Land use and carbon sequestration in arid soils of northern Patagonia (Argentina)

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Abstract

The objective of this work was to characterise the total and soluble carbon content in soils under different land use: apple (*Malus sylvestris)* plantation, forest plantation (*Pinus sp*.) and alfalfa pasture (*Medicago sativa*), on different sites of the Rio Negro valley (Chimpay, Vista Alegre, Villa Regina) in northern Patagonia, Argentine. The results were compared with data from nearby soils with natural vegetation. The values for soil carbon significatively increased ($P < 0.05$) in the pines plantation, alfalfa pasture, and in older (> 15 years) apple cultivations. In arid regions, carbon storage in soils is a relevant advantage due to its positive influence on soil properties, apart from a positive effect on atmospheric carbon sequestration.

Key words: alfalfa, apple, carbon, land use systems, organic farming, pasture, pine forest, sequestration, soils in arid regions, water soluble carbon

Zusammenfassung

Einfluß der Landnutzung auf die Kohlenstoffspeicherung in ariden Böden Nord-Patagoniens (Argentinien)

Ziel der Forschungsarbeit war die Quantifizierung des Einflusses unterschiedlicher Landnutzungsformen (Apfelplantagen, Kiefernwald, Dauergrünland mit Luzerne, natürliche Vegetation) auf die Kohlenstoffgehalte in Böden dreier Regionen im Tal des Rio Negro von Nord-Patagonien (Chimpay, Vista Allegre, Villa Regina) in Argentinien. Die größten Kohlenstoffanreicherungen wurden unter Kiefernwald, gefolgt von Dauergrünland mit Luzerne und alten Apfelplantagen (> 15 Jahre) gefunden. Neben einem Beitrag zur Verbesserung der Funktionalität der Böden in ariden Gebieten stellt die Anreicherung von Kohlenstoff durch nachhaltige Landnutzung auch einen bedeutsamen Beitrag zur Verbesserung der globalen Situation der Kohlenstoffbilanz dar.

Schlüsselworte: Apfel, aride Zonen, Kiefernwälder, Landnutzungsformen, Luzerne, Kohlenstoff, Kohlenstoffspeicherung, ökologische Landwirtschaft, wasserlöslicher Kohlenstoff

1 Introduction

Soil organic matter is a key indicator for soil quality. The most labile components of the organic matter are thought to participate in supplying nutrients for plant growth, and the intermediate labile components must be periodically replenished to maintain an adequate level of organic matter, fertility and sustainability (Rosell et al., 2001).

The aspect of sustainability is a striking argument to increase the levels of organic matter in soils, because of improving the functionality of soils and the contribution to the global carbon balance. Soil organic matter could be considered as one of the most important national resources and it must be given its proper rank in any conservation policy worldwide (Wallace, 1994).

Carbon storage in soils is a relevant issue in soil science nowadays due to its relationship with the abatement of atmospheric CO_2 concentrations produced mainly by industrial emissions. Global warming is a reality which was acknowledged by governments, and the role of forests to mitigate greenhouse gases in the atmosphere, mainly CO_2, was examined on a global scale. The Intergovernmental Panel on Climate Change (IPCC) considered that forestation could offset 7.5 % of the carbon that is likely to be emitted by burning fossil fuels up to 2050. As a consequence, individual countries are claiming forest carbon sinks to cut fossil fuel emissions, and some companies are starting independent carbon offset projects (Cannell, 1999).

The ecological function of trees has also been valued from an economic point of view by estimating possible damage deriving from global warming, or marginal values for each ton of carbon calculated on the basis of expenditures to be made in order to reduce greenhouse gas emissions, and with the calculation of the value of each ton of carbon stored (Lescuyer and Locatelli, 1999).

Forests and specially pinus plantations have been investigated extensively concerning their role for carbon sequestration in soils, but there are also reports from Canada including field and farmyard shelterbelts and poplar plantations (Kort et al., 1997); *Cryptomeria japonica* plantations in Taiwan (Chen et al., 1999); and clonal rubber trees in smallholder plantations in Indonesia (Grist et al., 1999).

