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FALLOW MANAGEMENT PRACTICES IN GUATEMALA'S WESTERN HIGHLANDS: SOCIAL DRIVERS AND BIOPHYSICAL IMPACTS[†]

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ABSTRACT

Land pressures and environmental degradation are driving forces behind shortened fallow periods in the tropics, often resulting in reduced crop yields and increased migration from rural areas. This paper describes contemporary fallow practices in the Western Highlands of Guatemala based on interdisciplinary data collected using participatory rural appraisal and qualitative research methods in combination with a quantitative evaluation of the impacts of fallow management decisions on soil fertility. Case studies of two communities in San Marcos department illustrate contemporary and traditional land use practices. Currently, over 70 per cent of families engage in a variety of fallow management practices, with combined cropping-fallow cycles within a field averaging 3–6 years. Despite the reduction in length of fallow cycles, new fallow practices in the study area appear to improve some aspects of soil fertility while also providing fodder and fuelwood. Calcium and magnesium concentrations in fallow soil were twice that of cropped plots, indicating that weathering reactions and atmospheric deposition during fallow periods are able to restore base cation fertility that is taken up by potato crops during cropping cycles. Soil in cropped plots, however, showed 25 per cent higher soil organic matter and five times higher nitrate concentrations than soil in fallow plots, which resulted from additions of compost and inorganic fertilizer to cropped plots. Nevertheless, the $^{13}C/^{12}C$ isotopic ratio of soil organic carbon indicated that as soil organic matter content decreases in cropped plots, the remaining carbon is increasingly degraded. Potential improvements in fallow management practices proposed by farmers and researchers are also presented.

KEY WORDS: grazed fallow; enriched fallows; fallow systems; seasonal migration; soil fertility; *Buddleia skutchii*; *Baccharis vaccinioides*; Andisol; Guatemala

INTRODUCTION

At any given time, a substantial portion of rural agricultural land is left fallow in many regions of the world (Fisher *et al*., 1999; Burgers *et al*., 2005; Denich *et al*., 2005; Langyintuo and Dogbe, 2005). Increasing efforts have been dedicated to studying the role of fallow management in sustaining soil productivity in low input agricultural systems in the tropics (Sanchez, 1999; Szott *et al*., 1999; Manley *et al*., 2000; Fernandes, 2005). However, the role of the fallow period in high altitude (above 2800 m) tropical agro-ecosystems has received relatively little attention. These areas are important because they tend to be densely populated by communities that derive their livelihoods from increasingly small farm holdings.

Fallow land can include pastures, secondary forest, or even severely degraded cultivation areas (Fisher, 1999), and fallowed fields are often subjected to intensive grazing, reflecting major pressures on traditional agricultural systems. The duration, composition, and management intensity of fallow lands are affected by increasing population, decreasing land availability, and changing access to markets, capital, and inputs.

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Shortened fallow periods have led to reductions in species diversity of natural fallows and decreased yields in subsequent cropping periods. In Central America, grassy species have replaced tree species in many fallow periods, with resulting declines in soil fertility (Buckles, 1995; De Clerck and Negreros-Castillo, 2000).

Fallow management strategies seek to improve the proportion of useful plants present during fallow periods in order to increase the return per unit land (Denevan and Padoch, 1987). These strategies have been variously categorized as economically enriched fallows (e.g., fallows providing products including firewood, forage, and medicinal plants in addition to traditional crops), and biologically enriched fallows (e.g., fallows which accumulate or circulate a greater amount of nutrients in a given fallow period) (Kass *et al*., 1993; Cairns and Garrity, 1999). These managed systems can be short-term (fast growing leguminous species to more rapidly replenish soil fertility for crops), or medium to long-term in which diverse species are used to rehabilitate degraded or abandoned lands and to obtain forest products (Rao *et al*., 1998).

The use of herbaceous legume species to compensate for shortened fallow periods has received substantial research attention in the Neotropics. Improved fallow productivity by combining planted herbeaceous legumes with woody fallow species has been demonstrated in Peru by Szott *et al.* (1994) and Alegre *et al.* (2005). Soil fertility management practices using velvetbean (*Mucuna* spp.) have been documented in Honduras (Buckles, 1995; Buckles and Triomphe, 1999), as have the effects of a short-term fallow system using **frijol tapado** (*Phaseolus vulgaris* L.) on soil phosphorous in Costa Rica (Derry *et al*., 2005).

Research on fallows in Latin America has also focused on improving grazed fallows with leguminous shrubs and forage grasses. Loker (1994) reported on improved fallow recovery for cropping following a managed grazed fallow using mixed grass/legume associations. Strategies for long-term improvement of **espinal** range-wheat fallow rotations in Chile, including the extraction of firewood, are presented in Ovalle *et al.* (1990). Managed fallow pastures also provide ecological value for biodiversity and conservation efforts (Petit *et al*., 1999).

