# Assessment of soil quality in agroforestry systems

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# Content

- Introduction
  - Concepts
  - Soil quality research in Talamanca, Costa Rica
- **Methods**
  - Different types of indicators
  - Soil quality index
  - Key results
- Conclusions/Perspectives

# INTRODUCTION

## Three functions of soil

1) Support for plants and organisms (Productivity)

2) Water regulation

3) Descompose Degrade

**Soil quality**

# Soil quality

- Definition. Is the capacity of a soil to function in a ecosystem, to maintain and improve the biological productivity, environmental quality and the health of plants and animals (Doran and Parkin 1994).

- The analysis of soil quality:
  - Allows to detect changes in soil (+ or -)
  - Is a primary indicator of sustainable management of soil
  - Is a critical component of the sustainable agriculture

  (Larson and Pearce 1994, Karlen *et al.* 1997, Herrick 2000)

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# ¿How to assess soil quality?

| Indicators | Soil functions | | |
|---|---|---|---|
| | Productivity | Water | Decomposition |
| **Physical** | **X** | **X** | |
| **Chemical** | **X** | | |
| **Organisms**<br>**Biological activity** | **X** | **X** | **X** |

**It is also necessary to characterize the system components and their management**

- The Indigenous Reserve in Talamanca valley, inhabited by Bri-bris y Cabécares indigenous people

Self-consumption crops: rice, maize and bean in the mountains
Commercial crops: cacao, banana and plantain predominant in the valley

# The case of soils of Talamanca valley, Costa Rica

- Cacao and banana in agroforestry systems (organic)

- Plantain monocrop, with application of inorganic inputs (herbicides fertilizer, fungicides, insecticides)

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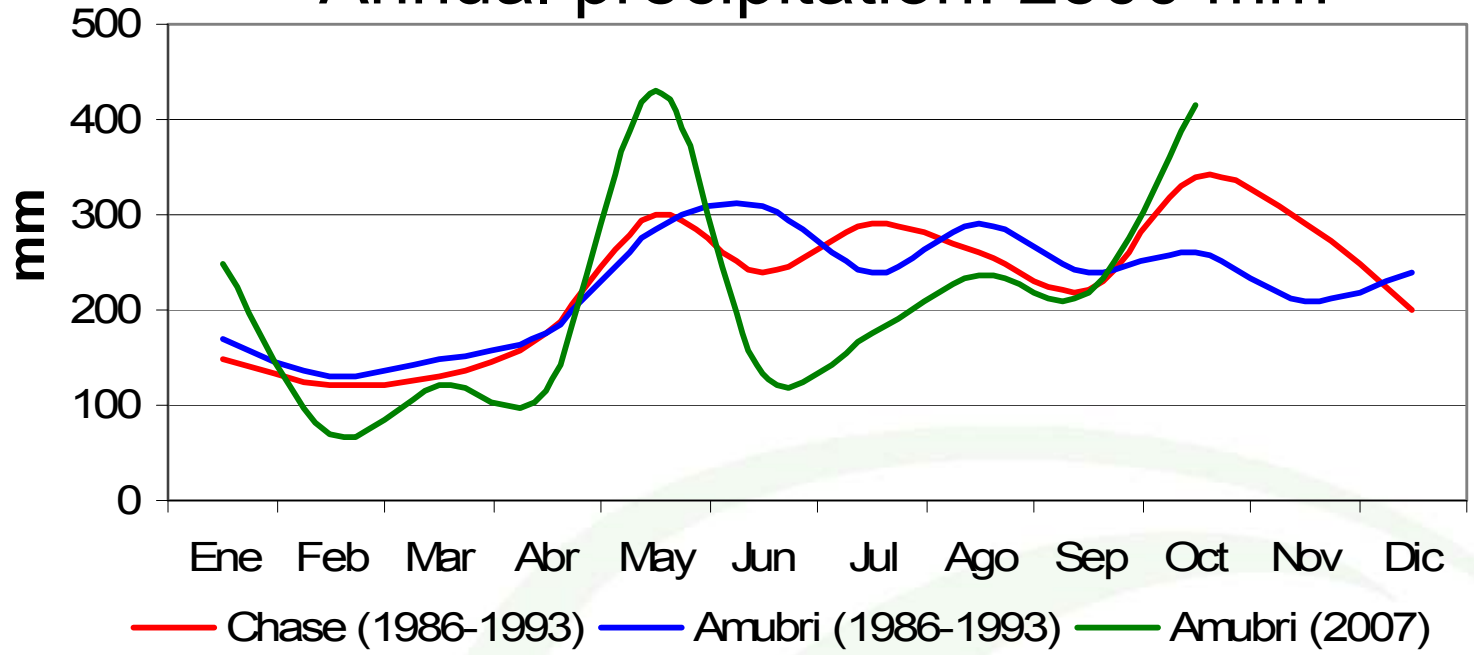
# METHODS

# Climate in Talamanca valley

Annual precipitation: 2500 mm




Mean Tº = 24 – 27ºC  Relative Hummidity = 84 – 90%

## Soils

Inceptisoles (50%)

Entisoles (30%)

# Systems (treatments)

| Systems | Repe_ titions |
|---|---|
| Cacao monocrop (CM) | 5 |
| Conventional plantain monocrop (CP) | 7 |
| Cacao-Laurel agroforestry system (CL) | 7 |
| Banana-Laurel agroforestry system (BL) | 7 |
| Secondary Forest (SF) | 7 |
| | Total of plots = 33 |

Each plot = 20 m x 50 m = 1000 $m^2$

Important: all plots in the same soil order (inceptisols)

