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Measuring farmers' agroecological resistance after Hurricane Mitch in Nicaragua: a case study in participatory, sustainable land management impact monitoring

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Abstract

A study using a participatory research approach and simple field techniques found significant differences in agroecological resistance between plots on "conventional" and "sustainable" farms in Nicaragua after Hurricane Mitch. On average, agroecological plots on sustainable farms had more topsoil, higher field moisture, more vegetation, less erosion and lower economic losses after the hurricane than control plots on conventional farms. The differences in favor of agroecological plots tended to increase with increasing levels of storm intensity, increasing slope and years under agroecological practices, though the patterns of resistance suggested complex interactions and thresholds. For some indicators agroecological resistance collapsed under extreme stress.

With the help of 19 non-governmental organizations (NGOs) and 45 farmer–technician teams, 833 farmers measured key agroecological indicators on 880 plots paired under the same topographical conditions. These paired observations covered 181 communities of smallholders from southern to northern Nicaragua. The broad geographical coverage took into account the diversity of ecological conditions, a variety of practices common to sustainable agriculture in Nicaragua, and moderate, high and extreme levels of hurricane impact. This coverage, and the massive mobilization of farmer–technician field research teams, was made possible by the existence of the Movimiento Campesino a Campesino (MCAC) (farmer-to-farmer movement), a widespread smallholders' network for sustainable land management.

An approach for measuring agroecological resistance is introduced, and it is suggested that comparatively higher levels of agroecological resistance are an indication of lower vulnerability and higher sustainability. However, the effectiveness of practices appears to be bounded by a combination of steep slopes, maintenance and design of soil conservation structures, and extremely high storm intensity.

The study concludes that the participatory research can contribute significantly to the monitoring and development of sustainable land management systems (SLM) among smallholders, and recommends a sustainable, participatory approach to agricultural reconstruction following natural disasters.
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Keywords: Sustainable land management; Impact monitoring; Sustainable agriculture; Participatory research; Vulnerability; Agroecological resistance; Hurricane Mitch; Campesino a Campesino Movement

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1. Introduction

1.1. The challenge of participatory, sustainable land management impact monitoring

Increasingly, sustainable agricultural development has focused on the development of Sustainable Land Management systems (SLM) (Hurn, 2000; Lefroy et al., 2000). However, it is difficult to predict the overall sustainability of a given agroecosystem, and impossible to prove it beyond the "test of time." Heuristically, probabilistic models and indicators of sustainability have helped researchers identify trends and calculate the possible impacts of specific farming practices on sustainability (Hansen, 1996). Different indices, models, and frameworks (e.g. SI, EPIC, FESLM) for evaluating sustainable land management, as well as the application of basic agroecological principles can also guide efforts to develop SLM (Altieri, 1983; Lefroy et al., 2000; Sands and Podmorea, 2000). However, environmental stochasticity and the spatial and temporal complexity of farming's constantly changing social and agroecological interactions demand continual redefinition of system goals and the corresponding readjustment of farming practices (Altieri, 1987; Norgaard, 1987; Gliessman, 1998). There is a constant, widespread and site-specific need for researchers and farmers to identify those practices leading away from sustainability, as well as to validate those that lead us towards more sustainable systems (Lefroy et al., 2000). Participatory Rural Appraisal techniques are now commonly employed by researchers, development professionals and rural communities to reflect on local socio-environmental trends (Chambers, 1994a,b,c). Similarly, Farmer Participatory Research and Participatory Technology Development have been widely used to develop and validate low-external input technologies to increase yields and lower production costs for small-scale farmers in fragile or degraded agroecosystems (Rhoades and Booth, 1982; Chambers, 1989; Rocheleau, 1994; Scoones and Thompson, 1994; Ashby and Sperling, 1995).

Nevertheless, due to economic constraints, few participatory approaches attempt to evaluate the actual impact of alternative practices. For the most part, sustainable agriculture projects assume that the practices they promote will improve sustainability without ever measuring the results to see if this is actually the case. The development of reliable indicators of sustainability for project managers and farmer-stakeholders is a central concern of SLM impact monitoring (Hurn, 2000; Steiner et al., 2000).

The primary motivation for the participation of 19 non-governmental organizations (NGOs) and over 800 farmers in this study was the desire to see if farms in the Nicaraguan Movimiento Campesino a Campesino (MCAC) were actually moving towards higher levels of sustainability. The occurrence of an extreme ecological disturbance, Hurricane Mitch, provided MCAC with the opportunity to assess a decade of SLM practices.

1.2. Sustainability, vulnerability and agroecological resistance

As a property of an agricultural system, sustainability is neither static nor deterministic, but probabilistic. At best, models describe the likelihood that particular management practices will lead to 'meeting the needs of the present without compromising the ability of future generations to meet their own needs' (WCED, 1987).

In agroecology, 'resistance' describes the ability of a farming system to resist the impact of a disturbance, while 'resilience' is the ability to recover from disturbance (Pimm, 1984; Herrick, 2000). Resistance and resilience are both indicators of the "probability" of sustainability (Gliessman, 1998). Natural disasters may be thought of as extreme ecological disturbances. Natural disasters, however, are not simply environmental phenomena, but rather, a combination of exposure to some natural hazard and human vulnerability (Wilches-Chaux, 1994; Smith, 1996). Vulnerability, understood as the level of difficulty to 'anticipate, cope with, resist, and recover from the impact of natural hazard' (Blaikie et al., 1994), can include natural, physical, economic, social, political, technical, philosophical/ideological, cultural, educational, and ecological components (Wilches-Chaux, 1994). Focusing on development, vulnerability can be expressed as an inverse function of the level of sustainability of a model or course of development. In central America, the United Nations Development Program views the reduction of vulnerability as a strategy for increasing sustainability (Cardenal, 1999).

Vulnerability as a measure of the levels of stress in a system, and of its capacity to withstand disturbance, can be divided into resistance and resilience. Increasing the levels of resistance or resilience will lower vulnerability and increase the probability of sustainability. Using this approach, trends towards or away from agroecological sustainability may be assessed by measuring trends in system resistance and/or resilience.

2. Methodology

2.1. Measuring agroecological resistance to assess sustainability

In October of 1998, Hurricane Mitch, one of the Caribbean's five most powerful hurricanes of the twentieth century, slammed into central America causing at least US$ 6.7 billion dollars in damage to infrastructure and industry, an amount equal to approximately 13.3% of central America's GNP. Over 10,000 died and 3 million were displaced or left homeless (Ecocentral, 1998; CRIES, 1999). In the wake of Hurricane Mitch, this study used basic agroecological indicators to compare the levels of resistance on "sustainable" farms using SLM practices, with neighboring, "conventional" farms (lacking those practices) over a large area of storm disturbance. Average differences in levels of resistance between sustainable and conventional farms were assumed to reflect relative differences in levels of sustainability.