This paper provides an interdisciplinary case study and characterization of changing fallow management practices in the Guatemalan highlands. The present study has three primary objectives: (1) to characterize smallholder fallow practices within indigenous farming systems in the Western Highlands of Guatemala, (2) to examine the relationship of those practices to food security issues and socio-economic change, and (3) to examine the impact of fallow management decisions on soil fertility. Case studies of two communities in San Marcos, Guatemala illustrate current land use practices and assess the potential for improvements in management of fallows as a component of sustainable agriculture in the region. Emphasis and results center on the evaluation of food security issues, the impact of economic conditions on changing fallow practices, and resulting influences on soil fertility following historical changes in fallow management practices.

METHODS

Site Description

The field study area comprised two communities in the semi-humid northern region of the state of San Marcos, Guatemala: San Pedrito (15·22°N–91·97°W) in the municipality of San Jose Ojetenam, and San Antonio (15·20°N–91·88°W) in the neighboring municipality of Ixchiguán (Figure 1). San Pedrito has an average elevation of 3200 m with an average annual temperature of 8°C, while San Antonio lies at an average 3000 m and has an average annual temperature of 10°C. Annual precipitation in the region averages 1200 mm falling primarily during the unimodal rainy season (May–October).

The population of San Marcos state is 87 per cent rural, and is one of the most stable rural populations in Latin America (Instituto Nacional de Estadísticas, 1998; Sistema de las Naciones Unidas en Guatemala, 1999). Principal crops grown in the study area are potatoes, wheat (*Triticum* spp.), and oats (*Avena sativa*). Potatoes and oats are cultivated at all elevations in the region. Corn, the main staple of the Guatemalan diet, does not grow in the region at altitudes above 3000 m, forcing 50 per cent of families in the two-community study area to migrate seasonally to work on coffee plantations in Chiapas, Mexico for several months during the year for income to purchase subsistence needs. Although none of Guatemala's major export crops (sugar (*Saccharaum officinarum*), coffee,

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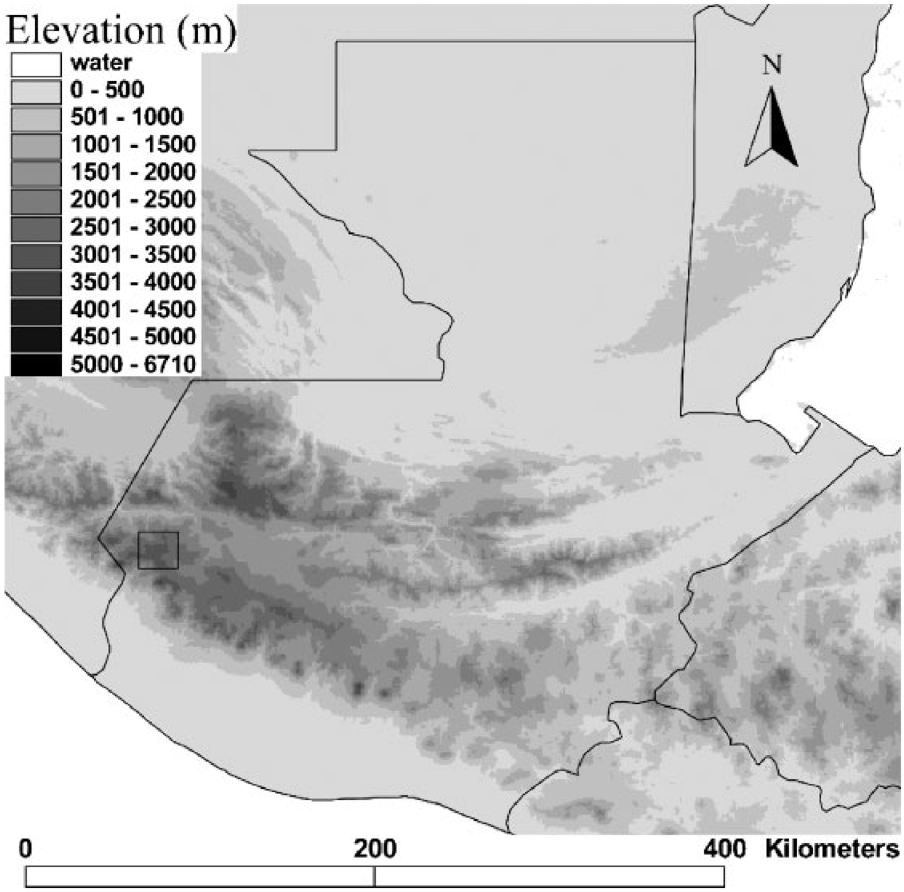

Figure 1. Study area (indicated by box) within Western Highlands of Guatemala. Elevation data from Global 30 Arc-Second Elevation Dataset (GTOPO30) (US Geological Survey, 1996).

banana (*Musa paradisiaca sapientum*), cardamom (*Elettaria cardamomum*)) are grown in the study area, as much as one-third of the total population of San Marcos state is engaged in the harvest of export crops at time of maximum demand, with up to 90 per cent of workers drawn from the poorest communities. Population growth (2·24 per cent per year in the 1990s) coupled with historical consolidation and unequal distribution of available land has led to a shrinking agricultural land base and an average population density of 170 people km^2 (Instituto Nacional de Estadísticas, 1998). A typical smallholder farm in the Western Highlands ranges in size from 0·4 to 2 hectares, supporting 5 to 15 family members.

