest types, Bolivia has one of the world's highest rates of absolute forest loss, mainly due to the spread of large-scale monocultures and cattle rearing (Urioste 2012; Mueller *et al.* 2013; Mueller *et al.* 2014). At the same time, high levels of vulnerability to food insecurity persist in many parts of the country (Castañón Ballivián 2014). Although there has been much progress in the reduction of poverty (FAO 2014), malnutrition prevails in about one-third of children under 5 years, and unhealthy diets and related diseases have increased (Cuesta *et al.* 2013; Castañón Ballivián 2014). During the global food price crisis of 2007/2008, food price hikes in Bolivia were above the Latin American and Caribbean average (Cuesta *et al.* 2013). With poverty and malnutrition still widespread in (but not restricted to) rural areas, the agricultural sector remains key to national food security (Castañón Ballivián 2014; FAO 2014). Bolivia's more than 700 000 small-scale farms produce most of the country's food (Castañón Ballivián 2014). The current Bolivian government under President Evo Morales has introduced measures to support small-scale farmers and enhance food security, including by providing access to land, public storage facilities, loans, extension services, social protection and cash transfers, and has strengthened the legal standing of cooperatives. The government also included 'food sovereignty' in Bolivia's 2009 constitution: Article 406 guarantees the prioritization of food produced in Bolivia, protection of the agricultural sector, and agroecological production and commercialization.

Agroforestry, food security and food sovereignty are linked in multiple ways. In Niger, for example, it was found that agroforestry had a positive influence on food sovereignty principles such as sustainable resource use and soil restoration, enhancement of local food systems, social control, social peace (by reducing resource conflicts) and the use of indigenous knowledge (Paris 2013). Such principles are absent from most conceptualizations of food security (Martínez-Torres & Rosset 2014). Accordingly, it has been argued that from a mere food security perspective, agroforestry systems tend to be regarded as not economically viable or not feasible, and that agroforestry is therefore more closely linked to La Vía Campesina's concept of food sovereignty (Nyéléni Declaration 2007) than to food security (Paris 2013).

Agroforestry is frequently mentioned in recent Bolivian laws and development plans – for example, in the Economic and Social Development Plan 2016–2020 (Plurinational State

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of Bolivia 2016), the Strategic Plan for the Agricultural Sector (MDRyT 2014) and the 2012 Framework Law No. 300 of the Rights of Mother Earth. This law establishes the concept of *vivir bien* ('living well') as a basis for an alternative sustainable development in Bolivia, promoting the conservation and regeneration of the environment and the recovery and strengthening of local and traditional knowledge (FAO 2014).

Agroforestry systems can refer to a large variety of land use systems incorporating trees, such as hedgerows, shade trees, home gardens with trees, living fences and silvopastoral systems (Nair 1992). This study takes a broad view of agroforestry that allows for the inclusion of a wide variety of practices combining trees and shrubs with agriculture and/or livestock keeping. Moreover, such a broad concept also enables inclusion of the ecological, economic and sociocultural services that agroforestry systems may provide, from erosion control to enhancing agrobiodiversity and dietary diversity while preserving traditional agricultural knowledge and generating food and income. Agroforestry systems have widely been described as ecologically, economically and socioculturally more sustainable and resilient to adverse environmental and socio–economic impacts as compared to monocultures (IAASTD 2008; Aguilar-Stoen *et al.* 2009; Lin 2011; Nair & Garrity 2012; ICRAF 2014). For example, the role of agroforestry in soil, water and biodiversity conservation has been discussed thoroughly in the literature (Nair 1992; Perfecto *et al.* 2005; Tscharntke *et al.* 2011). Diversified farming systems, among them agroforestry, have also been linked to healthier and more diverse diets for farming families as well as urban populations (Kumar & Nair 2004; Altieri & Toledo 2011). Agroforestry is becoming even more important in the context of climate change, which significantly affects Bolivian agriculture (McDowell & Hess 2012; Seiler *et al.* 2013). Civil society organizations (CSOs), including farmers' associations, information and education networks, and other non-governmental organizations, have promoted and implemented agroforestry systems in different parts of Bolivia, often with the objectives of establishing alternatives to the spreading cultivation of coca, increasing food security in remote communities, or adapting to and mitigating climate change (PNUD 2008).

Johnson's (1998) description of agroforestry activities, practices and stakeholders in Bolivia is, to my knowledge, the only inventory of the field. In this study, it is hypothesized that agroforestry in Bolivia has expanded since then – especially under the Evo Morales government, which has promoted it in several laws and development plans. The study was guided by three research questions: What is the current state of agroforestry implementation in Bolivia? What role does agroforestry play in achieving food security and food sovereignty? And what are the main challenges that agroforestry in Bolivia faces? First, initiatives of agroforestry in different ecoregions are described. Then, how farmers, CSOs and policymakers assess the opportunities and main challenges of agroforestry in Bolivia in a food security and sovereignty context, and what they believe is needed to sustain and develop agroforestry and expand it to other parts of the country where food insecurity prevails is analysed.

