Characterization of the Phenomenon of Soil Crusting and Sealing in the Andean Hillsides of Colombia: Physical and Chemical Constraints

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Abstract: Soil degradation is increasing around the globe, bringing challenges that demand an investigation of influencing factors. This study investigates the new degradation phenomenon of soil crusting and sealing on volcanic Inceptisols in Andean hillsides. Crusting and sealing are commonly accepted soil deterioration factors that create unstable surface conditions and soil erosion. On an Inceptisol in Santander de Quilichao in Colombia, field trials were conducted on existing erosion run-off plots using Cassava as the main crop.

During the investigation, field samplings and analyses were taken of: penetration, shear strength, infiltration and cassava yield. Results from penetration and shear strength measurements clearly showed chicken manure's significant influence on soil structure. Chicken manure generally led to structural constraints. In addition, chicken manure plots displayed a reduction of infiltration. This strengthens the hypothesis that inappropriate fertilizer management is one of the key factors of structural deterioration on Inceptisols in the Andean environment.

Further research is necessary to find out sustainable soil treatments in Andean hillside farming.
Keywords: soil crusting, soil sealing, soil erosion, chicken manure, Inceptisols, tillage system

1 Introduction

Soil erosion is a major problem worldwide. Climatic impacts aside, the main reasons for soil erosion are both, inappropriate land-use and improper fertilizer management, (LAL and STEWART, 1990; OLDEMAN, 1990; EL-SWAIFY, 1991) as well as socio-economic constraints (STEINER, 1994, MUELLER-SAEMANN, 1998 *et al*.). In the process of acquiring a basic knowledge of soil degradation, efforts have focused on structural changes at the soil surface (SUMNER and MILLER, 1992; SUMNER and STEWART, 1992; BRESSON, 1995; VALENTIN and BRESSON, 1998)). Recent observations indicate that the physical and chemical degradations of soils in the Andean zone are partly related to the phenomena of soil crusting and sealing.

Soil crusts are thin layers of hardened soil on the surface, occurring on dry soils (ROTH, 1992; BRESSON, 1995). The term "soil sealing" is used to describe superficial impermeabilities mainly occurring in wet circumstances. Soil sealing occurs if dissolved aggregates infiltrate in the soil pores leading to compact soil horizons and thus reducing infiltration (SCHEFFER-SCHACHTSCHABEL, 1998). Both phenomena negatively impact water infiltration, and reduce air permeability and seedlings' emergence (USDA, 1996, BAJRACHARYA *et al*., 1996, LE BISSONNAIS, 1990). Due to the reduction of water infiltration, the surface run-off increases; resulting in enhanced soil erosion and reduced harvest yield.

The soil crust development of Andean soils of volcanic origin is not yet well understood. Therefore, the aim of this work is to characterize the phenomenon of soil crusting on Andean Inceptisols. This project is supported by special project funds from the DAAD/Germany, the Eiselen Foundation/Germany, the BMZ/Germany and the University of Hohenheim/Germany.

2 Materials and methods

Location: Field research was conducted at the Santander de Quilichao Research Station, Dep. Cauca of Colombia (3°6'N, 76° 31' W, 990 m.a.s.l). Trials had been installed on an amorphous, isohyperthermic oxic Dystropept (Inceptisol), developed from fluvially translocated partly weathered volcanic ashes. The field site has a bimodal rain distribution with two maximas in April-May and October-November, with a mean annual rainfall of 1799 mm, a rain intensity up to 330 mm/h and a mean annual temperature of 23.8°C. The measurements of soil crusting have been made on 27 Wishmeyer Standard Erosion Experimental Plots. These plots, originally designed by the soil conservation team from the University of Hohenheim as completely randomized blocks in three repetitions, have been used since 1986 (Table 1). They were sampled at 0 to 5cm depth.