The native forest cover in the study region was mostly cleared for cattle ranching in the 1800s. The remaining forested areas are limited to communal and municipal woodlots with multiple social and ecological functions, including the protection of water sources. Due to climatic, ecological, and management factors, natural succession to forest is slow; the few areas that have not been cultivated or grazed for more than 20 years remain shrubby with few individual plants taller than 2–3 m. Vegetation in grazed fallow plots includes low, thickly rooted forbs such as *Arnica* spp. with more shrubby vegetation allowed to grow along plot edges. Fields are prepared manually using a large hoe, and tillage depth averages 25 cm.

Historically, these communities maintained seasonal plots in the lowland piedmont region to plant maize, where communal land tenure supported a sustainable crop rotation that included a fallow component of 6–8 years in both lowland and highland areas. By the 1830s, however, land tenure laws re-classified communal fallow land as **valdía**,

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or unused and thus available for expropriation and/or public sale. This drastically reduced community land holdings in the highlands. In the mid-1800s, the government-sponsored expansion of new coffee plantations in the southern coast region effectively cut off access to the maize cultivation zone for highland indigenous communities. At this time, highland indigenous communities were forced (often through government labor quotas) to perform seasonal wage labor on lowland coffee plantations for income to buy maize. Seasonal migration to labor in the lowlands in order to supplement subsistence grain production is a practice that has continued to the present day among the majority of highland small farmers (Berger, 1992; McCreery, 1994).

The historical consolidation and expropriation of indigenous lands, coupled with rising populations and a 35 year civil conflict, have had serious consequences for sustainable land use practices incorporating a fallow component in the Guatemalan highlands. Population pressures and lack of access to cultivation areas in the southern coast no longer allow the traditional practice of shifting agriculture, and intensive cultivation has led to severe soil erosion, lower yields, decreasing food security, and dependence on seasonal migration for supplementary income (Elias and Wittman, 2005; Wittman and Geisler, 2005). The constraints of a finite local land base and unequal distribution of land resources on the expanding agricultural frontier in the region have led to conflicts and violence. Intensive grazing has resulted in severe degradation of remaining common areas used for this purpose, and many of these areas have since been closed to communal grazing. This closure has had a tremendous impact on fallow management and other land use practices as small, non-communal land holdings came to be utilized for grazing as well as crop production.

Fallow System Characterization

A participatory fallow system characterization (Fisher, 1999) was carried out in cooperation with eight agroforestry extension agents, two community education promoters, local leaders, and community members (men, women, and children), and included a variety of Participatory Rural Appraisal (PRA) activities and soil sampling for subsequent chemical analysis. In each community, the PRA resulted in the preparation and verification of a community map, community history, seasonal calendar (indicating agricultural activities, varying labor demands, etc.), a transect map of the community, focus groups, and a set of stakeholder interviews (28 per cent of families interviewed in San Pedrito, N = 12 and 12·5 per cent of families in San Antonio N = 18, participants randomly selected). As part of longer term ethnographic research in the region, interviews were also conducted with village and municipal officials, municipal forest technicians and extension agents, and leaders of agroforestry and pro-development committees at the village level. Interview and focus group questions covered agronomic practices including fallow management, changes in forest and communal land management practices, crop residue management and soil fertility, as well as migration, food security, and other socio-economic issues.

Soil Sampling and Analysis

Volcanically derived soils in the study area are classified as haplustands (e.g., typic Andisols in a sub-humid moisture regime) in U.S. Soil Taxonomy (Soil Survey Staff, 1996), and have received ashfall from volcanic eruptions from the Santiaguito volcano near Quetzaltenango as recently as 1991. Haplustand soils are characterized by high silt and organic matter concentrations, as well as rapid weathering of volcanic ash (Van Wambeke, 1992). Globally, the Andisol soil order covers a small land area; however Andisols tend to be the most densely populated and intensively used tropical soil (Van Wambeke, 1992).