METHODS

Bolivia has some of the most biologically diverse ecosystems on Earth, with ecoregions ranging from the high Andean regions and Altiplano (northern and southern Puna) to the eastern Andean slopes and inter-Andean valleys (Yungas, Tucuman-Bolivian forest, montane Chaco, inter-Andean dry forests and Prepuna) and the lowlands (south-western Amazon, Cerrado, flooded savannahs, Chiquitano dry forest and Gran Chaco) (Ibisch & Mérida 2004). Agroforestry was already practised in the Andes by the Incas (Chepstow-Lusty & Winfield 2000), but people in the south-western Amazon also have a rich knowledge of trees and tree management in subsistence agriculture (Reyes-Garcia *et al.* 2008; Bottazzi *et al.* 2013). As the form an agroforestry project takes depends heavily on the local ecosystem, projects were categorized according to the ecoregions of Bolivia.

The study focused on agroforestry systems that formed part of a livelihood strategy (thus excluding field trials), at the project/initiative level (rather than counting individual farms separately). Using snowball sampling (Patton 2002) – that is, asking study participants to recommend others working in agroforestry or on comparable projects – more than 50 agroforestry initiatives throughout the country were identified.

Research took place from May to September 2014. A total of 42 initiatives in 25 municipalities were visited and transect walks were conducted and techniques and plant species used were documented. A total of 62 open-ended interviews with 24 agroforestry farmers, 31 CSO representatives and seven policymakers were conducted. The CSO representatives and policymakers had all been directly or indirectly involved in agroforestry projects (e.g., through a government programme or passage of a law). In cases where adverse weather and road conditions or the location's remoteness prohibited a visit to the agroforestry initiative, a meeting was held with the person who was actively involved in the initiative (e.g., as a consultant or farmer) in one of Bolivia's major cities (La Paz, Cochabamba, Santa Cruz and Tarija). There were several initiatives where a contact person or the exact place could not be identified; thus, the number of agroforestry initiatives may be much higher than what this study was able to assess.

Instead of a questionnaire, an open-ended interview guide was used, which made it possible to capture issues brought up by interviewees and allowed individual perspectives and experiences to emerge (Patton 2002). The interviews explored the scale and duration of project activities, the type of support farmers received (such as financing, materials or extension services), the main economic activity and the trees and crops promoted by the initiative, participants' views on the challenges and the potential of agroforestry in the context of food security and food sovereignty, as well as needs

for support that the interviewees found worth mentioning. The information was coded according to the topics listed in the interview guide and additional topics brought up by interviewees, and submitted to qualitative content analysis to identify patterns and trends (Patton 2002).

RESULTS

Agroforestry initiatives were identified in all ecoregions except the Cerrado, Prepuna and southern Puna. Table S1 offers a description of the larger agroforestry projects. Information on the number of families using each of the different practices or the exact extent of practices could not be obtained, as many interviewees had little contact with and knowledge of other agroforestry practices in their ecoregion (especially those in remote areas). However, all interviewees regarded the potential of agroforestry in Bolivia as high or very high if economic and institutional obstacles were removed and incentives provided. Examples of agroforestry initiatives in the different ecoregions are described below, along with study participants' comments on the agroforestry systems' potential benefits for food security and food sovereignty as well as challenges to their implementation.

Description and potential of agroforestry systems in different ecoregions of Bolivia

Montane Chaco

Here, cattle rearing (for meat and milk) provides the most important livelihood for many families. Four interviews conducted with two agroforestry farmers and two CSO representatives near Camiri (about 300 km south of Santa Cruz de la Sierra) indicate that the seven-month dry season, prolonged even further by climate change, together with unsustainably high animal stocks often leads to food insecurity. The interviews revealed that silvopastoral systems were common but that vegetation degradation from constant grazing posed a challenge. A CSO representative reported around 120 fodder plant species in silvopastoral systems in the Bolivian part of the Gran Chaco region, including both annual and perennial plants, for example, the tree species quebracho blanco (*Aspidosperma quebracho-blanco*), algarrobo blanco (*Prosopis alba*) and algarrobo negro (*Prosopis nigra*). This interviewee also explained that biomass produced on grazing lands amounted to around 400 kg of dry matter ha^{-1} $year^{-1}$ (with around 10 ha needed per animal unit), whereas silvopastoral systems produced more than 1000 kg of dry matter ha^{-1} $year^{-1}$ (with around 4 ha needed per animal unit). Trees were described as crucial to the survival of cattle during the long dry season, but the implementation and sustainable management of silvopastoral systems was mostly a question of fencing to allow the plants to recover from grazing. Fencing had led to a five-fold increase in annual dry organic matter production per hectare over the last few years in some such silvopastoral systems. However, as the cost of fencing was high – the interviewee estimated 10 400 bolivianos for 25 ha (US$1438, July 2015) – many families did not install it, and the effects of land degradation from overgrazing can be widely observed. According to another CSO representative interviewed in the town of Camiri, unsustainable land management in the Bolivian Chaco results in a state of emergency being proclaimed and emergency relief organized by the government every year because many cattle die during the dry season.

