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Carbon in soils of Montesinho Natural Park, Northeast Portugal: preliminary map-based estimate of its storage and stability

Fonseca, F.*, de Figueirido, T.

Instituto Politécnico de Bragança (IPB/ESAB), CIMO – Mountain Research Centre, Campus de Santa Apolónia, 5301-855 Bragança, Portugal

*Corresponding author: ffonseca@ipb.pt

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Abstract

Short title: Carbon in soils of Montesinho Natural Park, NE Portugal

The Montesinho Natural Park, NE Portugal, is a protected area of 75000 hectares, well-known for its natural values. In addition, it provides important ecosystem services, as the contribution to carbon sequestration. The paper aims at contributing to better understand the role of soils in carbon storage and its stability in the Montesinho Natural Park. The Soil Map of NE Portugal was the main information source used in the study specifically that regarding carbon and nitrogen of 14 soil profiles, representing the soil units identified as dominant in Montesinho Natural Park area. Carbon content in 0-30 cm depth was taken as indicator of carbon storage and the corresponding C/N ratio an indicator of its stability. Leptosols and Cambisols are the most represented soil units, occupying 76 and 20% of the Montesinho Natural Park area, respectively. Luvisols and Alisols together represent 2.5% of total area. Cambisols are the ones that store more carbon per unit area (7.2 kg m^{-2}), followed by Leptosols (5.5 kg m^{-2}), Alisols recording the lowest values (2.2 kg m^{-2}). The carbon storage is higher in the higher altitude areas, cold and wet, soils having expressively higher carbon storage where the average annual temperature drops from 12 to 10 ºC and rainfall exceeds 1000 mm. In general, carbon stability in soils follows a similar pattern to carbon storage.

Keywords: Soil carbon storage, C/N ratio, Montesinho Natural Park (Portugal)

1. Introduction

The Montesinho Natural Park (PNM), NE of Portugal, is a protected area of 75,000 hectares, renowned for its natural values. These include species, communities and ecosystems, and landscapes classified for their high value, subject to conservation and management measures (IPB/ICN, 2007). In addition to these values, this territory may perform functions and ecosystem services, namely the contribution to carbon sequestration, an important aspect in controlling the levels of greenhouse gases in the atmosphere (IPB/ICN, 2007; IPCC, 2000). These services add value to the area and responsibility in its management, particularly in terms of changes in land use.

Carbon storage in ecosystems of these regions is strongly dependent on the soil (Bompastor *et al*., 2009). Some examples illustrate the dynamics of the soil compartment in relation to carbon storage, either continuous in time, or episodic. The processes of organic residues decomposition and, in a different time scale, interventions in land use that contribute to accelerate them, are both In the first case; wildfires are in the second one (Post and Kwon, 2000, Fonseca *et al.*, 2006; Yimer and such., 2006, Ordóñez *et al.*, 2008). These examples underline that, in the context of other dynamics resulting from climate change plausible scenarios, carbon storage should not be singly considered in the assessments. Indeed, the contribution of terrestrial ecosystems, and specifically the soil, to carbon sequestration, and to reduce CO_2 levels in the atmosphere, is not

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static and, therefore, it must also be evaluated in terms of temporal variability, or, conversely, stability. The variations in soil represent the main source of temporal variation of the potential for carbon storage in terrestrial ecosystems in temperate zones. In fact, although other sources (interventions in land use and management, as well as fire, already mentioned above) may prove to be more important, their nature is episodic or sporadic. The C/N ratio is best known indicator of soil organic matter stability. Even recognizing the conceptual weaknesses due to its strictly chemical nature, the C/N ratio has shown great robustness as an indicator of the organic residues decomposition degree in soils (Enriquez *et al*. 1993; Springob and Kirchmann, 2003; Boerner *et al*., 2008, Thomsen *et al*., 2008).

This study firstly aims at contributing to better understand the role of soils in carbon storage at PNM area, thus allowing preliminary quantification of an ecosystem service, especially important under climate change scenarios. Secondly, it aims also at estimating the temporal stability of carbon storage, with regard to the processes of soil organic material decomposition.