Land use is a major factor affecting carbon storage in soils. After 1945 soils in USA accumulated carbon largely as a result of fire suppression and forest growth on abandoned farmland. An example for this are the USA, where during the 1980's, the net flux of carbon attributa-

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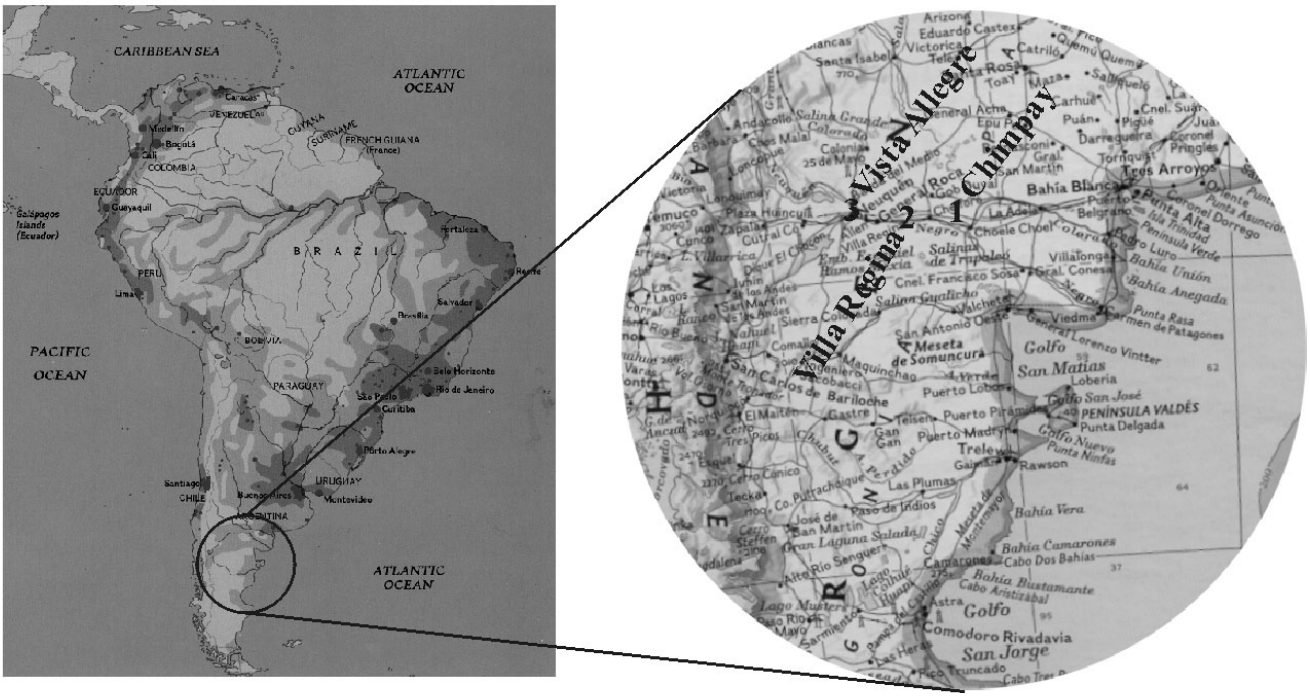

Fig. 1:
Survey sites for carbon sequestration in northern Patagonia, Argentine

ble to land management offset 10-30 % of fossil fuel emissions (Houghton et al, 1999).

In sustainable agriculture, environmental degradation and pollution by agricultural products have to be minimized, so from an ecological point of view, the maintenance of stable yields could also be based on the increase of soil organic matter content. In Iran, for instance, it was decided to increase soil organic matter by 1 %, evaluating that carbon sequestration in soils not only increases yield of the crops, but also decreases the atmospheric CO_2 content (Golchin et al., 1999).

The objective of this work was to study the relationship between different land use forms and soil carbon contents in arid soils of northern Patagonia (Argentina).

2 Materials and methods

In February 2001, surface soil samples (0-3 and 0-20 cm) were collected from Torrifluvents in the Rio Negro Valley in northern Patagonia, Argentine (Fig. 1). The climate is semiarid with an annual mean rainfall ranged between 140 and 206 mm, and an annual mean temperature varies between 21.8 and 23.9 ºC among sites. The annual mean potencial evapotranspiration is 750 mm.

2.1 Description of the sampling sites and plots

Site 1: Chimpay (Río Negro); 39 ^{o} 10 ‘S. , 66 ^{o} 9 ‘W.
M1: high yielding apple plantation, (22 years in production)
M2: high yielding apple plantation, (5 years in production)
A: *Medicago sativa* pasture (5 years old)
T1: control plot: levelled soil ready for plantation and irrigation, with natural vegetation: *Poa ligularis, Bromus setifolius, Larrea divaricata and Prosopis alpataco philippi.*

Site 2: Villa Regina (Río Negro); 39 o 6 ‘S., 67 o 5’W.
P: Pine forest (15 years old)
M3: apple plantation (22 years in production)
T2: control plot with natural vegetation: *Larrea divaricata and Prosopis alpataco philippi, Schinus poligamun, Baccharis salicifolia.*