Soil was sampled from six cropped plots, four fallow plots, and one undisturbed plot. The latter plot, located within former communal grazing lands that were deforested more than 50 years (and potentially hundreds of years) prior to sampling, was not grazed for more than 20 years prior to sampling, and was never cultivated according to village authorities and elders. As the undisturbed plot exhibited no known biological, chemical, or physical indicators of infertility or degradation, it served to represent background soil conditions against which the impacts of land use practices on soil fertility could be assessed.

Soil samples were collected from 0 to 30 cm (depth of tillage) from smallholder farm plots in equivalent landscape positions (mid-slope with similar slope and aspect), differing only by land use history. Two parallel down-slope oriented transects were established in each plot. Samples were collected at three locations at 5 m

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increments on each transect. The six samples for each plot were mixed and the composite sample air-dried prior to transport to the Cornell Nutrient Analysis Laboratory for subsequent analysis. At Cornell, samples were dried to constant mass in a forced-air furnace at 60°C and analyzed for available macro and micro-nutrients, and soil pH and nitrate (NO_3) by standard methods. Total carbon and nitrogen were determined from gas chromatography after dry combustion in a carbon and nitrogen analyzer. The ratio between ^{13}C and ^{12}C was analyzed for soil carbon using isotope ratio mass spectroscopy, and is reported in $\delta^{13}C$ notation as per mil deviation from the Pee Dee Belemnite standard (Peterson and Fry, 1987).

Soil properties were compared statistically between fallow and cropped land uses by two-sample t-test, and were considered statistically different for $p < 0{\cdot}05$.

RESULTS AND DISCUSSION

San Pedrito

San Pedrito is inhabited by 45 families who have various forms of land tenure (rent, own, or borrow), with farms ranging from 0·2 to 2·0 Ha. Potato is grown as a staple crop by 100 per cent of families on land they own; 66 per cent of families rent additional land from neighbors or within the municipality for additional potato cultivation. Reasons given for renting additional land included a need to conserve what little land is owned for sheep grazing, and severe degradation of previously cultivated plots. On average, 3·5 **cuerdas** (0·1 ha) are cultivated with potato per family. Only 16 per cent of those interviewed reported planting oats, while two families in the community reported experimentation with wheat and lima beans (*Phaseolus lunatus*), but with poor results due to the severe climatic conditions. Most farmers reported a significant decrease in soil fertility in their lifetimes, with 66 per cent reporting that even with the use of chemical fertilizers, potato yields have declined substantially, with some farmers reporting a 75 per cent reduction in yields since the 1970s. In addition, farmers report that recent unpredictability in rainfall patterns has led them to plant their potato crops several months in advance of traditional first rains. This risk management strategy has significantly reduced the fallow period between crops as farmers endeavor to utilize residual soil moisture for potato cultivation.

All families interviewed reported problems achieving food security from on-farm production, with the total potato production consumed within 5–7 months after harvest. In order to supplement household income and purchase corn (which, as previously indicated, only grows in the lowest elevations of San Antonio and does not grow at all in San Pedrito due to climatological constraints), over 90 per cent of San Pedrito's inhabitants migrate to coffee plantations near Tapachula, in Chiapas, Mexico for 2–5 months to assist in the harvest of coffee.

In the 1970s, communal grazing lands in San Pedrito were closed to public use by municipal authorities following recognition of the severe land degradation caused by complete deforestation, overgrazing by sheep, and intense soil erosion. This restriction led to a significant drop in animal holdings for the majority of village families, although some families with relatively more private land continued to maintain sheep, grazing them on the fallow agricultural land.

San Antonio

San Antonio is inhabited by 144 families with land holdings ranging from 0·3 to 3·6 hectares per family. From the colonial period until the 1970s, the people of San Antonio primarily produced potato, oats, and wheat, migrating to the coast of Guatemala and Chiapas, Mexico, to work in the coffee plantations in order to buy corn. However, in the mid-1980s farmers with holdings below 3000 m began planting maize using commercial fertilizers and production techniques brought from lower altitudes. This has led to a significant decrease in migration, with only 38 per cent of families in San Antonio maintaining seasonal migration to coastal coffee plantations in Chiapas. However, 61 per cent report a decrease in potato yields over the last 20 years, while 33 per cent report that soil conservation measures and intensive applications of chemical fertilizer have resulted in fairly stable yields.

Communal grazing lands have been closed to use for 15 years in San Antonio due to an ongoing dispute over ownership and boundaries with the municipal seat. Consequently, as in San Pedrito, sheep have been grazed on

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whatever land was left fallow between cropping seasons. In July of 2000, however, the conflict was resolved and a large expanse of the formerly communal (and severely degraded) land was parceled out to San Antonio community members on an individual basis.