The sustainable farms in the study belong to smallholders working within a multi-institutional farmers' movement for sustainable agriculture, known in central America as farmer-to-farmer or, MCAC (Holt-Gimenez, 1996). The farming practices commonly encountered in MCAC include a wide range of soil conservation and agroecological management practices, tested and promoted by smallholders in central America for over 20 years (Bunch, 1985, 1995; Annis, 1992; Selener et al., 1997). With the support of the National Farmers and Cattle Ranchers Union (UNAG), and dozens of NGOs, MCAC has spread its "farmer-to-farmer" approach throughout Nicaragua since 1987. At present, there are well over 1000 promotores (farmer-extensionists) serving over 10,000 farm families in Nicaragua (Hocdé et al., 2000b; PCAC, 2000).

The most common SLM practices found on MCACs farms include structural, agronomic and agroforesty techniques. Conventional smallholders in Nicaragua commonly use a mix of traditional and "semi-technified" practices that use external chemical inputs without the benefit of machinery or irrigation (Table 1).

Obviously, there is some mix and overlap between these two categories, as some conventional farmers employ some SLM techniques and vice-versa. In general, however, MCACs 10,000 farms are sustainable "islands" in a conventional "sea", covering approximately 4% of Nicaragua's 240,000 farms (Maldider and Marchetti, 1996). However, MCACs farms are geographically very widespread, thus providing an opportunity to compare SLM and conventional practices over a broad range of ecological conditions.

The farmers, promotores and technicians in MCAC are experienced in on-farm, farmer-led experimentation, participatory technology development, and farmer-to-farmer training (Hocdé et al., 2000a). This extensive network of local expertise was the basis for the design and implementation of the 3-month field study that used paired observations to compare agroecological resistance between sustainable and conventional farms.

2.2. Participatory research design and training

The methods of observation and measurement employed in the study were a hybrid of simple field techniques commonly used by farmer-promoters in MCAC (Holt-Gimenez, 1995), and field methods for agroecological assessment used to teach agroecology (Gliessman, 1999). Selected indicators attempted to address the erosive nature of the hurricane: topsoil; depth to moist soil; per cent vegetation; landslides; rill erosion and gully erosion. Economic losses from crop damage were estimated and inventories of farm practices were recorded. These indicators were considered unbiased and able to fulfill the qualities for sensitivity, transformability, collectability and communicability outlined by Liverman et al. (in Zinck and Farshad, 1995).

A random selection of farms affected by the hurricane would not have yielded sufficient numbers of sustainable farms. Therefore, a purposive selection method was used.

Table 1
SLM and conventional practices

Type	Practices				Function
SLM practices[a]					
Mechanical practices	Contour plowing	Rock and vegetative contour bunds	Contour ditches	Terraces	Soil and water conservation/ management
Agronomic practices	Cover/inter/relay cropping with grains and legumes	Intensive, in-row tillage reduced use of chemical inputs	Compost, vermi-culture, animal manure	Integrated pest management: traps, organic pesticides and repellents, beneficial insects	Fertility, soil building, weed and pest control, water conservation, Soil protection, increased land equivalency ratio
Agroforestry	Woodlots	Multistory and alley cropping	Vegetative strips	Live fences	Fuel, fodder, timber, fruit, reduction of runoff, nutrient pumping/cycling, habitat for beneficial insects, shade
Conventional practices					
Mechanical practices	Plowing/cultivating with (not against) the slope		Dibble-stick planting		Create seedbed, reduce labor input
Agronomic practices	External chemical inputs (fertilizers, pesticides, herbicides)		Slash and burn		Supply nutrients, control weeds and pests

[a] In general, farmers from MCAC initiate SLM with mechanical soil and water conservation practices. Farms that had implemented one or more of these practices were classified as agroecological, those that had not were considered conventional.

First, approximately 30 NGOs working in SLM that used farmer-promotores were invited to participate in the study. After presenting the idea and basic concepts in a general meeting, 19 NGOs decided to participate.

During the month of March, 1999, researchers met on nine different occasions with NGO technicians to develop a single set of field methods and to select research areas. Each technician selected two promotores to form a three person, field research team. From one to five farmer–technician teams were formed by each NGO. Field methods and the field sheet were developed and field-tested prior to these training workshops on three different occasions with the promotores and technicians from one of the NGOs. Forty-five farmer–technician teams were trained in nine different 1 day workshops conducted on farms in potential research areas. A total of 140 promotores and technicians were trained.

Researchers helped teams select sites from within their own project areas where Hurricane Mitch had caused destruction. Teams were trained in field methods and then instructed to identify 10 farms that they considered had implemented the best set of SLM practices within their particular project. To qualify for the study, each sustainable farm also needed a neighboring conventional control farm, either bordering or close nearby, with the same topographical conditions (slope, cardinal orientation, location in the watershed, surrounding topography and vegetation) to form a paired observation.

The number of paired sites was large (442), and fairly representative of smallholder practices, ecological conditions, and storm effects for the Pacific region of Nicaragua (Fig. 1).

The methodological challenge was to train a large number of research teams sufficiently well to take consistent, unbiased measurements in highly variable ecological conditions. The importance of precision and unbiased observation was a central theme in team training. To control observational error between teams, technicians were all trained by the same researchers using the same methodology and field manual. To eliminate measurement errors between pairs of farms observed by the same team, the same person within the team always made the same measurements. As a field check, farmer-owners accompanied the research team during the data collection on both sustainable and conventional farms, signing off on the field sheet to indicate that in their view, observations and measurements were unbiased.

2.3. Field procedure

Paired comparisons began by observing the farm from the highest point in the topography. Farmers used the term “agroecological” to describe the plot on the sustainable farm. First, a representative plot, either “agroecological” or “conventional”, of approximately 0.5–1.5 ha was selected and measured. In many cases, farm size was so small that farm and plot were the same unit. A map was drawn of the plot showing boundaries, landmarks, crops, structures, areas of damage and/or erosion, slope direction, and surrounding vegetation. Plot location in the watershed, on the hillside, and the general topography were recorded on a standard field sheet by the technician. The plot was divided into 1–3 lots based on visually estimated changes in slope. Slope and indicators were measured on each plot using the following methods, generally familiar to technicians and promotores:

Slope: Averages of 3–5 measurements, depending on the evenness of terrain. Teams used carpenter’s line levels on 2 m lengths of cord and metric tapes to make measurements. Measurements were divided by two and then averaged.

Soil Profiles: 1–3, 50 cm deep profiles per lot, depending on slope. Slopes of over 15% had profiles taken at the top, middle, and bottom of the lot. Farmers measured depths in centimeters of litter and topsoil, as well as the depth to subsoil and depth to moist soil. The differentiation between topsoil and subsoil was based on changes in color and texture. Depth to moist soil was determined by changes in soil color and by touch.