Site 3: Vista Alegre (Neuquén); 38 o 45’S, 68 o 11’ W.
1: Valley
M4: apple plantation (15 years in production) traditional management
M4o: apple plantation (15 years in production) organic management
T3: control plot with natural vegetation: *Poa ligularis, Bromus setifolius, Larrea divaricata and Prosopis alpataco philippi.*
2: Highland area (“albardón”)
M5: apple plantation (12 years in production) 2 years high yield apple mount
T4: control plot with natural vegetation: *Poa ligularis, Bromus setifolius, Larrea divaricata and Prosopis alpataco philippi.*

Five soil samples per plot were collected along transect of 100 m. Each sample consisted of three sub-samples. Samples were taken from two depths: 0-3 cm and 0-20 cm. Total carbon was analyzed by means of the Walkley-Black method (Page, 1982). Soluble carbon was extracted with distilled water (Davidson et al., 1987). Soil texture is loam to sandy loam, pH value varied between 7.7 and 8.6. Soils are not saline neither sodic. The extractable Bray 1 Phosphorus content varied between 15 and 25 mg kg^{-1}, exchangeable bases like calcium, magnesium and potassium are not deficient (Giuffré et al., 2002).

Statistic analysis (ANOVA and Tukey test) was performed on the data to evaluate statistical differences between carbon contents on different sites and plots.

3 Results and Discussion

Soil carbon is one of the most used and reliable chemical indicator for soil quality and functionality (Doran et al., 1996).

3.1 Total Carbon content in 0-3 cm and in 0-20 cm layers

As shown in Fig. 2, a significant differences ($P < 0.05$) were found for the total carbon content in the 0-3 cm and the 0-20 cm layer of the site/plot combinations for (“situation” in Fig. 1) situations A, P, M4o and M1.

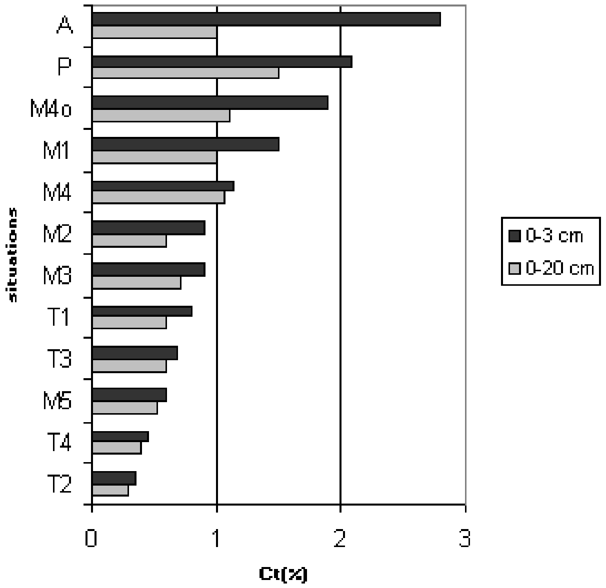

Fig. 2:
Total carbon contents in 0-3 cm and 0-20 cm layers of soils under different land use forms in northern Patagonia, Argentine
Remarks: Site: “Chimpay”,: plots: M1: old apple plantation, M2: new apple plantation, A: pasture, T1: control; Site “Villa Regina”:, plots: P: Pine forest. M3: old apple plantation; T2: control; Site “Vista Alegre (valley)”, plots: M4: apple plantation under traditional management, M4o: apple plantation under organic management; T3: control; Site “Vista Alegre (highland)”, plots: M5: old apple plantation, T4: control.

The highest total carbon content in the 0-3 cm surface layer was found under pasture (A), which revealed also the highest difference between layers (180 %). Pastures are well known as management situations that are ideal to restore organic matter in soils (Cambardella and Elliott, 1993; Studdert et al., 1997).

For the pine forest (P), the carbon increment in the surface amounted to 40 %. The pine forest showed a marked accumulation of organic material in the surface horizon, which mainly originated from the deposition of foliar.

The “organically” managed apple plantation (M4o) had a 69 % higher carbon content in the top layer of the soil but also in the entire 0-20 cm sampling depth. Key feature of the organic management of this apple plantation was a high cover with plant residues material between the tree lines, as a strategy to control the growth of weeds.

The high yielding old apple plantation at Chimpay (M1), with external inputs as commercial fertilizers and irrigation during the past 22 years, showed an increase of 50 % in the total carbon content of the surface layer compared to the 0-20 cm sampling depth.

