Estimation of Carbon Inputs to Soils from Wheat in the Pampas Region, Argentina

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Abstract: Recently soils have gained more attention within the global change debate as the largest terrestrial carbon (C) pool. Different soils and vegetation types have substantial impacts on many of the processes that take place in the ecosystem functioning and thus in soil organic C stocks. An accurate estimation of vegetation C inputs to soils may aid in more precise estimation of the future release or sequestration of soil organic C. Wheat production affects C inputs and thus soil C sequestration in soils. The objective of this research was to evaluate C inputs by wheat, from 1993 to 2002 in the Pampas Region. The estimated C input rate by wheat was greater in the humid subregion than in the semiarid subregion: 0.9 and 0.75 Mg C/ha/year, correspondingly. This pattern agrees with the observation that precipitation constrains plant production in arid to subhumid ecosystems. The average organic C input by wheat into the soils throughout the period was 8.1 Mg C/ha in the humid subregion and, 6.75 Mg C/ha in the semiarid subregion.

Keywords: Pampas Region; soil organic carbon; wheat

The importance of agroecosystems as a sink for CO_2 has been recognized since increased yields, decreased tillage and increased residue inputs lead to accumulations of soil carbon. There are three principal reservoirs regulating the carbon cycle on earth, the oceans, the atmosphere and the terrestrial systems. Soils have gained more attention within the global change debate as the largest terrestrial carbon (C) pool (Perruchoud *et al.* 2000). A satisfactory quantity of soil organic C is considered crucial for sustainable agriculture and mitigating C flux to the atmosphere. A decline in soil C usually decreases crop productivity and alters the ability of the soil to act as a sink for the atmospheric CO_2 and therefore have an impact on global climate change (Rasmussen *et al.* 1998). Different soil types and vegetation types has substantial impacts on many of the processes that take place in the ecosystem functioning and thus in soil organic C stocks (Yimer *et al.* 2006). Accordingly, an accurate estimation of vegetation C inputs to soils may aid in accurate estimation of the future release or sequestration of soil organic C. Wheat influence soil C sequestration, with a potential impact on C input. In most cases, the greater the amount of residues returned to the soil, the greater the soil organic C level. Therefore, determining the C input by wheat is important to determine the potential for C accumulation in soils (Oades & Martin 1986). The carbon budget of agroecosystems is essential in the global terrestrial C cycle, but has been difficult to quantify on a larger scale due to spatial and temporal variations in climate, soils and agricultural practices. One approach to overcoming this difficulty is the application of C budget equations at a regional scale (Alvarez & Lavado 1998; Marland *et al.* 2001a, b). Although, previous studies analyzed soil organic C, they did not link C input with soil C stock. The carbon budget of an agroecosystem is simply defined as the difference between carbon into and out of the soil. The carbon balance of a situation can be calculated as a function of crop yields. An approximate C balance includes: carbon inputs result from crop residue retention, roots, while output is due to soil carbon mineralization among others (ALVAREZ *et al.* 2006). The Pampas Region is considered one of the most suitable areas for grain crop production in the world (HALL *et al.* 1992). It has been documented that no till systems increased C inputs and reduced C release in Pampas Region, but at the moment C contents derived from no till wheat were not calculated at a regional scale (MIGLIERENA *et al.* 2000; STUDDERT & ECHEVERRIA 2000). The objective of this study was to evaluate C inputs and consequently soil C accumulation by wheat, through 1993 and 2002 in the Pampean Region of Argentina.

