

Quantification of some soil properties as affected by land use, and its implication for vegetable farm systems

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Abstract

Sustainability of vegetable farms depends on development of farming systems that can at least arrest soil deterioration, and ideally improve soil fertility. We assessed soil quality as baseline for a larger study on farming systems redesign in Uruguay. Specific aims were to quantify soil properties in vegetable crop fields on different soils; to evaluate the effect of past land use on these properties; and to assess how this changes could affect soil moisture supply capacity. Samples were taken from 4 cropped fields and from adjacent undisturbed land in pairs on 16 farms with soils representative of the region, Hapluderts and Argiudolls. In cropped fields, SOC at 20 cm depth was 14.9 g/kg on average, and 11.3 g/kg on the coarser Argiudolls. Compared to the undisturbed situation SOC depletion was 35% on average, and 41% on coarser Argiudolls. Geometric mean diameter of stable aggregates decreased from 2.72 mm to 2.36 mm. Soil moisture supply capacity - a main function of soil is negatively affected by the depletion of SOC and decreased aggregation. Given the increasing frequency of drought and constraints on irrigation capacity, soil management alternatives that improve these properties are needed.

Key Words

Horticulture, deteriorated soils, soil quality, physical fertility, Molisols, soil organic matter

Introduction

Vegetable production is the third most important agricultural activity in Uruguay in terms of number of farms and labour. The activity is concentrated in the departments of Montevideo and Canelones, with 27000 ha or 70% of the total area dedicated to vegetable crops (DIEA, 2001). The region has been identified as the area with most severe erosion in the country (RENARE, 1999). Country-wide the number of farms specialized in vegetable production decreased by 20% in 10 years (DIEA, 2001), and by 34% in the south of the country (DIEA, 1999). Farmers that remained had to produce more to maintain their income level (PRONAPA, 1997). Such intensification of the production increased pressure on already deteriorated soils and led to production inefficiencies (Dogliotti, 2003).

The importance of reducing soil erosion and improving physical and biological fertility for sustainable development of vegetable farms in South Uruguay was highlighted by Dogliotti *et al.* (2005). In a context where fertilizers are widespread but major constraints exist for irrigation, one of the main causes of reduced soil productivity might be the reduction in soil moisture supply capacity (SMS). A reduction in SMS is linked to a depletion in SOC, reduced porosity and structural stability (Brady and Weil, 2002). Quantification of changes in those properties in relation to past management supports reflection on directions for re-design of soil management strategies. In addition, a baseline soil quality assessment is needed to evaluate the effectiveness of implemented re-designs. Such information is currently not available for vegetable farms in the South of Uruguay. The purpose of this work was to provide an assessment of soil quality as baseline for a larger study on farming systems redesign in Uruguay. Specific aims were to quantify soil properties in vegetable crop fields on soils representative of the region; to evaluate the effect of past land use on these properties; and to assess how this changes could affect SMS.

Methods

Sites description

The study was conducted in Southern Uruguay, and is part of a project (EULACIAS, EU FP6 INCO DEV) which aims to design, implement and evaluate sustainable vegetable farming systems through a co-innovation process based on a group of pilot farms. Sixteen farms in Montevideo and Canelones were selected to represent the variation in existing vegetable production systems. Re-design on the participating farms included changes on erosion control support measures, use of rotations with forage and cover crops, and incorporation of plant residues and animal manure.

Edaphic environment and soil characteristics are described in Table 1. The climate is sub humid, subtropical to temperate. Potential evapotranspiration in summer is greater than precipitation. Rainfall varies greatly between years.

Table 1. Soil type, characteristics, and edaphic environment of fields sampled.

Soil type	Texture in the topsoil	Edaphic environment
Typic Hapluderts	Clay, Clay loam, Clay silty loam	Gently rolling to strongly rolling highlands. Soils developed from quaternary or tertiary sediments, deep, black or brown.
Paquic (vertic) Argiudolls	Clay, Clay loam	
(Abruptic) Argiudolls	Loam, Silty loam	Strongly rolling highlands. Soils developed from sediments and influence of crystalline, moderately deep, and brown. And flat lowland landscape. Soils developed from quaternary sediments, deep, brown soils, rather lixiviated.

Land use on all farms was intensive vegetable farming during at least 20 years, with inverting soil ploughing twice a year on average.