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# SOIL QUALITY INDICATORS

**Most often used indicators (key indicators –minimum data set) found in the scientific literature**

| Physical | Chemical | Biological |
|---|---|---|
| • Bulk density<br>• % of soil in aggregates (structure)<br>• Texture | • pH, acidity<br>• Ca, Mg, K, P, Cu, Mn, Zn, Fe<br>• C total<br>• N total<br>• C/N<br>• Organic Matter | • Nematodes<br>• Mycoparasites<br>• Microbial respiration<br>• Microbial biomass<br>• Mineralization index<br>• Metabolic quotient<br>• Catalase (enzyme)<br>• Earthworms<br>• Litter biomass |

# Statistical analysis

– ANOVA: complete randomized design, bi-factorial in split plots

Large plot: systems (SF, BL, CL, CM, CP)

Sub-plot: seasons (dry and rainy)

$$Y_{ijk} = \mu + S_i + \epsilon_i + E_j + SE_{ij} + \epsilon_{k(ij)}$$

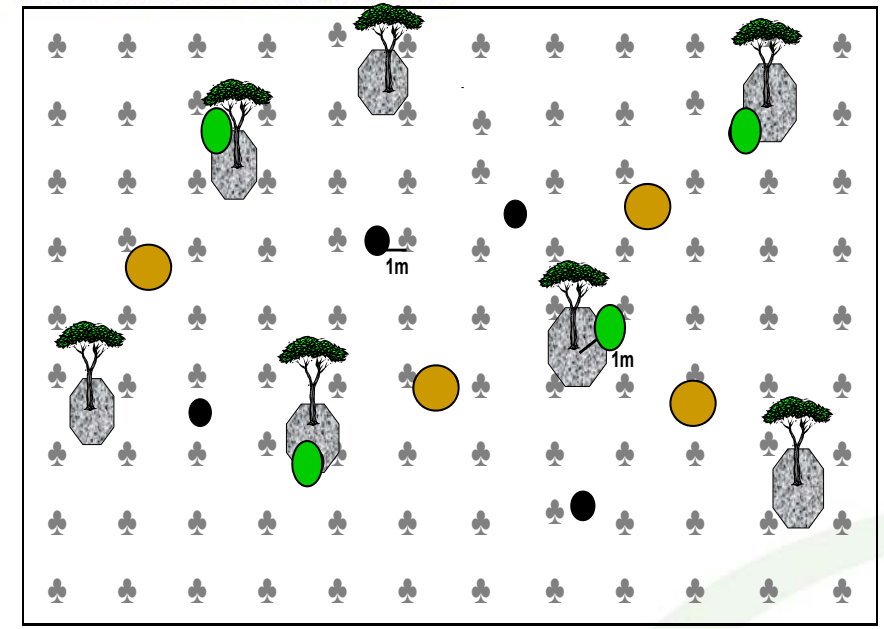
- Test LSD Fisher (95%)

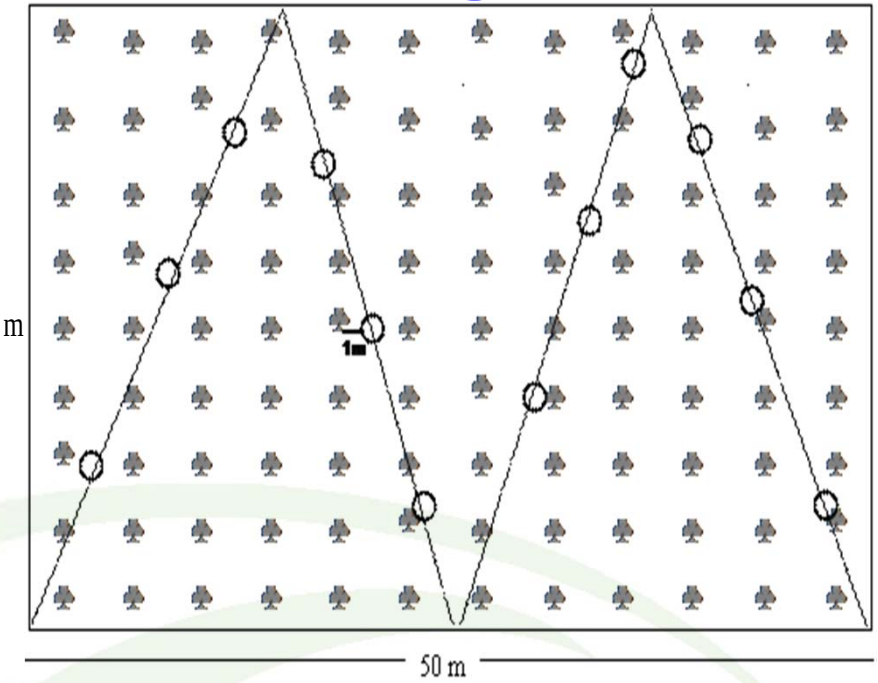
- MANOVA: principal components

- Correlation analysis

} The most important indicators

# Soil sampling




●●● 12 subsamples in cacao and laurel AFS

○ 12 subsamples in CP, CM Y SF

For bulk density, counting of earthworms and litter: 3 sampling points were taken

To obtain one composite sample per plot

# Sampling depth

- 0-5 cm: the major part of the microbiological activity
- 0-20 cm or more: physical and chemical indicators

But, it is important to have the same soil samples for all the indicators

The ideal sampling will be:

- 0-5 cm
- 0-20cm
- 20-40cm

# Chemical indicators

| INDICATOR | METHODS | SOURCE |
|---|---|---|
| pH<br>Acidity (cmol(+) $kg^{-1}$)<br>Ca (cmol(+) $kg^{-1}$)<br>Mg (cmol(+) $kg^{-1}$)<br>P (mg $kg^{-1}$)<br>K (mg $kg^{-1}$)<br>Cu (mg $kg^{-1}$)<br>Mn (mg $kg^{-1}$)<br>Zn (mg $kg^{-1}$)<br>Fe (mg $kg^{-1}$) | pH-meter in water<br>Extractable acidity trough chemistry degree with standardized solution of NaOH 0,01 N<br>Extraction of P, K, Cu, Mn, Zn with the method Olsen Modified; For Ca, Mg and acidity with KCl 1 N. The lecture of P with colorimetric method; the determination of the other elements (K, Cu, Mn, Zn, Ca y Mg) trough spectroscopy by atomic absorption | Díaz Romeu and Hunter (1978) |
| % C total*<br>% C total<br>% N total | C total and N total were determined with the method of combustion in auto-analyzer equipment | Briceño and Pacheco (1984) |
| % Organic matter (OM) | % organic matter = % C x 1,724 | Bertsch (1995) |
| C/N | C/N = C total / N total | Bertsch (1995) |

# Chemical results

**Soil chemical indicators of five land management systems, Talamanca, Costa Rica. Means (± standard deviation) and analysis of variance. Year 2007**

| Indicator | Land management systems | | | | | p value ANOVA |
|---|---|---|---|---|---|---|
| | SF | CL | BL | CM | CP | |
| N total (%) | 0.33±0.03 a | 0.27±0.09 ab | 0.19±0.03 c | 0.21±0.03 bc | 0.19±0.05 c | 0.0003 |
| C total (%) | 2.92±0.30 a | 2.43±0.91 ab | 1.58±0.38 c | 1.89±0.39 bc | 1.65±0.40 c | 0.0003 |
| Organic matter (%) | 5.03±0.52 c | 4.20±1.56 bc | 2.73±0.65 a | 3.26±0.67 ab | 2.84±0.68 a | 0.0003 |
| C/N | 8.96±0.42 a | 9.07±0.52 a | 8.25±0.91 a | 9.11±0.68 a | 8.79±0.47 a | 0.135 |
| pH | 5.16±0.53 a | 5.33±0.49 ab | 5.92±0.20 b | 5.73±0.15 ab | 6.77±0.71 c | <0.0001 |
| Acidity(cmol(+) $l^{-1}$) | 2.59±3.20 a | 1.51±2.25 a | 0.09±0.04 b | 0.17±0.13 ab | 0.05±0.01 b | 0.002 |
| K (mg $kg^{-1}$) | 114±39 b | 87±41 ab | 92±72 ab | 65±27 a | 192±47 c | <0.0001 |
| P (mg $kg^{-1}$) | 4.3±1.46 a | 5.21±2.88 a | 8.7±4.14 b | 6.74±2.93ab | 11.23±4.35 c | <0.0001 |
| Ca (mg $kg^{-1}$) | 2771.64±2164 b | 1666.76±659 a | 2853.06±183 b | 1852±607 ab | 5296±655 c | <0.0001 |
| Mg (mg $kg^{-1}$) | 422±209 b | 449±301 b | 504±331 b | 402±371 b | 805±216 a | 0.0029 |
| Cu (mg $kg^{-1}$) | 12.2±3.87 b | 8.94±4.21 a | 7.14±3.11 a | 6.88±2.02 a | 9.43±3.50 a | 0.0018 |
| Zn (mg $kg^{-1}$) | 11.16±8.68 b | 3.44±2.64 a | 1±0.58 a | 1.4±1.54 a | 1.84±0.7 a | <0.0001 |
| Mn (mg $kg^{-1}$) | 64.89±34.32 b | 50.34±46.97 b | 6.69±1.69 a | 13.3±13.15 a | 5.04±2.75 a | <0.0001 |
| Fe (mg $kg^{-1}$) | 198±142 bc | 225±161 c | 115±58 a | 132±41 ab | 50±14 a | 0.0003 |

SF: secondary forest; CL: organic cacao-laurel; BL: organic banana-laurel; CM: organic cacao in monoculture; CP: conventional plantain in monoculture. Different letters in rows indicate significant differences among land management systems (LSD Fisher, $p<0.05$). Complete randomized design was applied.

# Physical indicators

| INDICATORS | | SOURCE |
|---|---|---|
| % soil aggregation:<br>% 2-8 mm<br>% 250 µm-2 mm<br>% 53 µm-250 µm<br>% < 53 µm | C in soil aggregates:<br>• g C 2-8 mm 100 g $^{-1}$<br>• g C 250µm-2 mm 100 g $^{-1}$<br>• g C 53 µm-250 µm 100 g $^{-1}$<br>• g C < 53 µm 100 g $^{-1}$ | Elliot (1986) |


Wet sieving

65ºC for 5 days

Determination of % of soil and C in each aggregate

| INDICATORS | METHODS | SOURCE |
|---|---|---|
| Bulk density (g $cc^{-1}$) | Soil sample with cylinder (known volume). Dry in oven (105ºC per 24 hours) | Henríquez y Cabalceta (1999) |




| | | | |
|---|---|---|---|
| Texture: | % Arcilla<br>% Arena<br>% Limo | Granulometric method of Bouyoucos | |