Contemporary Fallow Management Practices

Fallow management for the purposes of grazing and firewood collection from shrubby species was reported by 70 per cent of families interviewed in the two communities. Most farmers rotate fallow/grazing plots with potato or oat production every 3–6 years (combined cropping and fallow periods), while the average time estimated by farmers to be necessary for soils to recuperate using grazed fallow practices is 6·3 years. In San Pedrito, 16 per cent of farmers responded that they do not leave any land fallow because they either do not have animals to graze or have too little total land. Several farmers with relatively more land reported leaving land fallow for up to 40 years to graze animals. An additional common practice reported by farmers is **truqueo**, the incorporation of weedy biomass accumulated during the 7 month long intercrop period between potato crops ''so the soil does not get hard''.

Since commonly held grazing land is no longer accessible in the study area, subsistence grazing, practiced by 80 per cent of those surveyed, is a key service provided by fallowed fields. However, only 60 per cent of respondents indicated that they have pasture land within their own agricultural plots; the remaining animals are either pastured illicitly on communal land, or, in very few cases (10 per cent of respondents), the animals are stabled and fodder is brought to the animals. Lack of available fodder was cited as the main obstacle to stabling animals in both communities. Thus, farm families must manage a system that incorporates both crop production and land dedicated to grazing. Livestock holdings average eight sheeps and 1–2 mules per family, while private land dedicated to grazing (in fallow areas) is limited to an average of 16 **cuerdas** (0·64 ha) per family.

Prior to controlled grazing of the emergent fallow vegetation during the dry season, crop residues are either directly grazed by livestock or collected for fodder (20 per cent of survey respondents), incorporated into the soil (51 per cent of respondents), or collected and composted with animal manure (24 per cent of respondents). Fallows are managed for firewood production based on the shrubby species **arrayan** (*Baccharis vaccinioides*) where land holdings are large enough to allow the practice, although this is reported for less than 20 per cent of farms.

Reductions in the length of fallow periods between successive cropping cycles were reported by most farmers and were attributed primarily to the subdivision of farm holdings between a number of heirs and the need to maintain grazing plots within the farm holding. The present ratio of cropping years to fallow years reported by farmers interviewed in the study ranged from 10:2 to 3:4, and was related to the size of land holdings owned and rented by individual families.

Soil Fertility

Soil macronutrient, micronutrient, and carbon characteristics are listed in Table I for cropped and fallow plots. Since soil pH of the samples was less than the dissociation constant for bicarbonate ($pK_1 = 6{\cdot}34$, Brady and Weil (1999)), there are no free carbonates present in the samples, and total soil carbon is equivalent to soil organic carbon (SOC). Soil carbon, the primary constituent of soil organic matter, was found to be greater in plots where crops were present than in fallow plots. The higher concentration of SOC in cropped plots than in fallow plots is best considered in the context of the farming system. Potato production in the study area includes incorporation of organic matter at planting, primarily composted foliage from agroforestry systems (*Buddleia* spp. and *Baccharis vaccinioides*) used as livestock bedding, in addition to crop residues and forest litter. Additionally, grazed fallows represent a net export of biomass as livestock are corralled close to the owners' homes (except during active grazing), leaving little manure in the field. When organic inputs are incorporated into soil during cropping, the high concentration of allophane in the soil retards the mineralization of organic matter (Van Wambeke, 1992), leading to an accumulation of SOC.

The isotopic ratio $^{13}C/^{12}C$ of soil carbon can be used to indicate soil organic matter degradation, where ^{13}C enrichment (less negative values in $\delta^{13}C$ notation, e.g., values closer to zero) is interpreted to suggest soil degradation and carbon turnover (Krull *et al.*, 2002). We found soil organic carbon to be significantly related to soil $\delta^{13}C$ for cropped plots, and enriched in ^{13}C relative to the undisturbed plot (Figure 2, $p < 0{\cdot}05$, $R^2 = 0{\cdot}81$). No

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Table I. Soil properties (0–30 cm) for cropped and fallow plots, San Marcos state, Guatemala

Land use	P ($mg\ kg^{-1}$)	K ($mg\ kg^{-1}$)	Mg* ($mg\ kg^{-1}$)	Ca* ($mg\ kg^{-1}$)	Fe ($mg\ kg^{-1}$)	Al ($mg\ kg^{-1}$)	Mn ($mg\ kg^{-1}$)	Zn ($mg\ kg^{-1}$)	Cu* ($mg\ kg^{-1}$)	pH ($mg\ kg^{-1}$)	NO_3* ($mg\ kg^{-1}$)	Total N* (per cent)	Total C* (per cent)	$\delta^{13}C$ (‰)
Fallow	0·52 ± 0·44	167·3 ± 35	117·6 ± 44·2	1379 ± 422	15·4 ± 4·4	782 ± 144	4·81 ± 0·98	0·28 ± 0·07	0·49 ± 0·19	5·86 ± 0·26	2·8 ± 1·6	0·55 ± 0·02	5·92 ± 0·17	−22·97 ± 0·49
Cropped	0·57 ± 0·29	196·2 ± 33	51·7 ± 10·3	765 ± 140	9·7 ± 2·2	666 ± 92	4·24 ± 0·67	0·27 ± 0·05	0·25 ± 0·05	5·68 ± 0·19	13·6 ± 2·2	0·71 ± 0·10	7·45 ± 0·90	−22·42 ± 0·29

Values are mean ± 1 SE, N = 6 for cropped plots, N = 4 for fallow plots.
*Soil properties are significantly different at $p < 0{\cdot}05$.