Disputed land borders due to unclarified land property rights were described as another obstacle to the sustainable management of silvopastoral systems. Positive aspects stressed by two farmers managing a silvopastoral system included the system's higher biomass production as compared to free grazing areas, and the fact that the cows were grazing in the shade – which, according to the farmers, led to a net energy gain expressed in increased meat and milk production.

High Andean regions and Altiplano

Agroforestry can be implemented even in the semi-arid Andean highlands near Oruro, where there are few trees to be seen. One farmer had been cultivating quinoa combined with native trees such as quishuara (*Buddleja coriacea*), fava beans, oats and garlic on 2 ha since 2008. He described his experience as positive in terms of pest suppression and subsistence food production, but stated that his initiative was rather isolated and regretted that he lacked contact with other agroforestry farmers and organizations to exchange positive experiences and find ways to disseminate them.

Further north-east, in the Tapacari province, the native trees queñua (*Polylepis spp.*) and quishuara are widely used as windbreaks and living fences, and crops are planted in residual queñua forests (Hinojosa 2010 The young shoots and leaves of these trees were consumed by local families (Johnson 1998), and agroforestry in the Bolivian Altiplano can create a beneficial microclimate for crops, reduce the impact of wind and frost, protect and restore soils, and improve soil fertility (Mahboubi *et al.* 1997). One interviewee mentioned the general importance of trees and shrubs in agricultural systems in the Altiplano for reducing pressure on the natural vegetation from firewood gathering (Aguilar *et al.* 2008).

Yungas (La Paz Department)

This is the main coffee-growing region of Bolivia as well as the main agroforestry region, with 36 331 ha of agroforestry systems in 2012/2013, followed by the Chaco with 10 517 ha (Bolivian National Institute of Statistics: www.ine.gob.bo). It is estimated that 90% of coffee in Bolivia is grown under agroforestry (Somarriba *et al.* 2012). Several interviewees mentioned that coca (*Erythroxylum coca*) monocultures were spreading fast in the Yungas, replacing more diverse agricultural landscapes – especially coffee (*Coffea arabica*) and cocoa (*Theobroma cacao*) agroforests – and thereby also reducing dietary variety. Coca is legal in the Yungas of La Paz, which are a traditional zone of coca production. Landholdings in the Yungas are usually small, and traditionally diversified systems and food crops have been replaced by intensive coca

monocultures which on steep slopes cause severe soil erosion and landslides (UNODC 2015). Some organizations have been promoting alternatives to coca, but interviewees said that local interest was low, as coca leaves fetched high prices within a short time.

The local CSO Ecotop has helped more than 200 coca farmers obtain organic certification for their coca plantations by adding native tree and shrub species, stabilizing slopes and diversifying their production. Pacaí varieties (*Inga spp.*), leguminous trees often found in agroforestry systems of the Yungas, fix nitrogen and accumulate high amounts of biomass, which can be pruned and used as organic matter to improve soils. Some varieties also produce a nutritious fruit that can be sold on local markets. Three coca farmers were interviewed, all of whom had diversified their coca monocultures with fruit trees (pacaí and others) and aromatic herbs such as quirquiña (*Porophyllum ruderale*). They stated that more work was required than in a monoculture, but that pest and disease suppression worked well and soil quality had improved.

More information is available on cocoa and coffee than on coca agroforestry in the Yungas. Previous research showed that cocoa farmers in the Yungas who managed an agroforestry system had higher cocoa yields than those who managed monocultures (Jacobi *et al.* 2013). Cocoa agroforestry farmers also had a higher subsistence level (amount of food consumed that was produced on their own farm) than monoculture cocoa farmers – 46 and 34%, respectively (J. Jacobi, unpublished data 2012). Interviewees said that local organizations provided cooking lessons and had published a book on traditional dishes using the produce from agroforestry systems, and that such dishes could be found increasingly at local markets and events. One example was the traditional drink *leche de majo,* made from the fruit of the palm *Oenocarpus sp.*, which is grown in agroforestry systems as well as collected from the forests (Knoblauch 2013). Interviewees from the Yungas mentioned increasing heat and erratic rainfalls as severe climate-change-related impacts on their livelihoods. A cocoa agroforestry farmer said that farmers have increasingly planted fruit trees in agricultural plots to create shade to work in.