MATERIALS AND METHODS

The Pampas is a huge plain of around 50 mil ha, within 28 to 40°S in Argentina. Mean annual rainfall ranges from 200 mm in the west to 1200 mm in the east and the mean annual temperature ranges from 14°C in the south to 23°C in the north. The area includes two subregions: semiarid and humid. Agriculture is performed in the humid and semiarid subregions since annual rainfall is acceptable for this purpose. Crop production is carried out mainly on Mollisols formed on loess-like materials. Almost 50% of the area is dedicated to agriculture, with wheat (*Triticum aestivum* L.), soybean [*Glycine max* (L.) Merr.], and corn (*Zea mays* L.) as the main crops. Since 1990, the use of no-till has increased exponentially; with around 80% of agricultural lands now cropped under this management (HALL *et al.* 1992). In order to estimate C inputs and accumulation by wheat at a regional scale, this study was developed using agricultural census data from 1993 to 2002 performed by the National Statistics and Census Institute (INDEC) (www.indec.gov.ar). Wheat yields and harvested areas data for the semiarid and humid subregions were extracted. Since wheat yields are different for each subregion, balance and yield estimations were made for each subregions separately using the same equation but different term values. Carbon inputs by wheat were calculated using a simplified version of the balance equation performed for the region (ALVAREZ *et al.* 2006). The equation only included yields and the conversion factor of the organic residues into soil organic matter. The ratio of straw biomass/grain biomass for wheat (2.0) was included in the conversion factor. An equal harvest index was assumed for the region. Root biomass was not considered in this analysis. Also, the equation used in this study did not include soil carbon mineralization term. As well there are more processes that influence the output and input of C besides mineralization and residues (e.g. soil respiration erosion, weed biomass) only those mentioned above were considered in the approach used in this paper. Finally, equation (1) is the sum of soil carbon input rate from wheat on mass per area and year basis, for the semiarid and humid subregions, separately.

∑ Average C input by wheat in both regions:

Average C input by wheat (Mg C/ha/year) = yield (Mg grain/ha/year) × CR (1)

where:

Yield = wheat grain yield (Mg) and harvested area (ha) in each subregion (semiarid and humid) per area and year basis

CR = (coefficient of wheat residue – C conversion to soil organic carbon)/0.4 Mg soil organic C/Mg grain

RESULTS AND DISCUSSION

State-wide, for the evaluated period, estimated wheat yield was greater for the humid subregion of the Pampas. Therefore, average crop production was 2.7 Mg grain/ha/year for the humid subregion and 2.1 Mg grain/ha/year in the semiarid. This pattern agrees with the observation that precipitation constrains plant production in arid to subhumid ecosystems (SALA *et al.* 1988; AMUNDSON *et al.* 1989; JOBBAGY & JACKSON 2000). As a result, the estimated C input rate was greater in the humid subregion than in the semiarid subregion: 0.9 Mg C/ha/year and 0.75 Mg C/ha/year, correspondingly. Since the coefficient of residue-C conversion to soil organic carbon (SOC) was the same for both regions, C input was directly controlled by wheat yield (or residue input) and precipitation. This is in accordance with the postulation that climate and plant production are the primary regional controls of C inputs and therefore the final amount of organic carbon in the soil profile. C sequestration involves both: C accumulations in plant biomass and in SOC. Researches on other similar agricultural sites have shown similar trends as those presented in this study. They demonstrated that agricultural soils are at steady state or slightly increasing their SOC (Jobbagy & Jackson 2000; Paul *et al.* 2003), Also, in other research in Pampas's semiarid agroecosystems under no-till, the soil C balance was near equilibrium (Bono *et al.* 2008). This was attributed to better management and the two to three fold increases in crop residue returns that have occurred in the last 50 years.

The estimated wheat yields were lower (approximately 1 Mg/ha) than those measured under experimental and field conditions for Pampas agroecosystems (Hall *et al.* 1992; Bono *et al.* 2008; Alvarez & Steinbach 2009). These differences should be attributed to better management conditions under field and experimental researches (eg. higher fertilizer rates, weed control). Furthermore, in these controlled environments C accumulation in wheat was different. Also, in these studies, the different conversion rate could have affected the crop yield and C accumulation by plants (Bridsey 1992; Bono *et al.* 2008). In addition, at a regional scale and for a long period of time, wheat yield differences could not be related to yield variability between years: for example, other authors using the National long term agricultural records observed that wheat cropping systems of the Pampas have been successful in increasing yield while maintaining or increasing relative yield stability. Additionally, this research estimated a similar average wheat yield for the Pampas region: 2.5 Mg/ha (Verón *et al.* 2002, 2004).

