EFFECTS OF NINE CASSAVA-BASED CROPPING SYSTEMS ON SUPERFICIAL SOIL STRUCTURAL DEGRADATION IN THE ANDEAN HILLSIDES OF COLOMBIA

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Abstract
Soil erosion is increasing in Latin America. This study was conducted to determine the influence of nine long-term cropping systems on Andean hillside soil; specifically the degradation of soil structure. During the course of studying each soil treatment, resulting changes in soil properties and their effects on water infiltration and crop yield were recorded. The effects of soil crusting and sealing were investigated during the period Jan 2000 - Dec 2001 in southwest Colombia. Physical parameters such as penetration resistance, shear strength, and infiltration capacity, as well as chemical parameters such as nutrient content, soil reaction, organic matter content and electrical conductivity were analyzed. Two types of soil crusting were observed during the project. One occurred due to splash impact of raindrops on barely covered soil surfaces. The second occurred due to excessive application of chicken manure. A seasonal increase in penetration resistance and shear strength in some treatments did not necessarily lead to restrictions in water infiltration. A nutrient-rich minimum tillage treatment, which displayed the highest penetration resistance of up to 46.4 kg cm^{-2} during the dry periods, presented no restricting effects on soil water intake (76.2 mm h^{-1} final infiltration in 2000) due to an optimal aggregate development during 14 years of cultivation. Measurements of physical and chemical properties showed that conservative soil treatments, like minimum tillage and crop rotations, improved soil structure and prevented the development of soil crusting with its associated negative effects on infiltration and yield. In contrast, treatments with destructive soil use, including the application of high amounts of chicken manure, were characterized by the highest reduction of infiltration due to soil crusting.

Additional Keywords: crusting, penetration resistance, infiltration, aggregation, conservation, erosion

Introduction
Soil erosion is a major global issue because of its adverse effects on sustainability. In Latin America, the reasons behind increasing soil erosion are twofold: climatic circumstances coupled with inappropriate land-use and mismanagement of soils, especially on marginal hillsides (Oldeman *et al*., 1990). Many researchers have identified soil crusting and sealing as a primary factors in soil erosion (Callebaut *et al*., 1985). However, the impact of long-term cropping systems on the degradation of soil structure in South America have received minimal scientific attention (Roth, 1992). Therefore the aim of this study was to acquire a basic understanding of the impact of nine Andean cassava-based cropping systems on the development of soil crusting and sealing, and its effects on nutrient content, water infiltration and cassava (*Manihot esculenta* C.) -yield.

Materials and Methods
Research site and treatments
Field research was conducted from January 2000 to December 2001 in Santander de Quilichao at the CIAT Research Station, Department of Cauca in southwestern Colombia (3°6'N, 76°31'W, 990 m.a.s.l.). Precipitation reached 2207 mm a^{-1} in 2000 and 1384 mm a^{-1} in 2001. Trials were installed on 27 Wischmeier- plots on a ferralic Cambisol (WRB, 1998) developed from fluvially translocated volcanic ashes.

The treatments are summarized below:
T1 Bare fallow; continuously clean tilled, no fertilizer, and no crop
T2 Cassava (*Manihot esculenta* Crantz) with chicken manure; All cassava treatments consisted of variety CIAT 523-07 in 2000 and CIAT 383 in 2001; planted as a sole crop and all planted 1 by 0.8 m (12,500 plants per ha), rototiller treatment, 4t ha^{-1} chicken manure
T3 Cassava; as a sole crop in monoculture, rototiller treatment, no fertilizer
T4 Cassava; as a sole crop in minimum tillage, no rototiller, 300 kg ha^{-1} mineral fertilizer
T5 Cassava; with chicken manure, as a sole crop, rototiller treatment, 8t ha^{-1} chicken manure

T6 Cassava; with chicken manure, as the main crop with Vetiver grass (*Vetiver zizanioides* L. Nash; CIAT No. 26898) as a double row life barrier occupying 12,5% of the plot area, rototiller treatment, 4t ha^{-1} chicken manure
T7 Cassava; as the main crop (1 by 0.8 m, 12,500 plants per ha) intercropped with *Chamaechrista rotundifolia* Stapf, rototiller treatment, and 300 kg ha^{-1} mineral fertilizer
T8 Cassava; as a sole crop, in rotation with *Bracchiaria decumbens* Benth. and *Centrosema macrocarpum* Stapf, 300 kg ha^{-1} mineral fertilizer
T9 Cassava; as a sole crop, with intensive rototiller treatment, 300 kg ha^{-1} mineral fertilizer