Vegetation: Research teams walked a straight, diagonal transect line across the plot. Percent vegetation was estimated by observing ground level (ground to knee), bush level (knee to head) and arboreal level (head and above) vegetation within a 50 cm, diameter hoop at 10 m intervals and at each plot boundary. (To correct for the change in perspective, arboreal observations taken at approximately >4 m were determined with arms extended and a “hoop” made with both hands by touching opposite thumbs and middle fingers to form a circle approximately 10 cm in diameter).

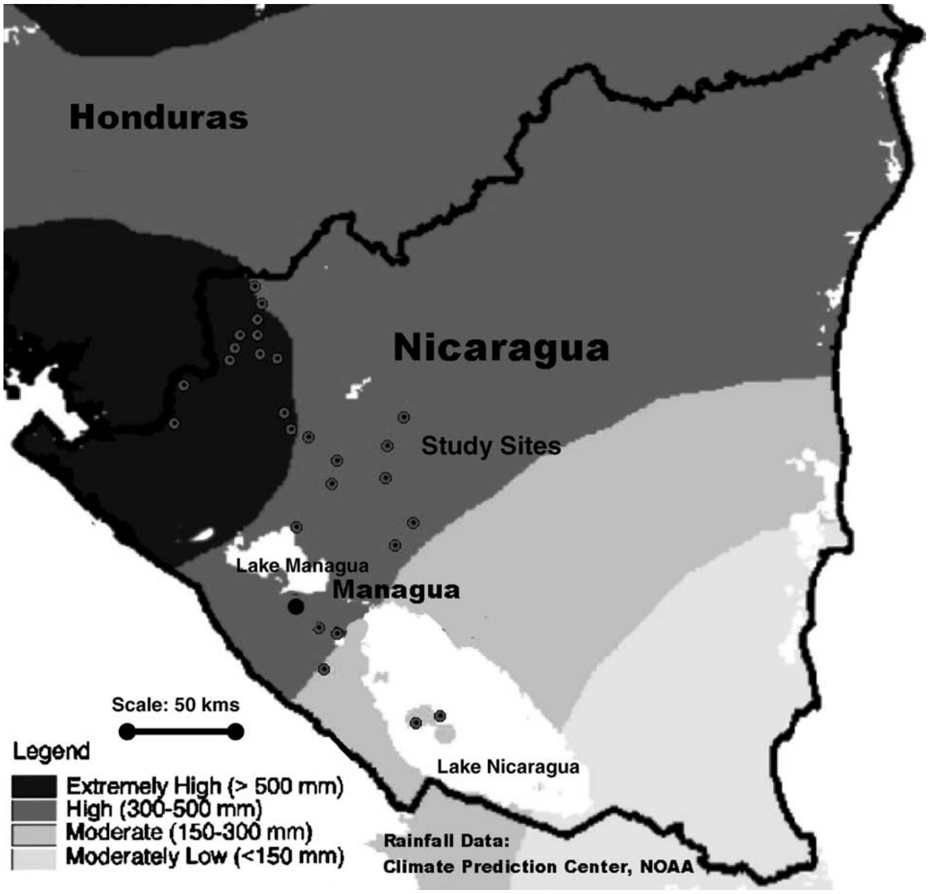

Fig. 1. Map of study sites and levels of hurricane intensity.

Gullies: Volume (m^3/ha) was estimated by measuring length and four cross-sections (depth, width top and width bottom) evenly-spaced along the length of gullies within the plot area. Erosion was considered gully (rather than rill) when the depth of the cut was greater than 20 cm.

Rill erosion: Area (m^2/ha) was not measured directly but estimated by measuring areas of exposed subsoil (length of the affected area and four widths at evenly-spaced intervals). Rill erosion areas were identified as those areas showing bare subsoil and/or rills $\leq$20 cm deep.

Landslides: Area (m^2/ha) was measured by measuring the length (i.e. from the top were soil was lost, to the bottom were it was deposited) and four widths at evenly-spaced intervals.

Net profit/loss: US$/ha. Were calculated based on estimates of the net value (after labor and input costs) of standing crops at the time of the hurricane, and the local market value just before the hurricane for annual crops. (Scarcity and speculation distorted prices just after the hurricane, as did food relief programs subsequently).

Teams carried out an inventory of practices that included the following categories:

- Manure application, intercropping, cover cropping, reforestation, alley cropping (measured in m^2/ha and years since implementation of the practice).
- No burning, contour plowing, living fences, crop rotation, stubble incorporation, 0-tillage: years since implementation; contour bunds (rock and

vegetative), contour ditches, gully fill (measured in length in meters, and year since construction).

- Terraces and windbreaks (measured in length and height in meters, material/species used, and years since construction).
- Barriers and Bunds (measured as number of barriers for those in gullies, and length in meters for bunds on the contour, materials used, and years since construction).

Following the fieldwork, the team conducted structured interviews with both farmers for their perceptions of the hurricane, the ways in which their farms were damaged, the reasons for the patterns of damage and the effectiveness of their farm practices. Every effort was made to identify and differentiate on and off-farm factors (e.g. farming practices versus roads, deforestation, etc.) contributing to the damage.

2.4. Data analysis

Paired plots that did not exhibit differences greater than 15% in slope were selected for comparisons and statistical analysis (422 pairs). Because landslides, rill and gully erosion only occurred on 10–30% of farms, only pairs with occurrence on one or both farms were considered in the analysis of these indicators. Data for landslides, rill erosion, gully erosion and net profit/loss were not normal and so were ranked to determine statistical significance. Student's paired, two-tailed *t*-tests and Wilcoxon Signed Rank tests were performed on overall differences $(a - c)$ between agroecological (a) and conventional (c) plots, and on differences when grouped and classed according to time (years under agroecological practices), slope, and intensity (precipitation from Hurricane Mitch). A blocked, three-way ANOVA analysis was also applied using time, slope and intensity as independent variables. Levels of time, slope and intensity were contrasted to determine differences at different age, slope and rainfall classes. To determine the effect of specific practices in relation to storm intensity, a multivariate analysis of covariance (MANCOVA) was carried out in which the standardized differences $[(a - c)/(a + c)]$ between agroecological and conventional plots for each indicator were correlated with the presence or absence of specific agroecological practices.

3. Results

There is a consistent pattern of differences between the agroecological and the conventional plots. Despite high ecological variability between paired sites, agroecological plots consistently have more topsoil, less erosion, more vegetation and lower economic losses than conventional plots. Median values were generally consistent with mean differences $(a - c)$, except in the case of net profit/loss (Table 2).

3.1. Topsoil, depth to humidity and vegetation

On average, agroecological plots had 40% more topsoil than conventional plots. Only 20% of the pairs observed showed conventional plots with as much or more topsoil than agroecological plots. In 50% of the observations, agroecological plots had ≥ 2 cm of topsoil and in 20% of the observations they had ≥ 5 cm (Table 2).