Table 1 The history of treatments in Santander de Quilichao

Treat	93/94	94/95	95/96	96/97	97/98	98/99	99/00	00/01
1	Bare fallow	Bare fallow	Bare fallow	Bare fallow	Bare fallow	Bare fallow	Bare fallow	Bare fallow
2	Cowpea, mF[1]	Cassava oF4[2]	Maize oF4	Cassava oF4	Cowpea oF4	Maize oF4	Cassava oF4	Cassava oF4
3	Cassava	Cassava	Cassava	Cassava	Cowpea	Cassava	Cassava	Cassava
4	Bush fallow	Cassava mF	Maize mF	Cassava mF	Cowpea mF	Cassava mF	Cassava mF	Cassava mF
5	Br[4] P[5]	Cassava mF	Maize mF	Cassava mF	Cowpea mF	Maize mF	Cassava oF8[3]	Cassava oF8
6	Co mF(V)[9]	Cassava oF4(V)	Maize oF4(V)	Cassava oF4(V)	Cowpea oF4(V)	Maize oF4(V)	Cassava oF4(V)	Cassava oF4(V)
7	Cassava Ca[6]	Cassava Ca	Maize Ch[8]	Cassava Co	Cowpea mF	Maize Ch	Cassava Ch	Cassava Ch
8	Br P	Br P	Maize mF	Br Cm[7]	Br Cm	Maize Cm	Cassava –	Br Cm
9	Bush fallow	Bush fallow	Bush fallow	Bush fallow	Bare fallow	Bare fallow	Cassava mF	Cassava mF

[1]mF = mineral Fertilizer. [4]Br= *Brachiaria decumbens* [7]Cm=*Centrosema macrocarpum*

[2]oF4 = organic Fertilizer. (Chicken manure 4 t • ha^{-1}) [5]P = *Pueraria phaseoloides* [8]Ch = *Chamaecrista rotundifolia*

[3]oF8 = organic Fertilizer. (Chicken manure 8 t • ha^{-1}) [6]Ca = *Centrosema acutifolium* [9](V) = Vetiver

Treatments

The treatments from December 1999 are described in Table 2. Before planting, the experimental plots have been limed with dolomitic lime (500 kg/ha) and plots with mineral fertilizer have been fertilized with 300 kg/ha mineral fertilizer (10N-30P-10K). Chicken manure from a local poultry farm had the following nutrient content (N: 3.43%, P: 1.82%, K: 2.73%, Ca: 3.32%, Mg: 0.64%, Fe: 1,364 ppm

Table 2 Treatments of 27 experimental plots in santander de quilichao from 1999—2001

Treatment	Plots			Cultivation in 1999—2001
(1) Bare fallow	25	26	27	Raking at the beginning
(2.) Cassava + 4t/ha chicken manure (trad.)	2	13	19	Rototiller, 4 t/ha chicken manure
(3) Cassava monoculture	3	11	24	Rototiller, no fertilizer
(4) Cassava minimum tillage	4	17	22	No tillage, mineral fertilizer
(5) Cassava + 8t/ha chicken manure	5	9	21	Rototiller, 8t/ha chicken manure
(6) Cassava+ 4t/ha chicken manure (Vetiver)	6	10	16	Rototiller, 4t/ha chicken manure
(7) Cassava + *Chamaecrista rotundifolia*	7	12	20	Rototiller, mineral fertilizer,
(8) Cassava rotation (*Brachiaria decumbens*	8	14	18	Rototiller, mineral fertilizer
(9) Cassava intensive tillage	28	29	30	Intensive Rototiller, mineral

To quantify and describe soil crusting and sealing, different measurement tools have been used in the field.

After planting Cassava in December 1999, field measurements with a Pocket Penetrometer (Model DIK-5560) were carried out.

Besides pentrometer measurement, a Hand Vane Tester (Model EL26-3345) was used to measure shear strength at the soil surface. Both tools were used weekly, each Penetrometer measurement 24 times and Torvane measurement 6 times per plot.

To describe direct effects of soil crusting and sealing on infiltration, a mini-rainsimulator was used in the field. Infiltration was measured by irrigating a defined soil area (32,5cm x 40cm) with a special amount of rain (90mm/h). The construction of this mini-rainsimulator enabled to subsample run-off periodically (every 5 min). The difference between irrigated amount of rain water and run-off data is defined as infiltration.

Cassava root yield in December 2000 was measured after harvest to determine the impact of soil compaction process.

3 Results and discussion

Penetrometer and Torvane*:* Results of Penetrometer and Torvane measurement are presented in Figures 1. During the wet season, penetration resistance was similar in all treatments. At the beginning of the dry season in May/June, differences between treatments were noted. Notably, the Cassava + 8 t/ha chicken manure became a hard soil (penetration resistance 25,4 kPa, shear strength 67 kg/cm²). Over time the minimum tillage plot generally became harder than other plots, but the well-developed and stable aggregate structure prevented negative impact on water infiltration (see below). The high amount of chicken manure caused a dispersion of clays in the wet season and resulted in uniform clods after drying. It was noticed that the Cassava monoculture and Cassava intensive tillage tended to be extremely soft, thus building up a single-grain structure also called pseudo-sand. Torvane measurement data tended to be similar to penetrometer measurement. Figure 1 indicates the increase in shear strength in the dry season especially within treatments of Cassava + 8 t/ha chicken manure.