Before planting all cultivated treatments were fertilized and limed. Dolomitic lime was applied at a rate of 500 kg ha^{-1}. The mineral fertilized treatments were fertilized at a rate of 300 kg ha^{-1} (10N-30P_20_5-10K_2O). All chicken manure plots received 4 t (8 t) ha^{-1} at the beginning of each cropping season. The nutrient contents consisted of: N: 3.2 %, P: 3.4 %, K: 4.1 %, Ca: 6.1 %, Mg: 1.0 %, Fe: 0.2 %, Mn: 0.6 %, Na 0.5 % in 2000 and N: 2.5 %, P: 3.4 %, K: 3.3 %, Ca: 11.8 %, Mg: 1.0 %, Fe: 0.4 %, Mn 0.5 %, Na 0.4% in 2001

Tools and methods
Soil crusting dynamics were investigated from both physical and chemical perspectives. Physical soil analysis consisted of weekly measurements with a Penetrometer (Daiki Soil and Moisture Sensors, Model DIK-5560) described by (Bradford, 1986) and shear strength measurements with a hand vane tester (Torvane, Model EL26-3345). Infiltration was measured with a mini-rain-simulator described by (Amézquita et al., 1999) suitable for infiltration measurements in marginal remote areas. Infiltration was measured in April/May and October/November in 2000 and 2001 by irrigating a defined soil surface area with a distinct amount of rain (90 mm h^{-1}). The difference between rain amount after 50 min and total run-off was defined as infiltration. Chemical soil analysis consisted of soil reaction, organic matter, nutrient content, and cation exchange capacity. Yield was measured by weighing fresh cassava roots after harvest. For statistical analysis, ANOVAS were tested following the General Linear Model with SPSS as statistical software. To separate significant means the Tuckey's test was applied.

Results and Discussion

All nine treatments were grouped into three categories to evaluate specific aspects of investigation, such as the impact fertilization on soil crusting, the influence of conservation systems on structural development, and the effects of different tillage treatments on soil structure and system stability. The manure group included T2, T3, and T5. The conservation group consisted of T6, T7 and T8. The tillage group included T1, T4, and T9. The cassava chicken manure treatments (T5, T6, and partly T2) demonstrated seasonal structural changes in both years (Table 1 and 2). In the major rainy seasons (March-May 2000 and 2001), no penetration and shear strength restrictions were investigated. In contrast, in both dry seasons (June-September 2000 and 2001) its superficial soil structure altered under field conditions and changed from a well-structured soil to a superficially crusted soil.

In general, chicken manure treatments in both years revealed chemical dispersion of clays during the cropping cycle, this was clearly observed in the field (especially in T5 and T6). It started with a dispersion phase during the first rainy season (March-May) and ended with a strong crusting phase (June-August). Similarly, the treatments with bare soil surfaces (T1 and T3) displayed strong slacking during the rainy seasons and consequently formed strong soil crusts, especially in 2000. This followed the observations of various authors (Callebaut et al., 1985) and resulted in a strong increase in soil erosion (data not presented here). A minimum tillage treatment (T4) showed the most significant increase in penetration resistance and shear strength, which did not result in major infiltration restrictions (Table 3). Infiltration was significantly lowest in the chicken manure treatment (T5) and in the monoculture treatment (T3).

Chemical soil analysis (Table 4) showed the highest pH, organic matter (OM) and nutrient content in the minimum tillage treatment which can be attributed to the beneficial effect of mulching, as also found by Derpsch et al. (1986). Bare fallow and monoculture led to a strong decrease in pH and OM as well as the exchangeable cations. Only Al was very high in T1 and T3.

Yield was significantly influenced by precipitation amount. Highest yield was achieved in T8, T2, and T4 in 2000 the year with increased precipitation, while T3 and T9 revealed significantly lower yields. In 2001, T4 could best resist the dryer soil circumstances and maintain root yield at a high level, while others (i.e. T2, T6 and T7) experienced a severely reduced yield due to water scarcity and increased competition for resources between cassava and its intercropped plants (Ruppenthal, 1995).