3.2 Effect of land use on the total carbon content in the 0-20 cm soil layer

In the Chimpay region, both the pasture A and the old apple plantation M1 showed a remarkable increase in the carbon content of 67 % in the soil relative to the control T1. However, the youngest apple plantation (M2, 5 years old) did still not show any significant difference to the control (Fig. 3).

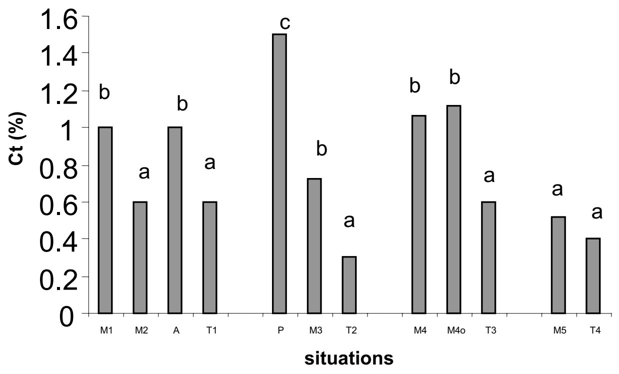

Fig. 3:
Total carbon content in the 0-20 cm layer of soils with different land use in northern Patagonia, Argentine
Remarks: Site “Chimpay”, plots: M1: old apple plantation, M2: new apple plantation, A: pasture, T1: control; Site “Villa Regina”, plots: P: Pine forest. M3: old apple plantation; T2: control; Site “Vista Alegre (valley)”, plots: M4: apple plantation under traditional management, M4o: apple plantation under organic management; T3: control; Site “Vista Alegre (highland)”, plots: M5: old apple plantation, T4: control. Different characters between plots designate statistical significant differences ($p < 0.05$).

In the Villa Regina region, the apple plantation M3 showed increased carbon contents compared to control of 253 %, but the highest carbon sequestration was found in the pinegrove, with an increase of 400 % in total carbon relative to control.

In the inferior valley area of Vista Alegre, the traditional and the organically managemenet apple plantation showed differences of their carbon contents of 77 % and 87 % relative to control. The highland of the valley ("albardón"), which is the most arid zone of the site, and the apple plantation M5 (12 years old) showed a carbon augmentation of 30 % with reference to the control plot.

A ranking of the different land use forms on the different sites according to their carbon sequestration looks as follows:

Pine forest (P) > organic managed apple plantation (M4o) > traditional managed apple plantation M4 > pasture (A) = old apple plantation M1 > old apple plantation M3 > new apple plantation M2 = control T1 = control T3 > apple plantation M5 > control T4 > control T2.

Control plots with native vegetation had the lowest carbon values (0.3 – 0.6 % Ct) which can be considered as characteristic for pristine sites.

All land use form produced a substantial improvement in carbon sequestration compared to their regional controls, except in the case of the new apple plantation M2 (5 years). The most important fact for this is that the older apple plantations conducted organic carbon total content to a new balance point in each one of the considered areas (Fig. 4).

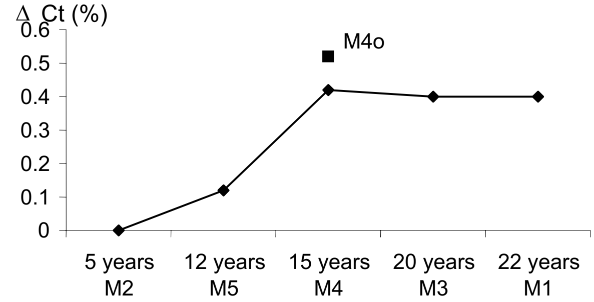

Fig. 4:
Total carbon content in the 0-20 cm layer of apple plantations of different age and management practice in northern Patagonia, Argentine

Fig. 4 shows a clear tendency towards a stabilization of carbon accumulation in apple plantations after 15 years of production.

Although Pine plantations showed the highest soil carbon contents they are ecologically less favourable because they are known for a higher water consumption, an increase of acidification and containment a lower biodiversity (Cannell et al., 1999).

These findings are in line with reports from Northern Ireland, where Cruischank et al. (1998) found that the amount of carbon stored in soils and vegetation was related with specific site conditions. The total carbon "density" of the vegetation in their investigation was 1.8 t/ha^{-1} for arable crops, 13.5 t/ha^{-1} for apple plantations and 62.4 t/ha^{-1} for coniferous plants. The total amount of carbon stored in soils was estimated to be between 4.4 Mt and 386 Mt. The data presented from this research (Fig. 4) work underline again that organic agriculture offers a way to increase carbon sequestration, despite the fact that it has substantially lower negative environmental costs than conventional farming (Pretty et al., 2000).