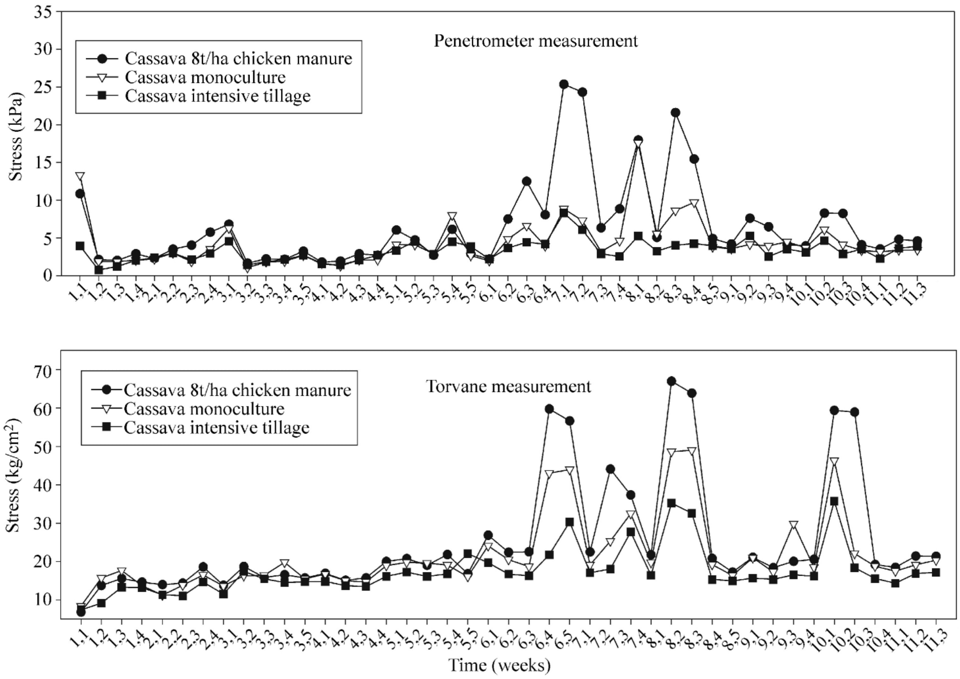

Fig.1 Influence of soil treatment and crop management on penetration resistance and shear strength, Santander de Quilichao, Jan-Nov 2000

In general, all treatments except the Cassava intensive tillage treatment had a high shear strength from June-July and turned from 13—22 kg/cm^2 in the wet season up to 43—76 kg/cm^2 in the dry season.

Infiltration: Results are presented in Figure 2. Cassava + 8t/ha Chicken manure had the lowest infiltration after 55 minutes with a final infiltration capacity of 36 mm/h.

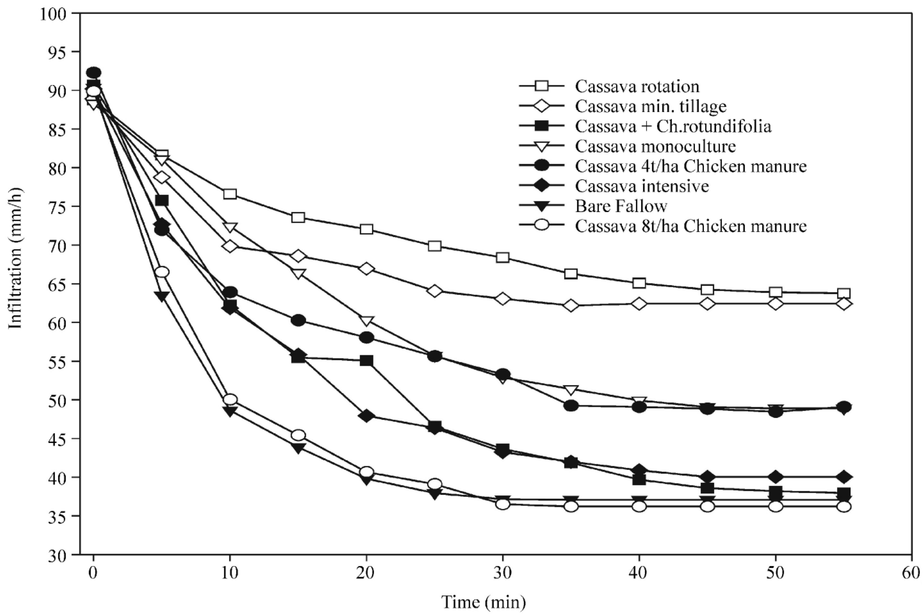

Fig.2 Effect of treatment on infiltration measured by rainsimulation, March 2000. Location: Santander de Quilichao