Table 1. Impact of climatic season on penetration resistance (in kg cm^{-2}) in grouped treatment systems (March-May and Juni-August 2000 and 2001), Santander de Quilichao, Colombia

Group	Treatment	2000		2001	
		Rainy season	Dry season	Rainy season	Dry Season
Manure	Cassava 4 t ha^{-1} chicken manure (T2)	3.2 a[1]	9.2 ab	2.1 a	4.6 a
	Cassava monoculture (T3)	3.1 a	6.7 a	2.2 a	4.3 a
	Cassava 8 t ha^{-1} chicken manure (T5)	3.5 a	12.3 b	2.4 a	7.8 b
Conservation	Cassava 4 t ha^{-1} ch. manure (V) (T6)	3.6 b	11.8 a	2.1 a	5.3 a
	Cassava + *Cham. rotundifolia (*T7)	3.5 ab	9.4 a	2.5 ab	4.8 a
	Cassava rotation (T8)	2.6 a	9.8 a	2.6 a	7.5 b
Tillage	Bare fallow (T1)	5.2 b	9.7 a	1.7 a	3.7 a
	Cassava minimum tillage (T4)	5.5 b	28.5 b	5.3 b	24.0 b
	Cassava intensive tillage (T9)	2.9 a	4.2 a	1.9 a	3.7 a

[1] Means followed by the same letter in column are not significantly different at p≤0.05 probability level, Tuckey-Test

Table 2. Impact of climatic season on shear strength (kPa) in grouped treatment systems measured (March-May and Juni-August 2000 and 2001), Santander de Quilichao, Colombia

Group	Treatment	2000		2001	
		Rainy season	Dry Season	Rainy season	Dry season
Manure	Cassava 4 t ha^{-1} ch. manure (T2)	15.6 a[1]	30.4 a	15.3 a	37.2 a
	Cassava monoculture (T3)	16.9 ab	28.5 a	15.4 ab	33.9 a
	Cassava 8 t ha^{-1} ch. manure (T5)	17.3 b	36.0 a	16.81 b	48.6 b
Conservation	Cassava 4 t ha^{-1} ch. m. (V) (T6)	17.0 b	34.1 a	16.6 a	42.0 a
	Cassava + *Cham. rotundifolia (*T7)	15.4 a	30.3 a	17.8 a	40.4 a
	Cassava rotation (T8)	14.6 a	30.6 a	19.6 b	60.8 b
Tillage	Bare fallow (T1)	20.5 b	35.9 b	13.6 a	28.2 a
	Cassava minimum tillage (T4)	22.9 c	53.2 c	41.5 b	78.1 b
	Cassava intensive tillage (T9)	14.9 a	21.9 a	13.7 a	27.9 a

[1] Means followed by the same letter in column are not significantly different at p≤0.05 probability level, Tuckey-Test

Table 3. Impact of treatment on infiltration (mm h^{-1}), measured in April/May and October 2000 and 2001, Santander de Quilichao, Colombia

No	Treatment	2000		2001	
		Infiltration after 50 min (mm h^{-1})	Standard Deviation	Infiltration after 50 min (mm h^{-1})	Standard deviation
T1	Bare fallow	52.1 a[1]	18.2	54.2 ab[1]	6.8
T2	Cassava 4 t ha^{-1} chicken manure	54.8 a	19.1	63.9 bcd	15.2
T3	Cassava monoculture	42.7 a	16.2	38.8 a	6.2
T4	Cassava minimum tillage	76.2 a	16.2	87.4 d	6.5
T5	Cassava 8 t ha^{-1} chicken manure	42.2 a	11.4	36.1 a	15.2
T6	Cassava 4 t ha^{-1} chicken manure (V)	49.6 a	15.9	59.3 abc	11.9
T7	Cassava + *Chamaecrista rotundifolia*	56.6 a	23.2	78.0 cd	9.9
T8	Cassava rotation	70.9 a	16.4	83.9 d	4.5
T9	Cassava intensive tillage	46.5 a	11.3	43.2 ab	12.6

[1]means followed by the same letter in column are not significantly different at p≤0.05 probability level, Tuckey's Test

Conclusions

The study of physical and chemical soil properties in nine cassava-based cropping systems revealed that conservative soil treatments, like minimum tillage and crop rotations, improved soil structure and prevented the development of soil crusting with its associated negative effects on infiltration and yield. In contrast, treatments with destructive soil use (T1 and T3, T9), including the application of high amounts of chicken manure (T5 and T6), were characterized by the highest reduction of water infiltration and yield due to soil crusting.