South-western Amazon (Pando Department)

Although remote and sometimes difficult to access, this region is historically connected to market chains for rubber, gold, timber and Brazil nut. Pando is the department where vulnerability to food insecurity is most widespread in Bolivia (MDRyT 2012). Brazil nut remains a primary source of income for around 6000 families who collect it from November to March from around 9 million ha of Amazon rainforest left in the region (Pokorny *et al.* 2013). According to two interviewees, many families are vulnerable to indebtedness, as they earn the bulk of their income during the Brazil nut harvest. Several organizations have implemented projects to diversify income sources and complement Brazil nut extraction with agroforestry, mostly focused on cocoa, copoazú and asai palm (*Euterpe oleracea*) (PNUD 2008). Interviewees saw the highest potential in cocoa landraces because of the increasing demand for these, and because dry cocoa beans are easier to store and transport than copoazú, asai and majo pulp (which require a cold chain). Interviewees regarded home gardens with trees providing food and animal feed as an excellent income supplement and buffer against food insecurity. Such gardens are commonly kept by smallholders in the northern Bolivian Amazon and combine palm trees such as asai and majo with vegetables and medicinal plants such as sangre de grado (*Croton draconoides*) and copoaibo (*Copaifera reticulata*). It has been found that complementary trees in smallholder cropping systems in the Bolivian Amazon can provide food and income at a very low economic risk and labour input (Hoch *et al.* 2012). It has also been explained that the preserved forests contribute significantly to the region's welfare, whereas in the neighbouring state of Rondônia in Brazil, which used to have similar forests, the production of cattle and soybean has degraded the landscape, severely limiting its economic value (Pokorny *et al.* 2013).

South-western Amazon (Chapare region)

The Chapare region accounts for around 30% of the country's area under coca plantations (UNODC 2015). According to a United Nations Office on Drugs and Crime (UNDOC) report from 2015, the area of coca cultivation in Bolivia has diminished by 34% – from 31 000 to 20 400 ha – between 2010 and 2014. The report attributes this reduction, most of which occurred in Chapare, to eradication programmes, local control mechanisms, and soil degradation leading to abandonment of coca plots. Law 1008 from 1988 limits the national surface under coca to 12 000 ha, but a decree from 2004 tolerates 1 *cato* (1600 m^2) of coca per family in Chapare. Although the Morales administration is rooted in the Chapare coca growers' movement, coca producers in Chapare claim that 1 cato is not sufficient for a family to make a living, and that the government does not respond adequately to their needs (Grisaffi 2013). Like in the Yungas, interviewees in Chapare did not see a real alternative to coca, although silvopastoral systems and agroforestry systems based on shade trees producing palm heart, coffee, cocoa, flowers, pineapples, green pepper, rubber and tea have long been promoted (PNUD 2008), and can be observed, for example, around the town of Chimoré. One interviewee calculated that 1 cato of coca could earn a family US$850–1134 every 3 months. Coca, according to him, was unique because the harvested leaves could be sold the same day and fetched a secure and high farm-gate price. Interviewees in the Chapare region said that diversification of coca plantations was not feasible there because the small area allowed per family incentivized input-intensive monocultures. However, a study conducted in the Valle de Sacta in Chapare comparing an agroforestry farm – which produced copoazú (*Theobroma grandiflorum*), peanuts, banana, plantain, camu camu (*Myrciaria sp.*), maracuya, flowers such as *Bromelia spp*, and cattle with fodder trees – with coca monocultures, found the agroforestry farm to be about 20% more profitable than the coca systems (Rosse 2015).

As another constraint to more diversified coca plantations, two coca farmers mentioned that there are very few studies and specific extension services or development programmes for sustainable coca cultivation due to its semi-illegality. The interviewees had observed that climate change in the Chapare region was increasing heat and prolonging dry seasons; they reported that rains had started at least 2 months later than usual in recent years.

South-western Amazon (Santa Cruz Department)

Hedgerows as windbreaks are prescribed by a supreme decree for landholdings over 50 ha and are recommended by the large-scale soy producers' organization ANAPO. As a result, stripes of leftover forest can be observed in parts of the soy cultivation area, with potential benefits for erosion control and biodiversity. However, the maximum distance between the hedgerows of ten times the altitude of the largest trees had not been observed – or hedgerows were not implemented at all – in the places visited near the city of Santa Cruz.