The indicator used to compare levels of field moisture did not establish field moisture per se, but compared the depth to moist soil from the dry soil surface. The assumption was that moist soil found closest to the surface indicated greater levels of field moisture. On average, farmers had to dig 10% less on agroecological plots than on conventional plots to reach moist soil. In 20% of the paired observations, moisture was at least 7 cm deeper on conventional plots. However, in 20% of observations, agroecological plots had moisture levels at least 3 cm deeper. In half the cases, there was no difference.

The measure of vegetation was considered both an indication of storm impact and a general indication of on-farm regenerative ecological processes. Agroecological plots had over one-fifth more vegetative cover than conventional plots.

3.2. Erosion: landslides, rill and gullies

On average, agroecological plots lost 18% less arable land to landslides than conventional plots and had a 49% lower incidence of landslides. Median values for both agroecological and conventional plots were much lower than the mean due to the presence of a few large landslides in both cases, though proportionally these were not very different from the difference in means. This may be due to large landslides

Table 2
Indicators of agroecological resistance

422 pairs	Agroecological	Conventional	a − c	S.E.	((a − c)/c) 100 (%)
Topsoil (cm)					
Mean	9.1	6.5	2.6***	0.21	+40
Median	8.0	5.0	–	–	–
Moist soil (cm)					
Mean	15.8	17.6	−1.6***	0.46	−10
Median	14.5	16	–	–	–
Vegetation (%)					
Mean	21.5	17.8	3.7***	0.41	+21
Median	20.9	17.3	–	–	–
Landslides (m^2/ha) $n = 79$					
Mean	607.3	740.2	56.8***	2.58	−18
Median	159.7	222.5	–	–	–
Rill erosion (m^2/ha) $n = 160$					
Mean	200.6	377.2	114.3***	3.66	−47
Median	57.6	129.8	–	–	–
Gullies (m^3/ha) $n = 164$					
Mean	104.4	339.8	117.2***	3.71	−69
Median	16.0	25.1	–	–	–
Net profit/loss (US$/ha)					
Mean	17.18	−18.54	17.63***	5.94	192.7
Median	−54.72	−55.79	–	–	–
No. of plots w/landslides	28	55	−27		−49
No. of plots w/rill erosion	56	132	−76		−58
No. of plots w/gullies	51	137	−86		−63

*** $P < 0.001$.

affecting both agroecological and conventional plots more or less equally (Table 2).

Agroecological plots averaged 47% less rill erosion than conventional plots. Median values were lower on both plots because of the incidence of large rill areas. However the median was proportionally lower on agroecological plots than on conventional plots, reflecting fewer “large” rill areas. The frequency of rill erosion among agroecological farms was 58% lower than on conventional farms. Eighty percent of conventional plots had up to 78.1 m^2/ha more rill erosion than agroecological plots.

Agroecological plots averaged 69% less gully erosion compared to conventional farms. Median values were also lower for both plots, due to the incidence of very large gullies. However, the proportional difference between mean and median is much greater on conventional than on agroecological plots (104:16 versus 340:25), indicating that large gullies on conventional plots were still larger and/or more frequent than those on agroecological plots. Eighty percent of conventional plots had at least 20 m^3/ha more volume of land loss to gully erosion than did agroecological plots. Gullies occurred 63% less on agroecological plots.

3.3. *Net profit/loss*

Average profits from agroecological farms were roughly equal to average losses from conventional farms. While agroecological farms averaged 193% higher farm incomes, median values showed only minimal differences in profit/loss between agroecological and conventional farms. Median net profit/losses were considerably lower than the mean on both agroecological and conventional farms, indicating both farms suffered equally (US$ −54.72 versus US$ −55.79), however the difference between mean and median was much greater in the case of agroecological farms, reflecting high profits on some of these farms (Table 2).

3.4. Agroecological practices

The results of a MANCOVA using 19 different agroecological practices as dependent variables to explain differences between paired observations with storm intensity yielded highly significant overall effects in topsoil ($P < 0.0012$) though not for any other indicators. Rock bunds, green manure, crop rotation and the incorporation of stubble all demonstrated strong positive effects on differences in topsoil depth between agroecological and conventional plots. Green manures appeared to have some effect on differences in rill erosion and gullies; windbreaks on depth to moisture, landslides and gullies; and fill on gullies, though the model was statistically weak for all of these. Ditches, terraces, barriers, mulch, legumes, trees, plowing (straight) against the slope, no-burn, live fences, and 0-tillage did not demonstrate statistically significant effects (Table 3).

3.5. Effects of stress/disturbance

To detect trends, the study looked at the differences between paired plots with respect to the number of years under agroecological practices (time), plot slope (slope), and the level of storm intensity (intensity). The effect of time is an inverse measure of stress based on the age classes of agroecological farms. The assumption is that the trends between different age classes reflect time trends on individual farms.

Generally, differences between agroecological and conventional plots are statistically significant at different scales of time, slope and intensity. While there is an overall tendency for these differences (a − c) to favor agroecological plots, the study encountered important exceptions in favor of conventional plots, and found revealing changes in the degree of these differences over time, slope and intensity.

Of all the indicators, topsoil was the most sensitive overall to time ($P < 0.0001$), slope ($P \leq 0.0057$) and intensity ($P \leq 0.0022$). Depth to moist soil, vegetation, and net profit/loss, all were significantly affected by time ($P < 0.0001$, $P \leq 0.0046$ and $P \leq 0.0413$, respectively) and intensity ($P < 0.0001$, all), but not slope. Time showed significant positive effects on gully erosion ($P \leq 0.0407$). Differences in rill and landslides were not significantly affected by time, slope, or intensity alone. However, combinations of intensity × slope were found to have multiplicative effects on differences for topsoil, depth to moist soil, rill erosion and net profit/loss. Combinations of intensity × time affected topsoil ($P < 0.0001$) and net profit/loss ($P \leq 0.0110$). Slope × time affected topsoil ($P \leq 0.0019$) and depth to moist soil ($P \leq 0.0164$). The combination of intensity × slope × time affected depth to moist soil ($P < 0.0001$) and rill erosion ($P \leq 0.0319$).

3.6. Measuring agroecological resistance

To interpret these trends in terms of resistance and sustainability, the following hypothesis is proposed:

Table 3
MANCOVA[a] significant positive effects of practices on agroecological indicators

Practices	Topsoil	Moisture	Rill	Landslide	Gullies
Rock bunds	0.0133				
Green manure	0.0021		0.0111		0.0005
Crop rotation	0.0016				
Stubble	0.0087				
Windbreaks		0.0080		0.0025	0.0003
Alley cropping					
Contour plowing					
Fill					0.0061
DF (model)	55/311	55/312	55/311	55/312	55/311
F value (model)	1.79	1.12	0.74	0.74	1.30
$P > F$ (model)	0.0012	0.2710	0.9168	0.9111	0.0858

[a] Multiple analysis of covariance, type 1 MS, $N = 369$.