2. Material and methods

The Soil Map of NE Portugal, in the tract corresponding to the PNM (Agroconsultores and Coba, 1991; IPB/ICN, 2007) provided background information for this work. This Soil Map (scale 1:100 000) follows the FAO/UNESCO (1987) legend and soil units are designated according to the sequence main unit, secondary unit (in some cases also tertiary unit), and lithology of soil parent material. The Soil Map of NE Portugal contains additional information on map units represented, namely climate, topography and land use (Agroconsultores and Coba, 1991). It should be stressed that map units, due to both the physiography of the area and map scale, correspond mostly to associations of soil units, labelled according to dominant soil unit. The relative spatial importance of dominant and sub-dominant soil units within the association is indicated in the source for each map unit. The information available and treated for this work was part of a database and a GIS, specifically built up on several steps previously undertaken, involving the authors (Araújo *et al.*, 2004; IPB/ICN, 2007; Edunather Project, 2009). Data treatment focused on carbon and C/N ratio of 14 typical-profiles representative of dominant soil units in PNM (Edunather Project, 2009). The criteria for selecting these profiles included the general knowledge of the spatial correlations, identified in the region, between factors of the pedogenic environment, processes depending on them and their expression in terms of morphological, physical and chemical soil properties. Moreover, it is important to note that the profile selection was carried out prior to and independently of this work. Carbon content (kg m^{-2}) and C/N ratio, both at 0-30cm soil depth, were taken as indicators of, respectively, C storage and its stability in soils. In the first case, the calculation was made with carbon concentration in the various horizons and their thickness, bulk density and coarse elements content. The results were integrated to a depth of 30cm, limit adopted to ensure assessments' comparability.

Also, the mineral soil surface layer is the main volume relevant for the spatial survey of carbon storage, according to the Kyoto Protocol requirements (Smith *et al*., 2002; Schulp *et al.*, 2008; Vesterdal *et al*., 2008). These indicators were computed and their spatial distribution analyzed in the PNM (Agroconsultores and Coba, 1991; IPB/ICN, 2007; Edunather Project, 2009).

3. Results and discussion

The Leptosols and Cambisols are the most represented soils units, occupying 76 and 20% of the PNM area, respectively. The Luvisols and Alisols together represent 2.5% of total area (Figure 1).

The carbon content in the soil down to 30cm depth varies from 18.2 kg m^{-2} in granite derived Umbric Leptosols to 1.3 kg m^{-2} in schist derived Dystric Leptosols (Figure 2). Average global carbon storage in the 0-30cm soil depth can be estimated, for the whole area, as 5 kg m^{-2}, a value that accounts for the spatial importance of dominant soil units represented in PNM and that agrees with other estimates for this geographic area (Bompastor *et al.,* 2009). Cambisols are the ones that store more carbon per unit area (7.2 kg m^{-2}), followed by Leptosols (5.5 kg m^{-2}), the lowest values being recorded in Alisols (2.2 kg m^{-2}) (Figure 3). These results can be explained by the preferential occurrence of Cambisols in gentler slope areas, where organic residues decomposition is conditioned by the higher moisture content when compared with Leptosols, that occur typically in steeper slopes areas (Figure 1). Besides the cases of Cambisols and Leptosols, umbric secondary units are not found in any other main soil unit, an evidence that suggests unfavorable pedogenic conditions for organic matter accumulation in the last cases. The C/N ratio varies from 11.1 in Cambisols to 14.0 in Fluvisols (Figure 3). It is well known that higher C/N ratios correspond to higher proportions of carbon stored in stable components of organic matter. (Springob and Kirchmann, 2003; Porta *et al*., 2003; Sierra *et al*., 2007).