It has to be emphasized that Cassava min. tillage as well as Cassava rotation treatment had both an excellent infiltration capacity. Minimum tillage influenced the soil structure positively in the way that aggregation over a long time period is supported. This helped to build up a soil structure, as also the mulch at the surface led to a better infiltration.

Yield: Results of harvest data are presented in Table 3. Overall, the best root yields were found in Cassava 4t/ha chicken manure and Cassava rotation. High Cassava root yields in these treatments are due to improved soil conditions such as moderate soil hardening, sufficient fertilization, enhanced soil aggregation and high water infiltration. In contrast, the lowest yields were found with Cassava monoculture and Cassava intensive tillage treatments. The Cassava monoculture treatment is characterized by a low nutrient content in the soil through insufficient fertilization over a long period of time.

Table 3 Cassava root yields, santander de quilichao, 2000

Treatment	Yield (t/ha)
Cassava monoculture	4.33 a
Cassava int. Tillage	11.98 b
Cassava + *Chamaechrista rotundifolia*	21.05 c
Cassava (V) 4t/ha chicken manure	21.90 c
Cassava 8 t/ha chicken manure	23.17 cd
Cassava minimum tillage	27.01 cd
Cassava rotation (*Brachiaria decumbens* + *Centrosema macrocarpum*)	30.59 e
Cassava 4 t\ha chicken manure	30.92 e

Means followed by different letters within the column are significant at 0.05 probability level (Duncan test).

The single grain structure and low infiltration capacity contributed to low root yield. The Cassava intensive tillage treatment is characterized by a breakdown of the pore system. Thus, leading to a lack of infiltration and reduced yields. In both treatments, roots were very small and economically worthless. Cassava 8t/ha chicken manure had high amounts of plant biomass but hard soil structure, preventing optimal development of Cassava roots. In Cassava minimum tillage treatment, root growth was limited to the area loosened before planting. Therefore yields in both treatments were lower than in Cassava rotation and Cassava 4 t/ha chicken manure.

4 Discussion

In summary, penetration resistance and shear strength showed no risk of structural damage in the wet season. This worsened in the dry season when Chicken manure treatment turned into hard and impermeable soils. Although, the minimum tillage treatment had high penetration resistance and high shear strength values, this caused no deterioration because of a good aggregation status. This can clearly be seen in the results of infiltration measurement. Monoculture and intensive tillage had neither high penetration resistance nor high shear strength. In contrast, these treatments easily built up the so-called pseudo-sand that lead to high proportions of small aggregates, and thus to high amounts of soil erosion. The more modern techniques of Minimum tillage and Cassava rotation had the best and most sustainable status. Those treatments had a good aggregation, showed adequate infiltration rates and did not suffer from human induced fertilizer damage, e.g. soil hardening due to chicken manure or deterioration of soil matrix through intensive tillage. Chicken manure, especially 8 t/ha, had a severe impact on soil surface. Further research is needed to specify the reasons why chicken manure has such an influence on aggregates. It is unclear which dispersion agent might be that leads to aggregate dispersion. Furthermore, structural changes through intensive tillage or minimum tillage have to be looked at more closely in order to ascertain how severely aggregate breakdown affects plant growth on Inceptisols.

5 Conclusion

Results from penetration and shear strength measurement showed the marked influence of chicken manure on soil structure. Chicken manure generally resulted in a deterioration of soil's structural status. A reduction of infiltration, especially in chicken manure plots, substantiates the hypothesis that inappropriate fertilizer management is one of the key factors in structural deterioration on Inceptisols. Dispersion of clays, generally cited as the main reason for soil sealing, is influenced by the impact of chicken manure. Further research will need to focus on the impact of fertilizers on the soil surface in order to design sustainable land-use systems for Andean hillside farming.

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