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Table 4. Influence of treatment on exchangeable and soluble nutrients in the surface horizon, at 0–5 cm depth, 2000 and 2001 in Santander de Quilichao

Treatments in 2000		pH	OM	N	P	K	Ca	Mg	Al	CECe
			(%)	mg kg^{-1}		cmol kg^{-1}				cmol kg^{-1}
T1	**Bare fallow**	4.3 a	5.6 a	1670 a[1]	-	0.1 a	0.2 a	0.1 a	4.7 d	5.0 a
T2	**Cassava 4 t ha^{-1} chicken manure**	5.2 cd	6.5 ab	2320 b	-	0.3 c	4.4 c	1.5 c	0.5 a	6.7 c
T3	**Cassava monoculture**	4.9 b	6.5 ab	2231 b	-	0.2 b	2.1 b	0.9 b	1.8 c	5.0 a
T4	**Cassava minimum tillage**	5.4 d	6.8 bc	2611 c	-	0.4 c	6.5 d	1.6 d	0.3 a	8.7 d
T5	**Cassava 8 t ha^{-1} chicken manure**	4.9 b	6.5 ab	2348 bc	-	0.4 bc	2.3 b	0.9 b	1.7 c	5.3 a
T8	**Cassava rotation**	5.0 bc	6.4 ab	2436 bc	-	0.3 b	4.1 c	0.9 b	0.9 b	6.2 b
Treatments in 2001										
T1	**Bare fallow**	3.8 a	4.8 a	2275 a[1]	5.4 a	0.1 a	0.3 a	0.1 a	3.9 c	4.5 a
T2	**Cassava 4 t ha^{-1} chicken manure**	4.7 d	6.1 bc	2721 a	47.1 b	0.3 b	4.8 d	1.5 c	0.4 a	6.9 d
T3	**Cassava monoculture**	4.3 b	5.7 b	2532 a	17.2 ab	0.2 a	2.3 b	0.8 b	1.9 b	5.1 b
T4	**Cassava minimum tillage**	5.2 e	7.1 d	2896 a	49.1 b	0.4 c	6.7 e	1.9 d	0.3 a	9.2 e
T5	**Cassava 8 t ha^{-1} chicken manure**	4.6 c	6.0 bc	2537 a	48.5 b	0.3 bc	2.7 b	0.9 b	1.8 b	5.8 c
T8	**Cassava rotation**	4.4 c	6.1 bc	2654 a	38.9 ab	0.2 a	3.6 c	0.8 b	1.5 b	6.1 c

[1]means followed by the same letter in column are not significantly different at p≤0.05 probability level, Tuckey's Test

Table 5. Influence of land use option on cassava fresh root yield in long-term cassava cropping systems, Sanatander de Quilichao, Colombia

No	Treatment	2000		2001	
		Yield (t ha^{-1})[1]	S.D.	Yield (t ha^{-1})	S.D. [c]
T2	**Cassava 4 t ha^{-1} chicken manure**	30.92 c	6.23	19.94 b	4.36
T3	**Cassava monoculture**	4.33 a	1.01	11.39 a	3.47
T4	**Cassava minimum tillage**	27.01 c	6.86	22.51 b	0.97
T5	**Cassava 8 t ha^{-1} chicken manure**	23.17 bc	4.30	20.20 b	1.82
T6	**Cassava 4 t ha^{-1} chicken manure (V)**	21.90 bc	0.63	7.94 a	1.43
T7	**Cassava + *Chamaecrista rotundifolia***	21.05 bc	2.69	6.79 a	1.57
T8	**Cassava rotation**	30.58 c	2.67	n.a.	n.a.
T9	**Cassava intensive tillage**	11.98 ab	3.45	19.46 b	1.07

[1] Yield values followed by the same letter are not significantly different at *P*≤0.05 (Tuckey's HSD-test).

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