The carbon storage is larger in the higher elevation areas, cold and wet, and expressively high storage is found where the average annual temperature (T) drops from 12 to 10ºC and rainfall (P) exceeds 1000 mm (Figure 4). This is the practical verification of the known effects of temperature and rainfall factors on the accumulation of organic matter in soils, through its influence on the decomposition rates of organic material (Spain, 1990; Post and Kwon, 2000, Schneider et al. 2005). Soil carbon has lower stability in drier and warmer areas, with C/N ratios ranging from 10.0 ($P < 600$ mm) to 11.3 ($12.5 < T < 14^oC$) (Figure 4), which is seemingly associated with higher biological activity in these environments, leading to lower amounts of carbon stored in soils. The soil parent material lithology is also reflected in soil carbon storage as the highest values were found in areas of granite derived soils (12.9 kg m^{-2}) and the lower in areas of sedimentary deposits (1.9 kg m^{-2}). Actually, this is simply the result of the spatial distribution of lithological spots within the PNM, and not specifically of the soil processes dependent of soil lithology with consequences for soil carbon accumulation. In fact, the granite outcrops occur in higher elevation areas (above 900 m) and sedimentary deposits at the lower altitude (about 600 m). In the former case, areas are colder and wetter, and less populated than the latter, and so agricultural land use is less common, shrubs dominating the vegetation cover (Figure 1 and Figure 5). Land use has a very clear effect on carbon estimated values, which, on average, are around 3 kg m^{-2} in agricultural soils, a value that is four times higher under forest cover, or even in shrubland (Figure 6). The soil carbon stability is much higher in shrub areas (C/N = 15.6) followed by forest areas (C/N = 13.8), than in agricultural land. The combined effects of the quantity and quality of biomass produced and not exported in each system, and the organic matter decomposition rates resulting from pedogenic environment in which the majority are installed, as well as the soil management practices commonly implemented, all together can contribute to explain these differences between generic types of land use found in PNM soil carbon stability (Thomsen *et al*., 2008, Martins *et al*., 2009).

4. Conclusions

The main soil units, Leptosols and Cambisols, which together represent about 95% of the total PNM area, store the largest carbon quantity per unit area (5.5 and 7.2 kg m^{-2}, respectively), both showing also similar stability of soil carbon. Among the environmental factors that contribute to explain carbon spatial variations in PNM soils are the climate, a direct result of topography because it is a mountain area, and land use are highlighted. As expected, the accumulation and stability of carbon increases with increasing precipitation and decreasing temperatures- As well, soil carbon storage and stability are favored by the existence of perennial vegetation cover (shrubs and forests). The overall weighted average of carbon stored in soil down to 30cm depth is estimated as 5 kg m^{-2}, for the whole PNM area.

References

Agroconsultores and Coba, 1991. Carta dos Solos do Nordeste de Portugal (Soil Map of Northeast Portugal). UTAD. Vila Real.

Araújo, J.A.T., Figueiredo, T., Castro, J.P. 2004. Sistema de informação geográfica da Carta de Solos do Nordeste de Portugal (Geographic information system of Northeast Portugal). Livro de Resumos do 1º Congresso Ibérico da Ciência do Solo. ESA/IPB. p147. Bragança.

Boerner, R.E.J., Huang, J., Hart, S.C. 2008. Fire, thinning, and the carbon economy: Effects of fire and fire surrogate treatments on estimated carbon storage and sequestration rate. Forest Ecology and Management 255: 3081–3097.

Bompastor, A., Figueiredo, T., Fonseca, F. 2009. Matos do Parque Natural de Montesinho, NE de Portugal – produção de serviços ecossistémicos (Shrubs.of Montesinho Natural Park, NE Portugal – production of ecosystem services). In: Actas do 15º Congresso da APDR, Cidade da Praia, Cabo Verde: 338–364.

Enriquez, S., Duarte, C.M., Sand-Jensen, K. 1993. Patterns in decomposition rates among photosynthetic organisms: the importance of detritus C :N :P content. Oecologia 94: 457–471.

FAO/UNESCO, 1987. Soil Map of the World. Revised Legend. Amended fourth draft. World Soil Resources Report nº 60. FAO, Rome.

Fonseca, F., Martins, A., Figueiredo, T., Guerra, A., Nogueira C. 2006. Evaluation of the effect of soil mechanical operations before plantation on the carbon storage and distribution on young forest stands. In: Gallardo Lancho, J.F. (Ed.), Medioambiente en Iberoamérica - vision desde la Física y la Química en los albores del Siglo XXI. Ediciones Mundi-Prensa.