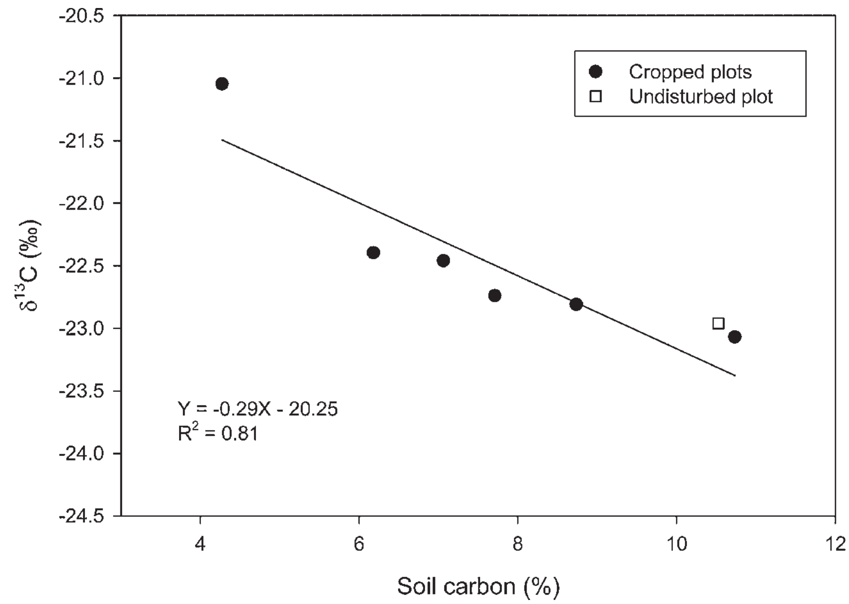

Figure 2. Soil carbon and $\delta^{13}C$ of soil carbon for cropped plots in the Western Highlands of Guatemala. Data for the undisturbed plot are plotted for reference.

relationship between SOC and $\delta^{13}C$ was found for fallow plots. For cropped plots with lower SOC contents, $\delta^{13}C$ values were suggestive of increased organic matter degradation. The data point that nearly coincides with the undisturbed plot on Figure 2 is the cropped plot with the shortest cropping history, which was converted from undisturbed vegetation and cropped for less than 3 years at the time of sampling.

Literature values for decomposition-related changes in $\delta^{13}C$ values of SOC range from 2 to 4‰ (Krull *et al.*, 2002), which is on par with the results of the present study. Soil $\delta^{13}C$ values (Table I) fall part way between the signatures expected for agroecosystems that are entirely supported by the C3 photosynthetic pathway (−28‰) and the C4 photosynthetic pathway (−14‰). Cropping activities in the study area are primarily C3 crops (e.g., potatoes, wheat, and oats), although some C4 residues from maize undoubtedly enter the system via composting of maize husks. It should be noted that the original C3 forest vegetation was cleared in all sample plots in the 19th century and replaced by a mixture of C3 and C4 grasses, and C3 forbs and shrubs.

Sampled fallow plots consistently demonstrated higher calcium (Ca) and magnesium (Mg) concentrations compared to cropped plots. Values for both Ca and Mg cations in fallow plots were twice that of cropped plots, and nearly equivalent to values for the undisturbed plot (1717 mg kg^{-1} for Ca and 126 mg kg^{-1} for Mg). This result is likely due to plant uptake of these nutrients by the potato crop, as Ca and Mg are of primary importance in potato production. Based on the 20 Mg ha^{-1} average potato yields reported by farmers, plant uptake is on the order of 22 mg Ca per kg of soil and 15 mg Mg per kg of soil, respectively (Rosen, 1991). Soil Mg concentrations approach the crop limiting concentrations for magnesium, 50 mg kg^{-1} (Rosen, 1991) in several of the cropped plots.