Three interviewees pointed out that there was hardly any control of or restriction on the use of agrochemicals in the country, and that heavy glyphosate spraying from airplanes in soybean production affected nearby peasant families and their food crops. Two interviewees highlighted agroforestry, especially the use of cuchi verde trees (*Gliricidia sepium*) in hedgerows, as a possible buffer for home gardens and small fields against aerial fumigation. A CSO representative confirmed that this had recently been discussed among farmers and organizations, but that they had not yet implemented it widely. Interviewees also mentioned that climate change caused more frequent and more severe flooding of their plots, more frequent and longer droughts, and increased heat.

Inter-Andean dry forests and northern Puna (Cochabamba Department)

Espacio Compartido en Sistemas Agroforestales (Shared Space on Agroforestry Systems, Ecosaf) is a local CSO aiming to bring agroforestry initiatives together and to serve as a platform for knowledge exchange. A national agroforestry congress is organized through their network every 2 years. The organization focuses on research and dissemination of highly diversified knowledge and labour-intensive 'dynamic' (also called 'successional') agroforestry systems based on a high density and diversity of plants. It has established several on-farm experimental plots in the departments of Cochabamba, Potosí and Chuquisaca, led by local farmers. Mainly focused on fruit trees, these systems also produce aromatic and medicinal herbs, firewood and fodder, among other things. Two interviewees described the importance of agroforestry for pollinators, especially bees. Ecosaf promotes high shares of native plant species, which provide flowers throughout the year. Fruit trees from the *Rosaceae* family, an important cash crop in the region, flower almost exclusively in September and October but depend mainly on bees for pollination. Interviewees in this region reported that climate change caused fewer, shorter and more intense rainfalls, damaging crops and increasing erosion.

Inter-Andean dry forests (Tarija Department)

The area around the southern Bolivian city of Tarija is known for its vineyards. An agroforestry system with grape vines climbing on molle trees (*Schinus molle*), which protected the grape vines from frost while providing an insect repellent effect as well as firewood has been previously described (Johnson 1998). Three interviewees in Tarija – two CSO representatives and one policymaker – confirmed these observations, and the CSO representatives added that the molle tree accumulated a considerable amount of organic matter, but that this traditional practice was increasingly being replaced by more intensive grape cultivation systems. They also mentioned climate change; two reported prolonged dry seasons, and one cited climate change as a reason for a decrease in the production of cherimoya (*Annona sp.*), a native fruit that fetches high prices.

Chiquitano dry forests

Here, smallholder diversified agriculture competes with soybean monocultures and cattle rearing. There is an estimated net present value of US$541 ha^{-1} $year^{-1}$ for smallholder agriculture as compared to US$270 ha^{-1} $year^{-1}$ for cattle ranching on artificial pastures in the department of Santa Cruz (Mueller *et al.* 2013). Four out of six interviewees in the Chiquitania region, both practitioners and policymakers, said that agroforestry was more profitable than the extensive cattle rearing, although the latter was more common. Three agroforestry farms with citrus trees amidst tall moringa trees (*Moringa oleifera*), which fix nitrogen and have a high nutritional value were visited. Farming families used moringa leaves in several dishes and also fed them to their livestock, explaining that they are nutritious and have beneficial effects on milk production in cattle. Three other interviewees described the potential of moringa trees as a fire barrier, a property mentioned for other leguminous trees (Johnson 1998). This may be important given that fire, often from slash-and-burn activities, represents the greatest environmental threat to agroforestry according to seven interviewees (Table 1). Agroforestry farmers and CSO representatives mentioned climate change in association with fewer and less predictable rains, associating these changes with deforestation of the Chiquitano dry forest.

Major challenges to agroforestry implementation in Bolivia

Interviewees identified ecological, economic, sociocultural and political challenges for agroforestry in Bolivia, which have a potentially negative impact on food security (Table 1).

Climate change was mentioned by all interviewees. Policymakers regarded it mainly as a threat to the country's food production, CSO representatives as a threat to the future of family farming, and farmers as a threat to their livelihoods

Table 1 Views of study participants (n = 62) on challenges facing agroforestry in Bolivia. The number of participants expressing a view is indicated in parentheses.