IPB/ICN (Instituto Politécnico de Bragança/Instituto da Conservação da Natureza), 2007. Plano de Ordenamento do Parque Natural de Montesinho – Caracterização (Land Use Plan of Montesinho Natural Park – Characterization). Bragança.

IPCC (Intergovernmental Panel on Climate Change), 2000. Land use, land-use change, and forestry special report. Cambridge.

Martins, A., Azevedo, S., Raimundo, F., Madeira, M. 2009. Decomposição de folhada de quatro espécies florestais no Norte de Portugal: Taxa de decomposição e evolução da composição estrutural e do teor em nutrientes (Decomposition of litterfall from four forest species in Northern

Spanish Journal of Rural Development, Vol. III (1): 71-78, 2012

DOI: 10.5261/2012.GEN1.06

Portugal: Decomposition rate, and structural components and nutrient dynamics). Rev. de Ciências Agrárias 32: 223-237.

Ordóñez, J.A.B., De Jong, B.H.J., García-Oliva, F., Aviña, F.L., Pérez, J.V., Guerrero, G., Martínez, R., Masera, O. 2008. Carbon content in vegetation, litter and soil under 10 different land-use and land-cover classes in the Central Highlands of Michoacan, Mexico. Forest Ecology and Management 255: 2074–2084.

Porta, J., López-Acevedo, M., Roquero, C. 2003. Edafología para la agricultura y el medio ambiente, Ediciones Mundi-Prensa, Madrid.

Post, W.M., Kwon, K.C. 2000. Soil carbon sequestration and land-use change: processes and potential. Global Change Biology 6: 317–327.

Edunather Project, 2009. [Documentação do projecto Piloto Leonardo da Vinci "Educational strategies for the promotion of natural heritage 2006-2009"] www.edunather.net.

Schneider, P.R., Finger, C.A.G., Sobrinho, V.G., Schneider, P.S.P. 2005. Determinação indirecta do estoque de biomassa e carbono em povoamentos de acácia-negra (*Acacia mearnsii* De Wild.) (Indirect determination of biomass and carbon storage in black wattle (*Acacia mearnsii* De Wild.). Ciência Florestal 15: 391–402.

Schulp, C.J.E., Nabuurs, G-J., Verburg, P.H., De Waal, R.W. 2008. Effect of tree species on carbon stocks in forest floor and mineral soil and implications for soil carbon inventories. Forest Ecology and Management 256: 482–490.

Sierra, C.A., Del Valle, J.I., Orrego, S.A., Moreno, F.H., Harmon, M.E., Zapata, M., Colorado, G.J., Herrera, M.A., Lara, W., Restrepo, D.E., Berrouet, L.M., Loaiza, L.M., Benjumea, J.F. 2007. Total carbon stocks in a tropical forest landscape of the Porce region, Colombia. Forest Ecology and Management 243: 299–309.

Smith, C.K., Oliveira, F.A., Gholz, H.L., Baima, A. 2002. Soil carbon stocks after forest conversion to tree plantations in lowland Amazonia, Brazil. Forest Ecology and Management 164: 257–263.

Spain, A.V. 1990. Influence of environmental conditions and some soil chemical properties on the carbon and nitrogen contents of some tropical Australian rainforest soils. Aust. J. Soil Res. 28: 825–839.

Springob, G., Kirchmann, H. 2003. Bulk soil C to N ratio as a simple measure of net N mineralization from stabilized soil organic matter in sandy arable soils. Soil Biology & Biochemistry 35: 629–632.

Thomsen, I.K., Petersen, B.M., Bruun, S., Jensen, L.S., Christensen, B.T. 2008. Estimating soil C loss potentials from the C to N ratio. Soil Biology & Biochemistry 40: 849–852

Vesterdal, L., Schmidt, I.K., Callesen, I., Nilsson, L.O., Gundersen P. 2008. Carbon and nitrogen in forest floor and mineral soil under six common European tree species. Forest Ecology and Management 255: 35–48.

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.