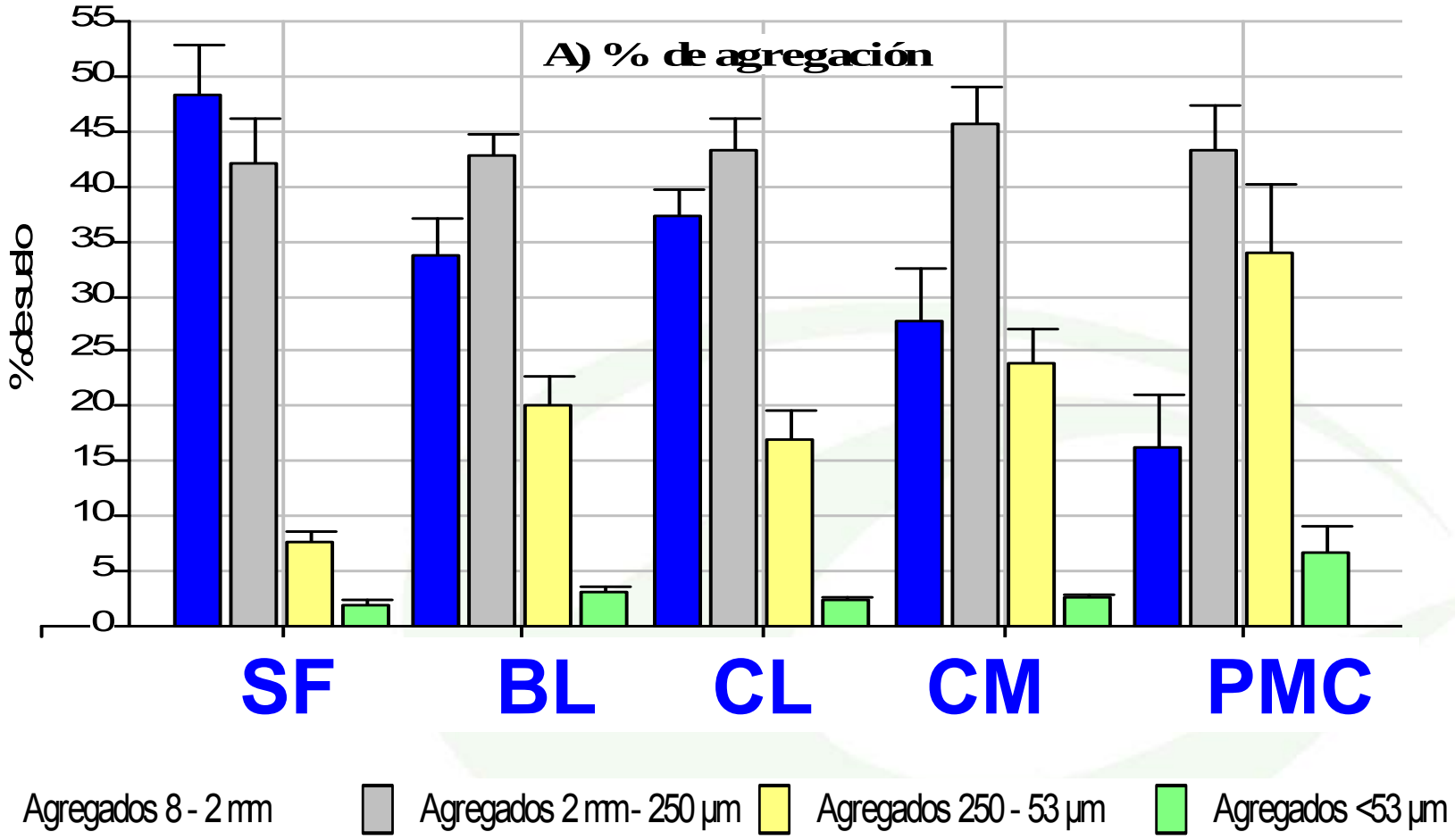
# Physical results

**Soil physical indicators of five land management systems, Talamanca, Costa Rica. Means (± standard deviation) and analysis of variance. Year 2007**

| Indicators | Land management systems | | | | | p value ANOVA |
|---|---|---|---|---|---|---|
| | SF | CL | BL | CM | CP | |
| Bulk density (g cm-3) | 0.78±0.07 a | 0.83±0.09 ab | 0.92±0.10 bc | 0.90±0.06 bc | 0.96±0.05c | 0.0024 |
| Sand (%) | 33.83±4.40 a | 44.11±9.20 a | 42.40±12.94 a | 47.20±11.52 a | 31.26±19.34 a | 0.1651 |
| Silt (%) | 32.11±6.91 a | 34.06±7.43 a | 41.83±12.33 a | 38.00±8.79 a | 46.06±13.44 a | 0.1240 |
| Clay (%) | 34.06±5.68 b | 21.83±9.13 a | 15.77±2.69 a | 14.80±7.33 a | 22.69±7.56 a | 0.0003 |
| % soil agg 2-8mm | 48.38±11.62 c | 37.33±6.28 bc | 33.83±8.54 b | 27.68±10.75 ab | 16.29±12.54 a | 0.0001 |
| % soil agg 250um-2mm | 42.19±10.4 a | 43.31±7.25 a | 42.83±5.05 a | 45.79±7.48 a | 43.16±11.28 a | 0.9671 |
| % soil agg 53-250um | 7.56±2.61a | 16.99±7.23 ab | 20.18±6.66 b | 23.95±6.95 bc | 33.84±16.93 c | 0.0005 |
| % soil <53um | 1.87±1.44 a | 2.36±0.82 a | 3.17±1.01 a | 2.57±0.61 a | 6.71±6.51 b | 0.0558 |

SF: secondary forest; CL: organic cacao-laurel; BL: organic banana-laurel; CM: organic cacao in monoculture; CP: conventional plantain in monoculture. agg: aggregates; Different letters in rows indicate significant differences among land management systems (LSD Fisher, $p<0.05$). Complete randomized design was applied.