Samples collection and analysis

On 16 farms topsoil (0-20cm) paired samples were collected from 4 cropped fields and a location that had not been cultivated during the past 20 years (under an old fence in most of the cases). This resulted in a total of 61 samples since in 3 cases no near-undisturbed situation was found. Samples were analysed at the Soil Laboratory of the MGAP for particle size by the hydrometer method, organic carbon by the dichromate oxidation technique, pH (1:2.5 soil-water and soil KCl suspension), and exchangeable bases by the sodium acetate method.

After two months from the last tillage operation, samples were taken for estimating physical properties at the Laboratory of INIA Las Brujas. A total of 16 duplicate samples of soil clods at 20 cm depth were collected with a spade for structural stability analysis. Structural stability was assessed by wet sieving and the geometric mean diameter calculated according to methodology described in Kemper and Chepil (1965). A total of 12 triplicate undisturbed samples at 5-10 cm and 15-20 cm depth were collected on each site with rings 5 cm wide and 3 cm height for estimating bulk density, the moisture-retention curve, and porosity, samples were processed in a pressure plate. Estimates of weight water content at wilting point were also made using the following empirical function adjusted for Uruguayan soils (Silva *et al.* 1988):

$$\%W_w \text{ at } 1500 \text{ kPa} = - 58,1313 + 0,3718 (\%SOM) + 0,5682 (\%sand) + 0,6414 (\%silt) + 0,9755 (\%clay) \quad (1)$$

Confidence intervals at 95% probability were calculated for all variables.

Results and discussion

Measured SOC in the “undisturbed” situation confirmed that even though those soils had not been cultivated for a long time, their SOC values were less than half those reported for the same soil types in Uruguay in pristine conditions (Duran, 2007). This study thus assesses the depletion of SOC over the last 20 years (Table 2).

Table 2. Mean and 95% confidence interval of soil organic carbon (g/kg) and percentage depletion at 20cm depth by soil type and land use.

Current use of land	Typic Hapluderts Cl, ClSiL, CiL ¹	Argiudolls Cl, CiL	Argiudolls SiL, L	All Samples
	g carbon / kg of soil			
Undisturbed for more than 20 yr	25.1 [21.8; 28.5]	21.5 [18.8; 24.1]	19.2 [16.2; 22.2]	22.8 [19.5; 26.0]
Vegetable cropped fields	16.9 [15.1; 18.7]	14.0 [12.4; 15.6]	11.3 [8.1; 14.4]	14.9 [13.6; 16.1]
	%			
SOC depleted	32.6 [30.5; 34.6]	34.8 [30.5; 39.2]	41.4 [38.5; 44.3]	34.6 [32.7; 36.4]
n	29	21	11	61

¹ Cl is clay, Si is silt and L is loam

On the “undisturbed” soils a trend of decreasing SOC was observed from Hapluderts to silty loam and loam Argiudolls (Table 2). A depletion of 34.6% of SOC was observed on average in all crop fields with respect to the “undisturbed situation”. Percentage SOC depletion was higher in L and SiL Argiudolls than in Hapluderts. As a consequence, on the vegetable cropped fields, SOC was higher in Hapluderts than in L and SiL Argiudolls (Table 2). Average lost SOC was 20.0 Mg/ha in an equivalent soil mass of 2500 Mg/ha with respect to the “undisturbed” sites.

The stronger depletion of SOC in coarser textured soils was expected, because these soils are more erodible, the reported average 50% enrichment of organic carbon in sediment transport by erosion processes for similar soils (Victoria *et al.* 1998), and because of coarser soils have less capacity to protect SOC (Hassink *et al.* 1997). This points to the need for extra attention for soil management techniques on these coarser textured soils.

Geometric mean diameters of aggregates stable to wet sieving (GMD) on 16 farms were on average 0.36 mm smaller than their undisturbed pairs and contained 43.8% less SOC (Table 3). These results are consistent with the literature that established a positive relationship between SOM and water stable aggregates (Carter, 2002) and negative relationship with tillage (Liebig *et al.* 2004). No differences in GMD were found among the three soil types sampled.

Table 3. Mean and 95% confidence interval (n=16) of structural stability and soil organic carbon on paired samples from vegetable farms at 20cm depth.