Challenges	*Views of study participants (n)*
Ecological challenges	Climate change is a severe threat to agricultural production (13), but also a chance to increase adoption of agroforestry (2)
	Threat of fire from uncontrolled slash-and-burn activities is a reason not to plant trees (7)
	Crops in diversified systems may compete for water, light and nutrients (2)
Economic challenges	The high initial investment and long wait until trees start to produce creates economic vulnerability (5)
	Development projects and CSOs advocating diversified farming often focus on cultivation and pay insufficient attention to helping farmers market the agricultural products they have encouraged them to grow (5)
	The supply of tree seedlings and seeds is insufficient (4)
	Timber extraction is easier and generates income more quickly than diversified agroforestry (4)
	Cattle are regarded as a savings account and are considered a more prestigious activity than food crops (2)
Sociocultural challenges	Theft of produce that non-agroforestry farmers do not have (8)
	Conflicts occur over livestock entering and grazing on agroforestry plantations (6)
	Conflicts and inequality exist between settlers and indigenous groups (3)
Political challenges	Financial resources are not allocated to agroforestry (20)
	Government officials do not recognize the socio–economic function of agroforestry (11)
	There is conflict between different government interests, such as economic growth based on resource extractivism vs. vivir bien and the 'rights of Mother Earth' (5)
	Local governments are too busy responding to emergencies (e.g., providing food aid) to work on preventing them (2)

and natural resources. Farmers' perceptions of increased temperatures match local climate data, for example, in the Yungas (Jacobi *et al.* 2013). Perceptions of and adaptation to climate change among Bolivian Quechua farmers who described that rains had become more concentrated and occurred within shorter periods have been analysed (Boillat & Berkes 2013). Similar concerns among farmers in five Bolivian Aymara communities have been identified (McDowell & Hess 2012). It has also been pointed out that climate change poses a high risk to the already vulnerable Bolivian peasant sector (Castañón Ballivián 2014).

All agroforestry farmers interviewed mentioned the importance of trees for adaptation to climate change, and two CSO representatives stated that climate variability and increasing weather extremes are becoming an incentive for agroforestry adoption, especially in the dryer Chaco and Chiquitania regions. Interviewees pointed to high start-up costs, low initial returns and difficulties in accessing markets as key economic challenges of agroforestry implementation. Sociocultural issues frequently included theft and damage from free-ranging livestock (Table 1): for example, an agroforestry farmer in the south-western Amazon near the town of Rurrenabaque said that the neighbours' cows and sheep had repeatedly entered her agroforestry system, which she had had to replant several times. She was in constant conflict with her neighbours, who, she felt, did not respect her agroforestry system and did not look after their livestock in a responsible manner.

An important political and institutional constraint on food production was land titling. The National Institute of Agrarian Reform (INRA) is in charge of providing, revising and redistributing land titles. In accordance with the law, these are granted on the condition that the land fulfils a 'socio–economic function'. INRA inspects landholdings in this regard, checking whether the land is effectively used, and is authorized to withdraw land titles if this is not the case. However, 11 interviewees stated that INRA only accepted deforested land that had been visibly worked on, or was stocked with cattle, as fulfilling its socio–economic function. According to these interviewees, agroforestry was not widely accepted as a fulfilment of the socio–economic function of the land, and two interviewees reported cases in which such land had been expropriated and later deforested.

Eight interviewees from CSOs stated that more long-term support for agroforestry systems was needed: project budgets often focused more on the establishment phase than on follow-up, leaving farming families with a system they did not always have the knowhow, capacity or equipment to manage (Pokorny *et al.* 2013). Some projects supported production but not the commercialization of the products, which remained a major obstacle for farming families. Three CSO representatives said that lack of long-term support could have adverse effects: when agroforestry plots are not well managed and do not yield the expected results, farmers become convinced that agroforestry is not a viable option for them, and may pass this belief on to their neighbours. Two interviewees also said that government agencies were too busy responding to emergencies, for example, distributing food aid, to advance preventive and resilience-building strategies such as farm diversification.

DISCUSSION

This study identifies and describes agroforestry initiatives in Bolivia, and explores links between agroforestry, food security and food sovereignty in Bolivia. Information from the interviews and official statistics on coffee and cocoa cultivation indicate that agroforestry in Bolivia has increased since Johnson's 1998 study (Somarriba *et al.* 2012). However, the present study cannot provide exact data on the extent of agroforestry in Bolivia, as many individual famers' initiatives are likely to have remained undocumented.

The examples and the list of agroforestry projects identified (Table S1) show that agroforestry systems in Bolivia contribute to food security as well as food sovereignty through sustainable resource use (see Montane Chaco and Inter-Andean dry forests examples), use of traditional knowledge (see Yungas examples) and diversified food production (see Yungas and south-western Amazon examples). They also benefit local food systems (see south-western Amazon, High Andean regions and Altiplano examples).

