Estabilidad estructural del suelo bajo diferentes sistemas y tiempo de uso en laderas Andinas de Nariño, Colombia

Soil structural stability under different land use systems and duration of use in the Andean hillsides of Nariño, Colombia

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RESUMEN

Con el fin de evaluar el impacto de largos periodos de uso del terreno en propiedades estructurales del suelo, se realizó un muestreo a 0-20 cm de profundidad en los siguientes tratamientos: Suelo no intervenido 25% de pendiente (testigo), uso en pastura por 25 años 25% de pendiente y uso agrícola rotación trigo-maíz (rt-m) de 25, 45 y 70 años de uso a 12% y 25% de pendiente, en un Inceptisol de la zona de reconversión del cultivo de trigo de Nariño (2.400 a 2.800 msmn), Colombia (longitud 75º 14´ oeste, latitud 0.5º 10´ norte, 2710 msnm, 80% HR, 12ºC). Los resultados mostraron diferencias significativas entre el tipo e intensidad de uso del suelo por largos periodos en distribución de tamaño de agregados secos al aire, estabilidad de agregados al agua y distribución de tamaño de poros. El incremento de la intensidad de uso disminuyó la estabilidad estructural y afectó la porosidad del suelo. El porcentaje de agregados estables al agua mayores a 2.0 mm fue significativamente mayor en suelo no intervenido (51.5%). El cambio a uso agrícola (rt-m) durante 25, 45 y 70 años disminuyó los agregados estables mayores a 2.0 mm a 36.9%, 35.3% y 29.1% respectivamente. La porosidad total del uso en pastura disminuyó en 18% respecto al testigo y tendió a disminuir al aumentar la intensidad de uso del suelo rt-m.

Palabras claves: *Dystric haplusteps***;** agregados; porosidad; trigo; Nariño**.**

ABSTRACT

To evaluate the impact of different land use systems on soil structural properties over long periods of time, sampling was performed to a depth of 0-20 cm with the following treatments: Forest, with 25% slope (control); pasture crops for 25 years, with 25% slope; and agricultural rotation of wheat-maize (w-mr), for 25, 45 and 70 years of use, each one of these last with 12% and 25% slope, in a Inceptisol (Dystric haplustepts) of the conversion area of wheat cropping, located at 2.400 to 2.800 masl in the Andean zone of the department of Nariño, Colombia (longitude 75º 14´ west, latitude 0.5º 10´ north, 2710 msnm, 80% RH, 12ºC). Results showed significant differences between the type and intensity of soil use over long periods of time in aggregate size distribution, aggregate stability and pore size distribution. An increase in the intensity of soil use decreased the structural stability and affected the soil porosity. The percentage of water stable aggregates larger than 2.0 mm was significantly higher in non-intervened soil. The control had 51.5% of water stable aggregates larger than 2.0 mm. Change to agricultural use (w-mr) over 25, 45 and 70 years, decreased the stable aggregates larger than 2.0 mm to 36.9%, 35.3% and 29.1% respectively. The forest change to pasture diminished the total porosity by 18%. The agricultural use (w-mr) over time caused a gradual decrease of the total porosity.

Key words*:* *Dystric haplusteps***,** aggregate; porosity; wheat; Nariño.

INTRODUCTION

The system of wheat cultivation in Nariño, Colombia (75º 14´ W, 0.5º 10´ N) occurs on long, steep slopes, with a high presence of smallholdings engaging in early and excessive soil preparation, and burning of harvest residues over long periods of time. This system exerts a high pressure on the land, causing erosion and loss of soil structure (Volverás, 2006). The principal effects of physical soil degradation are seen in changes in structural properties. Tillage modifies the shape (geometry and arrangement of the soil particles and pores), stability (ability to maintain shape), and the capacity to restore the structural condition. A good soil structure should consist of a high proportion of stable macro-aggregates (2-10mm in diameter), and a good proportion of pores with a diameter of more than 75 µm in order to permit drainage and aeration during the raining season. At the same time, good soil structure should have an adequate volume of medium sized pores (30-0.4 µm) in which available water is stored during the dry season.

In studies carried out in Andean soils planted with wheat and maize in the department of Nariño, it was found that after 80 years of land use, the actual soil level was 80 cm below the original level, corresponding to a loss of one cm per year of use (Volverás, 2006). Additionally, the infiltration rate decreased 70.4% compared to the control (forest), and runoff increased with increasing intensity of land use.