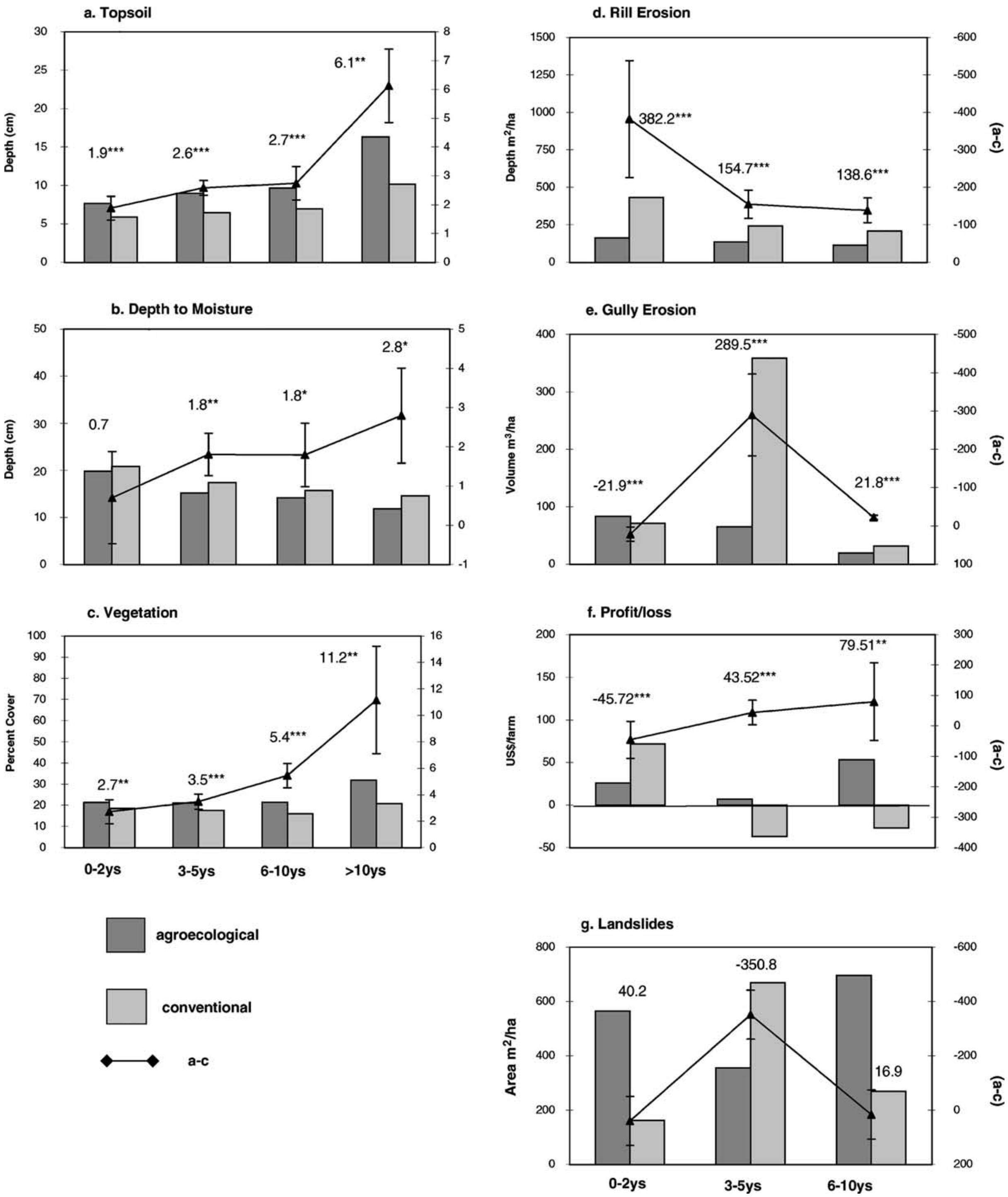

Fig. 2. Agroecological resistance and time under sustainable practices for agroecological farms. Resistance is the average of the differences between agroecological and conventional plots (a − c). There were 68, 244, 84, and 8 paired plots in 0–2, 3–5, 6–10 and >10 year categories, respectively.