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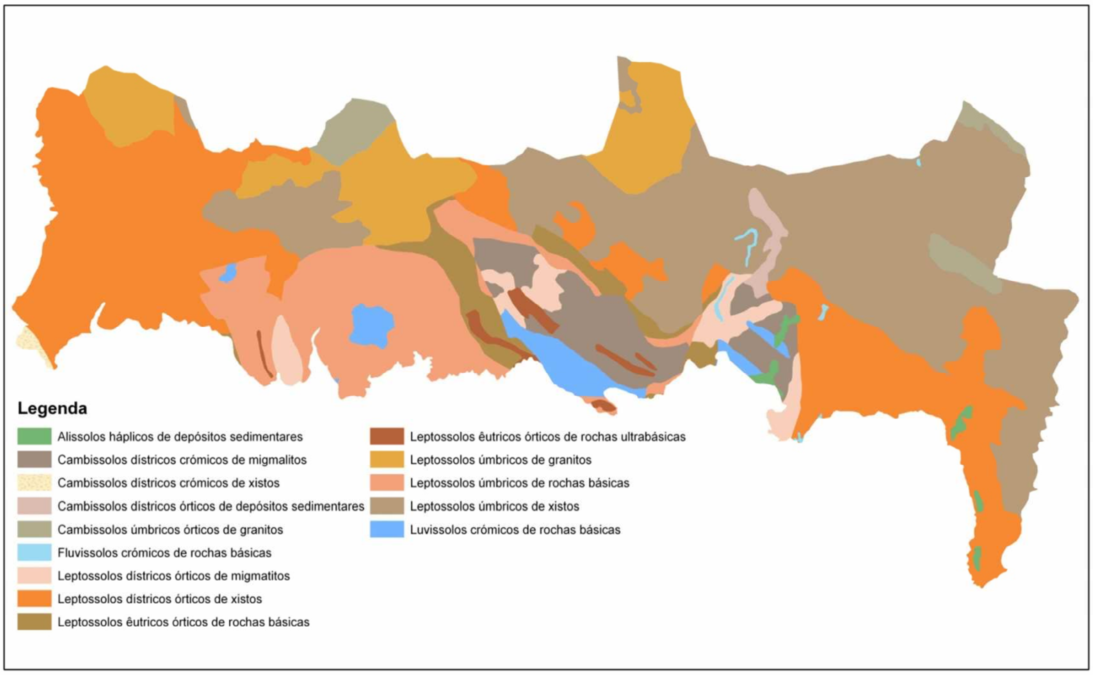

Figure 1. Soil map of Montesinho Natural Park: main soil units (Agroconsultores and Coba, 1991; IPB/ICN, 2007, FAO/UNESCO, 1987)