Because soil structure degradation affects other physical, chemical and biological properties of the soil (Hakansson and Lipiec, 2000), and decreases productivity, the shift to more sustainable land use (conversion) is important for the wheat cultivating zone in Nariño, which covers 16,000 ha over 10 municipalities of the department. Given the need to identify sensitive properties that can be used as indicators of the land use conversion potential, the present study aimed at evaluating the impact of the type and intensity of use on the structural stability in an inceptisol (*Dystric Haplustepts*), cultivated for long periods with a wheat-maize rotation (w-mr).

MATERIALS AND METHODS

Following the wheat harvest (June 2005), soil sampling was carried out at a depth of 0-20 cm to determine the bulk density (Forsythe, 1980), aggregate size distribution (air-dried), water stability of aggregates (Yoder, 1936), pore size distribution (characteristic humidity curves), size distribution of particles, plowing depth, and organic material present in the zone, and treatments, as described in Volverás, Amézquita and Tafurt (2007).

A completely randomized design was used, with eight treatments: non-intervened soil with 25% slope (control); pasture crops for 25 years, with 25% slope; and agricultural rotation of wheat-maize (w-mr), for 25, 45 and 70 years of use, each with both 12% and 25% slope. Three repetitions were used, corresponding to smallholdings between 0.4 y 1.0 ha. Data analysis as carried out using the statistical packet SAS version 8.0. Analysis of variance, Tukey test ($P < 0.05$) for mean comparisons, and descriptive analyses by variable were performed in order to determine the effect of the system or type of land use on some physical properties.

RESULTS AND DISCUSSION

Impact of type and intensity of land use on soil properties

The analysis of variance showed highly significant differences for physical soil properties (Table 1). The type and intensity of land use negatively impacted the physical properties of the soil. Compared to the control, the bulk density in the pasture and the land under agricultural use for 25, 45 and 70 years increased by 27.6%, 8.5%, 8% and 13.2% respectively. With the exception of the 45 year treatment with a 12% slope, the shift to pasture and w-mr agricultural use gave density values above 1.03 g cm^{-3}, in contrast to those reported by Salamanca (2000) in studies in the Andean zone of Colombia. Among the w-mr agricultural use treatments, there were minimal differences in both actual density and bulk density, suggesting that soil volume is lost prior to 25 years of agricultural use.

Intensive land use (w-mr) over long time periods caused loss of organic material (OM) and changes in the textural class, through a gradual decrease in the proportion of clay: after 25 and 70 years of W-MR use the proportion of clay was reduced by 12% and 10% respectively, and the proportion of sand increased. The shift in textural class from FAr in the control to F after 25 years of w-mr use, and to FArA after 45 years w-mr use, showed that in a few years negative modifications are made to soil properties that are difficult to return to initial conditions, affecting soil processes and properties such as humidity retention, pore distribution, organic material content, and nutrient levels. Continuous and excessive tillage over long periods of time, on bare soil due to the burning of harvest residues, generated changes in the volume of soil and textural class through the continuous destruction of surface aggregates (Lal, 1993).

Table 1. Changes in some soil properties related to use type and intensity over 70 years in the Andean zone of Nariño.

Treatment	Bulk density (g cm^{-3})	Actual density (g cm^{-3})	Texture class	Size distribution of particles (%)			OM (%)	Plow depth (m)
				Sand	lime	Clay		
Control	0.97 cb	2.19 a	FAr	41.09 b	25.83 bc	33.08 a	6.78 bac	0.000 c
Pasture	1.34 a	2.46 b	FAr	41.38 b	29.35 ba	29.26 a	4.97 bc	0.000 c
w-mr 25 yrs 12%	1.06 cb	2.42 ba	F	49.78 a	29.04 bac	21.17 b	5.20 bc	0.244 ba
w-mr 25 yrs 25%	1.05 cb	2.40 ba	F	46.88 ba	29.15 bac	23.97 b	6.72 bac	0.211 b
w-mr 45 yrs 12%	1.03 cb	2.34 bc	FArA	47.03 ba	31.04 a	21.92 b	7.77 ba	0.200 b
w-mr 45 yrs 25%	0.88 c	2.28 dc	FArA	50.82 a	29.24 bac	19.40 b	8.67 a	0.200 b
w-mr 70 yrs 12%	1.08 b	2.42 ba	FArA	52.24 a	24.61 c	23.15 b	5.42 bc	0.266 a
w-mr 70 yrs 25%	1.12 b	2.41 ba	FArA	51.31 a	25.37 bc	23.87 b	4.52 c	0.288 a

Values with the same letter are not significantly different (P< 0.05)

Impact of the type and duration of use on soil aggregation

The use of the moldboard plow with animal traction in hillside crop systems since the 1960s has increased plowing intensity, as this method turns the soil, and plowing depth is greater than with the spiked plow. This type of plowing on steep slopes cause soil displacement of almost 1 cm a year, to the point where land with 70 years of w-mr agricultural use has soil levels 70cm below the initial condition (Volverás *et al*., 2007). Moldboard plowing has allowed the farmer to deepen and maintain the depth of plowing in soils with many years use, a practice that, together with the frequent burning of harvest residues, has caused the physical loss of soil fertility.