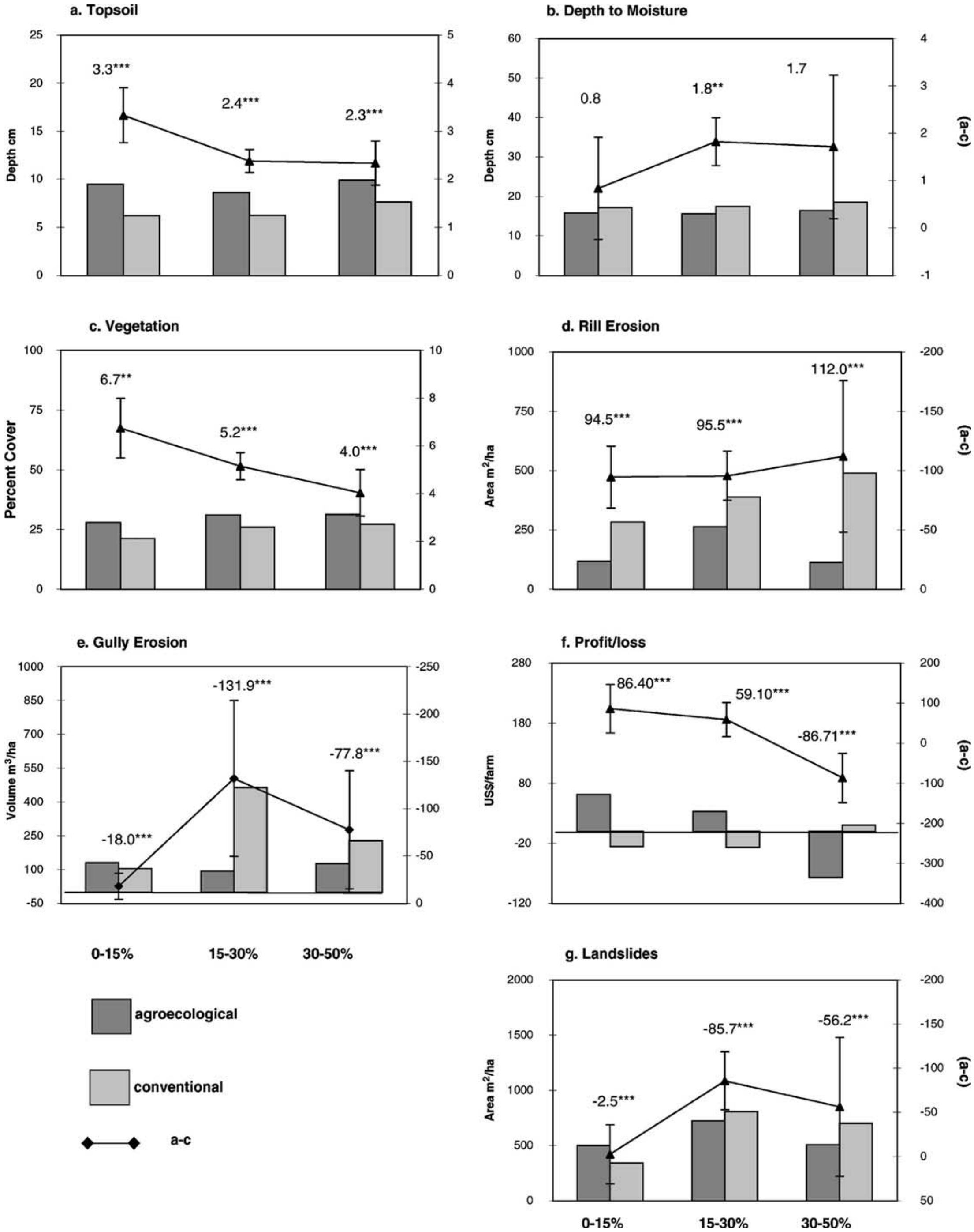

Fig. 3. Agroecological resistance and slope. Resistance is the average of the differences between agroecological and conventional plots (a–c). There were 83, 250 and 86 paired plots in 0–15, 15–30 and 30–50% slope categories, respectively.

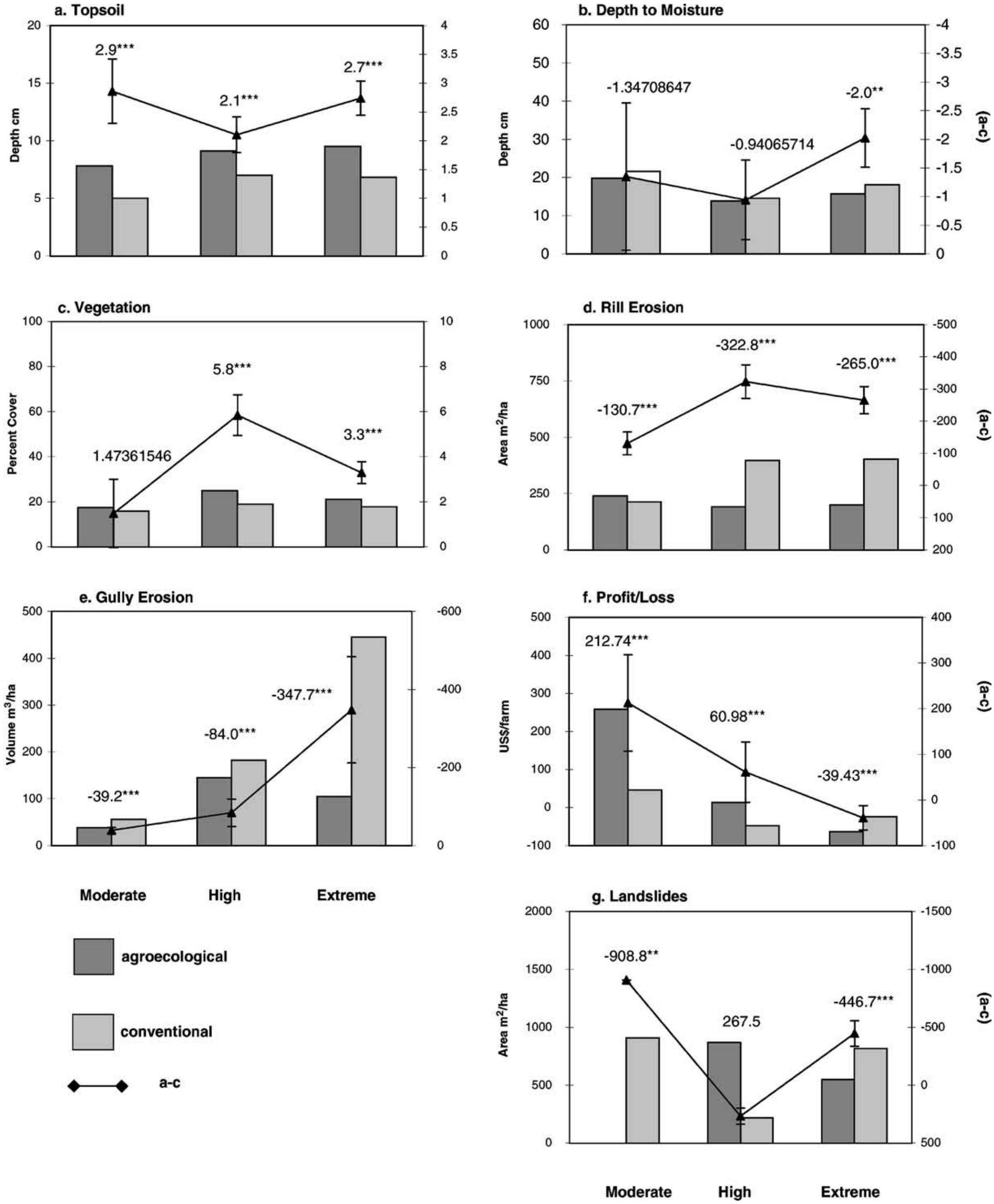

Fig. 4. Agroecological resistance and storm intensity (determined as millimeters of rainfall between 5 October to 17 November 1998). Resistance is calculated as the average of the differences between agroecological and conventional plots (a–c). There were 76, 125, and 221 paired plots in moderate (150–300 mm), high (300–500 mm), and extreme (>500 mm) rainfall categories, respectively.