In Pampas region, other researches recorded 3.3 Mg C/ha/year of C input from a typical crop rotation (wheat followed by corn or soybean) (Miglierena *et al.* 2000; Satorre & Slafer 1999). Subsequently, wheat accounted for about 32% (approximately, 1.05 Mg C/ha/year) of the total carbon input rate. As reflected above, estimated C input by wheat differed substantially between humid and semiarid subregions. For the evaluated period average wheat yields presented small differences between subregions (0.6 Mg/ha). The major reason for the large C inputs differences between subregions, was a result of dissimilarities in biomass production in the semiarid and humid regions. Biomass accumulation rates, per year, were higher in the humid subregion, since it presented better climatic conditions (elevated precipitations) for wheat production. This variation was associated with higher wheat yield and thus higher residue inputs. The greater the amount of residues returned to the soil, the greater the soil organic C level (Duiker & Lal 1999). Consequently, another possible mechanism by which soil C increases in no-till in relation to tillage management is due to the effects of tillage systems on soil available water content.

The average organic C input to soils throughout 1993 and 2002 by wheat was 8.1 Mg C/ha in the humid subregion and, 6.75 Mg C/ha in the semiarid subregion. An estimate of cumulative C input levels for a rainfed wheat system after 10 years in California ranged between 8.3 Mg C/ha and 20 Mg C/ha (Kong *et al.* 2005). These C input differences were probably due to higher N fertilization rates applied in California and the incorporation of cover crops in alternating winters. Therefore, these systems received significantly higher C inputs than the systems commonly used in our region.

During 1993 and 2002, total C input to soils from wheat in Pampas Region represented about 425 000 Gd C (Gd = 1 000 000 kg). Carbon input estimations were only a bit lesser and had a similar trend like those obtained under long term wheat experiments in Pampas Region (Miglierena *et al.* 2000). This might have occurred because, under optimal conditions is more probable to obtain higher wheat yields and as a result superior C inputs. Therefore, the method applied in this research was appropriate to calculate a more realistic input of biomass C to soil at a regional scale (Alvarez *et al.* 1998; West & Post 2002; Kong *et al.* 2005; Alvarez 2009).

Since SOC levels usually change only slowly with time following a change in cropping management, long-term analysis of C inputs by crops are necessary to detect future differences in SOC. In terms of C sequestration potential, SOC responds linearly to increasing rates of residue or C additions in both medium- and - long-term periods (Alvarez *et al.* 1998; West & Post 2002; Kong *et al.* 2005; Alvarez 2009). Analysis of the Pampas Region C input by wheat must be considered essential, because it represents a very important portion of the soil C budget inside the country and within the whole world. In future studies, estimation of C inputs and further accumulation in soils by wheat or other crops, should incorporate the regional level and the spatial distribution, contributing to a more precise representation of soil C stocks at a regional scale.

References

Alvarez R. (2009): Predicting average regional yield and production of wheat in the Argentine Pampas by an artificial neural network approach. European Journal of Agronomy, **30**: 70–77.

Alvarez R., Lavado R.S. (1998): Climate, organic matter and clay content relationships in the Pampa and Chaco soils, Argentina. Geoderma, **83**: 127–141.

Alvarez R., Steinbach H. (2009): A review of the effects of tillage systems on some soil physical properties, water content, nitrate availability and crops yield in the Argentine Pampas. Soil and Tillage Research, **104**: 1–15.

Alvarez R., Russo M.E., Prystupa P., Scheiner J.D., Blotta L. (1998): Soil carbon pools under conventional and no-tillage systems in the Argentine Rolling Pampa. Agronomy Journal, **90**: 138–143.

Alvarez R., Steinbach H.S., Lavado R.S., Gutiérrez Boem F.H. (2006): Organic Matter: Agronomic Value and Dynamics in Pampean Soils. Faculty of Agronomy, Buenos Aires. (in Spanish)

Amundson R.G., Chadwick O.A., Sowers J.M. (1989): A comparison of soil climate and biological activity along an elevational gradient in the eastern Mojave Desert. Oecologia, **80**: 395–400.

Birdsey R.A. (1992): Carbon Storage and Accumulation in the United States Forest Ecosystems. GTR WO-59, Northeastern Forest Experiment Station, Radnor.