# % of soil in aggregates (structure)



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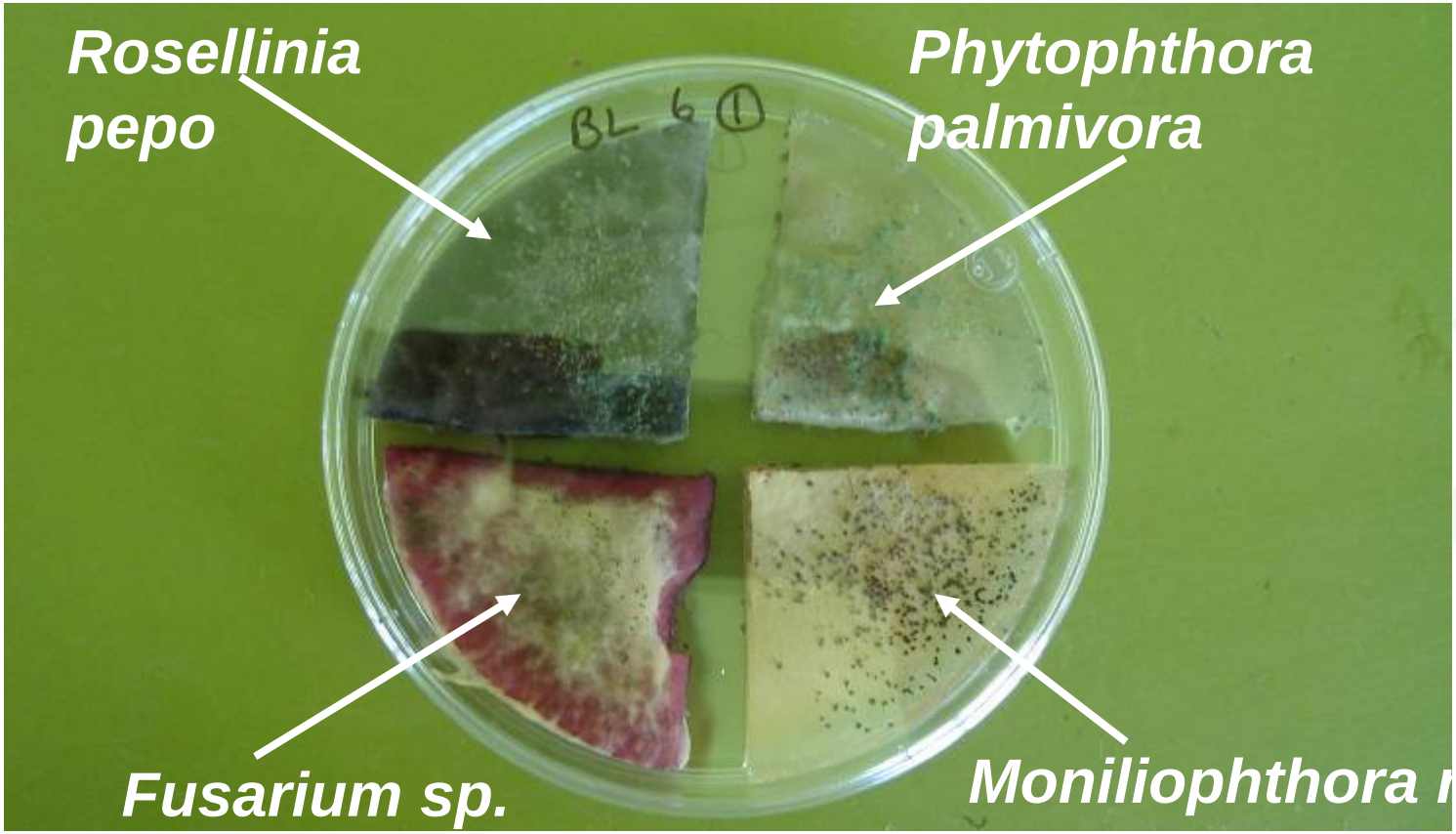
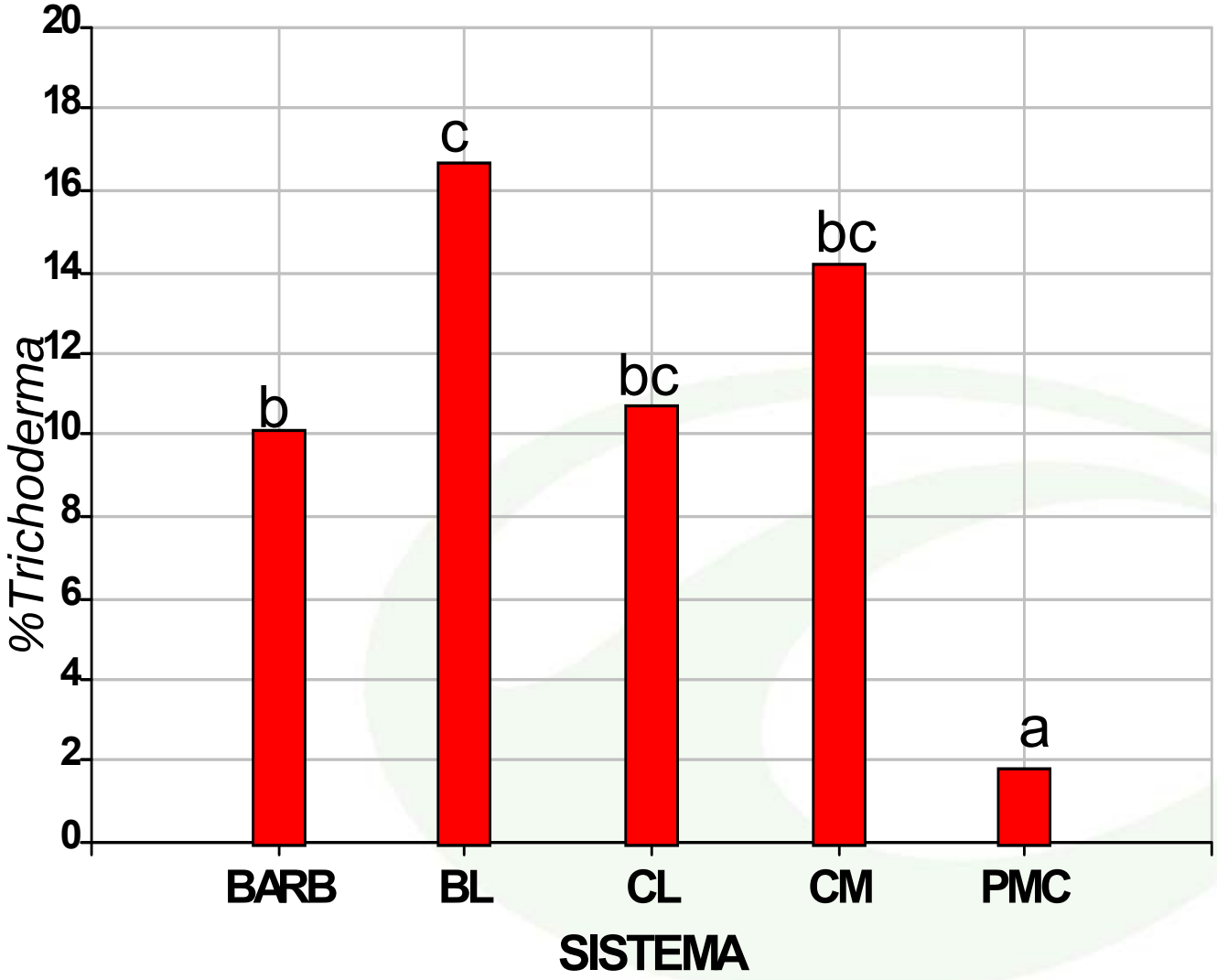
# Biological indicators