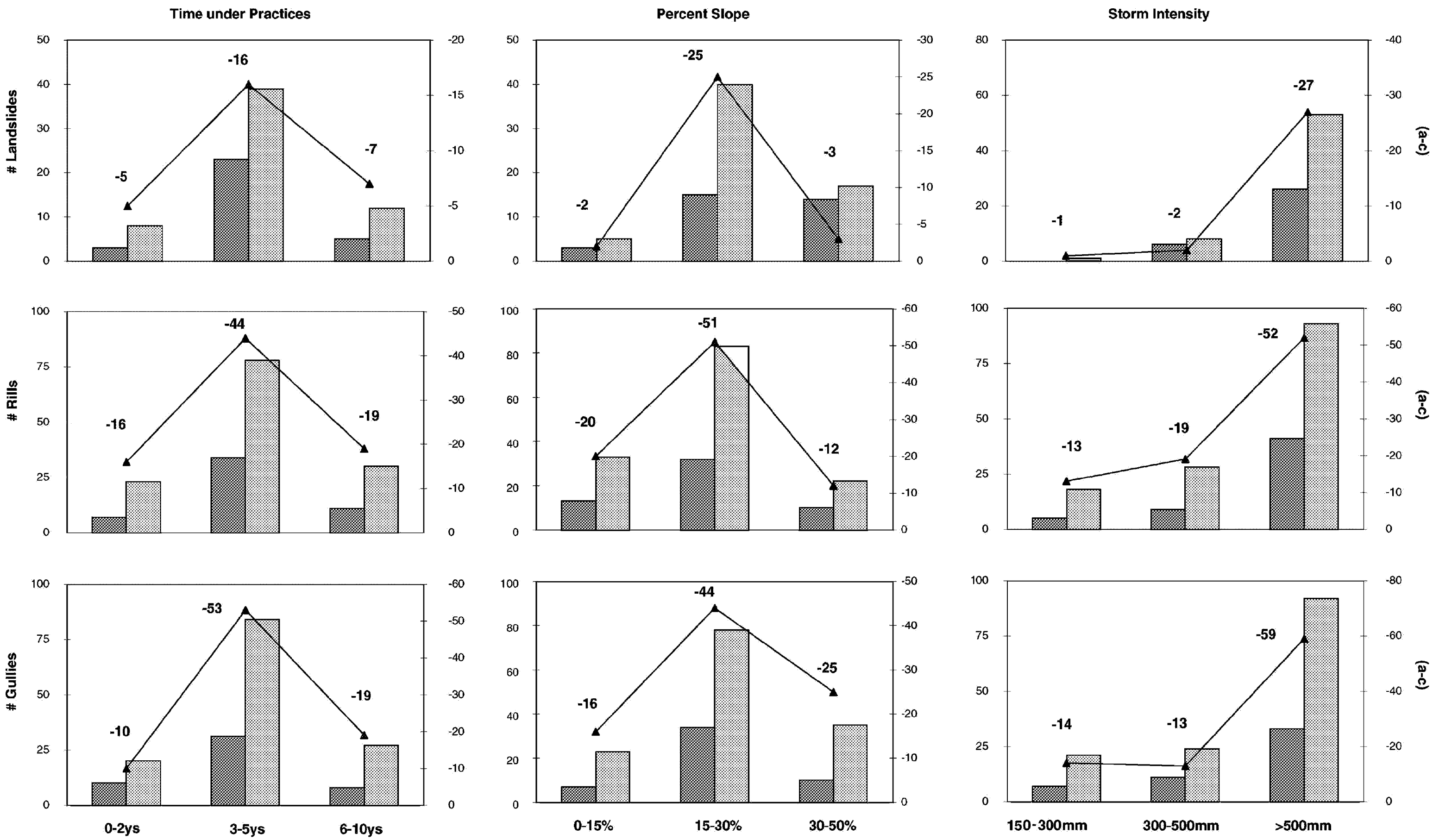

Fig. 5. Agroecological resistance (a–c) as measured by the incidence (#) of landslides, rills and gullies with time, slope, and storm intensity.

> Relative differences in agroecological indicators between more sustainable and less sustainable farms increase with increasing stress and disturbance. Stress will eventually reach a "resistance threshold" beyond which any further increase in stress or disturbance will result in the collapse of these differences.

If these assumptions hold true, then the observed differences between agroecological and conventional farms (a − c) under increasing slope, storm intensity, or time under cultivation would suggest trends and thresholds in agroecological resistance, vulnerability and, by inference, sustainability (Conway, 1985, 1986).

Considering only those indicators and classes that were found to be statistically significant, patterns under stresses and disturbance are revealing. Resistance to erosion (topsoil) increases steadily in the early years of agroecological practices, then significantly and dramatically (>100%) after 10 years (Fig. 2a). However, this increase can be counteracted (separately and in combination) by significant decreases in resistance at 15–30 and 30–50% slopes (Fig. 3a), and at high (300–500 mm) storm intensity (Fig. 4a).

Infiltration capacity (depth to moist soil) increases steadily over time under agroecological practices (Fig. 2b), but only increases significantly on steep slopes (Fig. 3b), and when subjected to increasing storm intensity (Fig. 4b).

Vegetation follows the resistance pattern for topsoil, increasing steadily, then doubling after 10 years (Fig. 2c). Resistance decreases steadily with slope (Fig. 3c), but first increases, then drops at extremely high rainfall (Fig. 4c).

Agroecological farms significantly increase resistance for net profit/loss 3–5 and 6–10 years under agroecological practices (Fig. 2f). However, this can be counteracted by a strong tendency of decreasing resistance with increasing slope (Fig. 3f), and storm intensity (Fig. 4f). resulting in collapse and reversal (negative resistance) for agroecological farms.

Topsoil, humidity, vegetation and net profit/loss were measured on all farms, and are generally sensitive to one or more measures of agroecological resistance. However, fewer measurements make it difficult to statistically confirm clear patterns of resistance for rill and gully erosion. Landslides were a poor indicator of agroecological resistance, overall.

Nonetheless, when frequency is considered (rather than area or volume), resistance patterns for landslide, rill and gully erosion are strikingly clear and consistent, increasing steadily for all three under intensity, but rising and collapsing under time and slope (Fig. 5a–i). These patterns reflect resistance thresholds on very steep slopes and on older agroecological farms.

4. Discussion

4.1. Findings

The findings from the study validate many years of hard work in soil conservation, forestation and agroecological diversity by farmers in the Campesino a Campesino Movement. Not only do they indicate better conservation and stronger economic resistance under MCACs agroecological practices, they also suggest that the regional estimates of environmental damage from Hurricane Mitch based on satellite imagery (USGS, 1999) were probably much too low (ECLAC, 1999). Farmers working with shovels and tape measures not only detected extensive laminar erosion, they also documented significant damage to vegetation. While differences of 1–6 cm in topsoil may appear small, losing just 2 cm of soil is approximately equivalent to an erosion rate of 100 tons/ha/year (Toness et al., 1998).

These trends in agroecological resistance suggest that SLM practices have been effective at building and conserving soil, water and vegetation over time, but that the stress of very steep slopes can significantly lower resistance to high and extreme rainfall events. As far as severe erosion is concerned, it appears that slope is most limiting for resistance, and, perhaps surprisingly, that older agroecological farms are actually less resistant to hurricanes than younger ones. Encouragingly, economic resistance increases over time, but alarmingly, this advantage can diminish to the point of collapse and reversal under combinations of extreme slopes and extreme storm intensity. This points strongly to economic thresholds for SLM practices under extreme conditions. It is also important to note that agroecological farms do not appear to develop positive economic resistance until 3–5 years under practices, suggesting a lag in the economic viability of SLM practices.

The development of SLM in central America explains the mechanisms behind some of these patterns. For years, farmers have initiated sustainable practices with rock bunds, contour ditches and live barriers. After about 3–5 years these conservation structures create gently sloping terraces that, under normal rainfall conditions, conserve both soil and water. Contour ditches no longer fill with water after normal rains and are often filled in and planted (Bunch and López, 1995). Over the last 5–8 years, many farmers have shifted to green manures and cover crops (e.g. *Mucuna spp*, *Canavalia ensiformis*, etc.) to conserve water, protect soil and supply organic nitrogen (Flores and Estrada, 1992; Buckles, 1994; Bunch, 1994). Many farmers then abandon labor-intensive maintenance on soil conservation structures, altogether (author's observation). Unfortunately, as several independent observers noted, younger agroecological farms with conservation structures still "tying" soil to the hillside resisted the storm better than older farms that did not (Bunch, 1998; Schlather, 1999). Soil and water conservation work in Central America over the last 10 years has concentrated on building soil and retaining runoff (Toness et al., 1998). Less attention has been paid to channeling excess water off the farm. Not only were older soil conservation structures weakened by lack of maintenance, they were not originally designed to handle extreme rainfall events. The drop in agroecological resistance to severe erosion over time and on very steep slopes indicates that MCAC farmers need to renovate, modify (e.g. reverse-slope bench terraces, sloped toe drains, etc.), and maintain conservation structures, to deal with excess runoff from extreme rainfall events.