Polycultures have long been reported to be more productive than monocultures when total output is taken into account (Tscharntke *et al.* 2012). For example, a recent comparison of cocoa cultivation systems in Bolivia showed that the total yield output of agroforestry systems between 2009 and 2013 was 161% higher than that of cocoa monocultures (M. Schneider *et al.*, unpublished data 2015). A major Bolivian newspaper calculated that agroforestry systems in the south-western Amazon of the Beni Department generated higher incomes than the widespread rice, corn or manioc monocultures, in addition to providing nutritious and diversified food throughout the year (La Razón 2013). Another study showed how farmers in Latin America grow coffee and cocoa as cash crops together with a variety of food crops in small-scale agroecological agroforestry systems, leading to a diversified diet and providing benefits to rural livelihoods and biodiversity (Perfecto *et al.* 2009); these outcomes are also key elements of food sovereignty.

Adapting farming systems and building resilience to climate change are important tasks in Bolivia, as climate variability – with increasing temperatures, prolonged dry seasons, erratic rainfall and more frequent extreme weather events – is predicted to severely affect agricultural production and possibly food security in the country. Some interviewees indicated that climate change is increasingly motivating Bolivian producers to include trees in their farming systems, even if only to create shade and thus improve working conditions. As one policymaker from La Paz pointed out: 'climate change is a chance to bring the different organizations and governmental bodies together, as it is affecting many different groups and is a topic that all have in common.'

Possibly the greatest agroforestry potential in Bolivia lies in silvopastoral systems for cattle rearing (Mueller *et al.* 2013): fencing, incorporating a fallow phase in the grazing cycle, and planting nutritious shrubs and trees that produce fruit in the dry season (such as algarrobo species) allow for a higher livestock density per hectare and help the soil and vegetation recover from grazing (Somarriba *et al.* 2012). The cost of fencing was reported to be the main obstacle to the adoption of silvopastoral systems. This suggests that there is a potential to align support for silvopastoral systems with existing government support for small- and medium-scale cattle rearing, for instance by linking access to credits with the implementation of silvopastoral systems. The government's Project of Rural Alliances, for example, provides credit, equipment and infrastructure to producers' organizations, and is an important means in this respect.

After silvopastoral systems, coffee is the biggest agroforestry sector in Bolivia. Diversified cocoa and coffee agroforestry is beneficial to social and ecological resilience and climate change adaptation (Philpott *et al.* 2008; Lin 2011; Tscharntke *et al.* 2011; Matocha *et al.* 2012; Jacobi *et al.* 2013; Babin 2014). Lack of short-term economic viability and a high labour requirement are often described as weak points of agroforestry when compared to monocultures. Accordingly, agroforestry systems need special attention from practitioners and policymakers if they are to be sustained and enhanced (Perfecto *et al.* 2005; Tscharntke *et al.* 2011; Babin 2014).

Interviewees said that coca monocultures competed with coffee agroforestry for land and resources in the Yungas (Barrientos 2011), and that large-scale soybean monocultures competed with local families' farming systems for land and labour in the south-western Amazon ecoregion. They indicated that both developments jeopardized agrobiodiversity as well as food production. As long as there are no real incentives for diversified farming systems, and laws regulating the expansion of industrialized cash crop cultivation are not enforced, the highly market-driven cultivation of coca and industrial oilseeds will continue to expand, depleting soils and biodiversity as well as affecting human health, especially in the Yungas and the south-western Amazon in the Chapare region and around the city of Santa Cruz de la Sierra (Catacora Vargas 2007; Hoch *et al.* 2012; Urioste 2012; Pokorny *et al.* 2013; Castañón Ballivián 2014).

Vulnerability to food insecurity is highest in the departments of Pando, Potosí and Chuquisaca (MDRyT 2012; Castañón Ballivián 2014). Agroforestry projects could therefore focus more on these three departments, which extend across Bolivia's main three topographical regions (Altiplano, sub-Andean mountain ranges and eastern plains in the lowlands) and many different ecoregions.

Isolation may increase the vulnerability of agroforestry initiatives, and more effort should be put into looking for and bringing together individual farmers' initiatives. Several CSOs have made efforts to connect different groups engaging in diversified farming linked to food production, and to mediate conflicts by supporting different livelihood strategies, such as hunting and gathering combined with the collection of wild cocoa. Such an intercultural dialogue would also be an opportunity to preserve, exchange and co-create knowledge on agroforestry (Martínez-Torres & Rosset 2014).

To efficiently support agroforestry initiatives, access to financial resources, technical support and market facilities should be improved, especially during the first years after establishment; this would help to bridge the 'hunger gap' resulting from high expenses and less available labour for other activities while plants are still too young to produce (Mercer 2004; Schnatmann 2006). 'Successional' or 'dynamic' agroforestry systems, which produce different crops at different stages of development, offer a promising approach in this context.