# Mycoparasites

| INDICATORS | METHODS | SOURCE |
|---|---|---|
| % Mycoparasites<br>% *Trichoderma*<br>% *Clonostachys* | Soil inoculation on four stump of phytopathogenic fungus, utilized as bait | Foley y Deacon (1985) |



# % Trichoderma



| INDICATORS | METHODS | SOURCE |
|---|---|---|
| Microbial respiration (mg $CO_2$-C $kg^{-1}$ $h^{-1}$) | $CO_2$ production in hermetic glasses, incubated at 25ºC for 24 hours | Zibilske (1994) |

20 ml
NaOH

10 g
Suelo

Incubación 24 horas

Titulación

HCl 0,5 N

| INDICATORS | METHODS | SOURCE |
|---|---|---|
| Microbial biomass (mg C-biom $kg^{-1}$) | Fumigation-incubation. Determination of microbial C with auto-analyzer equipment | Anderson e Ingram (1993) |

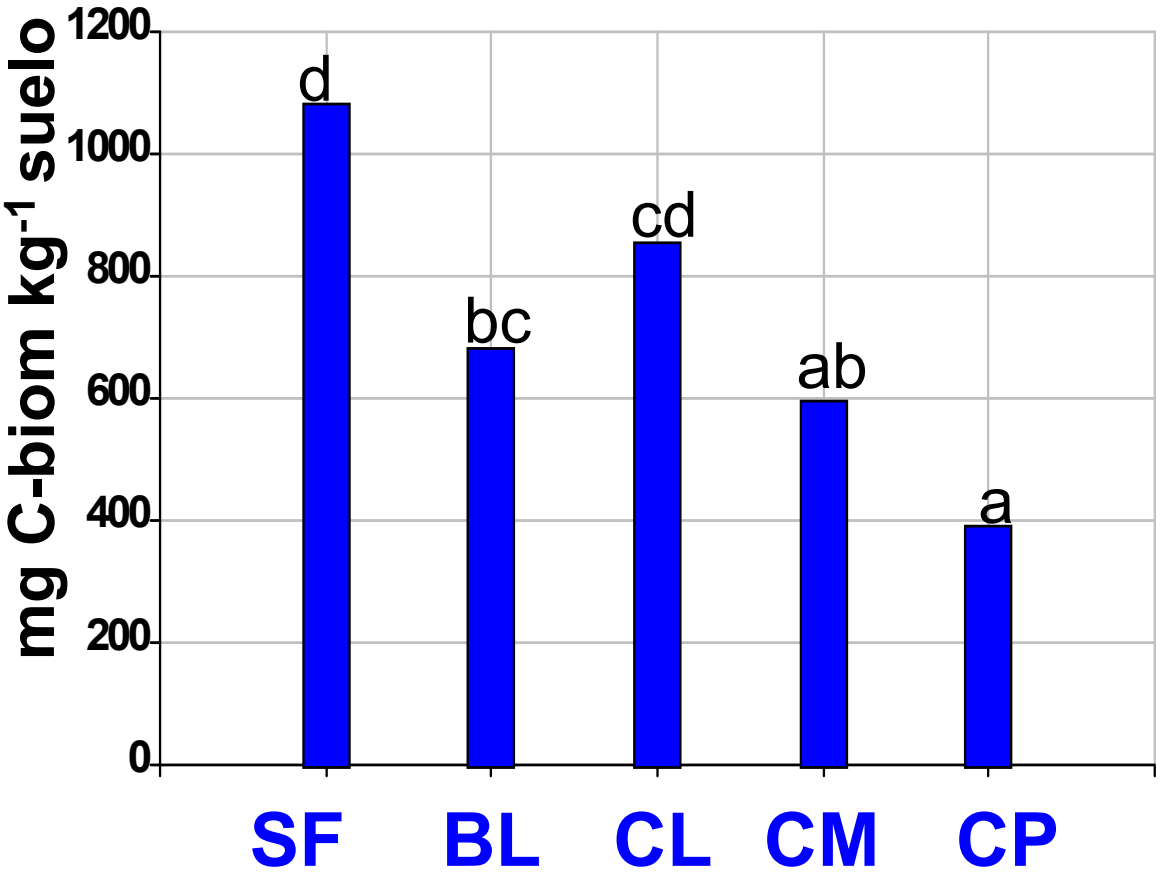
Clorofor mo


48 hours

C analysis

| INDICATORS | CALCULATION | SOURCE |
|---|---|---|
| Metabolic quotient<br>(µg $CO_2$-C $mg^{-1}$ C-biom $h^{-1}$) | $qCO_2\text{-}C = \frac{CO_2\text{-}C}{\text{C-biom}}$<br><br>$CO_2$-C: microbial respiration<br>C-biom: microbial biomass | Visser y Parkinson (1993) |
| Mineralization index of C<br>(% C 10 $days^{-1}$) | $IM = \frac{CO_2\text{-}C}{\text{C-total}} \times 100\%$<br><br>$CO_2$-C: microbial respiration<br>. | Stanford y Smith (1972) |

# Microbial biomass



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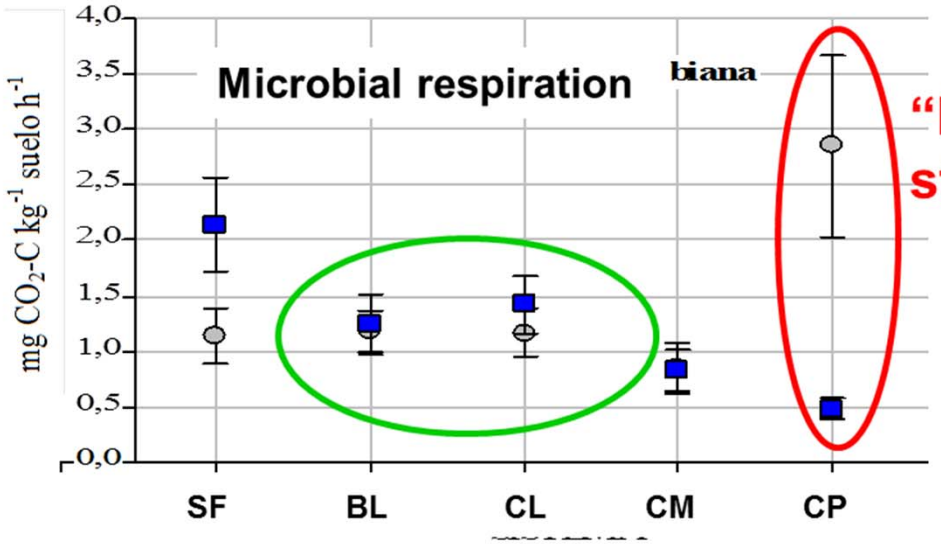
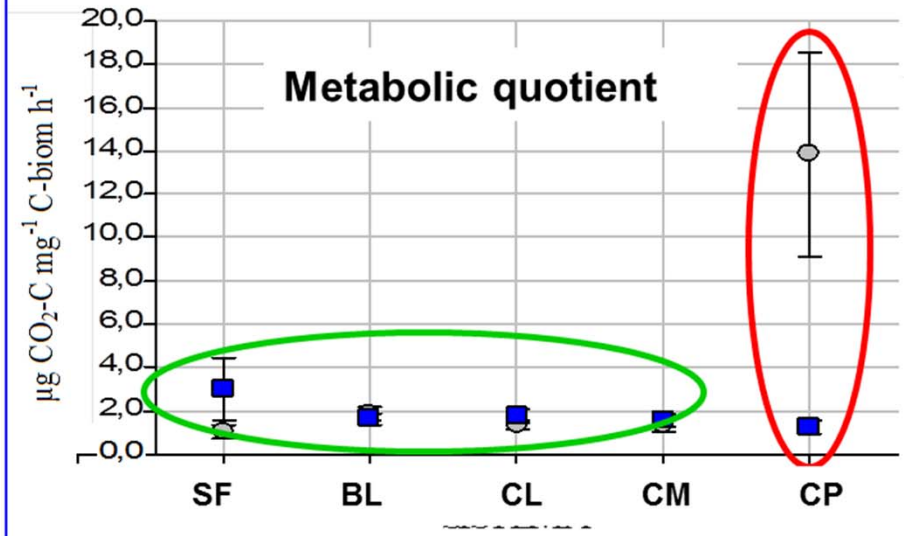
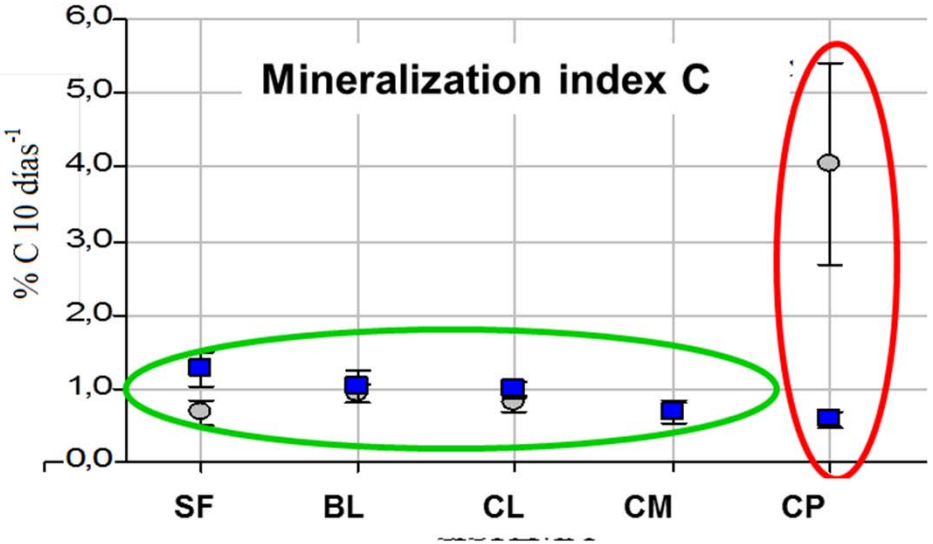
# Microbial activity