Current use of land	Structural stability GMD ¹ (mm)	SOC (g/kg)
Undisturbed for more than 20 years	2.72 [2.55; 2.89]	24.0 [19.5; 28.5]
Vegetable crop fields	2.36 [2.19; 2.53]	13.5 [11.5; 15.5]

¹ GMD = geometric mean diameter (Kemper and Chepil, 1965).

Bulk density, macroporosity, water retention at 10 kPa, and total porosity did not differ statistically between cropped and undisturbed either at depth of 5 to 10 cm or at depth of 15 to 30 cm. Water retention at field capacity tended to be higher in the undisturbed soils (Figure 1A) than in the cultivated soils, averaging 6 mm more water per ten cm of soil. We estimated the reduction of water availability to be 17% on average in cropped fields compared with their undisturbed pairs (Figure 1B). The higher water retention in undisturbed samples was mainly explained by higher organic matter content compared to the cultivated soils. The pedotransfer function of Silva *et al.* (1988) underestimated water retention by 19 and 12% on average in cultivated and undisturbed soils, respectively, deserving future research.

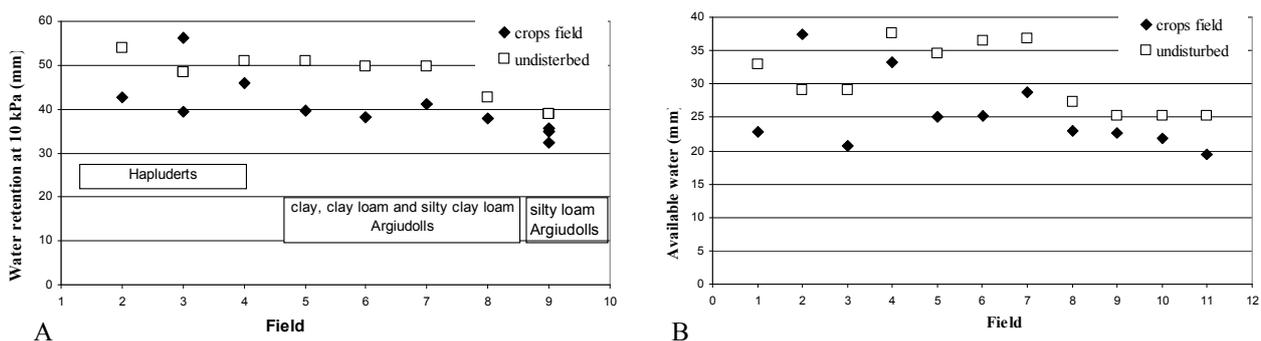


Figure 1. A) Measured soil water retention in the top 10 cm depth on different farms’ fields. B) Available water = (measured Wv retention – estimated Ww at 1500 kPa with the equation by Silva *et al.* (1988)* bulk density).

The capacity of soils to supply water to the crops is a crucial soil function in a context of increased frequency of drought events and constraints to irrigation. Processes that affect the soil moisture supply (SMS) are infiltration, root exploration, available water capacity and transpiration. Air and water infiltration and available water capacity are influenced by SOM content and soil aggregation (Carter, 2002). Root exploration would be larger in non compacted, and well aggregated soils as well. Our measurements indicate that past management in vegetable fields is negatively affecting the SMS through a reduction of SOM content and stable aggregates. Reduction in SMS is likely to be higher than the estimated reduction in available water since a reduction in water infiltration and root exploration is expected due to reduced

aggregate stability and compaction by tillage. Further research is needed in order to quantify the magnitude of the relation between SMS and infiltration and root exploration to aid the design and evaluation of improved soil and crop management practices aimed to increase SMS in different soil types under rain-fed vegetable production.

Conclusion

Vegetable crop fields in South Uruguay, grown on already deteriorated soils, have been managed so intensively during the past 20 years, that average loss of 20.0 Mg/ha of SOC in an equivalent soil mass of 2500 Mg/ha with respect to undisturbed soil pairs was detected. Soil moisture supply, a major function of soil, is negatively affected by the depletion of SOC and associated weaker soil aggregation. Further research is required to quantify the magnitude of the relationship between SOM and SMS in the studied systems, to evaluate the impact of current soil practices, and to design new management strategies. Soil management recommended for L and SiL Argiudolls should be more conservative than for Hapluderts.

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