Differences between Ca and Mg concentrations in cropped and fallow plots are significant, and likely result from *in situ* and *ex situ* processes. In soils derived from volcanic ash, Ca and Mg form soluble salts on the particle surfaces of volcanic ash which then weathers quickly (Witham *et al.*, 2005). Additionally, deposition of Ca and Mg in marine aerosols and dust has been shown to be significant to maintaining soil fertility in regions receiving significant marine inputs (Chadwick *et al.*, 1999). Since the study area is situated 80 km inland in an area of high atmospheric deposition (>1000 mg m^2 y^{-1} as dust; (Chadwick *et al.*, 1999)) and is located less than 40 km from Cabricán, the center of lime production in western Guatemala (Hostnig *et al.*, 1998), both exogenous and endogenous sources could contribute to replenish soil cations during fallow periods. It may be that there are continuous Ca and Mg inputs from atmospheric deposition and *in-situ* weathering of volcanic ash that is either

DOI: 10.1002/ldr

taken up by growing potatoes, accumulated during fallow periods, or mobilized down gradient from undisturbed areas once cation exchange capacity of undisturbed soils is satisfied.

Soil nitrate (NO_3) concentrations were five times greater in cropped plots than in fallow plots. Inorganic fertilizer was reported as widely used in the study area, although application rates are low, and fertilizer is placed directly adjacent to crop plants following emergence. Total soil N was 30 per cent higher in cropped plots than in fallow plots, while the total N for the undisturbed plot was twice that of the fallow plots.

In summary, even the relatively short (3–6 years) contemporary fallow periods appear sufficient to recuperate soil base cation concentrations of Ca and Mg, although the mechanism remains unclear. Nitrogen fertility is achieved during the cropping cycle primarily through additions of compost and inorganic fertilizer. Compost additions are also the source of enhanced soil carbon in cropped plots, which was 26 per cent greater than in fallow plots (Table I), although cropped plots had 30 per cent less soil carbon than the undisturbed plot. The $\delta^{13}C$ values of cropped plots and their relationship with soil carbon suggest that the soil organic matter in cropped plots with low soil carbon is degraded in addition to being depleted.

Future Directions for Improved Fallow Management Practices

In Guatemala's Western Highlands, extension services have focused on improving agricultural productivity and sustainability through the implementation of agroforestry systems and the use of chemical fertilizers, but the fallow component has been largely ignored. Brief fallow periods during intercrop periods, small plots left fallow for 1–3 years, and degraded pasture land recently returned to production through changing land tenure arrangements are optimal areas for the implementation of improved fallow systems that can increase soil fertility, decrease erosion, and provide alternative products such as firewood or forage during the fallow period.

Local extension programs have begun experimenting with improved fallow management practices as a component of agricultural and agroforestry extension programs, building on the traditional practice of leaving trees along field edges for fuel wood and livestock browsing. Agroforestry practices that have been implemented by farmers include the planting of multipurpose trees and soil conservation through terracing and rock erosion barriers, with fuelwood species placed along contour lines. A recent program, supported by the local and municipal governments in conjunction with extension services, arranged for communal land closed to grazing 15 years ago due to overgrazing and environmental degradation to be loaned for 5 year periods to active agroforestry working groups. These groups are expected to rehabilitate these severely degraded communal areas using interventions that include terraces, cultivation of nitrogen-fixing legumes, and reforestation using native species including **salvia** (*Buddlea skutchii* and *B. megalocephala*) for firewood production. In these systems, potato production continues until the tree canopy precludes crop production. The pilot project has produced encouraging results, both in the establishment of tree species and in crop production. This opportunity for new access to land offers a unique window for farmer experimentation with fallow management between potato crops, primarily involving the enrichment of fallows using various plant species. These include the endemic and nitrogen-fixing *Lupinus montanus*, as well as green manure and cover crops that have been used successfully in other high altitude regions such as hairy vetch (*Vicia villosa*) and white sweetclover (*Melilotus albus)* (Beingolea, 2001; Bunch, 2001).

In addition to the additional land made available by the municipal land rehabilitation program, market access for farm production has also increased as roads have been improved in the region. Both of these factors provide more on-farm security and less risk, encouraging local farmers to implement innovative and experimental approaches to fallow management as a means to better achieve food security. Improved fallow management may also reduce the pressure to begin crop production on previously uncultivated marginal lands. Investigation of possibilities for improved fallow management carried out in conjunction with efforts to address the social constraints challenging adoption of new techniques offers an integrated approach for extension services to smallholder farmers in the region.

A follow-up workshop organized by a regional agroforestry extension program that involved community promoters, extension agents, and government agricultural and forest extension agents resulted in recommendations of alternative methods for regaining soil fertility during the short ($\sim$7 months) fallow periods between cropping seasons. Techniques to restore soil fertility in extremely degraded and abandoned plots recently opened for

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production included various agroforestry options in combination with nitrogen-fixing green manure cover crops. The workshop included discussion of the potential use of economically enriched fallows, biologically improved fallows, and constraints to fallow management. Economically enriched fallows could add value to traditional cropping systems with products such as firewood, forage, medicinal plants, while biologically improved fallows have the potential to accumulate a greater amount of nutrients in a given fallow period which are then made available to the subsequent crops (Cairns and Garrity, 1999).