Bono A., Alvarez R., Buschiazzo D.E., Cantet R.J.C. (2008): Tillage effects on soil carbon balance in a semiarid agroecosystem. Soil Science Society of America Journal, **72**: 1140–1149.

Duiker S.W., Lal R. (1999): Crop residue and tillage effects on carbon sequestration in a Luvisol in central Ohio. Soil and Tillage Research, **52**: 73–81.

Hall A.J., Rebella C.M., Ghersa C.M., Culot J.P. (1992): Field crop systems of the Pampas. In: Pearson C.J. (ed.): Field Crop Ecosystems: Ecosystems of the World. Vol. 18. Elsevier, Amsterdam, 413–450.

INDEC. The national agricultural data 1993–2002. Available at www.indec.gov.ar

Jobbagy E.G., Jackson R.B. (2000): The vertical distribution of soil organic carbon and its relation to climate and vegetation. Ecological Applications, **10**: 423–436.

Kong A.Y.Y., Six J., Bryant D.C., Ford Denison R., Van Kessel C. (2005): The relationship between carbon input, aggregation, and soil organic carbon stabilization in sustainable cropping systems. Soil Science Society of America Journal, **69**: 1078–1085.

Marland G., Fruit K., Sedjo R. (2001a): Accounting for sequestration carbon: The question of permanence. Environmental Science Policy, **4**: 259–268.

Marland G., B.A. McCarl, Schneider U. (2001b): Soil Carbon: Policy and economics. Climatic Change, **51**: 101–117.

Miglierena A.M., Iglesias J.O. Landriscini M.R. Galantini J.A. Rosell R.A. (2000): The effects of crop rotation and fertilization on wheat productivity in the Pampean semiarid region of Argentina:1 Soil physical and chemical properties. Soil and Tillage Research, **53**: 129–135.

Oades J.M., Martin J.K. (1986): Input of carbon from wheat plants. Soil Biology and Biochemestry, **18**: 445–449.

Paul E.A., Morris S.J., Six J., Paustian K., Gregorichm E.G. (2003): Interpretation of soil carbon and nitrogen dynamics in agricultural and afforested soils. Soil Science Society of America Journal, **67**: 1620–1628.

Perruchoud D., Walthert L., Zimmermman S., Lüscher P. (2000): Contemporary carbon stocks of mineral forest soils in the Swiss Alps. Biogeochemistry, **50**: 111–136.

Rasmussen P.E., Albrecht S.L., Smiley R.W. (1998): Soil C and N changes under tillage and cropping systems in semi-arid Pacific Northwest agriculture. Soil and Tillage Research, **47**: 197–205.

Sala O.E., Parton W.J., Joyce L.A., Lauenroth W.K. (1988): Primary production of the central grassland region of the United States. Ecology, **69**: 40–45.

Satorre E.H., Slafer G.A. (1999): Wheat production systems of the Pampas. In: Satrorre E.M., Slafer G.A. (eds): Wheat: Ecology and Physiology of Yield Determination. Haworth Press, New York, 333–348.

Studdert G.A., Echeverria H.E. (2000): Crop rotations and nitrogen fertilization to manage soil organic carbon dynamics. Soil Science Society of America Journal, **64**: 1496–1503.

Verón S.R., Paruelo J.M., Sala O.E., Lauenroth W.K. (2002): Environmental controls of primary production agricultural systems of the Argentine Pampas. Ecosystems, **5**: 625–635.

Verón S.R., Paruelo J.M., Slafer G.A. (2004): Interannual variability of wheat yield in the Argentine Pampas during the 20th century. Agriculture, Ecosystems and Environment, **103**: 177–190.

West T.O., Post W.M. (2002): Soil organic carbon sequestration rates by tillage and crop rotation: A global data analysis. Soil Science Society of America Journal, **66**: 1930–1946.

Yimer F., Ledin S. AbdelKadir A. (2006): Soil organic carbon and total nitrogen stocks as affected by topographic aspect and vegetation in the Bale Mountains, Ethiopia. Geoderma, **135**: 335–344.