In the wheat zone of Nariño, the production of harvest residues (stubble and chaff) is scarce and with a wide C /N ratio, with a slow rate of decomposition associated with the climatic conditions of the region. From the physical standpoint, the loss of humus causes a reduction in aggregation, porosity, and infiltration capacity, and increases runoff and erosion. Compared to the control, the shift to pasture and w-mr agricultural use over 25 to 70 years reduced the content of organic material by 26.7%, 24% and 33.4% respectively. The level of OM for 25 and 70 years of w-mr was of concern, and was similar to the process reported by García (1990), who found a reduction of 3.9% over 25 years.

Effect of type and duration of use on soil aggregation

Soil structure, defined as the arrangement of soil particles and intervening porous space, can also be defined in terms of the size distribution of pores, which determine the capacity of soil to transmit and retain water, and intervene in interception processes, mass flow and diffusion for nutrient supply (Lawrence, 1977; Amézquita, 1994). A high proportion of micro-aggregates can be considered as an indicator of soil structural degradation (Boersma and Kooistra, 1994; Amézquita, 1994), indicating a relationship between soil dispersion, infiltration, erosion and structural modifications due to the effect of the type of land use. At any given moment, it is more important to know the structural stability than the structural state, given that the first is dynamic and changes with water, and land use practices. The shift to w-mr agricultural use had a negative effect on the size distribution of dry air aggregates and reduced the grade of soil aggregation (Table 2).

Table 2. Changes in the size distribution of air-dried aggregates (%), by effect of different types and intensities of land use over 70 years in the Andean zone of Nariño.

Treatment	Distribution (%) of aggregates by size (mm)							
	> 6.3	6.3-4.0	4.0-2.0	2.0-1.0	1.0-0.5	0.5-0.25	0.25-0.125	< 0.125
Control	15.88 ba	17.01 a	22.20 a	13.41 ba	14.02 b	5.356 c	6.767 b	5.34 d
Pasture	21.39 a	13.14 ba	18.59 b	12.64 b	14.00 b	6.367 bc	8.400 bdc	5.48 dc
w-mr 25 yrs 12%	10.46 ba	9.522 bc	15.61 c	12.50 b	17.78 a	10.99 a	13.79 ba	9.34 bdac
w-mr 25 yrs 25%	10.87 ba	10.86 bc	15.63 c	12.01 b	17.17 a	9.833 ba	13.18 ba	10.47 ba
w-mr 45 yrs 12%	13.03 ba	11.07 bc	16.67 b	12.47 b	16.44 a	8.733 bac	11.87 bac	9.70b ac
w-mr 45 yrs 25%	7.80 b	8.97 c	17.06 b	15.30 a	17.25 a	9.078 ba	11.99 bac	12.51 a
w-mr 70 yrs 12%	15.89 ba	13.32 ba	17.81 b	12.58 b	16.32 a	7.878 bac	8.856 bdac	7.34 bdc
w-mr 70 yrs 25%	21.78 a	13.04 ba	17.39 b	12.12 b	13.57 b	6.500 bc	8.111 dc	7.40b dc

Values with the same letter are not significantly different (P< 0.05)

In the control and the pasture nearly 55% of the aggregates were larger than 2.0 mm; after 25 and 45 years of w-mr agricultural use, the proportion of aggregates larger than 2.0 mm decreased to 35.6% and 33.8% respectively; after 70 years of w-mr they tended to increase as a consequence of the increased deterioration in physical conditions generating hard lumps which did not respond to dry sieving.

The type and duration of land use generated changes in the size distribution of stable aggregates and affected the structural stability (Table 3); the control and the pasture presented a much more regular behavior in the size of stable aggregates. Only in the control were 51.5% of stable aggregates larger than 2.0 mm; the shift to w-mr agricultural use after 25, 45 and 70 years reduced stable aggregates to 36.9%, 35.3% and 29.1% respectively, as a response to a greater intensity of use, which promoted low levels of OM, and a predominance of large particles in the soil (Table 1).