Economically enriched fallow interventions identified as viable possibilities by project participants included the planting of native woody species such as **salvia** (*Buddlea skutchii* and *B. megalocephala*) and **arrayan** (*Baccharis vaccinioides*) on contour lines for firewood production. Camacho *et al.* (1999) have noted that *B. skutchii* offers significant possibilities to improve sheep production given its high nutritional value, and can substitute for up to 50 per cent of sheep diet. Its ease of reproduction, excellent firewood properties, and its demonstrated ability to grow fairly rapidly on disturbed or degraded land in the study area make this species a popular choice with local farmers.

Biologically improved fallows in the context of the Guatemalan highlands are potentially limited due to climatic conditions. However, farmers have begun experimenting with the native legumes *Lupinus montanus* and *L. ehrenhergii*. Hostnig *et al.* (1998) note that *Lupinus* spp. were traditionally used as green manure in the Guatemalan highlands until the 1970s, when farmers began using chemical fertilizers and compost (**broza**) in potato production. The re-introduction of nitrogen-fixing *Lupinus* spp. offers an interesting possibility to add organic matter and to increase soil nutrients between cropping seasons, helping to conserve soil moisture and improve potato yields. This intervention could complement the current practice of incorporating manure and other organic matter at planting time. Significant leaf drop from *Buddlea* spp. and *B. vaccinioides* along field margins also provides mulch, leading to more rapid soil recuperation. Since soil N in fallow plots was half that of the undisturbed plot, biological N fixation is an avenue to increase soil N during fallow periods.

The most practical measures likely to be utilized in the near to medium future are the expanded implementation of agroforestry systems, improved home compost systems and further farmer experimentation with *L. montanus* as a green manure cover crop during shortened fallow periods. This experimentation may involve sowing green manure cover crop seeds when potatoes are harvested in order to make use of residual moisture and subsequently incorporating the accumulated green manure cover crop biomass during preparation of soil for the subsequent crop.

The main constraint to sustainable land management practices identified by both farmers and extension agents was the **minifundio** system (e.g., system of small landholdings) due to increased population and a long history of unequal land distribution. While current changes in land tenure could ease this pressure for a short while, land pressure and food security will continue to be problematic unless significant changes are made in current land-use practices that improve soil fertility and result in long-term yield stability. Additional constraints identified in both of the communities were climate change (reported as less reliable weather patterns), cultural resistance to changes in land management practices, lack of information, language differences between Mam and Q'eqchi' speaking villagers and extension agents, seasonal and rural–urban migration, and lack of communication with other farmers. The work of farmer organizations such as the agroforestry working group in San Pedrito is helping to improve access to information, and the training of farmer extensionists is leading to improved communication with other farmers in surrounding communities. Improved land tenure following the reallocation of communal land plots in San Pedrito is expected to improve food security and ease current land pressure, and could reduce the current dependence on migration, as was the case in San Antonio. It is anticipated that a more continuous presence in the community as a result of reduced migration will give families more time and incentive to experiment with short-term fallow improvements.

CONCLUSIONS

Grazing of fallows as practiced by farmers in the Western Highlands of Guatemala appears central to livelihood strategies of village households. Decisions regarding the timing of rotation between grazed fallow plots and cropped plots based on soil fertility observations by farmers were consistent with results from soil analyses. Soil

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nitrogen and carbon were found to be greater in cropped plots than in fallow plots, while fallow plots were found to be enriched in Ca and Mg, essential nutrients for subsequent potato production.

The decision to leave land fallow is informed by a mixture of factors, including land tenure, labor costs and expected benefits associated with additional cultivation, assessment of the expected benefits to be gained from soil recuperation, and non-crop agricultural needs such as grazing. Fallow plots offer recognizable benefits associated with grazing, firewood, and forage production. Recent changes in land tenure (both the long-term lease recently introduced in San Pedrito and the transfer of property rights from communal to private ownership in San Antonio) offer new possibilities for the rehabilitation of degraded communal land through economically enriched and/or biologically improved fallow management.

Kass and Sommariba (1999) note the need for further research on how fallow management can help overcome biophysical and socio-economic constraints to sustainable agricultural production. Understanding traditional land use and migration patterns can help delineate a baseline for the formulation of new land management practices that place more emphasis on the incorporation of improved fallow systems. In the face of rapid population growth and severe environmental degradation as a result of deforestation, over-grazing, and soil erosion, changing land tenure arrangements provide a unique opportunity for the incorporation of fallow management techniques as preventive maintenance against soil erosion and degradation, while providing additional non-crop benefits. Given the trend of decreasing length of fallows reported by farmers and the limited land base available to future agricultural production in the region, further study of Guatemalan highland fallow practices and other fallow systems is needed for the development of viable farming systems incorporating products and services traditionally provided by fallows.

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