**Equilibrium in microbial activity**




**"Microorganisms stress"**




Rainy season  Dry season

# Orthogonal contrasts

**Orthogonal contrasts (p values) among land management systems in function of soil biological indicators. Talamanca, Costa Rica, Year 2007**

| INDICATORS | SF vs.(CL, BL, CM, CP) | CM vs. (CL,BL,CP) | (CL, BL) vs. CP | BL vs. CL |
|---|---|---|---|---|
| Microbial biomass | 0.0001 | -------- | 0.0014 | -------- |
| Microbial respiration | -------- | -------- | -------- | -------- |
| Metabolic quotient | -------- | -------- | 0.0006 | -------- |
| C mineralization index | -------- | -------- | 0.0044 | -------- |
| Catalase activity | 0.014 | -------- | <0.0001 | 0.0002 |
| Small earthworms | -------- | -------- | -------- | -------- |
| Medium earthworms | 0.0004 | -------- | -------- | -------- |
| Large earthworms | 0.0055 | -------- | 0.0389 | -------- |
| Total earthworms | 0.0016 | -------- | -------- | -------- |
| Phytopathogenic nematode | 0.075 | -------- | 0.0079 | -------- |
| Saprophyte nematode | -------- | -------- | -------- | -------- |
| H Phytopathogenic nematode | -------- | -------- | 0.0288 | -------- |
| % *Trichoderma* | -------- | -------- | 0.0023 | -------- |
| % *Clonostachys* | -------- | -------- | -------- | -------- |
| Litter | 0.0001 | -------- | 0.0018 | 0.0001 |

SF: secondary forest; CL: organic cacao-laurel; BL: organic banana-laurel; CM: organic cacao in monoculture; CP: conventional plantain in monoculture. agg: aggregates; --------: statistically similar (p>0.05).

# Soil quality indexes (SQI)

## Ex.: additive soil quality index (ASQI) (Andrews *et al.* 2002)

Steps:

1) Analysis of variance (ANOVA) among land management systems for all indicators. Indicators which show significant differences were retained

# 2) Principal components

| Componentes Principales | CP1 | CP2 | CP3 |
|---|---|---|---|
| Eigen value | 22,12 | 11,19 | 1,85 |
| Proportion | 0,61 | 0,31 | 0,05 |
| Prop Acum | 0,61 | 0,93 | 0,98 |
| **Indicators** | | | |
| Microbial biomass | **0,21** | -0,04 | 0,04 |
| Metabolic quotient | -0,12 | **0,25** | -0,07 |
| Earthworms | **0,19** | 0,08 | **0,27** |
| Trichoderma | 0,05 | **-0,26** | **0,31** |
| Catalase | -0,04 | **0,21** | **0,43** |
| Phytopatogenic nematodes | -0,03 | **-0,23** | **0,20** |
| pH | **-0,19** | 0,13 | 0,08 |
| Organic matter | **0,20** | 0,04 | **-0,20** |
| Nitrogen | **0,21** | 0,05 | -0,14 |
| Phospurus | **-0,19** | 0,11 | 0,17 |
| Potasium | -0,07 | **0,28** | -0,01 |
| Soil aggregates 2-8mm | **0,20** | -0,06 | 0,13 |
| Bulk density | **-0,21** | 0,02 | 0,10 |

Indicators that show significant differences are subjected to principal component analysis to reduce the co-linearity and redundancy among the indicators. Principal components with value greater than one are retained, and within each component the indicators of greatest weight are selected (those that had an absolute value of within 10% greater or lesser than the highest absolute value);

3) The final list of indicators are classified into two groups to calculate The ASQI

- **For the indicators "higher is better"**

$$SQI = \frac{\text{value of each indicator}}{\text{Highest value of the indicator}}$$

- **For the indicators "lower is better"**

$$SQI = \frac{\text{lowest value of the indicator}}{\text{value of each indicator}}$$

$$ASQI = \sum SQI \,/\, \text{number of indicators}$$

**With > ASQI value > Soil quality**

# Additive soil quality index of five land management systems, Talamanca, Costa Rica. Means (± standard deviation) and analysis of variance. Year 2007

| Additive soil quality index (ASQI) | ---------- LAND MANAGEMENT SYSTEMS ---------- | | | | | p value |
|---|---|---|---|---|---|---|
| | SF | CL | BL | CM | CP | |
| SQI 13 indicators dry season | 0.59 b | 0.48 a | 0.49 a | 0.45 a | 0.51 a | 0.0095 |
| SQI 6 biological rainy season | 0.54 c | 0.42 b | 0.40 b | 0.47 b | 0.30 a | 0.0003 |

SF: secondary forest; CL: organic cacao-laurel; BL: organic banana-laurel; CM: organic cacao in monoculture; CP: conventional plantain in monoculture.
Different letters in rows indicate significant differences among land management systems (LSD Fisher, $p<0.05$).

# Conclusion

- Considering all of these indicators in an integral overview, none of these land management systems (CL, BL, CM, CP) had a “complete soil quality”. Only the SF appeared to have the best soil quality, but after a certain period of recovering.

# Perspectives

It would be interesting to compare the soil quality with other agroforestry systems with different shade canopies and managements.

In Cameroon there are cacao agroforestry systems with applications of fertilizers and pesticides ¿how is the soil quality?

# Literature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