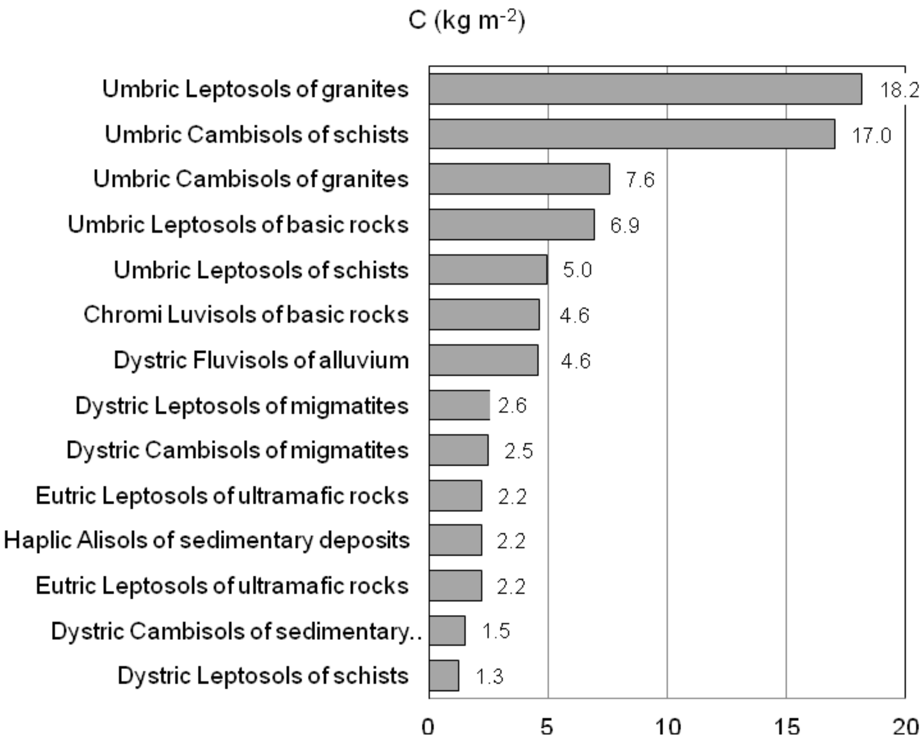

Figure 2. Carbon content (kg m^{-2}, 0-30cm depth) in dominant soil units in PNM

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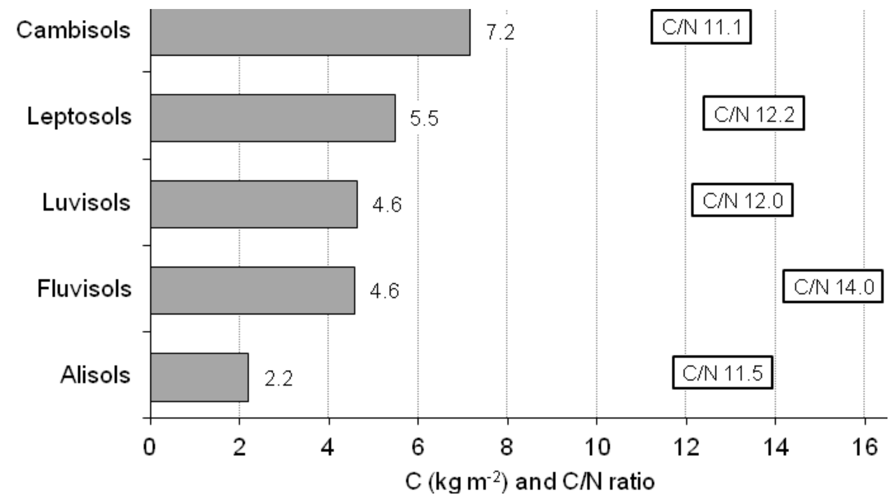

Figure 3. Average carbon content (kg m^{-2}) and C/N ratio down to 30cm deep in main soil units in PNM

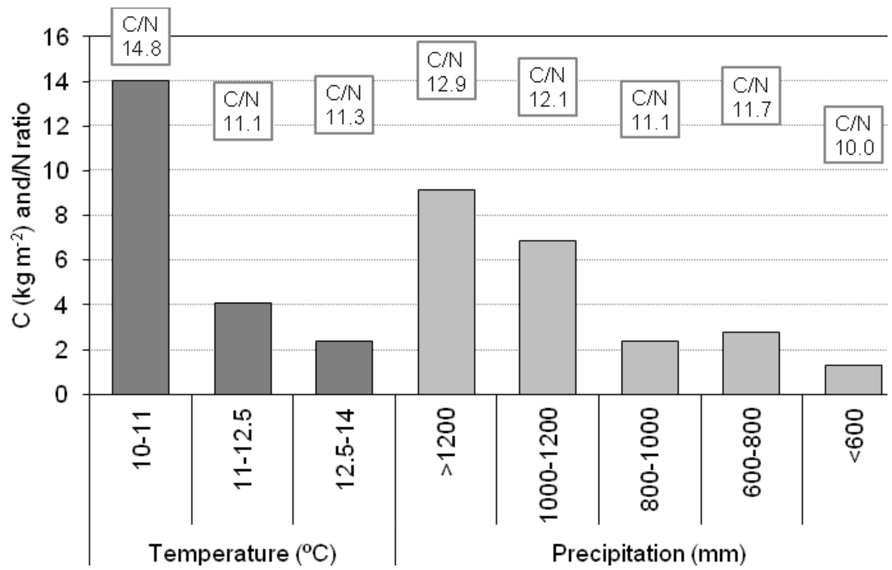

Figure 4. Carbon Content and C/N ratio in the soil down to 30cm in depth: effect of climatic zone