Bolivia's innovative laws and new constitution may represent a strong framework for such efforts, but enforcement remains slow and inconsistent (Mueller *et al.* 2014; Sager 2014), whereas large-scale soy producers benefit greatly from energy subsidies and the expanding industrial and transport infrastructure for export crops (Suárez *et al.* 2010; Urioste 2012; Castañón Ballivián 2014). It has been described how the Bolivian state has taken up food sovereignty, linking it to a rhetoric of decolonization and independence from foreign governments and organizations, rather than viewing it as peoples' sovereignty over local, sustainable and socially just food systems (McKay *et al.* 2014), as others have defined it (Martínez-Torres & Rosset 2014). Scholars have documented the persistence and even expansion of a resource extraction model, whereas they have found little evidence of the advancement of a sustainability agenda (Urioste 2012; Fabricant 2013; McKay *et al.* 2014). Nonetheless, expectations of the Morales government remain high, given that food sovereignty is mentioned as a priority in the Patriotic Agenda 2025, Bolivia's core development plan, which is meant to bring ministries and civil society together in participatory processes and policy coordination to fight undernourishment and food insecurity (FAO 2014). However, the economic resources allocated to relevant programmes are insufficient, and there are considerable deficiencies in implementation (Castañón Ballivián 2014). This might be related to the understanding of food sovereignty as national self-sufficiency in terms of food products, which does not necessarily question the extractivist and disequalizing models of food production (McKay 2014). The lack of transformative processes that address structural inequalities and advance food sovereignty becomes visible, for example, in the fact that INRA is not sufficiently questioning land concentration and foreignization in the country's rapidly expanding soybean cultivation zone (Urioste 2012; McKay 2014). Moreover, there are contradictions between the Framework Law of the Rights of Mother Earth, which prohibits the conversion of forest (Art. 25.4) and other legislation. Examples include Law 337 (Support of Food Production and Forest Restoration), which implies advancement of the agricultural frontier and creates expectations of absolution for illegal deforestation (McKay 2014); or Law 144 (Productive Agricultural Community Revolution), which facilitates forest clearing in the name of achieving food sovereignty and living well (Mueller *et al.* 2014).

The Joint Mitigation and Adaptation Mechanism for the Integrated and Sustainable Management of Forests, developed as an alternative to international carbon trade schemes, promotes the integrated management, sustainable use and protection of forest areas (see Art. 54 of the Framework Law of the Rights of Mother Earth). In 2012 the United Nations declared the Joint Mechanism eligible for Reduction of Emissions from Deforestation and Forest Degradation (REDD) payments. This may provide an opportunity for incentivizing agroforestry systems in the future.

For this to happen, strong and effective local institutions must be developed that are capable of implementing Bolivia's innovative legal framework. This in turn requires institution-building processes that involve all relevant stakeholders, which remains a major challenge (FAO 2014).

A first important step towards policy support for agroforestry initiatives would be the official and *de facto* recognition of a socio–economic function of agroforests for local livelihoods and food sovereignty by INRA. Current land titling mechanisms have been described as drivers of deforestation, which is widely used as a proof of the land's socio–economic function (Mueller *et al.* 2014).

CONCLUSION

In Bolivia, there are many agroforestry initiatives, both long-standing and new, and they exist in most of the country's ecoregions. They face numerous challenges but have a strong potential to improve food security and, through traditionally diversified production used in local food systems, food sovereignty. It can be assumed that there are many more individual initiatives than described in this study. Many of them may be highly innovative but have remained isolated.

The main challenges for agroforestry resulted from climate change, neighbouring slash-and-burn activities and economic vulnerability, especially in the first years after establishment. The traditional forms of agroforestry still practised in many parts of Bolivia provide an opportunity to integrate exogenous and endogenous knowledge – work that CSOs could engage more in.

To avoid further loss of tree and crop diversity and the associated loss of knowledge and impoverishment of diets, a comprehensive national policy of organizational, institutional and economic support for diversified farming is needed. To ensure that support is efficient and taken up by farmers, it must be designed together with them. Bringing different agroforestry actors together in organized groups may be the most effective means of ensuring the enforcement of Bolivia's innovative laws (especially the Framework Law of the Rights of Mother Earth) and development plans. CSOs have an important role to play in this, as seen in examples from the Yungas and the inter-Andean dry forests around Cochabamba, where well-established agroforestry-related organizations are building capacity and providing technical support.

To enhance rural communities' food sovereignty and the adaptation of smallholders' livelihoods to climate change, policymakers need to enforce the Law of the Rights of

Mother Earth and the implications of the concept of *vivir bien*. This includes supporting the numerous existing agroforestry initiatives through a national policy, and supporting CSOs that are locally accepted and have long-standing experience. Official recognition of the socio–economic function of agroforestry systems, along with subsequent awareness raising, is a crucial precondition for such support.

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Supplementary material

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