The collapse of economic resistance on very steep slopes and at extreme storm intensity suggests that though there may be room for improvement, some conditions are simply too extreme to farm successfully using current agroecological practices. The lack of economic resistance in the early years of establishing agroecological practices also points to the need for initial support or subsidy for SLM on storm-prone hillsides.

The study also revealed that while MCAC has spread primarily among farmers working on 15–30% slopes, it has "spilled out" to those working on gentle and extreme slopes as well.

4.2. Design

The very large sample size of the study, taken over a very large area, was key to identifying statistically significant results, though this also had the disadvantage of introducing high levels of ecological variability, and reduced statistical power for a more fine-grained analysis. Organizing future research within pre-defined agroecological domains (Conway, 1986) could help reduce the noise from this variability.

While the study took general types of practices into account, the specific designs and systems of management for those practices are highly diverse. Further, not only do practices interact, they overlap, and wane or disappear as limiting factors change and farmers incorporate new innovations. Characterization and comparison of different management systems and specific practices would help with precision, though this would obviously require much more time in the field.

One important aspect of resistance not addressed by the study is that farmers generally do not introduce SLM practices until they have experienced significant "involution", i.e. falling returns to labor and capital, despite increasing intensification, e.g. use of fertilizers, pesticides and herbicides (Geertz, 1963; Netting, 1993). This makes their present advantage all the more significant. Also, indicators were selected specifically for an intensive rainfall event. Others should be developed for other natural and anthropogenic hazards, e.g. drought, market failure, etc.).

Because of widespread participation in the study, the purposive selection resulted in a fairly representative sample of SLM in Nicaragua, as reflected by the range for 'years under agroecological practices.' Since the only criteria used in selecting conventional control plots was their topographical similarity and proximity to the neighboring agroecological plots, these can be considered random and representative of conventional agriculture among Nicaraguan smallholders. The sample spread also reflected the general conditions for smallholder agriculture in Nicaragua, most of which takes place on hillsides.

Longitudinal studies of SLM projects are rarely done in the field over extensive areas. Multiperiod models of sustainability have difficulty translating changes in farming conditions into effects on possible land uses over time, and thus are poor predictors of sustainability (Jansen et al., 1995). As Walters and Holling (1990) point out, the act of management changes the system being managed. In the study, farmers stated that, 'Ten years worth of erosion took place in a week.' While intensity cannot be used as a direct analog for weathering, when combined with time, a picture of vulnerability emerges that provides a unique window into the potential agroecological sustainability over time.

The concept of 'thresholds' in sustainability assessment usually refers to ranges and the "irreversibility" of land degradation processes under certain practices (Zinck and Farshad, 1995). The thresholds of agroecological resistance in this study do not refer to ecological functions per se, but to ecological conditions. Thus, we do not know how long soil on MCACs farms will be conserved, or how long farms will be profitable. Rather, we have identified the parameters under which their practices are more sustainable than their conventional neighbors. This approach does not preclude or replace simulation models. Rather, it leaves the problem of prediction aside in favor of assessing the relative effectiveness of existing practices under different levels of stress and disturbance.

4.3. Methods

Methodologically, the study itself was a very large experiment in participatory research. This type of applied, interactive science generally requires more work from researchers because of the difficulty of balancing scientific validity with the complexity of sharing methods with farmers (Poudel et al., 2000). This tension can lead to trade-offs between the scientific rigor needed to insure confidence and validity, and the methodological simplicity needed to insure quality participation on the part of farmers. This problem was overcome in this study by taking a few key, simple measurements on many farms, rather many complex measurements on relatively few farms.

Much was learned about the appropriateness of some field procedures for farmer–technician teams, and improvements could be made in procedures and field instruments. A tremendous amount of time was invested in reviewing, checking, and in some cases, recollecting data. While maps drawn by the field teams proved essential for accepting or rejecting questionable entries in the database, a greater understanding of data processing and statistical procedures by the participating field technicians and agronomists could help improve the quality of the data. Importantly, the ability to make accurate field observations using the methods of this study was very much dependent on the experience of the observer. Promotores with years of experience digging soil profiles in farmer-to-farmer workshops were much more consistent in their measurements than young technicians with limited experience. Preparation and practice in the field will improve data quality.

5. Conclusions

SLM farms in the MCAC are clearly faring better than their conventional neighbors, particularly on hillsides in the hurricane-prone Central American isthmus. The familiar practices of contour barriers, green manures, crop rotation and stubble incorporation are effective at building and conserving topsoil. Nonetheless, extreme storm intensity combined with very steep slopes can limit and sometimes overcome the effectiveness of SLM practices, particularly if basic soil conservation structures are not designed to channel excess runoff, or are not maintained.

While SLM projects may provide important economic alternatives for resource-poor farmers in the medium and long-term, because of low economic resistance in the start-up period, these may not be a ready option for destitute farmers, nor are they necessarily sustainable for farmers on very steep hillsides. This does not imply that conventional farms are by default more sustainable. However, it does mean that advocates for SLM in central America will have to address land-use capability, ecologically based land reform, and possibly, changes in short and medium-term agricultural credit and pricing policies in order to support the widespread introduction, improvement and maintenance of SLM techniques.

The study's broad-based learning experience was shared among researchers, technicians, promotores and farmers, and benefited the participating NGOs by providing them with an indication of the agroecological impact of their work. Projects not only have a solid baseline for future SLM impact monitoring of their work, they can potentially compare their progress with others, and together could make important regional and national recommendations.

The fact that NGOs and farmers were able to coordinate on a national level to carry out the study opens up important opportunities for decentralized approaches to sustainable agricultural research. Follow up studies with a focus on agroecological vulnerability could open new ways of researching agroenvironmental problems. Once agroecological domains and indicators are chosen, and once field methods are mastered, the approach measuring agroecological resistance could be re-applied to address agroecological resilience as well as resistance.

This study was motivated by a desire to contribute to agricultural reconstruction following Hurricane Mitch. Participants felt that it was essential to rebuild Nicaragua's agriculture in a participatory, sustainable way, and that the study could help define and identify local capabilities. Given the high occurrence of natural disasters in Central America, participatory, sustainable reconstruction should be a high priority for relief and development efforts. Our findings confirm that promising methods and human resources are available for that task.

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