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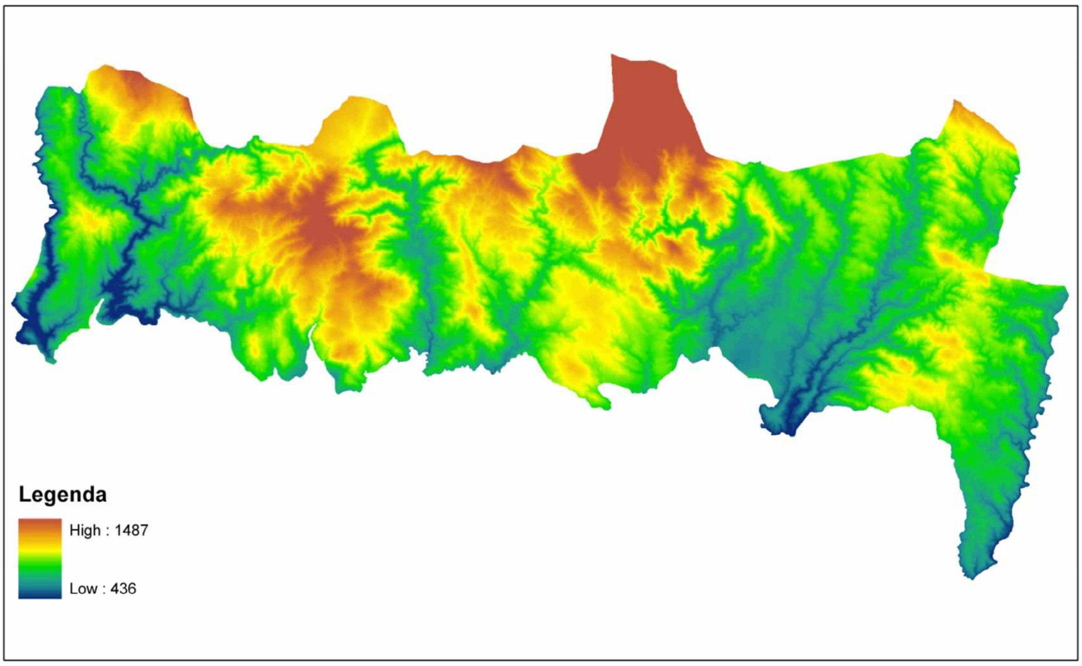

Figure 5. Hypsometric map of PNM (IPB/ICN, 2007; Edunather Project, 2009)

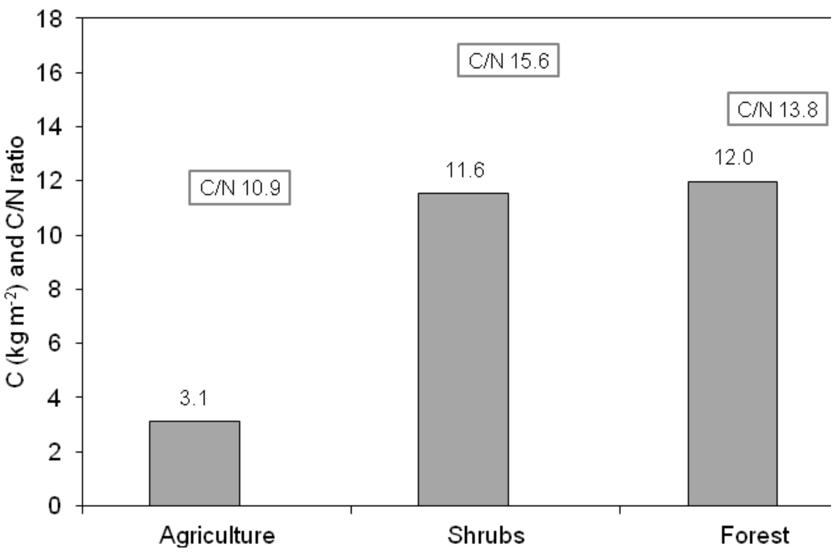

Figure 6. Carbon Content and C/N ratio in the soil down to 30cm in depth: effect of land use