Table 3. Changes in the size distribution of water stable aggregates (%) by effect of different types and intensities of land use over 70 years in the Andean Zone of Nariño.

Treatment	Percentage of stable aggregates by size (mm)					
	> 6.3	6.3-4.0	4.0-2.0	2.0-1.0	1.0-0.125	< 0.125
Control	24.21 a	10.10 a	17.24 a	13.41 b	14.57 b	20.50 ba
Pasture	24.84 a	7.800 b	13.84 ba	14.57 b	21.08 ba	17.84 ba
w-mr 25 yrs 12%	15.81 ba	6.711 b	14.40 ba	17.46 a	23.74 a	21.86 ba
w-mr 25 yrs 25%	17.46 ba	6.922 b	14.23 ba	16.32 a	19.49 ba	25.62 ba
w-mr 45 yrs 12%	24.61 a	7.133 b	13.50 ba	16.03 a	19.14 ba	19.59 ba
w-mr 45 yrs 25%	12.69 ba	7.066 b	15.54 a	17.18 a	19.30 ba	28.19 a
w-mr 70 yrs 12%	24.22 a	8.466 ba	13.66 ba	16.42 a	19.71 ba	17.53 b
w-mr 70 yrs 25%	11.24 b	6.533 b	11.30 b	16.73 a	25.99 a	28.14 a

Values with the same letter are not significantly different (P< 0.05)

The results of the study showed that after 25 years of w-mr agricultural use, nearly 45% of the stable aggregates were smaller than 1.0mm, reaching 54% after 70 years of use.

Total porosity and size distribution of pores

The analysis of variance showed highly significant differences between treatments in total porosity (%), macropores (%), mesopores (%), and micropores (%). Increased intensity of land use in terms of duration and plowing, affected the total porosity, and the size distribution of pores; the total porosity of the pasture was reduced by 18% compared with the control. Between the treatments of w-mr agricultural use there were no statistical differences in total porosity, suggesting that the shift in land use can negatively affect soil volume over short periods; although no differences were observed between the control and the w-mr agricultural use, total porosity tended to reduce with increasing duration of land use (Figure 1).

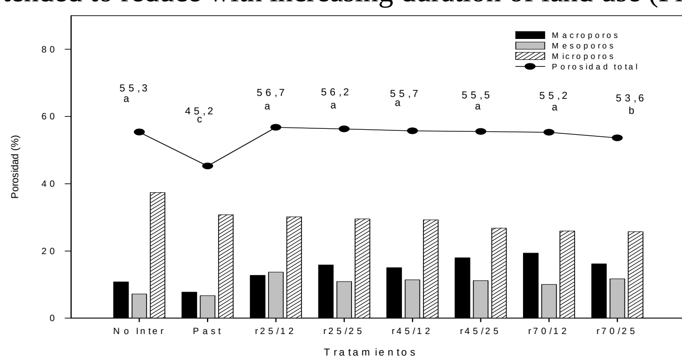

Figura 1. Cambios en porosidad y distribución de tamaño de poros en función del tiempo de uso del suelo.

Figure 1. Changes in porosity and pore size distribution as a function of the duration of land use.

The shift to w-mr agricultural use improved the size distribution of pores; in the control, micropores represented 68% of the total porosity, and after 70 years of w-mr agricultural use, this was reduced to 48%. These changes generated a gradual increase in the meso- and macro-pores, as a result of the temporary beneficial effect of plowing (Amézquita, 2004), which makes available a deeper part of the soil profile, and the root biomass produced by consecutive crops of the Gramineaes, wheat and maize.

However, the size distribution of pores suggested problems with drainage and nutrient flow from soil to plant, given the levels of macro- and mesopores, and the textural composition of the soil. The reduction in total porosity, and the increased bulk density reduces the water content to zero suction, and the hydraulic conductivity at saturation (Pla, 1 990).

CONCLUSIONS

- In Andean hillsides in Nariño the type of land use affects soil structure. The uses with greatest plowing intensity reduced the proportion of macro-aggregates, structural stability and soil volume.

- An increase in the intensity of land use generated shifts towards textures dominated by large particles.

- Agricultural use over long periods on hillsides, caused degradation related to soil loss, reduction in the organic material and structural stability, and negative changes in the proportion of particle sizes.

- A shift to more sustainable soil use requires broad and systematic soil studies that allow areas to be defined that, from a biophysical standpoint, support land use conversion.

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