3.3 Water soluble carbon

Availability of soil carbon to heterotrophic microbes influences the degradation of soil organic matter (SOM) and, consequently affects nutrient availability for plants and soil microorganisms. Despite the vast amount of organic carbon present in soil, most of the soil carbon is chemically recalcitrant and/or physically inaccessible to microorganisms. Therefore the identification and operational separation of labile carbon from bulk SOM is of great interest. Microorganisms gain a significant proportion of their energy from the water-soluble carbon pool because of its small molecular size and easy accessibility to microorganisms (Wagai and Sollins, 2002). Fig. 5 presents the amount of water soluble carbon in the soils of the investigated sites and plots.

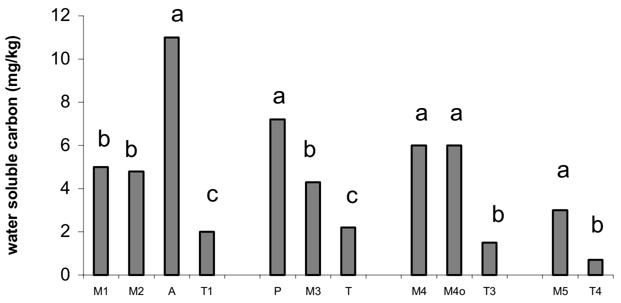

Fig. 5:
Water soluble carbon content in the 0-20 cm layer of soils with different land use in northern Patagonia, Argentine
Remarks: Site "Chimpay", plots: M1: old apple plantation, M2: new apple plantation, A: pasture, T1: control; Site "Villa Regina", plots: P: Pine forest. M3: old apple plantation; T2: control; Site "Vista Alegre (valley)", plots: M4: apple plantation under traditional management, M4o: apple plantation under organic management; T3: control; Site "Vista Alegre (highland)", plots: M5: old apple plantation, T4: control. Different characters between plots designate statistical significant differences ($p < 0.05$).

The results in Fig. 4 show that the highest water soluble carbon contents were found under pine, alfalfa and the lowest values always in the control soils, which underlines that land use has a beneficial effect on the carbon supply for soil microorganisms. These values could be related to differences in carbon storage and in biological activity. The amount and biodegradability of labile carbon pool are known to be affected by several factors (e. g. soil type, depth in soil profile, liming and N fertilization). Boyer and Groffman (1996) stated that land use also affected DOC (dissolved organic carbon), that is the difference between total soluble carbon and inorganic soluble carbon.

4 Conclusions

Carbon dynamics may be the key for to managing soil organic matter in order to enhance soil quality and ecosystem functionality (Gregorich et al., 2000).

The result of this research shows the potential of land use management in the area of northern Patagonia to increase the carbon storage relative to pristine situations. Data for total and water soluble carbon have been proven to be useful for the assessment of environmental sustainability of different agroecosystems.

The rate of accumulation of soil organic matter is often higher on fertilized and irrigated fields, but this fact carries a carbon 'cost' that is seldom assessed in the form of CO_2 emissions during the production and application of inorganic fertilizer. Irrigation of semiarid lands may also produce a sink for carbon, but its contribution to soil carbon must be discounted by CO_2 that is emitted when energy is used to pump irrigation water (Schlesinger, 2000).

As Hayes and Smith (1999) stated, the greenhouse issue is unique in that the South influences a global asset that is greatly valued by the North: Earth's climate. Negotiations to date have been stalled by ideologies transposed from prior North-South conflicts into the greenhouse arena.

Nevertheless, for countries of the southern hemisphere, the benefit of increasing organic matter in soils can be measured in terms of better soil quality and the improvement of the functionality of dry soils. Squires (1998) considered that dry lands have the potential to be a sink for significant amounts of carbon, especially if they are restored to their ecological potential, and that the soil store of carbon in these systems is a very important pool, since it is stabilized for hundreds to thousands of years.

Another impact of the increase of organic reservoir in soils is the reduction of the risk of erosion, due to better aggregation. The most severe erosion occurs in the ecologically-sensitive regions of Asia, South America and Oceania (Lal and Kimble, 1998).

The results of this research are in line with those of Smith et al. (2000) who investigated the role of soil management for carbon sequestration in arable soils. They stated that by a sophisticated management of soils in the United Kingdom alone could contribute with 49 % to the European Union carbon emission reduction target.

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